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IOWA GEOLOGICAL SURVEY

VOLUME XXXIII

Annual Report, 1927

with an

Accompanying Paper on

Deep Wells of Iowa

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THIRTY-SIXTH ANNUAL REPORT OF THE STATE GEOLOGIST

IOWA GEOLOGICAL SURVEY,
DES MOINES, DECEMBER 31, 1927.

To Governor John Hammill and Members of the Geological Board:

GENTLEMEN: The most important resource of all the natural resources of Iowa is water. Knowledge of this fact has stimulated the Iowa Geological Survey, ever since it was organized in 1892, to investigate thoroughly this great asset of the state. For more than thirty years Professor William H. Norton has been in charge of studies pertaining to the quantity, quality, conditions of occurrence, and other features of our underground waters. As a result of the work done by Doctor Norton and his assistants, the Survey has been able to furnish much valuable information to the people of the state regarding our water supply. The most comprehensive report which has been published is Volume XXI of the Reports of the Survey. This volume, which was prepared in coöperation with the United States Geological Survey, is entitled Underground Water Resources of Iowa. In the Introduction to this Report Doctor Norton stated:

> "The need of the scientific investigation of artesian waters is obvious to all. Many of these deep zones of flow lie far below the surface and below the sources that supply the common wells. The local well driller can not be expected to know either the quantity or the quality of artesian waters or the depth at which they can be reached. Town councils in considering municipal supply often send committees to the nearest towns which have deep wells to obtain such facts as may throw light upon the local problem. Information thus gathered may be useful or it may be misleading; it is always insufficient and inconclusive. There is needed the skillful interpretation of data collected from a wide area, a knowledge of the geologic structure and acquaintance with the distribution and movements of deep waters. For house wells in towns, and for common farm

> wells, the knowledge of local conditions held by the well drillers of the district is ordinarily sufficient. Yet even here a scientific knowledge of general as well as local conditions often makes it possible to suggest new and better sources of ground water or new and better methods of utilizing those now in use.
>
> The object of the investigation, whose results are here presented, is to furnish to each community so far as possible deductions made from the entire body of facts obtainable, showing whether artesian water can be found at that locality, at what depths it may be reached, through what formations the drill must pass, what mineral compounds—healthful or harmful—the water is likely to contain, how high it will rise, how large will be its discharge, and how such a supply will compare in cost, purity, permanence, and general availability with that from other sources."

It was in 1912 that Volume XXI was published. The information it contains has been and will continue to be of great service to all persons interested in underground waters. Since the publication of this volume, more than fifteen years ago, many deep wells have been drilled in different parts of the state, in connection with which many additional data have been secured by Doctor Norton and other persons connected with the Survey. In order that this information may be available to the citizens of Iowa Doctor Norton has prepared a supplement to his former report. The title of the supplement is Deep Wells of Iowa. This splendid paper, accompanied by a short paper by Doctor James H. Lees, Assistant State Geologist, on Well Water Recessions in Iowa, is herewith submitted to the Board with the recommendation that both papers be published as Volume XXXIII—the Thirty-Sixth Annual Report of the Iowa Geological Survey.

Advance figures for the output of mineral products in Iowa in 1927 indicate that amounts and values are about as follows:

Cement, barrels shipped	5,661,234,	value	$ 9,124,405
Clay products		value	5,193,380
Coal, tons mined	2,949,622,	value	9,304,000
Gypsum, tons sold	723,942,	value	6,713,497
Sand and gravel, tons sold	3,981,143,	value	1,839,726
Stone and lime, tons sold	1,278,056,	value	1,267,033
Total value			$33,442,041

This is a decrease from the production of the previous year of $2,543,738.

Respectfully submitted,

GEORGE F. KAY,
State Geologist.

DEEP WELLS OF IOWA
(A Supplementary Report)

By

W. H. NORTON

WITH A CHAPTER ON

Well Water Recessions in Iowa

By

JAMES H. LEES

AND A TABLE OF IOWA TOWNS GIVING

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DEEP WELLS OF IOWA

Introduction

Since its organization in 1892 the Iowa Geological Survey has recognized the importance of underground water resources and has made them one of the chief objects of its investigation. Three special reports[1] have been published setting forth the development of these resources up to 1912. The county reports have treated more or less fully of the wells and springs of their respective districts. Moreover, advice has frequently been sought and given to well drillers and contractors, municipalities, railways, and other corporations and private individuals as to the underground water supplies available to them.

The present paper is intended only to supplement the reports already published. Since the publication of the latest report in 1912 at least 150 deep wells and prospect holes have been drilled in Iowa, areas have been explored whose water resources were little known, and in some of the oldest drilling territory, where well records had been singularly wanting or imperfect, new and complete data have now been obtained for the first time. In some instances the conclusions of earlier reports have been modified, in many instances confirmed, by new facts deserving permanent record.

Of all the mineral resources of a state, underground water ranks among the first in amount of output and in the value of its product as measured by the indispensable services it renders. The wells of Iowa may be regarded as its most valuable mines. The deeper wells, now numbering at least 400, have an annual output running into billions of gallons, while the hundreds of thousands of shallow farm wells and house wells, ending in drift or country rock, yield in the aggregate an output of a value perhaps as great.

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1 Norton, W. H., Thickness of the Paleozoic Strata of Northeastern Iowa: Iowa Geol. Survey, vol. III, pp. 169-210, Des Moines, 1895.

Norton, W. H., Artesian Wells of Iowa: Iowa Geol. Survey, vol. VI, pp. 115-428, Des Moines, 1897.

Norton, W. H.; Hendrixson, W. S.; Simpson, H. E.; Meinzer, O. E.; and others, Iowa Geol. Survey, vol. XXI, pp. 29-1214, Des Moines, 1912.

The period covered by this investigation has been one of urban development in Iowa and has witnessed the change in the water supply of towns from house wells to a municipal supply. It has witnessed also the wide introduction of sewerage and therefore the vastly increased amount of water required for urban uses. It has also seen an increasing pollution of streams. Rivers which half a century ago might have been considered for public supply have become common sewers. Their waters if used require unintermittent and thorough filtration and chemical disinfection.

In the location of the towns of Iowa water supply was probably never even considered as a deciding factor. The eminently proper place for the county seat was often held to be the geographic center of the county even if on a high and dry divide. The site of towns on streams was fixed by a mill site, the convergence of traffic at a ferry, but perhaps never by the advantage of abundant water for public and private uses. Pioneer Iowa depended on shallow house wells and cisterns for water supply.

But with the infection of the soil shallow house wells became unfit for use. And with the installation of sewerage and growth in population shallow wells also became entirely inadequate to meet the increased demand, except in a few favored localities. Hence the problem of water supply for Iowa municipalities during recent decades—a problem by no means yet completely solved.

Naturally the first resort for towns whose shallow well supply proved insufficient was the sinking of deep wells to tap the stores of artesian water in pervious rocks lying perhaps a thousand, perhaps two or even three thousand feet beneath the surface. At this point the Iowa Geological Survey has been able to give first aid.

For the distribution, amount and quality of the available underground waters at any locality depend on the composition, structure and attitude of the rock formations. These characteristics have been learned from field studies in areas of outcrop. The experience of drillers in Iowa and adjacent states has been gathered, so that over a very large part of the state the deep geology is fairly well made out even to greater depths than the drill can profitably go. Thus the Saint Peter sandstone, one of the most readily identified of the water beds, has been traced from its outcrops in northeastern Iowa where it stands about 1200 feet above sea level, to the southwestern corner of the state where it has sunk to 1853 feet below sea level. Contour maps are drawn (Plate I) showing the probable approximate elevation above or below sea level of this reliable formation at almost any locality. To obtain the probable distance which it is necessary to drill in order to reach the Saint Peter, one needs only to subtract its elevation above sea level, as shown approximately by the Contour map, from the elevation of the locality obtainable for any railway station, or to add the elevation of the Saint Peter if that formation lies below sea level.

In the report of 1912 on Underground waters, forecasts were made also for the towns not already supplied with artesian water whose size and location made not improbable the sinking of deep wells in the near future. These forecasts showed the depth to the various water beds of the artesian field and the nature and thickness of the formations through which the drill would pass. And on consultation by drillers or by their clients additional facts have also been given as to deep well prospects. The general reliability of these forecasts has been confirmed on the whole by the numerous wells drilled the last fourteen years.

Because of the very large body of facts at its disposal the Survey has been able to render a unique service to all concerned in problems of water supply. The advantage of disinterested and reliable advice to municipalities and others who have the sinking of deep wells under consideration is evident.

For well drillers and contractors the Survey offers a clearing house by which any firm can draw upon the experience of all for many years, as well as the technical knowledge and skill of geologists.

It is a pleasure to find that well-men often consult the Survey, have read thoroughly its reports, are well acquainted with the deep geology of the state, and have even adopted the rather formidable and changing scientific nomenclature of the formations. Drillers are thus able to base their bids on pretty well assured geologic conditions. It is unnecessary to increase these bids to cover improbable contingencies, or to lose on contracts by reason of unexpected difficulties. Over a good deal of Iowa, well drilling is fairly well standardized, a condition which makes for the benefit of well drillers and their employers.

Before making bids and signing contracts, drillers have asked the advice of the Survey as to the depth of the different water beds—an important matter where a contract specifies casing to the Saint Peter—and as to the lengths of casing necessary to case out caving shales and deleterious waters.

After drilling has gone deep both drillers and their employers sometimes refer the question of going deeper to the Survey. In some instances the advice has been given to stop work at once, and thousands of dollars have been saved in a single well when the advice as been followed. In certain cases the advice has been disregarded and the drilling continued with good results, namely, proving the accuracy of the forecast, increasing respect for the judgment of geologists, and confirming and extending our knowledge of the deeper strata of the state. In other cases the advice has been given to go on to still deeper-lying water beds and some very large flows have thus been secured.

It is well to remember the limitations of our knowledge of the subsurface rocks. They are not open to inspection. They can be photographed by no rays. Their nature, and the valuable minerals, such as oil and water, which they may contain are everywhere a matter of inference, and the accuracy and extent of the inference must depend on the accuracy and fullness of the data from which the inference is drawn.

These data are, first, the observations made of the outcrops of the formations where they form the country rock. The facts obtained by this field study of the geological formations of Iowa are reliable and definite, though not exhaustive. But it is not to be expected that the formations will carry their outcrop characteristics unchanged for scores and hundreds of miles as they sink deeper and deeper below the surface. Rather is it probable that they will thicken or thin, change in their dip, and become altered in composition. And formations quite unknown from surface outcrops may appear among the deeper strata. Where a water-bearing sandstone, for example, lies on an old erosion surface it may differ in thickness from a few grains where it rests on a buried hill-top to many feet where it fills a pre-existing valley. A sandstone, water-bearing at its outcrop because of open texture, may with distance become impervious as its interstices are filled with clay or cemented with lime. And although the lie of the strata in Iowa is singularly uniform—a fact that tends to make the state rich in artesian waters, but poor in oil and gas and monotonous in scenery—upfolds and downfolds may occur in the deeper strata without any surface expression. All these variations are unpredictable and can be discovered only by the drill.

To a very large extent, therefore, our knowledge of the deep geology of Iowa must depend on the second group of data—the information secured from deep well drilling. It is believed that in large measure this information is dependable and the general accuracy of the forecasts based upon it confirms its reliability. Our debt, therefore, to the drillers and to the owners of deep wells is very great for the painstaking efforts they have often made to place their facts at the disposal of the Survey.

But it must be remembered that all of this group of data is second-hand and not open to correction by personal investigation. Such data must vary widely in fullness and accuracy. The statistics of a city well furnished by officials may be set down from complete original, and well-kept records, or perhaps from a generalized memory called into hurried and reluctant action by repeated solicitations. It is sometimes evident that the owner of a well just completed knows little or nothing about his valuable property except possibly its depth.

Drilling firms are necessarily the ultimate sources of information, and often are the most reliable and ready. Yet practice differs widely. A firm may regularly keep full and accurate records of a well, submit them to a competent geologist along with a complete set of samples of the drill-cuttings, and furnish the owner of the well and the Geological Survey the full statistics of the well, its depth, diameters, casings, packings, water beds, results of tests for capacity, and log of the rocks passed through. Other firms may keep full records of the wells they drill on the time sheets of their foremen, but although these firms are usually ready to place such facts at the disposal of the Survey, it requires considerable uncompensated time and trouble on the part of busy men. And still other firms apparently keep no records and give their employers nothing beyond a receipted bill for payment. When the well needs repairs this lack of information will be found regrettable for financial reasons.

All owners of deep wells should recognize their right to this information, and if necessary should make it a matter of the contract. And all well drillers should recognize the advantage of imparting it. All statistics are, or should be, at hand on completion of the well. Taking frequent samples of the cuttings involves much time and pains on the part of workmen, but it is well worth the trouble, and either the drilling firm or its employer can have the samples examined in laboratory by the Iowa Geological Survey without expense.

Drillers' logs are an essential part of the geologist's data. Only the driller knows and can record the hardness of a given rock as tested by the time taken to drill a unit distance and by the wear on the bit. In his time sheets he sets down, or should set down, any slight change in the rock, so that streaks of shale in limestone, or of limestone in shale, for example, are defined, which escape notice if the only data are samples of cuttings taken at intervals of even as little as ten feet. The driller usually records the presence of water in any bed as evidenced by fluctuations of water level or the washing away of cuttings. He sets down the kind of rock in which the drill is working. He can give the depth more exactly than ordinarily can be determined from sample cuttings taken at regular intervals.

Yet drillers' logs often require interpretation and confirmation. The practical, hard-working, skilful well driller is not a lithologist. He has neither the time, the experience, or the laboratory equipment for accurate determinations of the materials of his slush bucket. If a rock, the Galena dolomite for example, crushes under the drill to a crystalline sparkling sand he may, and sometimes does, set it down as "sand", "sandrock" or "sandstone". And a geologist working without samples of the cuttings may suppose it the Saint Peter sandstone, for example, or that here the Saint Peter consists of upper and lower members separated by limestone. Hard shale is labelled "slate", soft shale often "soapstone", "mud rock", or "gumbo". Well cemented fine-grained sandstone cutting to chips, is often called "lime". Granite may be called "red sandrock" and schist "black lime". Quartzite may be labelled "granite" because of color and hardness.

Even in so simple a matter as color, it must be remembered that the cuttings as the driller sees them are usually covered with a wash of fine rock flour. This the geologist in laboratory removes, or judges the color by fresh broken surfaces.

As to such ambigous rocks as those of the Franconia, the driller is no more infallible or consistent than are geologists.

The driller's log should always be confirmed by a full set of sample cuttings, but even here there are possibilities of error. A sample taken from the slush bucket represents the rock in which the drill is working, but it may also contain a larger or smaller amount of material fallen from higher levels in the well. From any uncased portion of the drill-hole rocks may be dislodged by the vibration of rods or ropes and by the drill and slush bucket as they are hoisted and lowered. Rocks such as shales and loose sandstones and conglomerates may at any time cave for structural reasons until cased out. Thus shale from the Decorah and Glenwood formations may be found at lower levels, and when the drill is working in the Saint Peter may simulate streaks of interbedded shale. Sand from friable sandstone may thus mingle with the fresh cuttings of lower limestones and shales. It must often be left undecided as to what material of a sample is native and what foreign, especially when it is not known when the casing was inserted which cased out caving layers. In the description of samples, therefore, the mention of any material does not necessarily imply that the material was present in the rock at the given depth.

When there is reason to believe that the different materials of a sample of cuttings are all native, there still may remain some uncertainty as to the manner of their association. A sample made up of quartz sand and minute chips of dolomite may represent streaks of sandstone in dolomite or of dolomite in sandstone, a dolomitic sandstone, or an arenaceous dolomite. In case of a dolomitic matrix, however, some imbedded grains may usually be found if the cuttings are not too fine.

Occasionally there is some ground for suspicion that the depth label is incorrect. If it has been copied from that of the first container, the original figures may have become nearly illegible and may have been misread. Original containers may have become misplaced before labelling. If the workman at the derrick should attempt to label a number of containers from memory the result is apt to be highly unsatisfactory to the workman in the laboratory. Whatever may be the cause of such errors, labels are not convincing when Pleistocene clays are labelled as occurring hundreds of feet deep in solid rock, or sands of Saint Peter facies far above the depth of other samples of that formation, or samples of nonmagnesian limestone among the dolomites of the Prairie du Chien.

Sometimes there is reason to believe that the sample has not been taken directly from the slush bucket, but has been scraped up from the dump, introducing bits of coal and cinder and cuttings from earlier emptyings. Suspicion may attach to a long run of samples singularly alike in their heterogeneity.

Subject to these possibilities of error and misinterpretation the cuttings from Iowa deep wells are accepted as on the whole reliable and authentic. It is upon them that the chief dependence has been placed since the organization of the Survey. While the drilling of deep wells is now less of an event locally than in the closing decades of the last century, and citizens are less apt to possess the collector's passion for cuttings as rare specimens, yet drilling firms recognize as fully as ever the importance of taking these samples and their scientific value.

It may be added that sets of samples should always be complete, taken from start to finish every ten feet at least, and at every change in the rocks. Little can be done with a few samples taken many feet apart. Even when such samples can be referred to individual formations, they give neither their upper nor lower limits, and important formations may be omitted.

A sample is sometimes labelled as representing a body of rock scores or hundreds of feet thick, while its own depth is not stated. In this case the assumed uniformity of the body of rock is sometimes quite probable, sometimes highly improbable, but it can neither be proved nor disproved.

Cuttings should be emptied from the slush bucket directly into the containers. They should never be washed, as the fine material of them is quite as valuable for identification as the coarse. Cheap and good containers are found in cigar boxes and glass fruit jars, and the Iowa Geological Survey is glad to furnish cloth bags with stout tags attached for labels. Labels should be written with a common pencil, not an indelible pencil, and every care should be taken that the figures are legible and remain so. Wet cuttings should not be placed directly in the cloth bags but should first be drained or the water is very likely to stain the labels and make their legends illegible.

The Geological Formations

Underground waters, their distribution and the amount and quality of them obtainable at any place depend largely on the structure and composition of the rocks. Of first importance, therefore, are the geological formations, not only in their areas of outcrop, but also in the larger areas where they are buried from view and are accessible only to the drill. The various members of the geologic column in Iowa in their relations to underground water have been treated in earlier reports and it is now necessary to summarize only the more important facts obtained in the preparation of the present paper. A list of these members is given herewith.

GENERAL SECTION OF IOWA STRATA

Group	System	Series	Formation		Character
CENOZOIC	Recent				Soil, geest, alluvium
	Quaternary, patches of Tertiary	Pleistocene	Wisconsin		Bowlder clay
				Peorian	Loess, forest bed, sand, gravel
			Iowan		Bowlder clay
				Sangamon	Gumbotil, soils, forest bed, sand, gravel
			Illinoian		Bowlder clay
				Yarmouth	Gumbotil, peat, soil, sand, gravel
			Kansan		Bowlder clay, gravel
				Aftonian	Gumbotil, peat, soil, gravel
			Nebraskan		Bowlder clay, gravel

GENERAL SECTION OF IOWA STRATA (Continued)

Group	System	Series	Formation	Character
MESOZOIC	Cretaceous	Upper Cretaceous	Colorado	Shale, limestone
			Dakota	Sandstone
PALEOZOIC	Permian	Fort Dodge		Gypsum, shale
	Pennsylvanian	Missouri	Wabaunsee Shawnee Douglas Lansing Kansas City	Limestones, shales, coal
		Des Moines	Pleasanton Henrietta Cherokee	Shales, coals, sandstones, limestones
	Mississippian	Iowa Series: Meramec	Ste. Genevieve (Pella) St. Louis Spergen Warsaw	Limestones, marls, sandstones
		Iowa Series: Osage	Keokuk Burlington	Limestones
		Iowa Series: Kinderhook		Shale, limestones
	Devonian	Upper Devonian	Lime Creek—State Quarry	Shale, limestones
			Cedar Valley	Limestone, shale
			Wapsipinicon: Davenport	Limestone
			Wapsipinicon: Independence	Shale
			Wapsipinicon: Otis	Limestone
	Silurian	Cayugan?	Salina ? nowhere exposed	Limestone, gypsum
		Niagaran	Gower Hopkinton	Dolomites
		Alexandrian	Waucoma	Limestone
	Ordovician	Cincinnatian	Maquoketa	Shale, dolomite
		Mohawkian	Galena	Dolomite
			Decorah	Shale, limestone
			Platteville	Limestone, shale
		Canadian	Glenwood	Shale
			St. Peter	Sandstone
			Prairie du Chien: Shakopee	Dolomite
			Prairie du Chien: New Richmond	Sandstone
			Prairie du Chien: Oneota	Dolomite
	Cambrian	Croixan	Jordan	Sandstone
			St. Lawrence: Trempealeau	Dolomite, marls
			St. Lawrence: Franconia	Shale, glauconite, marl
			Dresbach	Sandstone
			Eau Claire (Not exposed in Iowa)	Shale,sandstone
			Mt. Simon (Not exposed in Iowa)	Sandstone, shale
			Red clastic beds (unnamed) (Not exposed in Iowa)	Sandstone, shale, conglomerate
PROTEROZOIC	Algonkian	Huronian	Sioux	Quartzite
ARCHEOZOIC	Laurentian?		Nowhere exposed	Granite, schist

PLEISTOCENE SYSTEM

Few facts relating to the glacial drift are obtainable from deep well records beyond its depth and thickness. Glacial tills and water-bearing sands and gravels are of prime importance to the driller of farm wells and the house wells of villages and towns and to the many hundreds of thousands of people in Iowa who derive their supply from them. But the deep well driller usually pays little attention to the drift. He goes through its water sands without testing their capacity, and all too frequently takes no samples until bed-rock is reached. Hence no attempt is made in this report to distinguish the different drift sheets.

Pleistocene deposits are found of abnormal thickness in old buried channels and deep filled valleys of present rivers at Washington, Riverside, Audubon, Denison, and perhaps at Van Horne, Grinnell and Stuart. At all these points it is more than 200 feet to bed rock.

The thickest drift in the state is usually supposed to exist in northwestern Iowa, but uncertainty has attached to many well records because of the possible failure of the driller to distinguish glacial clays from Tertiary clays and from Cretaceous shales. The wells of this area here reported give nothing exceptional for the drift except at Holstein, where, if the samples are authentic, glacial tills are found as deep as 380 feet and may extend to the first sample of bed rock at 420 feet.

CRETACEOUS SYSTEM

In northwestern Iowa the drill normally pierces below the drift the shales and limestones of the Colorado group of the Cretaceous, passing thence into the well known water bed of the Dakota sandstone. The Colorado group is well developed at Orange City, where it attains a thickness of 330 feet. At Inwood none of the Cretaceous can be identified from an imperfect log. At Sioux City the Colorado and a large part of the Dakota lie above the level of the rivers and of the well curbs. As at many towns in northwestern Iowa, the Dakota sandstone furnishes part or whole of the supply at Sioux City and Orange City.

Beneath the sandstones of the Dakota group shales whose rank is undetermined are found at several places. Some may belong to the Dakota group; others to Paleozoic systems. At Sioux City shales, red and whitish, 70 feet thick occupy this horizon. At Orange City 8 feet of red shale with 37 feet of underlying gray shale rests on a sandstone attributed to the Saint Peter. As the sand grains included in the red shale are well rounded both shales may be classified plausibly as Glenwood.

At Emmetsburg the Dakota sandstone is parted from Paleozoic dolomite by bright brick-red ochreous shale of finest grain, 22 feet thick, with some angular included grains of sand, and black nodular grains of ironstone up to five millimeters diameter. At West Bend a "red marl" separates the Dakota sandstone from Mississippian cherts and at Ayrshire a red shale is reported as underlying the Dakota sandstone. At Algona a "fine sandstone" attributed to the Cretaceous rests on 5 feet of limestone which in turn overlies 10 feet of "red shale". At Holstein shales 170 feet thick intervene between the exceptionally thick drift and the Mississippian. Here the Cretaceous sandstone is wanting and the shales may be Pennsylvanian, although at Cherokee a thick body of shale and sandstone at the same horizon has been placed with the Cretaceous.

In western Iowa heavy shales beneath the drift and the Dakota sandstone may be Pennsylvanian in age. The red shales of the Pella beds at Fort Dodge suggest that some of the red shales above mentioned may even be Mississippian.

PENNSYLVANIAN SYSTEM

Data as to the character and thickness of the Pennsylvanian, or Coal Measures, will be found in the records of several new wells located on the widespread area of outcrop of this system. In a number of instances the logs of the drillers will be found more complete and accurate than data from the samples of the cuttings. In the Missouri series frequent changes in the character of the strata are common, and samples taken every ten feet miss thin beds of sandstone, shale, limestone, fire clay and coal, which a carefully taken log records.

In wells of the Des Moines series it is unfortunately rather common for drillers to take no samples until the somewhat monotonous shales which constitute the bulk of this stage are passed through. The abnormal record of the deep well at Manson (p. 246) is interpreted as probably that of the fill of a pre-Pennsylvanian valley—or possibly of a pre-Cretaceous valley—by deposits in part continental.

MISSISSIPPIAN SYSTEM

According to the classification of Weller and Van Tuyl,[2] the Mississippian system of Iowa includes the following subdivisions: the Meramec group, consisting of the Ste. Genevieve (Pella), St. Louis, Spergen, and Warsaw formations, the Osage group, consisting of the Keokuk and Burlington, and at base the Kinderhook group, embracing a heavy basal shale and various formations of limestone, shale and sandstone not discriminated in this report.

In deep well sections the Mississippian is approximately demarked from the Pennsylvanian where the shales of the Des Moines or its basal sandstones give place to the cherts and limestones of the earlier system. Pella shales or St. Louis sandstones occurring at the summit of the Mississippian might easily be wrongly included in the Pennsylvanian.

The delimitation of the Mississippian at base from the Devonian is even more difficult in deep well sections than in the field, where in the northeast part of the area of outcrop the place of the Sheffield shale, ranked at present as Mississippian, may perhaps be decided by fossils to be Devonian, and in the southeast, where some doubt still attaches to the place of the Sweetland Creek shales, now ranked as Devonian.

In several deep well sections in Illinois Udden has successfully discriminated the Kinderhook shale from the Sweetland Creek by the presence of microscopic *sporangites* in the latter. In Iowa deep well sections this discrimination has not been made, and it is probable that some shales attributed to the Kinderhook include Devonian shales also, Sweetland or Lime Creek.

In the well sections of southeastern Iowa the Kinderhook shale (including perhaps Upper Devonian shale at base) carries the thickness of its outcrops and of the well sections of earlier reports. At Fairfield this shale is 250 feet thick, at Morning Sun

2 Van Tuyl, Mississippian Strata of Iowa: Iowa Geol. Survey, vol. XXX, pp. 42, 43.

and Brighton about 280 feet, and at Winfield and Donnellson about 325 feet. At Riverside in Washington county it measures 175 feet, but here the upper part may be cut away by the filled valley of English river. At Keokuk it measures 204 feet.

To the northwest the Kinderhook shale thins. At Nevada it measures 80 feet, at Des Moines 185 feet, at Rippey 45 feet. At Webster City it is represented perhaps by argillaceous limestones and at Fort Dodge it is about 60 feet thick and contains beds of limestone. At Gowrie it measures 50 feet. Further to the northwest, at Holstein and Algona, it is not recognized.

In southwestern Iowa it has but a moderate thickness, at Audubon 50 feet, at Stuart 41 feet and at Greenfield 55 feet. At Oakland a shale 97 feet thick struck at 1486 feet may be the Kinderhook. In that case the entire Mississippian at Oakland has the not excessive and yet sufficient thickness of 396 feet.

DEVONIAN SYSTEM

The upper limit of the Devonian terrane is usually drawn in deep well sections at the summit of the limestones which underlie the body of shale whose upper portion at least is Kinderhook. The lower limit is difficult to define except where nonmagnesian or slightly magnesian limestones, perhaps with shaly beds, give place to typical Niagaran dolomites. But the Wapsipinicon stage of the Devonian contains dolomitic beds and the Salina of the Silurian is by no means fully dolomitized, and west of Marshalltown it is usually the Salina on which the Devonian rests.

Near the western edge of the area of outcrop the Devonian is assigned a thickness of 165 feet at Waterloo, 231 feet at Van Horne, and 220 feet at Oakdale. Farther west, at Nevada, it is probably at least 240 feet thick and 120 feet thick at Des Moines. At Stuart and Rippey a thickness of 155 feet is assigned to this system.

In southeastern Iowa the Devonian rocks appear to be about 140 feet thick at Brighton and 100 feet thick at Washington. At Donnellson no more than 140 feet can be given to both the Devonian and Silurian.

SILURIAN SYSTEM

The Silurian system of Iowa is of special interest in its relations to ground water. The Niagaran limestone throughout its area of outcrop and along its western edge forms a capacious reservoir within easy reach. Its solution channels are many and large and it has the advantage of an impervious floor in the Maquoketa shale. Over this area wells of about 300 feet or less which reach the base of the formation may yield an adequate supply for villages and towns. Such wells are as safe as any where the limestone has an impervious cover of boulder clay. But where the limestone is not thus protected its solution channels may carry contaminating surface waters too deep to be shut out by casings. The recent Niagaran well at Manchester is but one of several examples of this danger.

As the Niagaran limestone dips beneath the surface to the west and south there is evidence that it comes to be overlain and replaced by gypsum-bearing limestones, which probably belong to the Salina group of the Silurian. These beds are of importance to the driller for any water they contain is likely to be objectionable on account of its permanent hardness and should be cased out. To the north the Niagaran limestone thins abruptly and it can not be certainly identified at Charles City, Mason City or Osage.

The Silurian in parts of the state beyond its area of outcrop contains also arenaceous beds which may be water-bearing and in western Illinois form reservoirs for oil.

SALINA

Gypsum-bearing beds referred to the Salina were found in Iowa wells drilled before 1910 at Marshalltown, Des Moines, Grinnell, Pella and Mount Pleasant. At Glenwood also and at Bedford gypsiferous limestones were found apparently below the horizon of the Permian, the probable horizon of the gypsum of Fort Dodge, and below also the stratigraphic level of the Mississippian, to which the gypsum of Centerville belongs. These also were tentatively referred to the Salina.

The inferences of the earlier reports have been confirmed by new wells at various points. At Des Moines, in the well of the

Northland Milk and Ice Cream Co., the gypseous beds of the Salina appear in considerable force 140 feet below the base of the Kinderhook shales. At Webster City gypsum associated with nondolomitic limestone is found in distinct beds 80 and 140 feet above the summit of the Maquoketa shales, and chips of gypsum with limestone occur in cuttings to 250 feet above that datum. At Nevada and Ogden well marked gypseous deposits were found at the Silurian horizon and they probably were found at Ames also. In southeastern Iowa gypseous beds occur 140 feet below the base of the Kinderhook at Brighton. The beds of gypsum and anhydrite at Mount Pleasant lie 120 feet below the base of the same shales.

At Stuart and Greenfield the gypseous beds of the Salina form a stepping stone between those at Des Moines and those at Glenwood and Bedford. Gypsum begins to appear in the cuttings of the Stuart well at 1375 feet and is found at intervals in chips with limestone to 1759 feet, 106 feet above the summit of the Maquoketa. At Greenfield gypsum occurs in the cuttings from a body of dolomite found 130 feet below the well defined horizon of the base of the Kinderhook shales.

HOING SANDSTONE

Sandy beds at the base of the Silurian were discovered by Calvin[3] in 1888 in a deep well section at Washington, Iowa, and this has been confirmed by the cuttings of the deep wells since drilled at this locality. At Sigourney also a bed 6 feet thick and composed of chert, limestone, and much quartz sand occurs at the base of the Silurian. At Des Moines in the Greenwood Park well a similar formation 22 feet thick was disclosed 55 feet above the top of the Maquoketa shale and separated from it by a bed of limestone. The same sandy bed was reached by the recent well of the Northland Milk and Ice Cream Company (p. 166).

At Stuart quartz sand and limestone chips form the cuttings representing the basal 24 feet of the Silurian. At Centerville a sandstone 50 feet thick overlies 60 feet of sandy limestone, which rests on shales assigned to the Maquoketa. At Shellsburg a fine-grained sandstone 30 feet thick rests on the Maquoketa shales.

3 Calvin, S., American Geologist, vol. 1, pp. 28-31.

Probably the basal sandy rocks of the Silurian at some of the above localities are the equivalent of the sandstone discovered by the drill in the Colmar oil field in western Illinois and called the Hoing sand.[4] The Hoing formation is described as spotty and discontinuous in distribution and lenticular in its deposits, with a thickness ranging from 5 to more than 30 feet. It is supposed to lie unconformably on the Maquoketa shale and to occupy hollows in the erosion surface developed on the shale during the erosion interval preceding the deposition of the Niagaran limestone. It thus consists of land deposits reworked by the transgressing Niagaran sea.

The arenaceous deposits at the base of the Silurian in Iowa well sections bear this interpretation. At Des Moines, where they rest on limestone, it is quite possible that, as in its outcrop in northern Iowa, the Maquoketa includes a limestone bed as its upper member.

ORDOVICIAN SYSTEM

MAQUOKETA SHALE

The facts gathered from recent wells as to this formation, so important as a confining bed in the artesian system, and so reliable as a marker in the interpretation of well sections, confirm the conclusions of earlier reports, but offer little that is new.

Considerable range in the thickness of the Maquoketa is found even in nearby sections. This is attributable to the variations in level of the land erosion surface developed on the shale before the deposition of the Niagaran limestones, and no doubt also to various classifications of transition beds and to various interpretations of sample cuttings. The interpretation of washed samples of the cuttings of shale and shaly limestone, from which the clayey constituents have been removed, may easily differ from that of unwashed sample cuttings of the same beds in a different well.

[4] Morse, W. C., and Kay, F. H., Bull. No. 31, State Geol. Surv. of Illinois, pp. 40-42.

Thickness of the Maquoketa Shale

Well section	Thickness in feet
Cresco	120
Oelwein	215
Preston (upper part perhaps cut away)	120
Delmar	225
Dewitt	201
Waterloo	230
Cedar Rapids	260
Shellsburg	170
Oakdale	145
Bettendorf	200
Van Horne	193
Nevada	50
Grinnell	240
Des Moines (Greenwood Park)	33
Stuart	119
Rippey	150
Denison	40
Audubon	90
Webster City	70
Fort Dodge	210, 190
Algona	40
Washington	200
Winfield	210
Brighton	110
Donnellson	5

To the north, as at Calmar, Cresco and Charles City, shale has been replaced by impure dolomites.

To the northwest the Maquoketa thins and at Emmetsburg may be represented by a shale only 4 feet thick. At Cherokee and Holstein it has apparently either feathered out or has been removed by erosion. To the southwest the shale was not recognized in the Council Bluffs and Omaha wells and probably was not reached at Glenwood and Bedford. At Nebraska City, however, the driller's log records a shale 114 feet thick at 2160 feet, which is pretty certainly the Maquoketa.

In the extreme part of southeast Iowa the Maquoketa feathers out and at Donnellson is but 5 feet thick.

GALENA, DECORAH AND PLATTEVILLE FORMATIONS

Beneath the Maquoketa shale the drill enters a group of limestones and shales which rests on the Saint Peter sandstone. In descending order this group consists of the Galena limestone, the Decorah shale, the Platteville limestone, and the Glenwood shale. The Glenwood shale is transitional to the Saint Peter sandstone and while here grouped with the formations which succeed it, is reserved for description in a later section.

In well sections where the Decorah is absent or unrecognized the group above the Glenwood is designated as the Galena-Platteville.

This group of formations is one of the most extensive in the Iowa geologic column, underlying all the state except a few townships in the northeastern county, and an undefined area in the northwest, where the Cretaceous rests directly on the Saint Peter or on still older rocks.

The lithologic characteristics of these beds are fairly constant throughout the state. While they are not of themselves sufficient for identification in the absence of fossils, in well sections where the Maquoketa and Saint Peter are present the group is identified with certainty, although its component formations may not be clear.

The cavernous nature of the Galena and the numerous powerful springs which issue from it at its juncture with the Decorah shale along its outcrops, suggest the fact that it is an important water bed, but that the circulation of ground water in it is through irregular and unpredictable solution channels and not in sheets.

Among the older wells such irregular waterways in the Galena were struck at Clinton, Davenport, Fort Madison, Sumner, Osage, Mason City, Hampton, Pella, Grinnell and Holstein. To this list are now added Algona, Calmar, Donnellson, Van Horne and Webster City. At Calmar, Donnellson, Mason City and Iowa City the Galena-Platteville furnishes the main supply.

GLENWOOD FORMATION

In the Geology of Allamakee County Calvin[5] described as a basal shale of the Trenton a shale five or six feet thick resting conformably on the Saint Peter sandstone. Later, in his survey of Winneshiek county, Calvin[6] found this shale more fully developed. He gave it a formational name from Glenwood township, where it reaches a thickness of 15 feet, and because of streaks and bands of sand of Saint Peter facies which it contained he classified it along with the Saint Peter sandstone as a formational member of the Saint Peter stage.

5 Calvin, S., Iowa Geol. Survey, vol. IV, pp. 73, 74, Des Moines, 1895.
6 Calvin, Iowa Geol. Survey, vol. XVI, pp. 61, 74, Des Moines, 1906.

Leonard[7] in his report on the geology of Clayton county finds this shale but 2 or 3 feet thick and nonarenaceous. He classifies it as the basal shale of the Trenton.

Norton, in his report on the Underground Water Resources of Iowa,[8] describes the Glenwood shale as widely distributed over the state. It is included in the Platteville formation, since from the point of view of the driller of deep wells it seemed best to retain the term *Saint Peter* in its most restricted sense and in well sections at a distance from the area of outcrop heavy shales above the Saint Peter sandstone might include the equivalents of the Decorah shale and of the Platteville limestone, there become predominantly shaly. Yet it is stated that ''if studied in the field some of these arenaceous transition beds would be classified with the Saint Peter''.

For the same reasons in the present investigation the Glenwood is placed with the Platteville, the Decorah and the Galena. If the sand which it carries in places aligns it with the Saint Peter the clay which is its constant constituent relates it to the Platteville, which in its lower beds has a tendency to become argillaceous.

The Glenwood probably has some economic value as a containing bed for the sandstone aquifer on which it rests. It forms a trusted marker as a member of the unique sequence of the Platteville earthy limestone, the hard dark green shale of the Glenwood, the clean sand of the Saint Peter and the dolomites of the Prairie du Chien.

In the deep well sections of northeastern Iowa the Glenwood has about the thickness of its outcrops. At Decorah, Monona, Calmar, Manchester, Waverly and Sumner its thickness does not exceed 10 feet. At Frederika the driller's log reports at this horizon 8 feet of ''gumbo'' overlain by 32 feet of ''blue shale'', probably in part Platteville.

To the west, in north-central and northwestern Iowa, the formation either thickens or merges with a shaly Platteville, perhaps also with the Decorah shale. At Charles City the shale overlying the Saint Peter sandstone is 73 feet thick and the up-

7 Leonard, A. G., Iowa Geol. Survey, vol. XVI, p. 251, Des Moines, 1906.

8 Norton, Iowa Geol. Survey, vol. XXI, pp. 82-84, Des Moines, 1912.

per layers of the sandstone apparently are somewhat argillaceous. At Osage and Hampton a thickness of about 40 feet is maintained, while at Mason City the shales immediately above the Saint Peter reach a thickness of 90 feet, including a thin bed of limestone. At Algona the driller's log records at this horizon shale 112 feet thick with three streaks of limestone aggregating but 11 feet. At Emmetsburg these shales are 95 feet thick and at Cherokee they may reach 50 feet. At Holstein (p. 225) there is an interesting succession of 90 feet of argillaceous dolomites, sandstone, shale and limestone.

In east-central Iowa the Glenwood is thin—10 feet or less—at Clinton, Maquoketa and Anamosa and is absent or unreported at Green Island, Cedar Rapids, Tipton and Vinton. At Oakdale the Glenwood is separated from the Saint Peter by a thin bed of limestone. At De Witt, where it is 13 feet thick, it consists of sandstone with inflammable oil shale overlying the typical green shale of its outcrops. At Bettendorf the Glenwood includes 15 feet of sandstone and 15 feet of subjacent shale. The same succession is reported by Udden at Rock Island.[9] At Sabula 25 feet of limy, clayey sandstone is parted from the clean sandstone of the Saint Peter by 25 feet of green fissile shale. At Letts the same succession lies within the limits of 30 feet.

In central Iowa the Glenwood is thin at Des Moines and Van Horne. At Grinnell it includes a thin basal bed of limestone. At Jefferson, Ames, Ackley, Webster City, Fort Dodge, Rippey and Gowrie its thickness lies between 25 and 35 feet. At Boone the place of the Glenwood in the stratigraphic column is occupied by 50 feet of shale arenaceous at base and with a thin layer of sandstone 15 feet from the top.

In southeastern Iowa the Glenwood is arenaceous or includes an upper layer of sandstone at Morning Sun, Winfield, Brighton and Washington. At Sigourney it is absent and at Donnellson it is represented only by a thin dolomitic sandstone. At Centerville it is 10 feet thick and contains no sand.

In west-central and southwestern Iowa the shales overlying the Saint Peter attain something of their thickness in north-central Iowa. At Denison and Audubon this body of shale is 80

9 Udden, J. A., Some Deep Borings in Illinois: Illinois State Geol. Survey, Bull. 24, p. 62, Urbana, 1914.

feet thick, including at Denison a bed of limestone not more than 10 feet thick and parted from the Saint Peter by a layer of limestone which comes within the same measure. At Stuart the Saint Peter is overlain by three beds aggregating 16 feet—a highly calcareous shale, a fine dolomitic sandstone of rounded grains, and at bottom a very sandy, limy shale. Sixty-four feet higher occurs a 5 foot bed of dark green shale with rounded grains. Some sandy shales are found also at several lower levels in the midst of limestones of Platteville facies. If these samples are authentic the shaly beds which represent the Glenwood may reach the thickness given the formation at Audubon and Denison.

SAINT PETER SANDSTONE

The Saint Peter sandstone is not only an important water bed, it is also a most valuable marker on account of its lithologic peculiarities as a clean soft sandstone of rounded and frosted grains. It underlies the entire state excepting a small area in the northwest which extends at least as far south as Inwood and, judging by the Worthington, Minnesota, deep well section (p. 366), as far east as Osceola county. In the northeastern corner of the state it stands at an elevation of about 1200 feet above sea level on the high divides between Upper Iowa and Yellow rivers. Gradually it sinks to the southwest until in a drill hole section at Nebraska City, opposite the southwestern corner of the state, it was identified in 1912 by the writer at 1853 feet below sea level. To the east of Nebraska City it probably lies still deeper and in the southwestern counties of Iowa the Saint Peter and the water beds below it are quite too far below the surface for profitable exploitation.

Because of the easy recognition of the Saint Peter and its statewide extent a contour map is inserted (Plate I) showing the probable elevation of its surface above sea level. Where the elevation is highly hypothetical the contours are drawn with broken lines. The data on which the map is based are the logs of hundreds of wells, and although the accuracy of the map can not exceed the accuracy of the data, it is believed that it will be found helpful. It must be remembered, however, that the map is based necessarily on the assumption that the dip of the formation between two given points is constant. Local upfolds and downfolds which find no surface expression can not be predicted in advance of the drill.

The Saint Peter is a fairly reliable water bed. Yields are reported from it at Brighton, Gowrie, Donnellson, Fort Dodge, Morning Sun, Orange City, Oakdale, Van Horne, Washington and Waterloo. The Saint Peter seldom furnishes the main supply and it is usually advisable to drill deeper to tap the more copious flows of lower water beds.

Basal Beds of the Saint Peter.—Normally in Iowa both at outcrops and in well sections the clean white sands of the Saint Peter rest directly on the dolomite of the Prairie du Chien. In several wells, however, the drill has struck at the base of the Saint Peter sandstone of normal type anomalous beds—chert conglomerates, red shales and red sandstones of special importance to the driller because of their exceptional facility in caving. To the geologist these basal conglomerates and other residual materials produced by the secular decay of the Prairie du Chien dolomites are of interest since they are records of a long erosion interval between the Prairie du Chien and the Saint Peter.

In the study of Iowa well sections these anomalous deposits were first noticed in Holstein city well no. 1. Here the beds below the Saint Peter sandstone include caving red and green shale and chert, with dolomite and sandstone and marl, either in distinct layers or as pebbles and matrix of a conglomerate. The thickness is undetermined but can hardly exceed 255 feet and probably is much less. For in city well no. 2 drilled 160 feet from well no. 1 the beds below the Saint Peter are quite normal and no caving material was encountered. The red shale and chert of well no. 1 are to be construed as a lenticular deposit and, if thick, as fill in a steep-sloped valley.

The section in well no. 1 from the base of the Saint Peter at 1485 feet to 1740 feet, where we have a bed of plastic blue shale resting on glauconiferous marl referred to the Saint Lawrence (Franconia beds) is described as follows:[10]

[10] Norton, W. H., Underground Water Resources of Iowa: Iowa Geol. Survey, vol. XXI, pp. 1006 and 1048.

Limestone (?) marly, arenaceous; described by driller as a "sandy rock which wears the drill; sand grains brought up in slush bucket; other drillings very light and float up in water; rock drills about one foot an hour, and does not cave" 1485–1520
Shale, red; "at about 1520 red marl was coming in and could not tell much about the formation from there down to 1890 feet as it was caving very badly all the way and caved more or less from there down to 2000 feet" 1520
Sandstone, fine-grained, blue-gray, dolomitic cement 1575
Sandstone and dolomite; quartz sand, considerable red shale and some green shale from above, and a little gray siliceous dolomite..1670
Chert, dark reddish brown, ferruginous, in small chips, arenaceous with minute particles of crystalline quartz; as similar chert and reddish argillaceous powder are found in nearly all the drillings below, this may have fallen in from 1520 1700
Sandstone and chert; sandstone fine-grained, in detached grains of clear quartz, many imperfectly rounded, and minute white cuttings showing quartz particles in dolomitic cement; chert, dark brown, ferruginous, dolomitic 1720

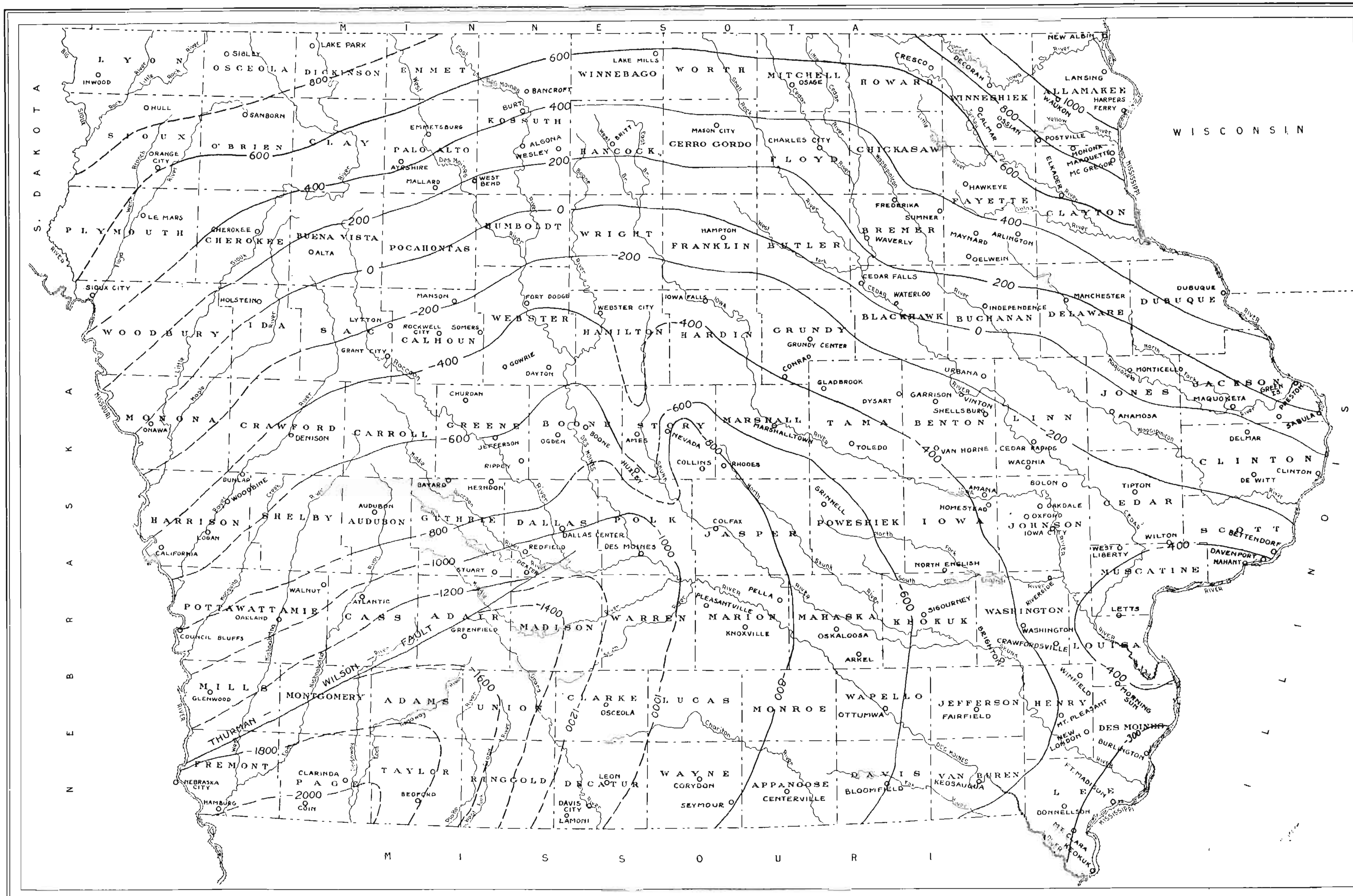
A prospect hole drilled in 1907 near Maquoketa afforded more satisfactory evidence of the nature of these anomalous beds beneath the Saint Peter sandstone, and here these beds were interpreted by the writer as continental deposits recording an unconformity.[11] The record of these beds and of a sample of cuttings of dolomite beneath them, referred to the Oneota, is as follows:

Sandstone, fine, brick red, considerable red argillaceous or ferric admixture; when washed in hot water drillings remain pink owing to the films of ferric oxide on grains of quartz sand; grains rounded, many broken; sand said by driller to contain seams of red shale; in log "red sandstone" 815–1056
Dolomite, light yellow gray, with much dark red and dark brown hard fine-grained shale; some light green shale; a fine yellow quartz sand; a fragment of red fine-grained sandstone set with pieces of green shale; all except dolomite probably foreign, at....1056

From the sample taken at 1056 feet it seemed clear to the writer that the drill was here working in dolomite, but the material assumed to have fallen in from the continental deposits above is also noteworthy, especially the fragment of red sandstone set with pieces of shale. This fragment is quadrate, its diagonal diameter 2 cm., and the sandstone incloses as a matrix a central mass of shale with bent and broken laminæ about its edges. The sample of the cuttings also furnishes a piece of laminated green shale in which two laminæ each about 2 mm. thick inclose a lamina of the same thickness of white sandstone.

While only one sample was supplied of the entire 241 feet described as "red sandstone with seams of shale" it was noted[12]

11 Norton, W. H., op. cit., p. 496.
12 Norton, W. H., op. cit., p. 79.



Map of Iowa showing contours at top of Saint Peter sandstone, and the location of deep wells and borings. By W. H. Norton. Figures show estimated elevation in feet above or below sea level. Contour lines in dashes are hypothetical.

that "the log was made out with unusual care by the foreman in charge of the work" and that an inspection of the slush piles after the well was nearly completed "showed so large an amount of the red sandstone as to give much support to the statement of the log."

A number of instances on record of similar red deposits discovered at this horizon in deep wells were cited: in Minnesota reddish deposits of limestone in a well at East Minneapolis and in one at the West Hotel[13] and in Illinois red marls at Lake Bluff and Winnetka,[14] Joliet,[15] Moline and East Moline.[16]

The basal beds of the Saint Peter shown in some deep well sections are inconspicuous or wanting in the Iowa area of outcrop. Yet Trowbridge[17] has observed that "in several places, notably in the vicinity of Church, the basal portion of the Saint Peter sandstone contains fragments of chert which came from the Prairie du Chien dolomite". Trowbridge also notes two phases of the Saint Peter in Iowa, an upland phase and a valley phase, the latter "highly and variously colored" as at Pictured Rocks, McGregor, and he goes on to say that "these differences within the formation are due doubtless to the different conditions which existed in the valleys and on the divides during the early part of the Saint Peter stage".[18]

In the states adjoining Iowa on the north, east and south the differences between the basal beds of the Saint Peter and its normal facies have been noted by a number of observers. Reference has already been made to typical well logs in Illinois and Minnesota. In Missouri, the basal member of the Saint Peter group, as described by Dake, the Everton, consists of an upper limestone and a lower group of sandy beds including a basal conglomerate of chert pebbles and sometimes of dolomitic pebbles as well, all in a sandy matrix. In one section this conglomerate is 10 feet thick.[19] Dake in commenting on Norton's interpreta-

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13 Hall, C. W., Bull. Minnesota Acad. Nat. Sci., vol. 3, p. 139.

14 Stone, Leander, Bull. Chicago Acad. Sci., vol. 1, p. 96.

15 Leverett, Frank, Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 2, p. 799.

16 Udden, J. A., ibid, p. 848.

17 Trowbridge, A. C., The Prairie du Chien-Saint Peter Unconformity in Iowa: Proc. Iowa Acad. Sci., vol. XXIV, p. 180, Des Moines, 1917.

18 Trowbridge, op. cit., p. 181.

19 Dake, C. L., Problem of the Saint Peter Sandstone: Bull. Missouri School of Mines, vol. VI, no. 1, p. 16, Rolla, 1911.

tion of the Maquoketa red sandstone as a continental deposit states that "this solution is also directly in line with the presence of red residual soils discovered by the writer at the base of the Saint Peter sandstone in Missouri."[20]

In Wisconsin, both Chamberlin and Wooster early noted at the base of the Saint Peter, conglomerate, chert and kaolinic masses.[21] Alden in 1918 recorded 12 deep wells in which red marl, red shale, red sandstone, grey and red chert occupy this horizon.[22] He also states that "at very many places throughout the belt of outcrop * * * there are small exposures of reddish, purplish, bluish, greenish or white clayey shale or sandy shale at or near the contact between the limestone and the overlying sandstone". "At Albany in Green County 3 to 5 feet or more of this loose chert was seen occupying a rounded and weathered surface of the limestone and underlying the undulating basal layers of sandstone, in whose lowest layers fragments of chert were included".[23] Referring to the red sandstone Alden notes that "at what exposures there are it differs from most of the Saint Peter formation in that infiltration of silica-bearing waters has led to the rejuvenation of a large part of the quartz crystals * *".[24]

In the Tomah and Sparta quadrangles, Wisconsin, Twenhofel and Thwaites[25] found that the basal parts of the Saint Peter involve "a variable thickness of red and green noncalcareous shales and fine-grained shaly yellow sandstones". "At any place where the base of the Saint Peter was observed it rests on a residuum of red clay and chert which is altogether without stratification. This residuum was derived from the weathering of the Oneota and possibly higher formations. In this article this unstratified material is assigned to the Saint Peter, although it developed during the time of erosion which intervened in this area between the Oneota and the Saint Peter and thus might be considered a distinct formation."

To the evidence from outcrops Thwaites has added that de-

20 Dake, op. cit., p. 68.

21 Geol. of Wisconsin, vol. 2, p. 287; vol. 4, p. 129.

22 Alden, W. C., Quaternary Geology of Southeastern Wisconsin: Prof. Paper no. 106, U. S. Geol. Survey, p. 79.

23 Alden, ibid, p. 81.

24 Alden, ibid, p. 82.

25 Twenhofel, W. H., and Thwaites, F. T., Journ. Geol., vol. XXVII, pp. 632-633, 1919.

rived from deep well sections.[26] In summation he states "The Saint Peter is dominantly a light gray * * * * * sandstone; below the sandstone are beds of purplish red and green shale, interstratified with layers of white disintegrated chert, and conglomerate with chert and limestone pebbles in a matrix of fine to coarse sand. These basal beds cave very badly in wells and must be cased off. At Shullsburg, Wisconsin, Galena, Illinois, and elsewhere they are a very difficult horizon to penetrate with the drill. The caved material mixes with cuttings from lower horizons making some records very hard to interpret." Again, speaking of the base of the Saint Peter Thwaites remarks, "The shales at this horizon are virtually all noncalcareous and appear to be more or less oxidized residuum from the underlying dolomites. The chert beds and conglomerates represent assortment of residual deposits by water."

Thus it appears that in Iowa as well as in Minnesota, Wisconsin, Illinois and Missouri the Saint Peter sandstone of normal type is underlain in places by beds largely made up of residual materials, the product of secular rock weathering and erosion of earlier formations and resting on an erosion surface of considerable relief. At least in part these materials may be regarded as continental deposits, such as valley fill, and color and oxidation, together with the apparent presence of pebbles of dolomite in the conglomerates, suggest accumulation under conditions of aridity. In deep well sections it is impossible to say to what extent such materials have been reworked by a transgressing sea.

To the writer it seems that these basal beds deserve to be distinguished from the Saint Peter by a formational name, both on account of their lithologic difference and the time and manner of their deposit. At least such a distinction would subserve the interests of well drillers and of geologists who deal with deep well sections, and it is hoped that an outcrop of the formation may be found which will supply a suitable name.

In the present report two additional deep well sections of these anomalous deposits are given, Preston and De Witt, both in northeastern Iowa and not far from the Maquoketa oil prospect. At Preston the Saint Peter sandstone of normal facies is under-

[26] Thwaites, F. T., Paleozoic Rocks Found in Deep Wells of Wisconsin and Northern Illinois: Journ. Geol., vol. XXXI, p. 529 et seq.; 1923.

lain by basal deposits, 365 feet thick, described by the driller as red sandstone, red shale, and clay and sand, which cut out entirely the Prairie du Chien formation.

At De Witt, the Saint Peter sandstone has an abnormal thickness of 223 feet and is underlain by 295 feet of conglomerates, red sandstones, red and green shale which extend to some depth into the Trempealeau. Detailed description will be found on pages 172 to 176. While some doubt exists as to the thickness of these basal deposits, because of extensive caving, there is no question that at both localities, as at Maquoketa, the drill was working in deep basal beds of the same nature as those of the outcrops in Wisconsin.

CAMBRIAN SYSTEM

The Cambrian rocks outcrop in but three counties of northeastern Iowa and their deeper strata are nowhere exposed to view, so that necessarily the first accounts of this great body of rock were incomplete. In the report on the geology of Allamakee county Calvin in his synoptic table recognizes only the Saint Croix stage of the Cambrian system, without any formational subdivisions. "The whole assemblage of Cambrian strata, so far as Iowa is concerned, represent continuous deposition under practically unchanged conditions."[27] Yet he identifies the equivalents of the Jordan sandstone and the Saint Lawrence limestone as defined by Winchell in Minnesota.

Norton in his first paper on the deep wells of Iowa[28] finds the succession of a sandstone, termed by him the upper Saint Croix, and dolomites, shales and sandstone, termed the lower Saint Croix. In his report on the Artesian Wells of Iowa,[29] however, Norton subdivides the Cambrian of Iowa in descending order into the Jordan sandstone, the Saint Lawrence dolomite and shales, and the Basal sandstone, the latter term including the Dresbach sandstone of the Minnesota geologists "with the unnamed shale beneath it and the Hinckley sandrock and the unnamed red shales and red sandrock beneath it" to the summit of the Algonkian.

27 Calvin, Geology of Allamakee County: Iowa Geol. Survey, vol. IV, p. 60, Des Moines, 1895.

28 Norton, Thickness of the Paleozoic Strata of Northeastern Iowa: Iowa Geol. Survey, vol. III, pp. 169-210.

29 Norton, Iowa Geol. Survey, vol. VI, pp. 140-142, 1897.

In the reports on Winneshiek and Clayton counties Calvin,[30] and Leonard[31] recognize the Jordan sandstone, the only Cambrian formation outcropping in the counties, and Leonard in his deep well sections follows the classification used by Norton as to the deeper Cambrian strata.

In his report on the Underground Water Resources of Iowa Norton[32] discards the term "basal sandstone," recognizes the Dresbach as the first clean sandstone below the Saint Lawrence dolomites and shales, and leaves undifferentiated the Cambrian strata below the Dresbach. It was noted, however, that these undifferentiated beds comprise two divisions in several well sections, as those at Dubuque, Manchester, Anamosa and Tipton, viz., upper marls or sandy and limy shales, and heavy underlying sandstones.

This historic resumé shows that Iowa geologists, not venturing to propose names for recognized formations without outcrop in their state, have adopted from time to time the nomenclature of geologists of adjacent states where these formations occur as country rock.

It now seems well to follow this precedent and designate the upper dolomitic beds of the Saint Lawrence dolomite and shales as the *Trempealeau* and the lower shales and shaly sandstones as the *Franconia*. The clean sandstone below the Franconia beds is already known as the Dresbach. The beds below the Dresbach so far as they are characterized by shales and shaly or dolomitic sandstones are now known as the *Eau Claire,* while the cleaner sandstones beneath are now termed the *Mount Simon.* In Minnesota the Saint Croix series is underlain by the Hinckley sandstone and the Red Clastics of Hall and Meinzer. Evidence that the latter formation is Middle Cambrian has recently been offered by Stauffer.[32a]

JORDAN SANDSTONE

The Jordan sandstone remains one of the chief aquifers of the Iowa artesian field. Of the wells listed in the present report

30 Calvin, Geology of Winneshiek County: Iowa Geol. Survey, vol. XVI, p. 62, Des Moines, 1906.

31 Leonard, Geology of Clayton County: Iowa Geol. Survey, vol. XVI, p. 237, Des Moines, 1906.

32 Norton, Iowa Geol. Survey, vol. XXI, 1912.

32a Stauffer, C. R., Bull. Geol. Soc. of America, vol. 38, p. 469 seq., 1927.

those of Algona, Bettendorf, Charles City, Delmar, Dubuque, Garrison, Grinnell, Hampton, Oakdale, Preston, Shellsburg, Stuart, Van Horne and Waukon found this formation water bearing.

Yet it must be said that the Jordan sandstone in places is so well cemented, so dolomitic, that its capacity as a water sand is slight or nil. At Waterloo it is highly dolomitic in its basal beds. Yet it was here in city well no. 1 that the main flow was found, perhaps in crevices. Much the same conditions prevailed at Shellsburg. At Oelwein the Jordan was found dry in the city well. In the well of the Chicago Great Western Railroad most of the water was found below the Saint Peter, but the exact horizon is unknown. At Washington, in city well no. 5, the Jordan is not reported as a water bed. At De Witt the Jordan sandstone is cut out by unconformity and apparently it yielded little at Nevada and Ogden.

In western Iowa, at Holstein, this formation is dubiously represented by a sandstone not more than 20 feet thick and it is unrecognized at Sioux City.

TREMPEALEAU DOLOMITE

The Trempealeau formation is rarely water bearing. Yet where its dolomites are sufficiently pure and the circulation of underground water favors, it may contain solution channels, such as are much more commonly found in the dolomites of the Prairie du Chien. The Trempealeau is reported as a water bed at Dubuque, at Washington and with some doubt at Waterloo. In eastern Iowa when sufficient water is not obtained above the Trempealeau, drilling may well be carried through it to the glauconitic shales and marls of the Franconia.

FRANCONIA BEDS

The shaly beds of the Franconia are well demarked in the wells which reach their depth, but they are seldom pierced through except in eastern Iowa, especially in the Mississippi valley where the Dresbach and Mount Simon sandstones are the objectives.

The Franconia forms a valued marker, with its greensands rich in glauconite, with its "marls," whose large quartzose constituents may be too fine to polarize with the usual brilliant colors of quartz—ambiguous beds which Winchell has well described as "greenish and shaly and yet not a shale, calcareous and not a limestone, magnesian but not a dolomite, finely siliceous but not a sandstone."[33]

The Franconia is thus identified at Waukon, Marquette, Dubuque and Bettendorf, De Witt, Delmar, Nevada, Grinnell, Ogden and as far west as Algona, Holstein and Sioux City. At Holstein, however, it is not demarked from similar beds of the Eau Claire as the Dresbach sandstone is here absent. In the deeper wells of the state listed in earlier reports the division of the Saint Lawrence between the Trempealeau dolomite and the Franconia shales is clearly made out for the most part, as in deep well sections at Anamosa, Clinton, Manchester, Mason City, Sumner, Tipton and Waverly. At Boone, where the Jordan apparently is absent, it is difficult to draw the line between the Prairie du Chien, which begins at 1900 feet, and the Trempealeau, which probably ends at 2425 feet, where the glauconitic beds of the Franconia appear. These glauconitic beds continue to 2840 feet, where clean sandstones come in which may be assigned to the Dresbach. At 2900 feet shales were struck, perhaps the EauClaire, which continue to the bottom of city well no. 2 at 2914 feet. But the red marls and shales reported by Beyer at the bottom of well no. 1 at 3000 feet lend some color to the classification of the beds below 2840 feet as Mount Simon. In that case the series of glauconitic shales, marls and sandstones from 2425 feet to 2846 feet embraces both the Franconia and the EauClaire, the Dresbach being absent as at Holstein.

At Des Moines the clean Oneota dolomites give place at 2418 feet to the Jordan sandstone. The lower limit of this sandstone is in some doubt but its thickness probably does not exceed 40 feet. The glauconitic beds of the Franconia begin at 2565 feet and similar beds with marls continue to the bottom of the well at 3000 feet. The deeper Cambrian sandstones either were not reached or have feathered out. The thickness of these glauconitic beds and marls, 435 feet, favors the supposition that they in-

33 Winchell, N. H., Geol. and Natural Hist. Survey of Minnesota, vol. i, p. 255, 1884.

clude both the Franconia and the EauClaire, and that the Dresbach is here absent.

DRESBACH SANDSTONE

The clean sandstones of the Dresbach make it a dependable water bed along the Mississippi at least as far south as Davenport. At New Albin it is cut away by the old channel of Mississippi river. At Marquette it yields bountifully. At Decorah, in the oil prospect drill hole, the Dresbach is pretty clearly marked in the driller's log. At Dubuque, Clinton and Bettendorf it produces generously. It is water-bearing at Delmar and De Witt.

West of the counties bordering Mississippi river it usually has not been necessary to drill as deep as the Dresbach sandstone. At Manchester it was found to be 152 feet thick, at Anamosa 180 feet, where it is recorded as the softest sandstone in the well, and at Tipton 150 feet thick. It was also gone through at Cedar Rapids in city well no. 1, but the records of the well do not discriminate the formations below the Jordan. From none of these wells is the Dresbach reported as water-bearing. If any flow was secured from it, it was unnoticed either because of having the same static level as flows from higher beds, or for other reasons.

The Dresbach is 30 feet thick at Algona, but there is no evidence of its presence at Holstein, and its place is uncertain at Des Moines and Boone. At Nevada the water-bearing sandstone at the base of the section may be the westward extension of the Dresbach.

EAU CLAIRE BEDS

The Eau Claire resembles the Franconia in texture and constituents, although with less glauconite, and may be expected to be dry. Yet crevices or exceptionally clean sands within it may yield water, as at Bettendorf.

MOUNT SIMON SANDSTONE

The Mount Simon furnishes the supply of the New Albin wells and at several levels yields generously to the deeper wells at Dubuque. At Clinton, where it was penetrated in city well no. 6, it furnishes a phenomenal supply. At Rock Island (Mitchell and

Lynde Building), the driller's log indicates, the Mount Simon was penetrated some 97 feet beginning at 2185 feet from the surface. In his generalized section of Rock Island and vicinity, Udden[34] states that this sandstone is water-bearing.

But of the Mount Simon as of the Dresbach it must be said that it is seldom advisable to drill to its depth except in the immediate valley of the Mississippi or the counties bordering upon it.

RED CLASTICS

These beds and the Archeozoic granites and schists on which they rest have been penetrated by the drill at a few localities since the preparation of the report of 1912 on the Underground Waters of Iowa. As was to be expected they were found dry.

SALT POOLS IN THE CAMBRIAN

Local pools of saline water are found rarely in the Cambrian strata of Iowa. In the northeastern district 27 wells footing in the Cambrian, excluding two wells at McGregor, have, according to Hendrixson's report of 1912, an average chlorine content of only 17.4 p.p.m. But a local pool at McGregor tapped by city well no. 2, apparently in the Eau Claire sandstone, gave its water 968 p.p.m. of chlorine and at Prairie du Chien salt water was found at about the same reported depth.

In the three deep wells at and in the vicinity of Lansing chlorine rises to an average of 59.7 p.p.m. This amount, although inconsiderable from the point of potability, is markedly high when compared with the average of the Cambrian waters of the district.

In north-central and northwestern Iowa Cambrian chlorine remains low: e.g. at Mason City 23, at Charles City 0, at Algona 9, at Holstein 12 p.p.m. In this area the chlorine of the Manson well, 206 p.p.m., is as exceptional as is its chemical analysis as a whole and its geological section also. The Manson well, however, does not enter Cambrian rocks.

In the east-central district the stratigraphically deepest well, that at Tipton, drilled 1240 feet below the top of the Cambrian,

34 Udden, J. A., U. S. Geol. Survey, 17th Ann. Rept., pt. 2, p. 842.

has but 2 p.p.m. of chlorine. Wells at Anamosa and Vinton, footing deep in the Cambrian, carry but 1 and 15 p.p.m. Grinnell, Homestead and Belle Plaine also are low in chlorine—34, 33 and 7 p.p.m.

At Cedar Rapids salt and heavily mineralized water is found at some point below 1450 feet, the base of the Jordan, but the Jordan and upper waters have a chlorine content of only 0,4 to 14 p.p.m.

In the Davenport area, however, lies a Cambrian pool of saline water of great importance, which will be described in detail later.

In southeast Iowa the percentage of chlorine in the deeper well waters is higher than in the districts mentioned, but in no case does it reach any marked concentration. Here the Cambrian water is in many cases less saline than that from upper horizons. At Burlington the park well, 2430 feet deep, has 161 p.p.m. of chlorine while wells in the city about 500 feet deep contain about 275 p.p.m. At Washington the city well reaching the Saint Lawrence contains 71 p.p.m. of chlorine, while another reaching only the Saint Peter contains 123 p.p.m. At Ottumwa the deepest well has a chlorine content of 119 while a mineral spring from the Mississippian has 533. The Keokuk wells, about 700 feet deep, are high in chlorine—632 to 674 p.p.m., but they draw their water from above the Saint Peter.

The deepest wells of central, south-central and southwestern Iowa show a moderate but by no means an excessive salinity. The wells about 3000 feet deep at Boone and Des Moines carry 128 and 124 p.p.m. The Mississippian and Pennsylvanian may yield water much saltier than the Cambrian. Three wells less than 800 feet deep, at Flagler, Knoxville and Pella, have a chlorine content of 925 to 1803 p.p.m. Deep wells in southwest Iowa penetrating the gypsum-bearing beds attributed to the Salina show an exceptional amount of salt—at Glenwood 282 and at Bedford 1420 p.p.m. At Bedford, however, a still saltier water with 2545 p.p.m. of chlorine was found at 1300 feet at the base of the Coal Measures.

Salt Water in the Davenport Artesian Field.—It has long been known from chemical analyses that the artesian waters of Davenport, Moline, Rock Island and their satellite towns contain a comparatively high percentage of common salt, although by no means enough to make them unpalatable or injurious. Of the six Davenport wells whose analyses are given in volume XXI of the Iowa Geological Survey the average chlorine content is 307 p.p.m. and the range is from 272 to 396 p.p.m. Well no. 2 of the Bettendorf waterworks showed on completion in 1925 391 p.p.m. and the Davenport swimming pool well on completion in 1922 showed 363 p.p.m. Wells at Moline and East Moline whose analyses are at hand show a range of 250 to 322 p.p.m. in chlorine.

The formations in which these wells foot range from the Galena to the Eau Claire, and the high percentage of salt is confined to no single aquifer. In fact the highest percentage in the analyses made before 1926 is found in a well footing in the Saint Peter.

At Silvis, Illinois, however, a well 1987 feet deep penetrating the Dresbach or below gave on completion in 1912 a somewhat higher chlorine content, 550 p.p.m. This amount, as stated by the analyst of the Illinois Department of Public Health, "might give the water a slightly salty taste but would not affect its sanitary quality".

In June, 1928, the Bettendorf Water Company informed this office that the water of well no. 2, drilled in 1925, had changed for the worse and was also injuring the water of their well no. 1, with which it communicates through porous strata. It was the inference of the company's officials that the change had not been a gradual one, but "must have come in all at one time". An analysis showed that the chlorine content had risen from 391.7 to 889.0 and the sodium chloride content from 553.82 to 1441.157 p.p.m. The common salt had risen 2.6 times and the total solids had nearly doubled. It now became necessary to cut off the highly mineralized water. The well was filled to the depth of 25 feet. A preliminary analysis indicated that the total mineral content was reduced from 2284 to about 1900 p.p.m. The well was then filled to 50 feet from the original bottom. The results are shown in the table below. The sodium chloride had now been reduced nearly one-half and the sulphate radicle more than one-third. But this betterment in quality had been purchased at high cost in quantity. The pumping capacity with the centrifugal pump in use had been reduced from about 400 to 150 g.p.m.

Analyses of Bettendorf Waterworks Well No. 2

Constituent	1925*	1928†	1928 After filling 50 feet†
	Parts per million		
Silica	16.00	....	5.8
Oxides of Fe and Al	4.40	0.60 (Fe ion)	12.20
Potassium	....	17.38	23.58
Sodium	321.80	617.92	332.52
Calcium	50.80	147.75	82.04
Magnesium	45.20	17.12	27.25
Chloride radicle	391.70	889.0	480.0
Nitrate radicle	00.00	0.6	0.1
Sulphate radicle	194.50	360.22	213.18
Carbonate radicle	192.50	0.0	0.0
Bicarbonate radicle	90.00	302.56	309.88
Total solids	1245.		
Total hardness gr.p.gal.	16.85		
Hypothetical combinations			
Magnesium carbonate	155.89	....	....
Calcium carbonate	126.89	....	....
Sodium carbonate	10.84	....	....
Sodium sulphate	287.64	158.471	111.951
Sodium chloride	553.82	1441.157	756.678
Potassium nitrate	....	.989	.162
Potassium chloride	....	32.423	44.859
Ferrous bicarbonate	....	1.910	....
Magnesium sulfate	....	84.758	134.911
Calcium sulfate	....	262.172	41.940
Calcium bicarbonate	....	285.606	282.081
Silicon oxide	....	6.500	5.8
Ferric oxide	....	....	.43
Aluminum oxide	....	10.340	11.77
Total solids		2284.326	1390.58

It will be noted that the filling of the well proved that the main flow came from below the Dresbach sandstone and considerably deeper than had been reported on the completion of the well.

This rapid and ruinous change in the Bettendorf well was unprecedented in the history of the wells at Davenport, some of which had been used for 40 years. Up to this time new wells, although drilled to maximum depth, had failed to disclose any saltier waters than earlier and shallower wells had tapped. But clearly there lies in or below the Eau Claire beds a water entirely too salt to be potable. Heavy pumping at Bettendorf at

* Made by Chemist of the Bettendorf Water Co.

† Made in Chemical Laboratories of State University of Iowa by R. K. Lewis.

length disturbed the equilibrium between the heavy salt water of this pool and the fresher and lighter waters of the overlying strata. As the fresh water was drawn off the salt water rose under artesian pressure, perhaps broke through, into the higher water beds with ruinous results.

A similar increase in saltness is on record in the case of numbers of deep wells near the ocean. After long and heavy pumping the normal flow of fresh land water seaward is reversed and gives place to invading brine. The frequent rise of salt water in depleted oil pools is well known.

A slight increase in salinity is seen in the Davenport city swimming pool well. In 1922 the chlorine content was 363 p.p.m. according to an analysis by the Hygienic Laboratories at Iowa City. In 1926 this had risen to 423 p.p.m. according to the same analysts.

The city officials of Silvis, Illinois, supply some data as to the city well under date of August 27, 1928. After mentioning the fact that "A few months ago the Continental Ice Company put a deep well pump into it and it has been pumping steadily ever since", the mayor states: "It is the opinion of some that the water has grown saltier since it is being pumped constantly, but we have had no analysis made to determine if this is true". Analyses by the State Water Supply Division were also inclosed which show that the chlorine content changed from 550 p.p.m. in 1912 to 592 in 1918, 650 in 1923, and 620 in January, 1924, and 590 in February, 1924. The increase in total solids was more considerable.

At Canton, Illinois, deep well water shows an increase in chlorine from 245 p.p.m. in 1898 to 885 in 1924 according to the analyses of the Illinois State Water Supply Division in their Bulletin no. 21. The source of this more saline water, however, is not necessarily from below. Coal mine wells in the vicinity give chlorine contents as high as 1010 p.p.m.

It is clearly shown by the experience at Bettendorf that hereafter in the Davenport field wells should not be sunk below the Dresbach sandstone. If the invasion of saline water should continue or spread, wells may be limited to the Jordan and higher aquifers. Furthermore, the equilibrium between the salt and fresh water in the field should not be endangered unnecessarily by the continued leakage of unused wells.

It is an interesting question how far the salt pool at Davenport extends into Iowa. It cannot reach De Witt to the north, whose deep well shows but 39 p.p.m. of chlorine, or to Tipton to the northwest, where the chlorine content is only 2 of a well which was sunk far below the strata of the footing of the deepest wells at Davenport. To the south the chlorine curve falls to 161 p.p.m. at Burlington and to the west to 200 at Wilton and to 102 at West Liberty. (See also Nahant, page 267.)

By consulting the analyses of public supplies in Illinois* it is seen that the Davenport salt pool lies at the northwestern corner of a large area in Illinois in which artesian waters show considerable salinity. North of the latitude of Davenport, in Whiteside and Lee counties the chlorine content is as low as in northeastern Iowa, e.g. 7 p.p.m. at Morrison, 22 at Amboy, 3 at Sublette. But to the south of this favored area, as the Saint Peter sandstone dips to 500 and 1000 feet below sea level in Henry, Bureau and LaSalle counties, and the Pennsylvanian forms the country rock, the chlorine curve rises sharply, e.g. to 470 p.p.m. at Atkinson, 412 at Buda, and 322 at Oglesby, all drawing on Saint Peter water. These contents, it will be noted, are approximately the same as that of the Davenport wells with the same footings. The deep well at Aledo, Mercer county, footing 1205 feet below the top of the Cambrian, reached a salt pool and was plugged at 1450 feet, but the water still carries 439.7 p.p.m. of chlorine. In Henderson, Warren and Knox counties, where the Saint Peter apparently does not sink below 500 feet below sea level, its water ranges in chlorine from 155 p.p.m. at Abingdon to 259 at Stronghurst. But as the Saint Peter dips toward Illinois river the chlorine curve rises again to an exceptional maximum of 825 p.p.m. at Ipava.

Deep Wells As Oil Prospects

For the most part the deep wells of Iowa have gone through the formations in which there was any probability of finding oil, and have therefore served as prospect holes for oil and natural

* Buswell, A. M., Illinois State Water Survey, Bull. no. 21.

gas, as well as for other valuable minerals. The importance of this secondary service is suggested by an editorial some years since in a leading daily newspaper advising the legislature to sink drill holes 5000 feet deep in all parts of Iowa to discover the rich stores of oil, copper and other minerals which without doubt lay hidden beneath the prairies. Compared with such a project the sinking of the hundreds of deep wells of Iowa has been simple and inexpensive. As a rule they have gone deep enough—although the deepest of them hardly exceed 3000 feet—to find any mineral wealth there possibly can be, and they have been amply paid for by the water they deliver. Still more simple and inexpensive is the maintenance of the Geological Survey, which collects and collates the facts regarding these wells, including those which bear upon the presence or absence of valuable minerals in the rocks of the state.

As to copper and iron and the precious metals, the futility of prospecting for them in Iowa is shown by an elementary knowledge of the geology of the state. As to coal, the areas where it may be found have long since been mapped. But in the case of oil the conditions of its accumulation are such that each deep well sunk has had some value as a prospect hole for that locality. Oil and natural gas are found throughout the world in a number of geological formations from the Pleistocene back to the Cambrian, and several of these formations, elsewhere oil-bearing, occur within the limits of the state. Nor as a rule will the geologist affirm in advance of the drill that in any given locality all the other necessary conditions for the accumulation of oil and gas are wanting. These conditions may be briefly stated as (1) an oil producing rock as source, usually a shale, (2) a porous rock as reservoir, usually a dolomite or sandstone, (3) an upfold, dome, or lens which, with (4) an impervious cover commonly a bed of shale, forms a trap within which the hydrocarbons accumulate under the pressure of artesian waters.

As each deep well is drilled in Iowa it is carefully examined for the presence or absence of these conditions. Laboratory study of deep well cuttings shows that several formations include in various places thin beds charged sufficiently with hydrocarbons to be inflammable. While these shales prove that locally the processes of petroleum making and leaching have been arrested, they yet suggest the possibility that elsewhere the same beds may have given rise to oil and gas which may have been leached out into containers in the overlying rocks.

In the wells described in the present report the Kinderhook shale at Donnellson shows traces of hydrocarbons; the Maquoketa shale carries near its base an inflammable shale at Bettendorf, Fort Dodge and Winfield; and the Glenwood shale includes inflammable layers at Oakdale, where a similar shale occurs higher up in the Platteville formation. Such instances suggest that possibly at other localities in Iowa the Kinderhook, Maquoketa or Glenwood shales may prove to be rich sources whose oil has leached into oil pools in overlying reservoir rocks.

Several formations, as the Niagaran and Galena dolomites, are sufficiently porous to form adequate reservoirs for oil and gas. The discovery in a few well sections in southeastern Iowa of arenaceous beds at the base of the Niagaran, which represent the Hoing sands of the Colmar oil field of western Illinois, suggests a possibility that somewhere in the state these sands may yet be found of sufficient thickness for oil accumulation, and that all other conditions may concur. This possibility, however, is so faint, and the distribution of the Hoing sands even in the Colmar field is so discontinuous, that no encouragement is given to any prospecting of them by the drill.

Deep well drilling has also shown the wide extent of shales thick and impervious enough to form the necessary covers for oil reservoirs. Such are the Kinderhook, the Maquoketa and in some areas the Glenwood, and the shales of the Des Moines and Missouri group of the Pennsylvanian system.

In general, the lie of the strata of the state is proved by its deep well sections to be too uniform to favor the structures necessary for oil accumulation. Yet occasionally, as at Oakdale, Ames, and perhaps at Fairfield, the drill has found marked upwarps of the deeper beds.

The outstanding fact remains that of the hundreds of wells drilled in Iowa scarcely one has shown even a trace of oil. They may have shown some of the necessary conditions for oil accumulation, but never oil. This is in marked contrast with some oil prospect holes, which are said to have yielded a barrel or so of oil before they were abandoned. Most of these prospects have kept their geologic facts under impervious cover. In summation, deep well drilling in Iowa offers little encouragement for oil prospecting, although it points out various favorable conditions. The field in Iowa regarded by Howell[35] as the one area which merits in any degree a test for oil, viz., the extreme southwestern part, is the area least prospected by deep wells.

The relations of an artesian circulation to the accumulation of oil and gas are not entirely clear. But of two areas—one with a permanently vigorous circulation of sweet artesian water for urban supply, the other with rich oil pools, to be replaced after a brief period by salt water—the former certainly is in the long run preferable for human habitation.

Deep Wells and Other Municipal Supplies

Deep wells form but one of several types of municipal water supplies in use in Iowa. The supplies of the state are drawn from static waters—lakes and the artificial lakes known as impounding reservoirs; from the flowing waters of rivers and smaller streams; from ground water rising in springs or tapped by various types of wells at different depths and reaching various water beds.

But few lakes large and deep enough for town supply are found in Iowa. The state is largely covered by the older drift sheets, and over these areas the topography is so mature that the indices of infancy such as lakes have been outgrown, effaced. In contrast the neighboring states of Minnesota and Wisconsin, surfaced very largely with the younger drift, still linger in the lake stage and are able to supply their largest cities and many of the smaller towns with lake water.

Only seven Iowa municipalities draw their water supply from lakes, and the population thus served is less than 10,000.

Impounding reservoirs, collecting the run-off from limited areas, supply sixteen towns, with a total population of 55,470. But two of these towns have populations above 10,000. Three

35 Howell, J. V., Petroleum and Natural Gas in Iowa, Iowa Geol. Survey, vol. XXIX, p. 36.

other towns have populations between 10,000 and 3,000, while no town thus served has a population less than 1200. The larger cities seem to be excluded by the amount of water thus obtainable under Iowa conditions and the smaller towns and villages by the cost of installation and operation.

Ten Iowa municipalities, population, 176,220, draw directly on rivers. Among these municipalities are Burlington, Council Bluffs, Davenport, Keokuk and Ottumwa, whose aggregate population is 167,381. River supply is thus favored by the larger rather than by the smaller cities and towns.

One hundred and sixty-one municipalities, ranging in size from the largest city in the state to some of the smallest villages, use the ground water of the alluvial sands of present rivers or of ancient glacial streams—ground water to which in some cases river water contributes by seepage. Water is obtained by shallow dug wells of large diameter, infiltration galleries, and driven and drilled wells, commonly less than 100 feet in depth. Thus are supplied Boone, Des Moines, Iowa City, Marshalltown and Muscatine (aggregate population, 181,985), a group of 14 cities between 3,000 and 10,000 population (aggregate population 64,478), 42 towns between 1,000 and 3,000 population, and about 100 towns and villages of less than 1,000 population.

Common wells in drift or country rock serve a larger number of Iowa communities than any other supply. This is the favorite supply of villages and smaller towns and is used also by nine towns with populations ranging from 3,000 to 10,000 (total population, 45,000) and by 25 towns from 1,000 to 3,000. One hundred and forty-eight communities using this supply have a population of less than 1,000.

Deep wells, setting the minimum depth of this class rather arbitrarily at 300 feet, supply 125 municipalities. This group includes six of the larger cities, Sioux City, Dubuque, Cedar Rapids (in part), Waterloo, Clinton, Mason City and Fort Dodge, with populations ranging from 20,000 to 71,000 in round numbers, total population 255,451. This group also includes 13 towns from 3,000 to 10,000 population, and 47 towns between 1,000 and 3,000 population. While this supply is among those favored by large cities and towns, the villages are precluded from it by its cost.

The statistics just given do not indicate any universal preference for any single type of water supply. No type can unqualifiedly be said to be "the best," the most desirable. Even the large cities of Iowa divide their choices between deep wells, shallow wells and rivers. Each type has its disadvantages and its advantages, and ratios and preponderances vary with the locality. Thus deep wells have been abandoned for shallow wells and shallow wells for deep wells. River supplies have been superseded by both deep and shallow wells and vice versa. Wells of both types have been replaced by impounding reservoirs, and a town with an impounding reservoir is now attempting to replace it with a deep well. The problem of water supply is essentially a local one for each community to solve as best it can. There are no general formulæ, applicable to the entire state, which will solve it.

It remains to sketch briefly some of the various superiorities and defects of different supplies under Iowa conditions as shown by the experience of Iowa towns.

Lake supply.—The general advantages of lake supply are the clarity of the water, since the lake acts as a settling basin and besides is often fed by springs, the bacterial purity of the water of feeding springs, the constancy and adequacy of the supply, and the low cost of delivery. In many shallow lakes of Iowa with mud bottoms several of these advantages are absent, and the bacterial purity of feeding springs does not insure against contamination by feeding streams and run-off and the sewerage of hotels and settlements along the shore. Two of the six Iowa towns using lake water have found it advisable to pass it through filters.

Impounding reservoirs.—The Iowa towns making use of this supply are all situated in south-central and southwestern Iowa on areas of maturely dissected Kansan drift underlain by the Coal Measures. The problem of water supply is thus difficult. Wells in drift tapping the Aftonian interglacial sands and any pre-Nebraskan sands on rock are commonly inadequate for the larger towns. The country rock is usually dry. The Cambro-Ordovician aquifers lie too deep for profitable drilling. The quality of deep well water also is poor on account of heavy mineralization. River towns are left a choice between taking water directly from the stream or from shallow wells sunk in flood plain sands. Fortunately the valleys of the mature streams of this region are commonly floored with wide flood plains, where cut in drift. Upland towns, however, situated on the high divides of the Kansan drift plain may be quite too far from streams for this resource. The impounding reservoir may be the last resort.

In various regions of rugged topography with droughtless summers the use of storage waters is very common. Iowa, however, has the inherent disadvantages of a prairie state, of deep fertile soil, and lying near the semiarid west. Long summer droughts, perhaps during a succession of dry years, occasionally occur. The relief of the land is low. Sites for deep reservoirs are few. Secure rock foundations for dams may be difficult to find. The gentle slopes of the hillsides are covered deep with easily washed soils. The land of the watershed is costly, for as a rule it is arable and its price is enhanced by nearness to the town. It is clear that in Iowa impounding reservoirs will have far less vogue than in a region like New England, for example. So far, they are confined, as we have said, to a single drift sheet and a single rock terrane. The driftless area in Iowa offers excellent sites for reservoirs, but here the artesian aquifers lie near the surface. The areas of the younger drift sheets are little dissected and offer accessible stream and well supplies. Where the Kansan drift overlies other rocks than those of the Coal Measures, the supply from wells in the country rock is open. Outside the area of outcrop of the Coal Measures with a cover of Kansan drift, no impounding reservoir has yet been built in Iowa.

In comparison with wells, storage waters have the disadvantage of all surface waters in that they have not undergone the natural filtration to which all ground water has been subjected. They are more turbid, more liable to bacterial infection and organic growths. On the other hand storage waters are soft and adapted to industrial purposes and locomotive supply.

Compared with underground waters, the impounding reservoir has the further disadvantage of rapid evaporation over a large surface with maximum depletion on this account at the time of minimum replenishing by rain and maximum municipal consumption. In the upper Mississippi valley loss by evaporation has been estimated at somewhat more than four feet per annum. In Iowa, reservoirs are necessarily comparatively shallow and the required supply is sometimes obtained only by two reservoirs. Compared with deep reservoirs, especially those of more humid climates, the large ratio of surface to cubic contents gives rise to an excessive percentage of evaporation loss.

In comparison with a river supply the impounding reservoir has the advantage that the drainage area is small, and can therefore be kept under strict sanitary supervision and control, and for the same reason the disadvantage that replenishment fluctuates with the local rainfall. The inevitable silting up of the reservoir is another disadvantage.

The impounding reservoir in Iowa is constructed like the "tanks" of the arid west by building a dam across a valley to collect and store the water of the run-off. Fortunately the flat divides of the Kansan upland in southern Iowa are narrow, and towns located upon them can usually find suitable valleys at negotiable distances along the dissected margins of the upland, locally termed "the breaks." The greatest reported distances of reservoirs from the towns do not exceed two and three miles. But as the reservoirs are commonly at a lower level than the towns, in two instances as much as 85 and 150 feet (measured from the reservoir floor), the operating expense is increased considerably by the lift.

The impounded lake is commonly fed only by the run-off of the watershed but at What Cheer a small stream and at Tabor springs contribute also. The low relief of the areas is seen by the fact that the hills immediately about the reservoirs stand only from 40 to 100 feet above the reservoir bottoms.

In every instance in Iowa the dams are constructed of earth. In some cases (e.g. Corydon, Lenox, Tabor) they are built with a core of cement, or (Osceola) of "rock," in order to prevent infiltration and the burrowing of animals. They are sometimes faced with concrete or riprap.

Iowa dams are built low, because of the relief of the land and the small storages required. The maximum height is at Centerville, 60 feet, the minimum at What Cheer, 6 feet, but these heights for the most part fall between 25 and 40 feet. At Fairfield and Lenox two reservoirs with comparatively low dams furnish the storage that in a single reservoir would require a higher dam.

The capacity of reservoirs in Iowa varies from 5 million gallons at Mount Ayr (population 1750) and 3 million gallons at What Cheer (population 1626) where there appears to be a rapid and fairly constant replenishment, to maxima of 110 million gallons at Centerville (population 10,000), 135 million gallons at Albia (population 6,000), and 180 million gallons at Fairfield (population 5948).

The amount in storage in dry seasons of course may be much less than the total capacity of the reservoir. Thus at Lenox the maximum depth of water, 28 feet, may be drawn down in drought to 10 feet, and at Osceola from 40 to 15 feet. Albia is reported to experience serious shortage in drought and to maintain an emergency supply in a small creek. In 1923 it was reported by the Iowa Insurance Service Bureau that at Centerville the total storage water available fell to 30 million gallons. "The emergency was met by reducing the consumption to 225,000 gallons a day, and to meet the consumption pumps were installed at a railway reservoir, at a mine and in a well, so that the water in storage should not be depleted. If the situation does not improve, water will be hauled in tank cars."

No other shortages, however, have been reported by Iowa towns.

The watersheds of Iowa reservoirs are all small, ranging from 40 acres to one or two square miles. They are owned by the municipality. With one or two exceptions, the land is kept under grass or forest. In these exceptional cases, portions are under plow or in pasture, conditions which make for turbidity in the stored waters, contamination, and rapid silting up of the reservoir.

In the best practice in the state separate settling basins are installed with rapid mechanical filters and chemical treatment of the water. Aeration plants are also under consideration. The need of settling basins is illustrated by the case of a reservoir holding but 5 million gallons, whose water is so turbid that pipes are continually clogged. In some cases the water is reported to have a disagreeable taste or odor in summer, but the number is few considering the organic growths common in shallow waters along the margins of reservoirs. In nearly all cases the supply is said to be satisfactory. The one exception is a town now using raw water, but this is to be remedied by filtration. Lamoni, which has used storage, has recently (1927) drilled a deep well.

It is expected that the number of impounding reservoirs will continue to increase and that the supply, when treated as are flowing waters, will prove satisfactory. It is hoped that generally larger reservoirs may be provided, securing storage amply adequate to long and recurring droughts, with the added advantages of deeper water in promoting clarification, bleaching, and the destruction of pathogenic germs, and in limiting the growth of shallow water organisms.

River supplies.—In contrast with the run-off impounded in reservoirs, rivers offer a supply constant and unfailing, owing to their far larger watersheds and their replenishment by springs during times of drought. Because they are always fed by ground water in part, the water of rivers is harder than that of the impounded run-off, but less heavily charged with calcium, magnesium and iron salts than is the water of most wells. As a rule river water is better than well water for manufacturing purposes, boilers, and for domestic use in cooking and the laundry.

In the matter of sedimentation, the river has no advantage over the reservoir when a dam is necessary to provide depth of water for the intake. Otherwise, as in the case of the Mississippi and Missouri river towns whose intake pipes are laid in open channel, the advantage is with the river, which continually sweeps its silt down stream.

No machinery is buried deep in ground inaccesible to inspection and difficult to repair. The cost of delivery to the distribution system is low, except in certain instances where upland towns have resorted to rivers flowing some distance away and considerably below their level.

It may be claimed for river supplies that they are dependable, permanent, equal to any present emergency or future requirement.

On the other hand, river water has the defect of its quality. The run-off from plowed fields, pastures and forested hillsides, the tributary streams which bring it their loads of silt, render it turbid with the inorganic waste of the land. By the same means it is contaminated with organic refuse. Moreover, lowly organisms which grow in the water may give it an unpleasant taste and odor.

There is now added in the case of Iowa rivers defilement by the sewage and industrial offal of the towns upon their banks. In testing these waters there is now often found the bacteria-coli group of micro-organism indicating fecal pollution. Iowa river water has become a dilute sewage effluent.

This does not signify that river water may not be so treated as to be safe. It is said that the sewage effluent of Paris, after treatment, issues potable and healthful, as clear, sparkling, and delicious as the water of springs. It may be added, however, that it is not used as a public supply.

The water of Iowa rivers is usually allowed to settle in settling basins; then treated with coagulants and chemical bactericides and forced through rapid mechanical filters. Bacteriological tests are made to insure efficiency. Such treated waters show at the state laboratories a very high per cent of safety (p. 69).

No slow sand filters have been built within the state and yet there have been typhoid epidemics in Iowa cities to warn against the possible consequences of carelessness at the gate at which the enemy is seeking entrance. As has been said by Simpson in his report on the water supply of Cedar Rapids, "The chief difficulty in connection with the use of river water arises from the fact that the organic matter in the water may unite with the chlorine used for purifying the water * * * and form certain organic compounds which impart very unpleasant tastes and odors to the water. * * * There is no known way to avoid these tastes and odors in surface water supplies."

Raw river water is used in Iowa only by some small towns on the Lower Des Moines river, which do not employ it for domestic supply, and by Council Bluffs, drawing on the Missouri river, the least dangerous, perhaps, of all rivers within or bordering upon the state.

There is no question that the use of rivers as water supply has been retarded and restricted by the function imposed upon them of carrying the sewage of the riparian cities and towns. At the present time one of the cities of the state which has long used river water is turning for this reason to a ground water supply. When the pollution of Iowa streams is no longer lawful, much larger populations no doubt will make use of river supply, the most copious, accessible and permanent of all.

Springs.—Little need be said of this supply, so few are the towns in Iowa which can avail themselves of it. Strong springs occur in considerable numbers, as for example the contact springs of northeastern Iowa at the junction of the Niagaran limestone and the Maquoketa shales and that of Galena limestone and the Decorah shales. Such springs may issue well up the hillside and afford considerable head when piped to the valley floor, but they are seldom near enough to towns for use as public supplies.

The purity of spring water commonly goes without question, yet the purest water is liable to contamination as it approaches the surface and issues from the ground. Some years ago Cedar Falls drew its supply from copious springs rising from Devonian limestone in the valley of Dry Run. In 1911 an epidemic of typhoid fever was attributed to the city supply and it was supposed that the springs had become infected through solution channels in the closely jointed limestone or by back water from the river. This supply was then superseded by 5 wells about 125 feet deep, sunk in the country rock, 1400 feet distant from the springs.

It will be noted that according to the table of page 69 springs furnish to the state water laboratory the largest per cent of unsatisfactory waters of all classes of public and private supplies.

Infiltration galleries and shallow wells.—Extensive deposits of sand and gravel at or near the surface, as on river flood plains, furnish natural storage basins of great capacity, rapid recharge and easy access. They act as natural filtration plants for ground water derived from the soak-in of the rain and for any percolating water from the stream. Wells sunk at the river bank, as at Bellevue and Guttenberg on the Mississippi, or on islands in the river, as the wells of the Boone plant on the Des Moines, and infiltration galleries, as those of the city of Des Moines on the flood plain of the Raccoon, may draw largely or even at times wholly on the river, but in contrast with the water of a river intake, the water of such wells and galleries has been more or less clarified by its passage through even a few feet of sand.

The normal movement of water in flood plain deposits is toward the stream. But at stages of high water and under heavy pumping the movement may be reversed, as the tests made by Kiersted at Muscatine illustrate.[36] For 3300 feet from the river there was found a slope of the ground water surface toward the river of 0.8 foot in 1000 feet and a rate of flow in this direction of at least two and one-half feet a day. But with the rise of the Mississippi the normal flow of ground water was first dammed and then reversed, reaching a slope inland of 0.84 foot in 1000 feet, and a flow from the river at about the rate just mentioned.

Water percolating from the stream brings in fine sediment, clogging the porous transmitting beds and diminishing the yield of wells and galleries. Excellent examples of the process are supplied by dams of impounding reservoirs, built of sand and fine gravel. "The initial leakage was high, but the embankment eventually became silted tight."[37] The same process goes on with ground water flowing toward the stream, but far more slowly, inasmuch as ground water carries very little sediment. Even deep artesian waters may in the same way clog their aquifers about the well tube, causing a diminishing yield.

The only example of infiltration galleries in Iowa is at Des Moines. The galleries are located on a tract of 1200 acres on the flood plain of Raccoon river. They are 11,821 feet in length and are sunk to a depth of 20-25 feet in uniform and coarse deposits. The newer galleries are constructed of rings of concrete. In addition the system includes 2375 feet of tunnel which will be increased soon by 2000 feet. The average daily pumpage in 1927 was 12,781,345 gallons, with some days' pumpage reaching 19 or

36 Norton, Underground Water Resources of Iowa: Iowa Geol. Survey, vol. XXI, pp. 563-566.
37 Flinn, Weston and Bogert, Waterworks Handbook, p. 193. New York, 1927.

20 millions. Flooding has been resorted to in times of drought. The pumps have a capacity of 85,000,000 gallons daily.

The principle of the collecting gallery is employed by several Iowa water works by leading into the city shallow well one or more pipe lines with open joints constructed of vitrified clay or cement tile.

The capacity of the natural sand reservoirs tapped by galleries and shallow wells depends on the extent, thickness, and porosity of the beds. The chief factor in their adequacy for a city supply is the ratio of replenishment to draft. Any reservoir natural or artificial, no matter how large, must in time go dry if the draft upon it exceeds by ever so little the amount by which it is recharged. Patches of flood plain under consideration by cities for water supply have been examined by the writer which no doubt would yield generously for a time, so long as storage exceeded draft. But they were not favored as the site of wells, for they were found to be cut off from replenishment from up valley by spurs of rock and their hinterlands apparently would be able to supply too little ground water on its way to the river.

For sanitary reasons, though not for yield, flood plains standing at some height above the river are preferable for well fields to lower bottom lands. There is less danger from overflow and consequent pollution. Above the water table there is a thicker zone, which is alternately dry, filled with air, and wet with vadose water. This zone of aeration and oxidation acts as a natural filter in which nitrites and ammonia are decomposed and pathogenic bacteria destroyed.

While this natural filter may be able to take care of the ordinary surface contaminations of pastures and forest lands and even for those of fertilized cultivated fields, it is not to be considered competent to disinfect the waste of a thickly settled area with perhaps leaky sewers. Cities built on flood plains may find cheap supplies within their residential districts, but ground water in need of chemical treatment has little to commend it over river water.

Not all flood plains are available for ground water supply for towns. Some are carved by the lateral cutting of the stream and consist of a bench of rock veneered with a thin layer of alluvial soil, as that of the Mississippi at Davenport and of the Cedar at Waterloo. Some are cut partly in rock and partly in dry glacial stony clays, as that west of the Cedar at Cedar Rapids, which happens to be traversed by a sand filled ancient channel. The most suitable flood plains are those built up by the torrential waters of Pleistocene rivers. Here deep beds of coarse sand and gravel are often overlain and sealed with finer deposits. Flowing wells may sometimes be obtained, as on the lower course of Prairie creek in Linn county, the Wapsipinicon valley in Bremer county, and the artesian basin of Belle Plaine.

Pleistocene sands outside present or ancient river valleys should be carefully tested for extent, thickness and replenishment. Unless adequate in these respects their first yield may be fallacious, and as at Boone they may have to be abandoned. The history of Iowa waterworks shows that it is fairly common for the shallow wells of the first installation to be found inadequate. New wells are put down, perhaps in a new well field served by a second pumping station. Or the town goes over to a deep well, river, or impounding reservoir.

But seldom do the towns which make use of the flood plain waters of the river valleys need any additional supply except that readily obtained by sinking other wells in the same water bed.

Several types of shallow wells are in use in Iowa. There are dug wells with diameters sometimes more than 20 feet, with sides of brick or concrete, drawing their water from the bottom. A gang of driven wells, with sand points, set at right angles to the line of ground water flow may discharge into a common suction pipe.

From the sanitary view-point shallow wells are looked on more favorably than rivers, but are held inferior to wells in drift and country rock and to artesian wells.

As Hinman has pertinently said,[38] "The shallow wells share the dangers of the deep well and have additional dangers of their own as a consequence of their being dependent upon shallower sources for their water. They are more dependent upon local weather conditions for their supply. Unusually wet or unusually

38 Hinman, J. J., Twenty-first Biennial Rept. Iowa State Board of Health, p. 79, Des Moines, 1925.

dry weather may bring a change from the normal quality. Most of the trouble of the shallow well comes from the conditions of the top and the upper part of the casing, which are often constructed in such a way that the surface water is not excluded. The upper ten or twelve feet of the curbing and the top of the well at least, ought to be water-tight. Surface drainage is likely at any time to carry with it material of a sewage-like nature and sewage, especially town sewage, is very likely to contain the bacteria which are the cause of typhoid fever and other intestinal disorders.''

From the viewpoint of production and cost of installation and operation, shallow wells are often the best investment. If another supply is chosen, it should only be after they have been given full consideration and ample tests, as at Dubuque, p. 79.

Wells in glacial drift and country rock.—This supply, as we have seen, is peculiarly adapted to small upland villages and towns. Wells in drift commonly have but a small yield. Wells in country rock may yield enough for towns of one or two thousand population and in exceptional cases for much larger towns. The areas of outcrop of the Galena, Niagaran, Devonian and Mississippian limestones offer many examples, and where at a moderate depth the limestone is underlain by an impervious floor of shale the prospect for a successful well is very promising. Yet two towns, De Witt and Delmar, under the most favorable conditions for wells in country rock, have recently superseded them with deep artesians.

The geologic sequence which results in some of the favorable conditions for wells in the country rock is clearly stated by Meinzer:[39] ''Obviously an ideal sequence of events has occurred where a limestone was exposed to leaching until it became cavernous and was then subjected to changes which raised the water table and immersed the cavernous part in the zone of saturation. This sequence of events has occurred in the north-central United States and has made excellent aquifers out of some of the prominent limestones of that region, such as the Galena limestone and the Niagara limestone. Before the glacial epoch these limestones lay at the surface over wide areas and

[39] Meinzer, O. E., Occurrence of Ground Water in the United States: U. S. Geol. Survey, Water Supply Paper 439, p. 132, Washington, 1923.

were subjected to extensive weathering. Then they were overridden by successive ice sheets and became covered with glacial drift. Today the water table in most places passes through the drift mantle leaving the underlying cavernous limestone within the zone of saturation. In these areas limestone is considered an excellent water bearer and many limestone wells will yield from 100 to several hundred gallons a minute. Where these formations are so deeply buried that they have never been leached they are often not regarded as aquifers by deep well drillers, who search for the water bearing sandstones below the limestones.''

Wells in drift and the country rock are usually drilled through a heavy cover of impervious glacial till, which effectually seals their water beds from surface contamination. In contrast to shallow wells and surface waters, the purity of this supply is assured under these conditions.

But the fact that the water is pure when it enters the well does not guarantee its purity when pumped into the mains. In some known instances surficial water has freely entered the well through rusted casings. Pollution from privy vaults and leaky sewers may find access also where the seal of glacial till is wanting or imperfect, and the casing is not effectively bedded and packed, or by means of crevices in the rock. If in conjunction with these conditions a sporadic case of typhoid fever occurs in the vicinity the epidemic which follows need not be attributed to an inscrutable Providence.

The recent experience of Manchester shows the possibility of wells in country rock both for good and evil. The first deep well for city supply was put down in 1896, is 1870 feet deep, and foots in the EauClaire beds of the Cambrian. After 30 years of use this deep well failed to meet satisfactorily the increasing demands upon it. In the language of the local press, ''During the hot dry season of the year the demand made upon the pumping system is exceedingly heavy and it is with great difficulty that the engineer at the pumping station can keep the stand pipe filled as it should be.''

After the selection of a proper site by dowsing with the witch willow, a new well, 212 feet deep and 14 inches in diameter, was drilled in the northeastern part of the city. Below 10 feet of soil this well penetrated the Niagaran limestone nearly to the impervious floor of the Maquoketa shale. At about 175 feet, in a crevice, a yield of 300 g.p.m. was obtained. The well was cased to 100 feet. The static level was 30 feet below the curb. The total cost of this supply, including pump and electric motor, pump-house, and connections with the city mains, was less than $10,000.

Unfortunately, although this well seemed to promise to provide so cheaply "a tremendous and inexhaustible flow of water of the highest purity * * * alone sufficient for local needs", it could not be used. The disadvantages soon became apparent of a supply drawn from a well in a country rock which is pierced by a network of crevices and solution channels, and is protected from the contamination of the surface waters of the surrounding town by only a ten foot cover of soil. The water of the well failed to permanently clear. Pumping still brings in "a brownish clay, like flour, matting up like clay". Three times the water has been found bacteriologically "unsatisfactory" by the State Board of Health. In November, 1928, the city is considering either drilling a new well to reach below the Maquoketa shales or installing an air lift in the well of 1896 and bringing it up to maximum yield by necessary repairs.

Artesian wells.—Perhaps the chief excellence of this supply is its purity. Artesian waters require no clarification, filtration, aeration, or chlorination. Without treatment they are potable and safe. They can not bring upon the community any of those diseases whose germs are water borne.

The high rank of artesian and other deep well waters is indicated by the following table supplied by Mr. J. J. Hinman, Jr., Chief of the Water Laboratory Division of the State Board of Health. It summarizes the results of more than 30,000 bacterial examinations of Iowa supplies.

Summary of Results of the Water Laboratory
Percentage Satisfactory

TYPE OF SOURCE	PUBLIC SUPPLIES		PRIVATE SUPPLIES	
	Feb. 1914, to June 30, 1926	Biennium 1924-26	Feb. 1914, to June 30, 1926	Biennium 1924-26
Springs	38.03	48.00	27.16	23.08
Shallow wells	39.32	46.65	18.35	17.47
Deep wells	66.40	73.35	66.10	56.55
Treated waters	86.18	90.81		
Filter plant effluents	94.84	92.94		

It will be noted that the excess percentage of safety of deep wells used as public supplies over shallow wells is about twenty-seven and the minimum depth of "deep wells" as the term is used by the Board of Health and generally by water engineers is 100 feet. No statistics are at hand as to the comparative safety of artesian wells, or of those deeper than 300 feet.

The comparative safety of deep wells is recognized in the regulations of the State Board of Health governing the examination of public water supplies. Water supplied by wells less than 100 feet in depth is to be analyzed at least once during each three months period; water from wells more than 100 feet in depth is to be analyzed at least once during each six months period, . . the water in both cases having been found satisfactory at the last examination.

While the artesian water which enters a deep well is no doubt organically pure, artesian wells are not necessarily perfectly safe wells. Like wells in the drift and country rock they may be contaminated with surface waters. Several typhoid fever epidemics have been traced to infected artesian wells. In a recent instance noted by Hinman,[40] a sewer communicating with the well pit through a drain pipe was able to back up into the well. At Waterloo and Manchester artesian wells have been found contaminated, but happily without infection by pathogenic bacteria. At Waterloo the water from a contaminated soil found entrance through the upper rusted casing. At Manchester the well is located on the bank of the Maquoketa river and heads in the Niagaran limestone. As was pointed out by the writer when the well was drilled,[41] it receives near the surface a supply of water from the same source as that of a powerful Niagaran spring near by, as well as from the deep lying Jordan sandstone. The water of the sandstone is above suspicion, that of the surface limestone has become polluted and is liable to dangerous infection. The remedy is to dissolve the partnership by replacing a short wooden temporary casing with a water-tight iron casing extending to or near the base of the limestone, which here is 225 feet thick.

No statistics are at hand as to the comparative safety of arte-

[40] Iowa State Board of Health, Biennial Report, 1924, p. 78.

[41] Norton, W. H., Artesian Wells of Iowa, vol. VI, Iowa Geol. Survey, p. 214, Des Moines, 1897.

sian wells and deep wells sunk in the drift and country rock. Both alike are liable to pollution by surface waters through defective casings and packings. But, on the whole, the artesians have the advantage of better construction. They are put down by highly skilled workmen with all appliances at hand. Casings are generally made of the best materials. Within the upper casing, which reaches through surface deposits to solid rock, there is often placed an inner casing extending hundreds of feet, carefully packed, and occasionally the space between the casings is filled with concrete.

Deep wells in the country rock which do not penetrate a cover of impervious clay are little if any safer than shallow wells, especially if their casings are short, since surface waters may descend and find access to the well through crevices and solution channels in the rock. A number of infected wells of this class are on record in Iowa.

A summary of the results of the examination of upwards of 33,000 samples of city water supplies of Iowa from April, 1914, to May 1, 1927, has been prepared for the writer by Jack J. Hinman Jr., Director of the Laboratories of the State Board of Health. From this report it appears that at no time the samples submitted from the following deep well supplies have been found "unsatisfactory:" Ayreshire, Donnellson, Hull, Huxley, Lansing, Manson, Marcus, Nevada, Pleasantville, Pocahontas, Rockwell, Wilton.

The following supplies have been found "unsatisfactory" but once during their history: Anamosa, Charles City, Dunlap, Dysart, Elkader, Lake Mills, Lytton, North English, Oakland, Tipton, Winfield. In the remainder of the deep well public supplies the water has been found definitely "suspicious" or worse two or more times, or is regularly chlorinated. It must be remembered, however, that a number of towns draw on both deep and shallow wells, and no data are at hand to show from which wells the contaminated water came.

But the fact that in 63 per cent of the towns of Iowa using deep wells in part or whole for water supply contamination has been proved on two or more occasions shows conclusively that deep wells, like shallow wells, may be polluted by surface waters. The advantage of deep wells lies in this. The shallow well, whose aquifer is unprotected by an impervious covering stratum, may draw on waters widely and hopelessly polluted. The deep well draws on a sealed aquifer whose water is above suspicion. If the water of a deep well is found contaminated it may be taken for granted that the contamination enters the well through the defective mechanism of the well, such as an imperfectly sealed or rusted casing, and therefore can be remedied.

It hardly need be added that an artesian supply does not confer immunity against epidemics of the typhoid group caused, as in some Iowa examples, by infected river water drawn into the mains on some emergency.

A second advantage of artesian wells is the capacity of the reservoir on which they draw. The Cambrian and Ordovician sandstones of the upper Mississippi artesian field are hundreds of feet thick in the aggregate and underlie thousands of square miles. There are, besides, vast volumes of water stored in the Prairie du Chien and other limestones belonging to the same artesian system. It is assumed that this reservoir, replenished by the rainfall over the area of outcrop of the several aquifers, is practically inexhaustible.

No doubt early estimates of the amounts of underground water were excessive. And a large part of underground water even of the most conservative estimates of its total amounts, is held too closely in the fine pores of rocks to be available for wells. The reports of drillers indicate that even the Saint Peter, the Jordan, the Dresbach and the Mount Simon sandstones are not filled throughout with gravity water ready to flow into the tube as soon as the formation is entered by the drill. While definite facts as to the precise depths at which water has been struck are regrettably few, it seems that even the leading aquifers supply water freely only at certain horizons, which vary in different wells, horizons at which the texture of the rock is sufficiently open to allow pressure flow. And any one of these ordinarily generous aquifers may locally yield no water from top to bottom, so far as drillers' reports give evidence. Any calculation, therefore of the amount of artesian water held in storage, based on estimates of the volume of aquifers, and their average per cents of pore space, and on the assumption that all pore spaces are water filled, is clearly excessive. Yet since in the artesian field of the Upper Mississippi valley the Cambro-Ordovician system of aquifers yields generously to practically all wells which tap it, we may conclude that, throughout this field, artesian water is moving slowly under pressure. Considering the vast area of the field and its constant replenishment by a copious rainfall over an extensive intake area it may be assumed that artesian water in Iowa is too great in amount to be exhausted or seriously depleted.

Objection is sometimes made to artesian waters because of hardness. It is true that as a rule they are more highly mineralized than the water of streams. Compared with other ground waters, the water of deep wells is less highly mineralized, as was found by Hendrixson[42], in the northeast, east central and north central districts of the state. In the remaining districts of the state the opposite obtains.

In general mineralization is excessive where the Cambro-Ordovician aquifers lie deep and are covered by Mississippian and Pennsylvanian strata, especially in southwestern and south central Iowa.

When the water of any well supply is found excessively or even moderately hard a chemical treatment of the water by a softening plant is often to be recommended on the score of economy.

The initial cost of artesian wells makes against their use by the smaller municipalities and against their duplication for emergency supply, as when a well is thrown out of commission for repairs. A large recent increase in cost may be noted by comparing the cost of the wells listed in the present report with the cost of those of the report of 1912. This is the natural result of the greatly increased price of labor and materials due in part to a depreciated currency. The competitive prices for drilling for oil is said also to be a factor. Contractors' bids take account not only of depth but also of the material to be penetrated, ease of drilling, risks of losing tools and the amount of required casing. Wells which pierce heavily bedded limestones for the most part, cost less than those in which there is much caving shale. Bids are apt to run high in order to cover uncertainties where the

42 Underground Water Resources of Iowa, vol. XXI, Iowa Geol. Survey, p. 165.

formations to be passed through, their character and thickness, are little known. Prices must be large enough to cover risks where the contractor assumes in any part the responsibility for the success of the well. Any dependable information as to the deep geology of the state, which diminishes these uncertainties and risks, must lower the cost of wells in the highly competitive market by which prices are now fixed.

Operation and maintainance of deep wells may also be expensive, operation when the static head is low and the lift large, maintainance when corrosive waters rapidly rust out casings and when wells tend to fill with sand.

A recent example is the well of the Sinclair Packing Company, Cedar Rapids, drilled in 1911 and 1471 feet deep. After fifteen years of use rusted casing allowed the Maquoketa shale to cave and partially block the well, reducing the pumping capacity from 900 to 300 g.p.m. In 1926 the well was recased and the pumping capacity was then found to be around 900 to 1000 g.p.m. However, while repairs were in progress a well 72 feet deep and 21 inches in diameter, of the Layne-Bowler patent, was sunk in the flood plain sands of the Cedar river. This shallow well yielded at first 1500 g.p.m., dropping in a few months to 1000 g.p.m., and as the water is somewhat colder and much less expensive to pump than that of the artesian, the deep well, though not abandoned, has been superseded at least for a time, and a second Layne-Bowler shallow well added.

Perhaps the chief objection made to an artesian public supply, especially for the larger towns, is that of deterioration, overdraft and ultimate inadequacy. Deep wells, it is said, suffer gradual decline, the static level lowers from year to year, pumping cylinders are hung at greater depths. Air compressors are installed with pipes reaching deeper and deeper in the well. The cost of pumping steadily increases while air lift pumps become less and less efficient with reduction in submergence. The delivery declines. New wells are drilled but because of interference do not add to the output in proportion to their cost. Finally the deep well supply will have to be supplemented or superseded by one of another type.

This melancholy forecast is hardly justified by the history of

Iowa deep wells. Some of the oldest city wells are still giving good service. But seven towns have abandoned an artesian well supply and this for various reasons. At Monticello a crooked drill hole made needed recasing impracticable, and a cheap supply was found in a well in the country rock. At Boone the inadequate yield of two wells, 3000 feet deep, was apparently due in part to the small diameters with which the drill hole was able to reach the deep lying aquifers. Shallow wells in glacial sands were substituted and when these failed a permanent if distant and expensive supply was found in island wells at the Des Moines river. At Sigourney the artesian water was found so heavily mineralized in 1882 that it was never put to use. Yet a still deeper artesian was drilled in 1923 for city supply. Centerville seems to have abandoned deep wells on account of the quality of the water and finally has gone over to the impounding reservoir. At Newton two deep drill holes failed to reach the Saint Peter sandstone on account of difficulties in drilling and the water obtained from upper aquifers was poor. At Mallard the city well filled with sand.

Fourteen towns using artesian wells for their municipal supply report diminishing yield or receding static level (1925), and there are probably other instances not reported. The deterioration of these wells in some instances signifies nothing of more general importance than the clogging of the aquifer immediately about the drill hole, or leakage or cave because of a rusted casing. In other cases an overdraft is evidenced. More water is drawn from the aquifer than can locally be transmitted in a given time. There is produced within and for an unknown distance about the well field an area of diminished pressure comparable to the cone of depression in the water table about a shallow well.

Conservation

The need of conservation of deep well waters is less obvious than that of oil, natural gas and coal. These resources once consumed, are not replaced; ground water is continually replenished, much as lumber supply is renewed by forest growth. Yet just as in a country's forests cutting may exceed growth, so in a well field the draft on ground water may be greater than recharge.

The fact that artesian water is already overdrawn in several Iowa cities and towns proves that its conservancy must be considered.

When a public well supply shows signs of overdraft blame is occasionally placed on private wells which draw on the same water beds. In Dubuque, Clinton, Mason City, Fort Dodge and Cedar Rapids and Sioux City there are, it is true, numbers of private wells, besides those of the municipal supply. But so far as artesian water is legitimately used and not wasted the total amount of water consumed by the inhabitants of the city and its industries is not thereby increased. It makes no difference to the static level and the adequacy of the supply whether a given amount of water is drawn from public wells or from both public and private wells. A consumer may find it to his advantage to sink a well of his own and discontinue the public service, but he does not thereby increase the draft or overdraft on the artesian reservoirs.

"The first adequate attempt to conserve artesian waters on a large scale," as has been said by Meinzer, is being made in North Dakota under Dr. Howard E. Simpson, State Water Geologist. In this artesian field 6,000 artesian wells have been drilled and form a very valuable asset of the farming communities of this area. For several years unchecked flowing wells have dissipated the pressure and over wide belts the static head has fallen below the surface. Since 1921 laws have been passed and campaigns of education conducted designed to prevent discharge from flowing wells beyond beneficial use, to prevent leakage, and to secure the sealing of disused wells. As a result the decline of the pressure has been checked and wells have been kept flowing that otherwise would have failed to flow.

Another region where the decline of artesian water of great economic value has brought about conservation by legislative measures is Oahu, one of the Hawaiian islands. Here about 600 wells form the main domestic supply of 100,000 people and are indispensible to the irrigation of sugar lands of great productive value. The maximum daily draft upon these wells is 350,000,000 gallons.

The laws of the territory of Hawaii are designed to prevent all waste of artesian water not only by flow without beneficial use but also by leakage underground. How great can be the leakage loss of an artesian well is shown by the tests made here for the first time with the current meter. In Honolulu alone the total leakage thus discovered amounted to 7,750,000 gallons a day, an amount equal to one-third the total daily consumption of the city. Of this loss 5,900,000 gallons were saved by suitable repairs.

In the Iowa artesian field the need for conservation is less in evidence than in the Dakota basin or Oahu. Water is little used for agricultural purposes. There is practically no waste from uselessly flowing wells. Only in a few areas is there any dangerous overdraft. But in these local well fields the need of conservation is serious and urgent. The static level has already receded far. Abandoned wells should not merely be capped to prevent flow; they should be plugged deep enough to effectively seal the aquifers. The nature of the rocks pierced by the Iowa wells does not lead to the anticipation of such an amount of leakage as that found in Oahu, but it is highly probable that a thorough investigation with a current meter in several Iowa well fields would disclose a large and continuous loss and that the stoppage of lateral escape of artesian waters would go far in maintaining their static level. The well owners in an artesian field share in a common supply. They are stock holders in a common property. The waste of one is the loss of all, and waste as defined in legislative statutes includes subsurface leakage. It may be that only by the strictest conservation will there remain enough for all, enough for any.

Artesian Supply of Iowa Cities

The experience of the larger Iowa cities which have used artesian wells for public supply is believed to be of special value and will therefore be given in some detail. Further data will be found under each of these cities in this report and in earlier water reports of the Survey. In every instance except one, Waterloo, there is a considerable use of artesian water drawn from private wells, so that the artesian yield is larger than the public consumption indicates. At Clinton the number of private deep wells is 18, at Dubuque 27, at Mason City 9. As the preference of some large consumers for private supplies can not be due to difference in quality, it is assumed to be due to difference in cost. And probably the cost factor, rather than quality, has led to the sinking of the private deep wells of Burlington (12), Davenport (20), Keokuk (14) and Ottumwa (8), and other towns, which use another type of supply.

CLINTON

The city of Clinton (population 24,151) is supplied by the Clinton Waterworks Company with water drawn from artesian wells, of which six have been drilled and five are now in use. These wells are described in the writer's report of 1912.

The first public supply at Clinton is said to have been water of the Mississippi river strained through compartments filled with sand and gravel. As early as 1886 the first two artesian wells were drilled, marking the installation of the present system, and three additional wells had been added by 1902. All these wells discharged into the reservoir by natural flow.

But as the initial head of the wells, which had been 44 feet above the curb in the case of first wells drilled, declined and their delivery under natural flow decreased, fears were entertained as to the permanence of the artesian system. It was thought that any additional wells would diminish the yield of those already drilled, and would not increase the total delivery in proportion to the expense. The water company therefore installed as a supplemental supply a mechanical filtration plant drawing on the water of the river and with a capacity of 1,000,000 gallons daily. This, however, proved unsatisfactory, and at the writer's suggestion the deeper water beds of the Cambrian, the "basal sandstones," were tapped in 1911 by a deep well, no. 6, which secured a phenomenal flow, lifting by lateral leakage the static level of several deep wells of the Clinton area.

In 1917 there again developed a need of increase of supply. One well, inconveniently situated, had been abandoned, and the five wells in use were piped directly to the pumping basin. Aided by a vacuum pump which removed the air from the connecting pipe, these wells were then giving a flow of 2,483,000 gallons daily. At the advice of Mead and Seastone, consulting engineers, an air lift system was installed in wells 2 and 3. Tests in 1917 showed in these wells alone an increase in delivery of 900,000 gallons daily. In 1925 well no. 6 also was put under air and in 1926 with 100 feet of compressed air was capable of furnishing the entire supply of 4,000,000 gallons daily, while in emergency four wells could be operated at once with a combined daily pumpage of 8,500,000 gallons.

It was the opinion of Mead and Seastone published in 1917 that "the artesian supply of Clinton can be made available for a city of at least 100,000 inhabitants and fully adequate not only for domestic but for all necessary fire service." This favorable forecast, which nothing has as yet invalidated, probably was based on the capacity of the Mount Simon artesian reservoirs, which so far have been tapped only by the waterworks wells.

Eighteen deep wells have been drilled in the Clinton area and two at Fulton, Illinois, in addition to the six drilled for public supply. Seven have been abandoned. In 1925 the head of wells still in use averaged 12 feet below the curb, a total fall of 56 feet since the first wells were drilled.

DUBUQUE

Dubuque (population 39,141) draws its supply from five deep wells, whose capacity of 6,476,000 gallons daily under air with a lift of 128 feet is more than twice the average daily consumption.

In 1910 the supply was obtained from four deep wells. Later two of these at a distance from the Eagle Point pumping station were disconnected and two additional wells were put down at Eagle Point.

In 1922 it became evident that steps must be taken to increase the supply. At this time the four deep wells delivered under a motor driven centrifugal pump 1,779,840 gallons daily, while a group of wells about 100 feet in depth penetrating the sands of the flood plain of the river added under pump 1,570,000 gallons.

In choosing between the extension of the deep well system and that of the shallow wells, it was taken into consideration that tests over a period of years had shown large interference among the shallow wells and a constant decrease in their capacity. Although few flood plains would seem to offer more advantageous water beds than those of Upper Mississippi river it was decided to develop the artesian wells, using the present shallow wells only for emergency supply. A fifth deep well was drilled (p. 183) and air lifts were installed, giving the combined pumpage, as stated, of nearly six and one-half million gallons daily. Apparently the deep wells of Dubuque will continue adequate for a number of years.

There are now in the local Dubuque field thirty-two deep wells, including seven which have been abandoned, all of which draw on the artesian reservoirs by leakage, pumping or natural flow. A discussion of the progressive loss of head due to local overdraft will be found on page 184.

FORT DODGE

In the report for 1912 on the Underground Water Resources of Iowa there were listed three city artesian wells, which furnished a flow supply adequate to the city's peak consumption of 1,600,000 gallons daily. During the ensuing seven years it was found necessary to drill four additional wells because of the filling up of the chief well and to meet an ever increasing demand.

In 1919 the supply had so far fallen short that, according to an official report, an old filtration gallery supplying river water was frequently drawn upon. It was said that the discharge of the wells had been growing weaker year by year, and it could be foreseen that in time they would cease to flow. The experiment of pumping well no. 1, tried in 1909, had not been a success. It was held that the other wells were of too small a diameter for the use of either centrifugal or plunger pumps, and they were separated too far for the use of the air lift. The hardness of the water was also offered as an objection to its continued use.

It was proposed, therefore, to entirely abandon the artesian supply and erect a mechanical filtration plant for the use of the Des Moines river water at an estimated cost of $400,000.

At the request of the city Council and the Webster County Medical Association the case was taken under advisement by the writer, who, after visiting the city, submitted the following report:

Mount Vernon, Iowa
June 7, 1919

To the Mayor and Council of the City of Fort Dodge, Gentlemen:

Your city is fortunate in having the privilege of a choice between several adequate sources. There are towns in Iowa which can not get water from deep artesians, or from artesians of moderate depth, or from shallow wells. There are towns too remote from rivers to utilize this source of supply, and some unfortunate towns have only the Hobson's choice of impounding surface waters.

Shallow Wells

If I may judge from a brief inspection of your area, this source of supply is not available at Fort Dodge, although it yields a large supply to a number of cities and towns, as, for example, Muscatine, Marshalltown and Boone. The requisite conditions for this supply are thick and extensive beds of pervious material and the water table. or saturation surface, near the surface of the ground. Those conditions are best met on flood plains of aggrading rivers, where stream-laid sands and gravels form natural water beds.

Unfortunately the upper Des Moines river has not been an aggrading stream. It is still so young that its valley is narrow and steep sided. There are no extensive bottoms built up of sand and gravel from which to draw ground water on its way to the river, or "the underflow," more closely connected with the stream.

At Fort Dodge the narrow flats below the water-works on the left bank are inadequate in area and are so built over that there would be danger of pollution. A more promising area, at first sight, for a gang of shallow wells is found on the right bank above the dam. But inspection shows that this flat is underlain slightly above water level in the river with a rock floor on which rest river deposits too fine to transmit water in any considerable quantity. Ground water supply from shallow wells may therefore be excluded.

Infiltration Galleries

For the same geologic reasons—the youth of the river and the consequent lack of heavy deposits of coarse waste on its bed and banks—there does not appear any very good opportunity for drawing on the water of the river by means of infiltration galleries. The most promising location is Duck Island. * * * * Bed rock, however, is so near, the alluvium of the island is so disconnected from the pervious deposits on the land, that the outlook is by no means as promising as when islands of sand and gravel rise from deep beds of the same material which extend beyond the river's banks.

Deep Artesians

Another source to be considered is that of the deep lying water beds of the Upper Mississippi artesian basin, especially the Saint Peter sandstone, the Prairie du Chien formation and the Jordan sandstone. This is the source of supply drawn upon by Mason City, Charles City, Waverly and Waterloo. It is that drawn upon by your city well no. 1.

As to the quantity of water to be obtained from these deep horizons we have on record the following facts. * * * * These tests indicate that under the pump, and using all the water beds, two or three wells tapping the Jordan sandstone would furnish enough water for a long term of years.

Quality of the Deep Artesian Waters

Unfortunately when well no. 1 was drilled no analyses were made of the waters coming in at different depths. We have, however, the analysis made by Hendrixson about 1910 (Iowa Geol. Survey, vol. XXI, p. 188). If this was made before the caving of the well it represents all waters coming into the bore-hole including those of the Jordan sandstone. Comparing this with Knight's analysis of the present water of the well in the table below it will be noted that the well water of 1910 was superior to that of 1919. It contained 26 parts per million less of calcium and magnesium, and 119 (about one-third) less of the sulphate radicle, and one-third less of iron and aluminum. On the other hand it contained somewhat more of common salt and chloride of magnesia. The basal waters, then, are somewhat better than the upper waters, if the first analysis was made when the well was still of its original depth.

It hardly need be said that the waters of artesian wells are bacterially pure. They offer immunity so far as water supply is concerned from those diseases whose germs are carried in drinking water so long as the casings are kept in repair and surface waters do not get into the well.

Cost of Deep Artesians

The cost of two or three deep wells reaching the Jordan sandstone is great, especially at the present time with the high price of labor and material. As with any machinery, that of a deep well needs repairs from time to time, and the deeper the well the greater the cost of needed repairs. For this reason you will no doubt seriously consider the cost of this supply as well as the difficulties and cost of maintainance.

I am aware of the mechanical difficulties in a deep artesian supply. Your deep well has seriously caved. Sand in the water is reported as being ruinous to your pumps. But it is my belief that both of these difficulties can be obviated both in the repairing of well no. 1 and in sinking other wells to the Jordan sandstone. Difficulties with corroded casings can be obviated, although at large expense, by the use of cast iron casings.

Artesians of Moderate Depth

The next supply to be considered is that from artesians tapping the Mississippian strata and perhaps the Devonian also. Mississippian rocks, exposed in the immediate vicinity of Fort Dodge, are widely extended over the upper Des Moines basin. Undoubtedly they carry large amounts of ground water which are under considerable head at low levels, such as the bottom of the Des Moines river valley. The Mississippian is composed of alternating beds of limestone, shale and sandstone. The shale beds are dry, but serve as covers to maintain artesian pressure. Much of the limestone is but slightly magnesian and is highly soluble. We may expect that ground water has worked out by solution a good system of branching channels. But it is impossible to predict the depth at which any such a channel will be struck by a well at any given point. Sandstones are few and in thin beds. If the records of the different wells are reliable, these sandstones are also discontinuous.

The Mississippian strata have been explored already by the city wells and by other wells sunk by private parties. The quantity obtainable by natural flow is thus pretty well ascertained. The initial flows and those of today are shown in the following table from estimates by Superintendent Pray.

Flow of City Wells of Fort Dodge

	Initial Flow in gallons per minute	Present Flow (1919) in gallons per minute
Well No. 2	80	50
Well No. 3	600	200
Well No. 4	60	15
Well No. 5	48	20
Well No. 6	80	50
Well No. 7	80	50
Total	948	385

The natural flow has thus diminished more than one-half—from 1,365,000 gallons per day to 554,400 gallons. Even with the present flow of well no. 1 added, estimated at 300 gallons per minute, or 432,000 gallons per day, we have a total well supply by natural flow of less than one million gallons per day, from 600,000 to 700,000 gallons short of the requirement.

To secure this extra amount two methods are to be considered, (1) pumping the present wells, (2) the sinking of additional wells. A cylinder pump, or an air lift, increases the discharge of water from a well in proportion to the depth at which it is placed. Thus at Charles City the yield of the city artesian, under natural flow 200 gallons per minute, was increased to 900 gallons per minute with a vacuum of seven pounds. At the State College at Ames the discharge was increased from 3525 gallons per hour to 7400 gallons by lowering the pumping cylinder from 105 feet below the curb to 270 feet. It seems probable that in accordance with the experience of other wells a large increase in supply from the Fort Dodge wells can be obtained by pump or air lift. The amount of this increase can not be definitely stated, but it can be ascertained by actual tests at comparatively little expense.

If an adequate supply can be obtained by pumping the present wells no additional wells will be needed as long as the pumped supply holds out. When it falls below the requirements of the city, new wells can be drilled. The present wells are admirably located to secure the maximum head and discharge. * * * * Additional wells can be placed up river from the waterworks on the low ground adjacent to the hydro-electric plant and up Lizard creek. Other wells could be sunk also in the valley of Soldier creek. * * * * It is my opinion that by pumping the present wells and by drilling new wells from 200 to 600 feet in depth from time to time a sufficient supply for Fort Dodge can be obtained for an indefinitely long period of years or at the least, for a period so long as amply to realize on the cost of the investment.

There are certain objections to the quality of this supply. It contains considerable iron. In the Municipal building a gelatinous rusty red deposit forms rapidly below the taps where the iron is apparently extracted from the water by plant slimes. A meter which had been in use for some time showed considerable deposit of this sort. The extent to which these iron deposits give trouble in basins and to laundries is no doubt well known to your citizens. The analyses indicate that it may give considerable trouble and annoyance. It would therefore be well to take the matter up with engineers to find the cost of removing the iron by aeration or filtration.

A second objection to the water of the wells is its hardness. The degree and kind of hardness is shown in the following table taken from analyses made for this investigation by Dr. Nicholas Knight of Cornell College. The numbers are parts per million.

Hardness of Fort Dodge Waters

Well	No. 1	No. 2	No. 3	Des Moines River
Lime and magnesia carbonates (temporary hardness)	161.90	326.00	222.6	238.8
Lime sulphate (permanent hardness)	455.9	235.3	270.8	316.2
Total	617.8	561.3	493.4	555.0

We may compare the hardness of the Fort Dodge wells with that of other deep wells in Iowa, as shown by the amounts of calcium (Ca.) and magnesium (Mg.) present, in parts per million.

	Ca. and Mg.
Fort Dodge, average of the three wells	171.4
Fort Dodge, well no. 1, when drilled	154.
Dubuque	88.
Charles City	91.
Clinton	92.
Waverly	96.
Mason City	115.
West Liberty	115.
Waterloo	116.
Ottumwa	127.
Cherokee	273.
Keokuk	279.
Burlington	457.
Belle Plaine	481.

Certainly the lime and magnesia present in the Fort Dodge well water is not so great as to be deleterious to public health. To persons unaccustomed to its use it might cause slight temporary digestive disorders, but again those accustomed to it might suffer similar troubles of the digestive tract on changing to softer drinking water. There is no valid or accepted evidence that such hard waters are the cause either of goiter or of urinary calculi.

As an industrial water, the water of the Fort Dodge wells is not to be commended. It has other disadvantages which no doubt you have considered. It will clog heaters and hot water pipes. It makes necessary the use of much larger quantities of soap than would a water entirely soft, and is less pleasant in bathing. Altogether, the cost of a hard water supply in plumbers' bills, in soap, and in the cisterns, tanks and lifts that many citizens install in order to secure soft water must amount in the aggregate to a very pretty sum.

Comparing the quality of the water of the shallower wells with that of the deep well we find no advantage with the latter. If therefore sufficient water can be obtained from wells from 200 to 600 feet deep there is no need of incurring the expense of drilling wells 1400 and 1800 feet in depth.

Filtered River Water

As a source of supply the Des Moines river has several points in its favor. This supply is abundant, inexhaustible, permanent. Machinery is accessible for repairs. The water is bacterially impure, yet the upper Des Moines doubtless contains less sewage than the middle Cedar, for example. Filtration is necessary for this supply. With care a filtration plant may be maintained at a high point of efficiency, as is shown by the history of the filter systems of several Iowa cities. The records of typhoid fever epidemics in Iowa cities also show how fatal may be a lack of care. As Turneaure and Russell state, "to obtain uniformly good results with economy requires very careful operation. The coagulant must be closely regulated to correspond with the quality of the water." These authors emphasize also the great care involved on the part of the attendants and the importance of having the whole plant under the control of regular and frequent bacteriological tests. With these precautions mechanical filtration can be made successful and efficient.

This supply is better than that of the wells for industrial purposes: iron is present in so small amounts in the river water at Fort Dodge that it will give no trouble in laundries or elsewhere.

Yet it will be carefully noted that the water of the Des Moines river at Fort Dodge, as shown by Knight's analyses, is by no means a soft water. At the time when the sample analyzed was taken, it contained 555 parts per million of calcium and magnesium carbonates and calcium sulphate, while the average contents of the three well waters in these salts was 557.5. Comparing the calcium and magnesium contents of the river water, 160.37 parts per million, with the waters of the deep wells listed in the foregoing table, it will be seen that the Des Moines river sample was more heavily charged with these elements than many of these wells. The following table taken from Hendrixson in vol. XXI, Iowa Geol. Survey, shows the comparative rating of the river water:

	Ca. and Mg. in parts per million
Average of 30 deep wells in ne. Iowa	94
Average of 35 deep wells in east central Iowa	150
Average of 16 deep wells in se. Iowa	199
Average of 13 deep wells in sw. and south central Iowa	223
Average of 10 deep wells in central Iowa	236
Average of 9 wells nw. Iowa	277
Des Moines river, May, 1919, Fort Dodge	160.

The reason for the hardness of the water of the upper Des Moines (which thus is about the average hardness of the deep wells in eastern Iowa) is not far to seek. The river is largely fed by ground water issuing from springs. Owing to the youth of the stream and the consequent lack of well developed tributaries there is a larger soak-in of the rainfall and less run-off reaches the streams than in the older rivers of eastern Iowa. Spring fed, the river thus contains large quantities of lime and magnesia carbonates and gypsum dissolved by ground water in its passage through the rocks and soils.

It must not be inferred that the river water is equally hard at all times of the year. When the proportion of run-off is greater, as at times of flood, the proportion of calcium and magnesium will be less (the water softer). At low water, in time of summer drought, when the supply will still more largely be from springs than in May when the sample was taken, it may be expected that the water will be still harder than the sample analysed. Some idea of the range in hardness may be gotten from the following table:

Analysis of Des Moines river water at Keosauqua, 1906-7 on the last week of the month.
in parts per million

	Sept.	Oct.	Nov.	Dec.	Jan.	Febr.	March	Apr.	May	June	July	Aug.
Ca and Mg	59	100	108	138	40	53	?	96	72	79	56	86

We have here an annual range from a minimum of 40 parts per million to a maximum of 138. The range at Fort Dodge will probably be as great. And at any given time of the year the water of the river at Fort Dodge will probably be considerably harder than at Keosauqua as the lower Des Moines river is more largely fed by the run-off.

Analyses of Fort Dodge Waters
in parts per million

A	Des Moines River,	May, 1919,	Knight
B	City well No. 1,	May, 1919,	Knight
C	City well No. 1,	1910 (?)	Hendrixson
D	City well No. 2,	May, 1919,	Knight
E	City well No. 3,	May, 1919,	Knight

	A	B	C	D	E
Total Solids	530.6	846.00	867.	618.6	561.6
Ca, Calcium	93.12	134.10	114.	135.28	112.52
Mg, Magnesium	67.25	46.25	40.	45.94	40.2
Cl, Chlorine	14.7	120.70	144.	14.7	14.7
HCO_3, Bicarbonate radicle	173.0	117.57	410.	217.64	152.12
SO_4, Sulphate radicle	224.55	323.75	205.	167.09	193.3
N, Nitrogen	2.2	0.1		0.05	0.1
Combined					
SiO_2, Silica	14.6	6.00		8.0	7.6
Fe_2O_3 and Al_2O_3, Ferric oxide and alumina	0.6	3.00	2.	14.0	8.6
NaCl and KCl, Sodium and potassium chloride	23.1	198.90	239.	23.1	23.1
Calcium carbonate	3.4	0.00		165.2	81.9
Magnesium carbonate	235.4	161.90		160.8	140.7
Calcium sulphate	316.2	455.90		235.3	270.8

In matters of engineering it is not my province to advise. The suggestions offered from the viewpoint of the geologist may, I trust, make somewhat easier your choice between the different sources of supply as you weigh their advantages and disadvantages, their relative cost of installment, their permanence and cost of upkeep.

In accordance with the tenor of the above report and the recommendation of Assistant State Geologist Lees and Dr. Kime of the County Medical Association, the city abandoned the filtration project and turned to the development of the artesian system. Well no. 1 was cleaned to depth of 1247 feet, which left it footing in the Galena limestone. In October, 1919, five of the wells were tested with the air lift with the following results:

Well	Natural Flow, G. P. M.	Air Lift Discharge, G. P. M.	Drop, Feet
No. 1	300	600	50
No. 2	55	200	140
No. 3*	350	......	......
No. 4	7	60	135
No. 5*	10	......	......
No. 6	90	250	75
No. 7	20	80	135
Total	832	1190	

* Not tested with air lift.

The judgment of the report as to the adequacy of the existing wells was thus verified. Five of the wells under the air lift, supplemented by the natural flow of no. 3, could supply 2,793,000 gallons per diem, over a million gallons in excess of the peak consumption.

In 1921 well no. 3, 8 inches in diameter, was abandoned and on its site a new well was drilled with a diameter of 17 inches and a natural flow of 750 gallons per minute.

After four years of successful use of the air lift it appeared in 1923 that it could be economically dispensed with if the natural artesian flow could be increased by drilling another well. Accordingly in 1923 well no. 8 was drilled, yielding a flow of 740 gallons per minute. Since that time wells nos. 1, 3, 6 and 8 have furnished alone the entire city supply. These four wells discharge 1480 gallons per minute by natural flow into a two million gallon reservoir, from which the water is picked up by high service pumps.

City wells nos. 1, 2 and 3 were described in the Underground Water Report of 1912.

City wells nos. 4 and 5 were drilled in 1914 by J. J. Becker, of Garner, Iowa. Well no. 4 has a depth of 400 feet, diameters, 8 and 6 inches. The principal supply was found at 200 feet. In 1919 the initial head of 20 feet above the curb had lowered to 9 feet and the original flow of 60 gallons per minute had decreased to 7.

Well no. 5 has the same diameters as no. 4 and a depth of 624 feet. Water was found at 300 to 400 feet, with a small vein at 100 feet.

In 1919 the initial head of 20 feet above the curb and the flow of 48 gallons per minute had diminished to 15 feet and 10 gallons.

Wells nos. 6 and 7 were drilled in 1916 by Thorpe Bros. of Des Moines. Well no. 6 has a depth of 283 feet and diameters of 10 and 8 inches. Water was found at 260 feet and the natural discharge was 190 gallons per minute.

Well no. 7 was drilled on Duck Island; depth 498 feet, diameters, 8 and 6 inches; water beds, 70-80, 315 and 473 feet. The initial head was 30 feet and the flow 80 gallons per minute.

Well no. 8 was drilled in 1923 by Thorpe Bros. Well Co. of Des

Moines. The depth is 1436 feet, diameters from 16 to 8 inches. The principal supply was found at 400 feet, and other water beds at 900 and 1400 feet. The head is 40 feet above the curb, and the discharge is 750 gallons per minute. The temperature is 52° Fahr. and the cost was $18,000.

At the close of 1928 the city has under favorable consideration the installation of a plant for water softening and removal of the iron.

MASON CITY

Mason City (population 20,065) draws from deep wells not only an ample public supply, but also the supply for industrial plants and railways equipped with their private wells. In 1910 the city obtained from six wells an average of 400,000 gallons daily with a maximum of 650,000 gallons. These wells were from 616 to 651 feet in depth and tapped the water beds of the Galena-Platteville limestones.

In 1910 it was found necessary to explore the lower water beds and city well no. 7 was drilled to the depth of 865 feet, penetrating the Shakopee dolomite to a depth of 40 feet. Five wells of corporations now drew on the same supplies as the city, the depth of these wells ranging from 405 to 816 feet.

As the increasing consumption by the waterworks and industrial plants pressed close on a supply apparently overdrawn, it was advised by this office to sink an additional well or wells to tap the lower waters of the Prairie du Chien and the Jordan. Accordingly city well no. 8 was drilled in 1912 to a depth of 1219 feet with a delivery of 1200 gallons per minute. In 1913 this office was again consulted as to deepening one or more of the shallower wells sunk in the reservoir. It was advised to avoid interference by drilling at a distance a well of the same depth as no. 8, and well no. 9, drilled in 1913, footing in the Jordan sandstone, also proved a capacity of 1200 gallons per minute.

The large yield of these lower aquifers has led to the abandonment of the shallower wells, nos. 1, 2, 3, 4 and 5, and the pulling of their equipment. Wells nos. 6 and 7 have been deepened to about 1200 feet and under air together with wells 8 and 9 have a combined delivery of 3900 gallons per minute. The city consumption averages about 1,300,000 gallons daily and under normal demands the entire public supply can be drawn from a single well. The city is thus far within its reserves, while railways and industrial plants draw on the artesian water beds by means of nine deep wells.

SIOUX CITY

Sioux City (population 71,227) draws its supply from 13 wells, from 323 to 341 feet deep and from 16 to 26 inches in diameter. The aquifer embraces heavy beds of porous sandstone (the Dakota) sealed by beds of clay or shale. (See logs, pp. 326-330.)

There are three pumping stations, one of which, the Main Street station, is held in reserve. At the Lowell station the wells are spaced 600 feet apart.

The pumping capacity of the individual wells differs, the highest being 3,000,000 g.p.d. Together they meet an average daily consumption (Venturi meter) of 6,000,000 g.p.d. and a maximum consumption of 13,000,000 g.p.d.

The present static level is 40 feet below the surface and is reported (1927) as falling at the rate of four inches yearly. In 1921 the recession for the previous 14 years was stated to be at the rate of one foot per year.

WATERLOO

Waterloo (population 36,230) draws its water supply exclusively (1927) from four deep wells. Previous to 1904, the supply was drawn from Cedar river, when a severe epidemic of typhoid fever traced to the city water led to the abandonment of the filtration plant and, on the advice of this office after a careful survey, to the installation of artesian wells. Wells no. 1, sunk in 1905, no. 2 (1907) and no. 3 (1911) are described in the writer's report of 1912. The description of wells nos. 4 and 5 will be found on pages 350-353 of the present report.

Well no. 1 has been abandoned because of "a chemical condition of the soil, causing casing to deteriorate so rapidly that it was cheaper to drill a new well in another location." Another report assigns infection as the cause. No trouble of this kind has occurred with the other wells.

The four wells now in use are located on a practically straight line about 5700 feet in length. The tested capacity at present of the four is more than 5,000,000 gallons daily while the peak consumption is but 3,000,000 gallons and the average daily consumption 1,500,000 gallons. The industrial plants of the city largely make use of the river water for boiler supply.

The usual lowering of the initial static level has taken place. In well no. 1 (1905) this level was found at 20 feet above the curb. In well no. 4, drilled nine years later, the head had fallen, but was still above the surface. Well no. 5 (1922) failed to flow. The static level in 1927 is reported at 40 feet below the curb for wells nos. 2 and 3 and 34 feet for well no. 4, while for well no. 5, whose curb is 8 feet higher, the static level apparently since its drilling has been 50 feet below the surface.

Since the above was written well no. 6 has been completed (December, 1928) and will be found described on page 352.

CEDAR RAPIDS

The city of Cedar Rapids, population 56,000, has a daily average consumption (1927) of 4,237,357 gallons, a daily average per capita consumption of 80 gallons, and a maximum daily consumption of 6,462,120 gallons.

While the main supply of Cedar Rapids is obtained from Cedar river, it has also been drawn largely from deep wells, and a supply from shallow wells has recently been under consideration. The water supply question of the city is at present writing still undecided, but it is believed that its experiences with different supplies are of sufficient value to warrant their relation here at some length.

The first public supply of the city, 1875-1888, was taken from a filter well on the river bank. In 1888 three artesian 5 inch wells were drilled from 144 to 160 feet apart at the apices of a triangle. The first of these wells was sunk to a depth of 2225 feet, reaching the Sioux quartzite, and thus piercing all the Cambrian aquifers. As a salty and corrosive water entered the well somewhere below 1450 feet, the well was plugged at that depth in 1894. The other wells were 1450 feet deep, footing in the Jordan sandstone, and no artesian since drilled has ventured below that aquifer. Unlike Dubuque and Clinton, Cedar Rapids is thus unable to draw on the deeper Cambrian water beds. Fortunately the Jordan sandstone here is thick and generous in yield.

The initial head of the Jordan water was 761 feet above sea level, 28 feet above the curb. The discharge was 250 g.p.m. from each well by flow under its own pressure.

In 1894 an artesian well, drilled for the Y. M. C. A. to the same depth as the city wells, showed a head of but 735½ feet above sea level. The flow of the city wells had now for some years been insufficient, and had been supplemented by raw river water. The water company had also lost much of its manufacturing patronage because of the hardness of the water. It was therefore decided not to further extend the deep well supply, but to seek a main supply from the river, continuing the deep wells only to supplement it. A mechanical filter plant was erected in 1895-6 at the site of the three deep wells. Had it then been known that deep wells could easily be made to yield 1000 g.p.m. at Cedar Rapids the decision might have been different.

By 1911 waterworks well no. 3 had been abandoned, the head of the city wells had fallen to 2 feet below the curb and their yield each to 150 g.p.m. The capacity of the filter plant was 10,000,000 g.p.d. and the average daily consumption 2,500,000 gallons. The deep wells were still used, as they are used today, chiefly when filtration is made more difficult or unsatisfactory, as during spring floods and the heat of summer.

In 1914, perhaps owing to dissatisfaction with river water, a tentative move toward an artesian supply was made by drilling, on the West Side, city well no. 4, 1591 feet deep, and 10 inches in diameter at bottom. The initial head of this well was 721 feet above sea level, 15 feet below the curb, about the head of Silurian waters in several wells. This well is now pumped by a vertical rotary pump and yields 1055 g.p.m., with the pump at 84 feet. The draw down is not known as the well is closed by the pump head, but of course can not exceed the limit of the intake.

Of the three original city wells situated on the small triangle at the waterworks nos. 2 and 3 are now abandoned owing to serious interference. Well no. 1 now shows a static level of 14 feet below the curb, lowering to 18 feet when the distant deep well of the Sinclair Packing Co. is pumped. It delivers under air from 900 to 1000 g.p.m. This well and well no. 4 now furnish about 2,500,000 gallons daily.

A change in water supply has been under careful and thoughtful consideration by the officials of the city and under vehement discussion by the people and the press since 1926. The filtration plant is old and must be rebuilt soon if the river is continued as the main supply.

As shallow wells were under advisement in October, 1926, the writer was consulted as to the proposition of a supply from proposed wells about 100 feet in depth tapping sands of the Cedar river flood plain within the city on the West Side, wells whose sufficiency was guaranteed for one year. It was then pointed out that the chief factor in sufficiency is not the capacity of the reservoir but the rate of its replenishment; that the flood plain, encircled by rock hills, has little replenishment except from rain and river; that the flood plain is largely cut in rock and glacial till and its water-bearing sands are limited to the course of a buried channel. In case shallow wells were to be considered as a supply it was advised to explore thoroughly the possibilities of the buried preglacial or interglacial channel underlying the flood plain of Prairie creek south of the city with its drainage area of over 200 square miles. The wide continuous flood plains of the Cedar river above Covington were also suggested.

The test well put down by the guaranteeing company on the West Side flood plain proved a failure, and several test holes were then sunk in the Prairie creek valley, some of which developed a large flow.

The writer was again called to advise in the situation and after a cursory reconnaissance pointed out the complex nature of the valley fill and the need of further tests to determine the extent and thickness and capacity of the water beds.

The City now employed Professor Howard E. Simpson of the University of North Dakota, Water geologist of that state, and consulting expert on municipal supply, to make a complete ground water survey. His report of December, 1927, discusses fully five local sources of ground water and also Cedar river.

The following synopsis of Simpson's report is as far as possible in excerpts.

1 *Springs.* A supply from the springs north of the city and on Indian creek rising from Devonian limestone is inadequate as the maximum supply available is 3,000,000 gallons daily. In common with all springs they are liable to surface contamination. When drawn off in large amounts by collecting basins and galleries, it would be necessary to watch the supply very carefully and take frequent sanitary analyses.

2 *The Silurian limestone.* A number of wells in the city foot in Silurian limestone at depths of from 150 to 450 feet. Their head is from 15 to 30 feet below the curb and their yield, depending in part on size of well and pump, reaches a maximum of 600 g.p.m. But no quantity sufficient for city supply could be taken without greatly lowering the head, drawing in shallow and probably contaminated water and endangering the supply. This source in Cedar Rapids should remain for industrial uses, where a cheap, cold, sanitary water is highly desirable.

3 *The Cedar River Gravels.* The gravels of the flood plain up river about Palo are probably the largest available source of a supply of this type to be found in the vicinity. With the growth and industrial development of the city these gravels may prove to be a most valuable water supply. Their distance from the city, however, makes it inadvisable to give them further consideration at this time.

The gravels of the buried channel of the flood plain within the city limits are not recommended for sanitary reasons, although in some wells they now deliver 1000 g.p.m. continuous service. There is no impervious clay cover and the river in some places at least, flows in a bed cut directly in this gravel deposit. This water is, however, highly satisfactory for cooling purposes, for which it is chiefly used, since it is the coldest water available and the most economical to pump. Its temperature is reported at 48° to 52° F., depending in part on the season and the amount of pumpage. The fact that heavy pumping sometimes runs the temperature up as high as 56° or 58° F. in certain of these wells clearly indicates that very shallow waters, possibly from the river itself, are drawn down into the intake under the heavy pumpage of summer. The taking of this supply within or below the city would necessitate treatment to make it safe for public use. It would offer little advantage over river water and should be considered only as an alternative of the river itself.

The Prairie Creek Gravels. A very complete survey was made by Simpson of the Prairie creek flood plain and its ancient buried channel. The character of the fill is indicated by the log of test hole no. 17:

Material	Thickness feet	Depth feet
Loam and clay	5	5
Sand and clay	10	15
Bluish white clay	15	30
Sand	5	35
Light blue clay	60	95
Blue clay	28	123
Sand and gravel	47	170
Fine sand	5	175
Clean sand and gravel	27	202
Coarse gravel	10	212
Rock		

The geological interpretation by Simpson of this log and of the ten samples of material taken from this hole is as follows:

Formation	Thickness feet	Depth feet
Alluvium, loess, etc.	30	30
Buchanan gravel	5	35
Kansan boulder clay	88	123
Aftonian gravel	89	212
Silurian limestone	2	214

Test holes nos. 9 and 8 with diameters of 5⅝ inches and 4 inches, with static heads of 28 and 20.7 feet, flowed on completion at the rate of 350 g.p.m.

The conditions which prevail in the Prairie creek artesian basin are very similar to those of the Belle Plaine artesian basin which gave rise to the most famous artesian well in America, the "Belle Plaine Jumbo". This basin, however, is neither as large nor as deep as that of Belle Plaine and we may not expect so great a head nor as large a yield as were found there. The Prairie creek basin is also a smaller duplicate of that of the Iowa river in the Amana colony and is possibly a part of the same artesian system.

The mineral quality of the Prairie creek gravel water is good, though it is moderately hard and unfortunately it appears to carry a larger amount of iron than any of the others considered. This would at least require treatment by aeration or otherwise for the removal of the iron. The sanitary quality is good, owing to the thick boulder clay deposited over the Aftonian gravel, and there would be no danger of contamination except through the well holes.

The quantity of water passing very slowly down valleyward through these Prairie creek sands and gravel is large, but how large is uncertain owing to the number of variable factors, the extremes of which even cannot be ascertained with accuracy. Just how much the yield obtainable may be is the most difficult problem encountered in this survey and the only one which cannot be solved with a reasonable degree of certainty. The amount, however, is large, amounting at least to several million gallons per day. It is possible that these gravels may yield a sufficient amount of water for the entire city supply. It cannot be depended upon as an exclusive source unless proved by further testing to yield much larger amounts than have yet been demonstrated.

The Deep Artesian Formations offer for the city the best available source of ground water supply in its natural state. It is an excellent drinking water and the only objection to its use from the standpoint of quality is its hardness. This is true, however, of all available water supplies. Deep artesian wells could undoubtedly be made to yield an abundant supply for the city for some years to come. The necessary consideration would be the number, the size, and the spacing of the wells. With wells finished at least 12 inches in diameter, and at least one-half mile apart, a yield of about 1000 g.p.m. per well could undoubtedly be secured. Eight million gallons daily could be secured from six of these wells. Two wells should be allowed in reserve, making eight wells in all. These should be spaced as widely as possible and located preferably in the city parks.

The possibility of deep artesian waters for city supply in eastern Iowa is fully demonstrated in Waterloo, Clinton, Dubuque and other cities. To take the entire supply from deep artesians, would, however, be so great a drain upon the deep artesian formations in the immediate vicinity of the city, when continued through a long period of years, that it does not seem advisable on account of cost to make this the exclusive supply.

As to Cedar river as a surface water supply Simpson states: The quality of the water from the mineral point of view, especially as respects hardness, is superior to that of any available ground water. The average total hardness of the year as calculated by the U. S. Geological Survey is 185.8 parts per million, or 10.85 grains per gallon, most of which is temporary. The river, however, is always polluted, and it must be purified before it is fit for domestic use. It may, however, be made entirely safe for domestic use at the same time that it is being clarified and softened, if softening is desired. The chief difficulty in the use of river water arises from the fact that the organic matter in the water may unite with the chlorine used for purifying the water, especially when it is necessary to use this in excess, and form certain organic compounds which impart very unpleasant tastes and odors to the water. This is especially noticeable in warm tap water, and water from a surface supply is always warm in summer. This warmth, which is frequently above 70° F., is also one of the chief objections to the river water.

The use of the rivers for sewer purposes in the past, and increasingly so in the present, is largely depriving the cities of this valuable source of water supply. It seems highly probable that within the next fifty years, possibly within twenty-five, the people will abolish the grosser forms of stream pollution and make this, the most abundant, economical and permanent of all water supplies, more readily available for public use. Pollution can never be entirely avoided, however, and the organic compounds characteristic of surface waters will necessarily be present with their tastes and odors. There is no known way to avoid these tastes and odors in surface water supplies.

The Future Supply. The Industrial Survey recently made by the Chamber of Commerce estimates that the population of Cedar Rapids in 1950 will be 100,000. The future needs of this increased population with its increased industrial needs may therefore be anticipated in the selection of a water supply at the present time. There should be 8,000,000 gallons per day immediately available and at least 10,000,000 gallons per day in sight for 1950.

This future water supply must be bacteriologically pure; it should be clear, cool, and free from unpleasant tastes and odors. It should also be relatively free from iron in solution and from corrosive minerals. I believe that the people of Cedar Rapids will also say that it should be soft.

While it may not be possible to meet all these requirements and have a perfect water, it is possible to closely approach this ideal and that within a very moderate cost. Low cost is only of less importance than quality and quantity, since low cost means larger usage and resulting cleanliness and beauty of the city.

A slight increase in cost in order to soften the public supply is more than repaid in cash to the average householder in the saving of soap consumption, the repairs of plumbing, the renewal of hot water tanks and boilers and above all in the saving of fuel for the heating of water in unscaled and sludge-free pipes. We need not mention what soft water means to the housewife in sanitation, comfort and beauty of the home.

Cedar Rapids may have quality water, clean, soft and abundant. It is recommended that the decision be first made whether the future water supply will be hard or soft. If the water is used without softening it is recommended that deep artesian formations be utilized as the primary source and the Prairie creek gravels as a secondary source. If soft water is desired any supply should be softened to about 138 parts per million and it is recommended that the Prairie creek gravels be selected as the primary source, provided on further prospecting and development it be found to yield in excess of 5,000,000 gallons per day, and that deep artesian wells be continued as a supplementary supply.

In accordance with specifications in the report of Professor Simpson another trial well was sunk in the Prairie creek valley. This well, 180 feet deep, was 24 inches in diameter. It yielded under the pump 1,500,000 gallons per day for 30 days with a draw down to 36 feet below the surface, or 42 feet below static level. By increasing the speed of the pump a discharge was obtained of

2,000,000 gallons per day for three weeks with a draw down to 55 feet below the surface of the ground.

Water was not struck in this test well until after an election was held as to a proposed bond issue for new water works. The proposition failed to carry. The firm of Alvord, Burdick, and Howson of Chicago was now employed as engineering experts. In their report it is stated as to the artesian supply:

"The entire region about Cedar Rapids is underlaid with water-bearing sandstones capable of yielding a supply adequate for either present or future needs if the wells are sufficiently distributed. The water is hard but could be readily softened."

As to the Prairie creek gravels as the source of the city supply this firm of engineers was less optimistic. "We have made a two months test of the J Street well (the last one drilled) and have observed the effect on the water levels in that well and others as far distant as two and one-half miles. From the data thus secured we conclude that the Prairie creek sands are too limited to furnish an adequate supply unless possibly by locating a number of pumping stations at intervals of several miles. We do not consider this a practicable source of supply for present and probable future requirements of Cedar Rapids." The requirements of the city had already been placed by the firm at 12,000,000 gallons per day, to supply the maximum consumption of ten years hence.

The firm therefore recommended that the existing plant be abandoned and a modern plant be built up valley opposite Ellis Park at a total expenditure, exclusive of land, of $640,000. Their estimate as to the costs of the supplies considered is as follows, each to be used as sole supply.

Supply	First Cost	Annual Cost
Deep wells	$ 885,000	$168,850
Prairie Creek gravels	1,250,000	200,000
Cedar River, steam	864,000	131,000
Cedar River, electricity	640,000	111,000

In November, 1928, the City in an election approved the issue of bonds for $660,000 for the proposed new water works.

ANALYSES OF WATER AVAILABLE FOR PUBLIC SUPPLY AT CEDAR RAPIDS

The following analyses were made in December, 1927, for Professor Howard E. Simpson by Professor G. A. Abbott, head of the Department of Chemistry, University of North Dakota. They are reproduced here with permission because of their value as an addition to our knowledge of the chemistry of Iowa waters.

Analyses of Waters from Cedar Rapids

Laboratory Number 2340. No. 1. Testhole no. 9. South side Prairie Creek. Artesian gravel. Depth 212 feet.

	Parts per million		Parts per million
Residue on evaporation	320	Sodium (Na)	5.06
Alkalinity to phenolphthalein	None	Calcium (Ca)	38.80
Total alkalinity (as $CaCO_3$)	278	Magnesium (Mg)	43.46
Total hardness (as $CaCO_3$)	278	Iron (Fe)	1.40
Temporary hardness	278	Chlorine (Cl)	7.80
Permanent hardness	0	Carbonate (CO_3)	166.80
		Sulphate (SO_4)	Trace

Hypothetical Combinations

Sodium chloride (NaCl)	12.87	Magnesium carbonate ($MgCO_3$)	152.04
Calcium carbonate ($CaCO_3$)	97.00	Iron oxide (Fe_2O_3)	1.62

A water of only moderate hardness, practically all of which is carbonate or "temporary" hardness. It is slightly corrosive, owing to the release of carbonic acid on boiling. In a boiler it would produce a sludge rather than a hard scale. It could be softened by boiling, or by addition of a little hydrated lime. I have reported the calcium and magnesium as carbonates, but they really exist in the water in the form of bicarbonates, which are decomposed by boiling.

Laboratory Number 2342. No. 3. City Waterworks Well No. 4. West Side Artesian. Depth 1450 feet.

	Parts per million		Parts per million
Residue on evaporation	642	Sodium (Na)	123.81
Alkalinity to phenolphthalein	None	Calcium (Ca)	71.56
Total alkalinity (as $CaCO_3$)	285	Magnesium (Mg)	34.51
Total hardness (as $CaCO_3$)	323.5	Iron (Fe)	0.10
Temporary hardness	285	Chlorine (Cl)	24.00
Permanent hardness	38.5	Carbonate (CO_3)	171.00
		Sulphate (SO_4)	248.12

Hypothetical Combinations

Sodium chloride (NaCl)	39.54	Magnesium carbonate ($MgCO_3$)	89.46
Sodium sulphate (Na_2SO_4)	314.53	Magnesium sulphate ($MgSO_4$)	44.70
Calcium carbonate ($CaCO_3$)	178.90	Iron oxide (Fe_2O_3)	0.14

A moderately hard water, somewhat corrosive, but non-scale forming. High in total solids due to a large amount of sodium sulphate.

Laboratory Number 2343. No. 4. Penick and Ford Company 429 foot well.

Silurian limestone.

	Parts per million		Parts per million
Residue on evaporation	434	Sodium (Na)	41.89
Alkalinity to phenolphthalein	None	Calcium (Ca)	84.20
Total alkalinity (as $CaCO_3$)	285	Magnesium (Mg)	25.33
Total hardness (as $CaCO_3$)	316	Iron (Fe)	0.20
Temporary hardness	285	Chlorine (Cl)	30.00
Permanent hardness	31	Carbonate (CO_3)	171.00
		Sulphate (SO_4)	46.91

Hypothetical Combinations

Sodium chloride (NaCl)	49.14	Magnesium carbonate ($MgCO_3$)	89.40
Sodium sulphate (Na_2SO_4)	25.27	Magnesium sulphate ($MgSO_4$)	37.26
Calcium carbonate ($CaCO_3$)	210.50	Iron oxide (Fe_2O_3)	0.28

Moderately hard water. Nearly all of the hardness due to calcium bicarbonate and removable by boiling. Slightly corrosive, owing to release of carbonic acid on boiling. Low in iron. Should give a sludge or soft scale in a boiler.

Laboratory Number 2344. No. 5. City Waterworks Well No. 1. Station Well.

Depth 1450 feet.

	Parts per million		Parts per million
Residue on evaporation	731	Sodium (Na)	75.14
Alkalinity to phenolphthalein	None	Calcium (Ca)	105.24
Total alkalinity (as $CaCO_3$)	285.0	Magnesium (Mg)	46.95
Total hardness (as $CaCO_3$)	480.6	Iron (Fe)	Trace
Temporary hardness	285.0	Chlorine (Cl)	52.48
Permanent hardness	195.6	Carbonate (CO_3)	171.00
		Sulphate (SO_4)	239.18

Hypothetical Combinations

Sodium chloride (NaCl)	86.58	Magnesium carbonate ($MgCO_3$)	18.39
Sodium sulphate (Na_2SO_4)	106.99	Magnesium sulphate ($MgSO_4$)	208.50
Calcium carbonate ($CaCO_3$)	263.10	Iron oxide (Fe_2O_3)	Trace

A very hard water. Forty per cent of the hardness is permanent hardness. A corrosive, scale forming water requiring softening to make it suitable for public supply.

Laboratory Number 2346. No. 7. Sinclair Packing Company gravel well.

Depth 72 feet.

	Parts per million		Parts per million
Residue on evaporation	1,469	Sodium (Na)	441.78
Alkalinity to phenolphthalein	None	Calcium (Ca)	120.00
Total alkalinity (as $CaCO_3$)	257.0	Magnesium (Mg)	33.54
Total hardness (as $CaCO_3$)	435.5	Iron (Fe)	.60
Temporary hardness	257.0	Chlorine (Cl)	603.50
Permanent hardness	178.5	Carbonate (CO_3)	154.20
		Sulphate (SO_4)	276.53

Hypothetical Combinations

Sodium chloride (NaCl)	994.50	Calcium sulphate ($CaSO_4$)	58.48
Sodium sulphate (Na_2SO_4)	155.49	Magnesium sulphate ($MgSO_4$)	162.50
Calcium carbonate ($CaCO_3$)	257.00	Iron oxide (Fe_2O_3)	1.14

A very hard salty water. The large amount of sodium chloride (common salt) suggests strongly the possibility that the well is receiving surface contamination, such as salt from the packing plant. Of course it might come from salt beds, but these are usually found at greater depths. The water is too salty for suitable water supply.

Laboratory Number 2347. No. 8. Penick and Ford Co. 70 foot gravel well.

	Parts per million		Parts per million
Residue on evaporation	575	Sodium (Na)	49.68
Alkalinity to phenolphthalein	None	Calcium (Ca)	155.80
Total alkalinity (as $CaCO_3$)	363	Magnesium (Mg)	30.58
Total hardness (as $CaCO_3$)	511.5	Iron (Fe)	.60
Temporary hardness	363.0	Chlorine (Cl)	92.00
Permanent hardness	148.5	Carbonate (CO_3)	217.80
		Sulphate (SO_4)	120.58

Hypothetical Combinations

Sodium chloride (NaCl)	122.44	Magnesium chloride ($MgCl_2$)	30.04
Calcium carbonate ($CaCO_3$)	363.00	Magnesium sulphate ($MgSO_4$)	129.60
Calcium sulphate ($CaSO_4$)	36.04	Iron oxide (Fe_2O_3)	.85

High in total solids and very hard. Twenty-nine per cent of the hardness is permanent hardness. A corrosive, scale forming water. Would require softening to make it suitable for public supply.

Laboratory Number 2348. No. 9. Marion Springs. Composite.

	Parts per million		Parts per million
Residue on evaporation	296	Sodium (Na)	14.79
Alkalinity to phenolphthalein	None	Calcium (Ca)	69.44
Total alkalinity (as $CaCO_3$)	218	Magnesium (Mg)	21.40
Total hardness (as $CaCO_3$)	262.5	Iron (Fe)	Practically none
Temporary hardness	218	Chlorine (Cl)	6.00
Permanent hardness	44.5	Carbonate (CO_3)	130.80
		Sulphate (SO_4)	20.57
		Iron oxide (Fe_2O_3)	Practically none

Hypothetical Combinations

Sodium chloride (NaCl)	9.99	Magnesium carbonate ($MgCO_3$)	37.88
Sodium sulphate (Na_2SO_4)	33.65	Magnesium sulphate ($MgSO_4$)	53.40
Calcium carbonate ($CaCO_3$)	173.60	Iron oxide (Fe_2O_3)	Practically none

Only moderately hard. Most of the hardness is carbonate or temporary hardness. Sludge forming rather than scale forming. Slightly corrosive to boilers. Fairly satisfactory for public supply. Could be softened by hydrated lime treatment.

Laboratory Number 2349. No. 10. McLeod Spring.

	Parts per million		Parts per million
Residue on evaporation	281	Sodium (Na)	17.91
Alkalinity to phenolphthalein	None	Calcium (Ca)	71.56
Total alkalinity (as $CaCO_3$)	213	Magnesium (Mg)	12.67
Total hardness (as $CaCO_3$)	237.65	Iron (Fe)	None
Temporary hardness	213	Chlorine (Cl)	6.00
Permanent hardness	24.65	Carbonate (CO_3)	127.80
		Sulphate (SO_4)	51.44
		Iron oxide (Fe_2O_3)	None

Hypothetical Combinations

Sodium chloride (NaCl)	9.88	Sodium sulphate (Na_2SO_4)	43.31
Calcium carbonate ($CaCO_3$)	178.90	Iron oxide (Fe_2O_3)	None
Magnesium carbonate ($MgCO_3$)	24.38		

Very similar to No. 9. Only moderately hard, and most of the hardness is temporary hardness. Sludge forming rather than scale forming. Slightly corrosive to boilers. Fairly satisfactory for public supply. Could be largely softened by treatment with hydrated lime.

Laboratory Number 2350. No. 11. Cedar River Water.

	Parts per million		Parts per million
Residue on evaporation	303	Sodium (Na)	.71
Alkalinity to phenolphthalein	None	Calcium (Ca)	71.56
Total alkalinity (as $CaCO_3$)	210	Magnesium (Mg)	32.04
Total hardness (as $CaCO_3$)	241.5	Iron (Fe)	.60
Temporary hardness	210	Chlorine (Cl)	24.00
Permanent hardness	31.5	Carbonate (CO_3)	126.00
		Sulphate (SO_4)	67.07
		Iron oxide (Fe_2O_3)	.85

Hypothetical Combinations

Sodium chloride (NaCl)	1.81	Magnesium carbonate ($MgCO_3$)	26.46
Calcium carbonate ($CaCO_3$)	178.90	Magnesium sulphate ($MgSO_4$)	83.70
Magnesium chloride ($MgCl_2$)	30.64	Iron oxide (Fe_2O_3)	.85

This river water is only moderately hard, most of the hardness being temporary. It is fairly high in iron. It is somewhat corrosive, due to magnesium chloride. A sanitary analysis would probably show that the water is somewhat polluted with organic matter and bacteria and it would probably require filtration or sterilization to render it fit for public supply.

Descriptions of Deep Wells

ALGONA

(Altitude 1204 feet, C. & N. Ry.)*

CITY WELL NO. 3

The third well for the city of Algona was put down by Thorpe Brothers Well Company of Des Moines in 1924-25. The depth is 1885 feet. Water was found from 250 to 300 feet in limestone, probably Mississippian in age, and from 500 to 650 feet in the Galena-Platteville limestones, yielding in a test at 800 feet 150 gallons per minute. The main supply was obtained from the Shakopee dolomite at 1063 feet and from the horizon of the Jordan from 1240 to 1270.

The static level of the water in the well is 100 feet below the surface of the ground. The well pumps 200 gallons per minute with the pumping cylinder at 200 feet. Under continuous pumping at this rate there is a draw down of 100 feet.

* Slight differences between altitudes of towns and of wells are due to the use of later data for the towns. See Ia. Geol. Survey, vol. XXXII.

Twelve inch casing extends to 206 feet and is succeeded by 958 feet of 10 inch casing and 741 feet of 8 inch casing. The casing is perforated at the water beds. The cost of the well is approximately $22,000.

When the well had reached the depth of about 1700 feet this office was consulted as to going deeper. In reply it was stated that it was highly improbable that another water bed would be found. "You may strike the red clastic series anywhere from the present bottom of the well to 1800 feet, or granite anywhere between where you are now and 2000 feet." "If you should take the gambler's chance and go on, stop when you come to the red clastics—red shales and sandstones—or to the granite." The advice to stop was repeated when at 1810 feet the red clastics were struck.

Notwithstanding these advices, the work was continued and as the red series proved unexpectedly thin (its thickness north of Algona in Minnesota measures 200 feet) granite was reached at 1830 feet. This obdurate rock was entered to the depth of 55 feet. The rate of drilling from 1812 to 1860 feet, 1.8 feet per hour, indicates some secular decay of the ancient land surface to a depth of at least 30 feet. From 1860 to 1885 feet the rate fell to 6 inches per hour in the sounder rock.

Record of Strata

	Depth in Feet
Pleistocene and Recent (130 feet thick; top 1200 feet above sea level):	
"Yellow clay"	0–35
"Black clay"	35–130
Cretaceous (71 feet thick; top 1070 feet above sea level):	
"Fine sandstone"	130–186
"Limestone"	186–191
"Red shale"	191–201
Mississippian, Devonian?, Silurian? (209 feet thick; top 999 feet above sea level):	
"Limestone"	201-204
Limestone, reddish buff, saccharoidal, rather slow effervescence in cold dilute HC1	204–212
Limestone, gray, compact, some pinkish, some whitish, rapid and moderately rapid effervescence	213–223
Limestone, brownish drab, rapid effervescence, in flaky chips	223–235
Dolomite, gray, crystals of calcite; bright green shale in large chips; some white chert	235–250
Limestone, light yellow and gray, rather slow effervescence	250–270
Limestone, dark gray, rather slow reaction; some limestone with rapid effervescence	270–325
Dolomite, drab, compact; 2 samples (darker from 360–400)	325–400

Ordovician:	
Maquoketa (40 feet thick; top 800 feet above sea level)—	
Shale, greenish, calcareous, in concreted masses	400–440
Galena to Glenwood inclusive (480 feet thick; top 760 feet above sea level)—	
Limestone, gray, earthy, argillaceous, rapid effervescence; shale	440–460
Limestone, drab and light yellow, rapid reaction	460–495
Limestone, blue gray, argillaceous, rather slow effervescence; much white chert	495–550
Limestone, rather slow response to acid; blue gray	550–665
Limestone, light buff, rather slow response	665–715
Shale, light blue; cuttings of limestone; residue of minute quartzose particles	800–820
Shale, dark greenish, calcareous, in hard concreted masses	820–860
Shale, as at 800	860–870
Shale, as at 820	870–890
Shale, greenish, fissile	890–900
Shale, as at 820	900–910
Limestone, dark drab and light gray, rapid reaction; much green fissile shale; a little quartz sand of well rounded grains	910–920
Saint Peter sandstone (80 feet thick; top 280 feet above sea level)—	
Sandstone, fine, white, Saint Peter facies; with some green fissile shale	920–940
Shale, green	940–950
Sandstone, fine, rusted	950–960
Sandstone, blue-gray, fine, grains well rounded, highly argillaceous with concreting powder; 2 samples	960–1000
Shakopee (90 feet thick; top 200 feet above sea level)—	
Dolomite, with much quartz sand	1000–1010
Dolomite and shale; in concreted masses of powder and fine chips; much quartz sand	1010–1020
Dolomite, light gray; much quartz sand	1020–1030
Dolomite, gray, in small chips	1030–1040
Dolomite, gray, vesicular; siliceous oölite; sandstone white, fine	1040–1050
Dolomite, light gray; 3 samples	1050–1090
New Richmond (70 feet thick; top 110 feet above sea level)—	
Sandstone, fine, white, larger grains well rounded; some flakes of calciferous sandstone at 1100; 3 samples	1090–1120
Dolomite, light drab, in minute chips; quartz sand and powder of shale; 2 samples	1120–1140
Sandstone, very fine, buff, calciferous	1140–1150
Sandstone, white, fine, rounded grains	1150–1160
Oneota (90 feet thick; top 40 feet above sea level)—	
Dolomite, light yellow-gray and gray, drab at 1210-1230; 8 samples	1160–1250
Cambrian:	
Jordan sandstone (90 feet thick; top 50 feet below sea level)—	
Sandstone, white, fine, larger grains well rounded; fragments of arenaceous dolomite; shale	1250–1260
Sandstone, with much dolomite in fine powder; 2 samples	1260–1280
Sandstone, white, clean, fine, larger grains rounded; 2 samples	1280–1300
Sandstone, whitish, fine; much microscopic angular quartzose material and dolomitic powder	1300–1320
Sandstone, gray, fine, rounded grains; 2 samples	1320–1340
Saint Lawrence—	
Trempealeau (50 feet thick; top 140 feet below sea level)—	
Dolomite, buff, in powder; some quartz sand	1340–1350
Dolomite, gray, in fine chips	1350–1360
Dolomite, argillo-arenaceous, in concreted masses	1360–1370
Dolomite, gray, hard, in small chips concreted with argillo-calcareous powder in light blue-gray masses	1370–1380
Dolomite, light blue-gray, argillaceous	1380–1390

Franconia (160 feet thick; top 190 feet below sea level)—
- Dolomite, gray, in chips and sand; highly glauconitic; with argillo-calcareous powder 1390–1400
- Dolomite, glauconitic; 2 samples 1400–1420
- Shale, light greenish, highly quartzose and dolomitic, glauconitic, quartzose matter minute and angular, in concreted powder and chips; 7 samples 1420–1500
- Shale, greenish and light purplish; slightly dolomitic; 5 samples 1500–1550

Dresbach (30 feet thick; top 350 feet below sea level)—
- Sandstone, white and gray, fine, larger grains rounded, some green, paper shale and glauconite at 1550; 3 samples 1550–1580

Eau Claire (230 feet thick; top 380 feet below sea level)—
- Sandstone, light greenish yellow, argillaceous, calciferous; 2 samples 1580–1600
- Sandstone, very fine, imperfectly rounded grains 1600–1610
- Sandstone, as above, light greenish yellow, argillaceous; 2 samples 1610–1630
- Shale, light blue, slightly calcareous 1630–1640
- Shale, dark green, glauconitic, arenaceous; 2 samples 1640–1660
- Shale, blue and green, plastic, at 1710 glauconitic and minutely arenaceous; 8 samples 1660–1730
- "Shale, blue"; no samples 1730–1770
- Sandstone, buff, fine-grained, in sand; some chips of soft light gray sandstone, as below 1770–1780
- Sandstone, gray, rather soft, of microscopic angular particles of quartz, argillaceous, slightly calcareous, in chips 1780–1790
- Shale, green-gray, non-calcareous, in hard concreted masses 1800–1810

Red Clastic series (20 feet thick; top 610 feet below sea level)—
- Sandstone, red and reddish brown, some grains 2 mm. in diameter, of clear quartz, surface stained; some black round grains, non-crystalline, harder than glass, opaque, brownish when pulverized; 3 samples 1810–1830

Archean (penetrated 55 feet; top 630 feet below sea level):
- Granite, or arkose, in fine sand of reddish feldspar, angular grains of quartz, and black mica; some rounded grains of quartz perhaps from above; 3 samples 1830–1860
- Granite: quartz, orthoclase feldspar, biotite mica 1860–1885

Driller's Log

	Depth in Feet		Depth in Feet
Yellow clay	0–35	Sandstone	1038–1063
Black clay	35–130	Limestone	1063–1091
Fine sandstone	130–186	Sandstone	1091–1121
Limestone	186–191	Limestone	1121–1254
Shale, red	191–201	Sandstone	1254–1342
Limestone	201–223	Shale	1342–1360
Shale	223–225	Shale	1360–1380
Limestone with shale	225–816	Limestone	1380–1424
Shale	816–833	Shale	1424–1469
Limestone	833–836	Limestone, very hard	1469–1480
Shale	836–856	Shale	1480–1483
Limestone	856–859	Limestone	1483–1487
Shale	859–915	Shale	1487–1551
Limestone	915–920	Sandstone	1551–1604
Shale	920–928	Shale	1604–1671
Sandstone	928–940	Shale	1671–1756
Shale	940–950	Sand rock	1756–1768
Sharp sand	950–960	Lime, brown, sandy	1768–1785
Shale and hard sharp sand	960–980	Shale, blue	1785–1808
Sandy shale	980–1020	Red shale, cavy	1808–1812
Sandy lime	1020–1038	Sandy red rock	1812–1885

*Mineral Content of City Well, No. 3, Algona**

	Parts Per Million
Bicarbonate	456.3
Chloride	9.
Sulfate	146.6
Silica	8.4
$Fe_2O_3+Al_2O_3$	14.8
Calcium	104.4
Magnesium	39.6
Na + K as Na	38.5
Total solids	589.4

ALTA, BUENA VISTA COUNTY

(Altitude 1514 Feet, I. C. R. R.)

The deep well of this city was completed in 1916 by Kiskadden and Anderson of State Center. The depth is 1465 feet and the diameters from 12 to 4 inches. A fair supply of water was found at about 500 or 600 feet. The main water bed was struck at about 1390 feet, 124 feet above sea level, and probably is the Saint Peter sandstone, since this aquifer would be expected at about this depth. The static level is 320 feet below the surface. On pumping there is an almost immediate draw down to 360 feet, where the water level remains constant under continuous pumping of 100 gallons per minute. The first pump installed was an air lift pump, but this has been replaced by a double cylinder pump, the cylinder hung at a depth of 390 feet. The water is reported as "soft."

An earlier well 72 feet deep supplies a very hard water at the pumping rate of 46 g.p.m. This well supply is used as far as possible on account of the cheaper lift. The cost of the deep well was about $6,000.

*Mineral Content of City Well, Alta**

	P.P.M.
Bicarbonate	422.1
Chloride	5.
Sulfate	354.8
Silica	13.2
$Fe_2O_3+Al_2O_3$	4.0
Calcium	231.7
Magnesium	33.3
Na + K as Na	63.2
Total solids	916.2

* Analysis by Dr. Harry F. Lewis, Chemical Laboratory, Cornell College, Mount Vernon. 1927.

ARKEL, MAHASKA COUNTY

(Altitude 855 feet, C. & N. W. Ry.)

WELL OF CHICAGO & NORTH WESTERN RAILWAY COMPANY

Driller's Log

	Depth in Feet
Soil	0–1
Yellow clay	1–53
Sand and Gravel	53–71
Yellow clay	71–90
Blue clay	90–122
Yellow gravel and sand	122–124
Blue clay	124–154
Shale mixed with sand	154–172
Limestone	172–198
Sandstone	198–203
Limestone	203–207
Sandstone	207–211
Limestone	211–223
Sandstone	223–226
Limestone	226–230
Sandstone	230–241
Limestone	241–252
Sandstone	252–255
Limestone	255–273
Shale, blue	273–282
Limestone	282–285
Blue shale	285–317
Limestone	317–327

ARLINGTON, FAYETTE COUNTY

(Altitude 1112 feet, C., M. & St. P. Ry.)

The well drilled for the town of Arlington in 1923 by B. Sharff of Oelwein is 823 feet deep and has diameters from 8 to 5½ inches. It is reported that the Saint Peter sandstone was struck at a depth of 775 feet (about 337 feet above sea level) and was 45 feet thick. The only other fact that is known of the well is that from 820 to 823 feet the drill was working in very hard limerock.

There seems to be some deviation from the normal dip of strata in this area, as the Saint Peter was estimated to lie about 400 feet above sea level and was so mapped in the report of 1912 on the Underground Water Resources of Iowa.

*Mineral Content of City Well, Arlington**

	P.P.M.
Bicarbonate	290.4
Chloride	5.
Sulfate	53.0
Silica	12.2
$Fe_2O_3+Al_2O_3$	3.2
Calcium	72.9
Magnesium	21.7
Na + K as Na	18.1
Total solids	331.3

AUBURN, SAC COUNTY

(Elevation 1232 feet above sea level)

An oil prospect drilled at the village of Grant City, a mile north of Auburn, by Calvin Reed of Bowling Green, Kentucky,

* Analysis by Harry F. Lewis, Chemical Laboratory, Cornell College, Mount Vernon, 1927.

was unfinished at the end of 1928. It had then reached the depth of 1315 feet. As the Pennsylvanian shales caved badly, no samples of the cuttings were saved until the Mississippian limestones were struck at 470 feet. The driller's log to this depth is as follows:

	Depth in Feet
Gravel	0–10
Shale	10–85
Glacial sand (water)	85–90
Blue shale	90–210
Black shale	210–250
Blue shale	250–450
Red shale	450–455
Brown sand (water, head 170 feet below curb, would lower by bailing)	455–470

Record of strata

	Depth in Feet
Mississippian (385 feet thick):	
Limestone, gray in mass, rapid effervescence in cold dilute HCl; white chert	470–475
Limestone, drab and gray, fine-crystalline, rather slow effervescence; 3 samples	475–535
Limestone, light blue-gray and yellow-gray, rapid effervescence; white chert	535–555
Limestone, buff, fine crystalline-granular, rather slow effervescence	555–560
Limestone, light yellow-gray, calcilutite, rapid effervescence; 3 samples	560–575
Limestone, light cream color, very fine of grain, in sand, rapid effervescence; 5 samples	575–600
Limestone, gray	600–605
Limestone, cream color or light yellow-gray, fine-grained or calcilutite, rapid effervescence; 11 samples	605–665
Limestone, gray	665–670
Limestone, light yellow-gray, fine-grained, rapid effervescence, some slow	670–680
Dolomite, light yellow-gray, in fine meal; 2 samples	680–695
Dolomite, light brown, in fine sand, speckled white with fine particles of chert	695–705
Limestone, gray, rather slow effervescence	705–710
Limestone, blue-gray, fine-grained, argillaceous, slow effervescence; 2 samples	710–720
Dolomite, brown; some white chert	720–725
Dolomite, gray; white chert	730, 733
Limestone, gray or blue-gray, slow effervescence; with gray or blue-gray chert; 4 samples	740–760
Chert, dark blue-gray and lighter; 4 samples	765–780
Limestone, gray and blue-gray, slow effervescence; chert of same color	785, 790
Dolomite, yellow-gray, fine crystalline-granular, in sand	800
Sandstone, gray, fine irregular grains, calcareous, with brisk effervescence; limestone, light yellow-gray, rapid effervescence	805
Dolomite, mottled dark and light gray, macrocrystalline, siliceous and argillaceous residue; shale concreting chips of dolomite into hard masses	815
Dolomite, drab, siliceous, argillaceous, macrocrystalline, in clean chips	820
Dolomite, very light gray, some gray and mottled, very fine grain; 4 samples	825–845
Shale, green-gray, pyritic, dolomitic, in lumps with fine chips of light gray dolomite; also shale, light gray, soft, noncalcareous, siliceous, best seen in fragments fallen from this stratum in samples below	850

Devonian-Silurian (295 feet thick):	
Dolomite, light yellow-gray and buff, fine crystalline-granular; 3 samples	855–865
Dolomite, light yellow-gray and buff, cryptocrystalline, very slow effervescence; 8 samples	870–905
Dolomite, blue-gray and yellow-gray, as above	910–915
Dolomite, yellow-gray and blue-gray and buff, cryptocrystalline; large fragment from 935; dolomite, buff, cryptocrystalline, with small cavities drusy with pearl spar; 7 samples	915–945
Dolomite, light blue-gray, soft, crystalline-earthy, somewhat vesicular, pyritic; some drab finely laminated shale	945–955
Dolomite, buff, gray and yellow-gray, some vesicular; 5 samples	955–980
Shale, light blue-gray, some drab, calcareous, pyritic, in lumps, inclosing fine chips of light yellow-gray limestone of rather slow effervescence	980–985
Dolomite, blue-gray, light blue-gray, and drab, rather slow effervescence; 6 samples	985–1020
Dolomite, brown and buff; 3 samples	1030–1050
Dolomite, light gray and yellow-gray	1060, 1070
Dolomite, brown, crystalline-granular, some in fine meal; 7 samples	1085–1140
Ordovician:	
Maquoketa (60 feet thick)—	
Shale, blue-gray, in chips; with dolomite	1150
Shale, dark greenish, noncalcareous, in hard masses inclosing chips of buff dolomite	1155
Shale, hard, light blue and green; light buff dolomite in fine chips	1160, 1170
Dolomite, buffish gray mottled darker, argillaceous, much green shale in chips	1180
Dolomite, buff, argillaceous, much light blue and green shale in chips	1200
Galena-Platteville (penetrated 105 feet)—	
Dolomite, brown and buff, fine-grained	1210
Dolomite, drab and gray, very fine of grain	1220, 1230
Dolomite, light yellow-gray and gray; 6 samples	1240–1315

Notes.—This prospect was drilled over the body of Cretaceous shales which have been used at Auburn for making clay wares and it seems probable that the "shale" of the driller's log from 10 to 85 feet is Cretaceous, probably Benton, and that the underlying "glacial sand" is in reality the Dakota sandstone. Both of these formations were recognized by Macbride in his survey of Sac county.[42a] The blue, black and red shale beneath probably is Pennsylvanian. The "brown sand, water bearing", at the base of the Pennsylvanian may be compared with the interesting brown arkosic sands at the same horizon in the deep well at Manson.

No attempt is made to subdivide the Mississippian. The heavy beds of cream-colored calcilutites and fine-grained light gray nonmagnesian limestones are noteworthy. The underlying blue and gray cherts and argillaceous dolomites from about 700 to 850 feet may represent the Kinderhook. As to the shale of the

[42a] Iowa Geol. Survey, vol. XVI, pp. 526-531.

Kinderhook the driller reports: "We did not get any Kinderhook shale to amount to anything; just a few streaks of it a foot or two thick." At Rockwell City a sample of shale and dolomite is supposed to represent a bed 220 feet thick, footing at about the same level, and is referred to the Kinderhook.

The shaly beds from 1150 to 1210 feet seem to mark the Maquoketa, although the shale is lithologically different from the "mud rock" Maquoketa shale of eastern Iowa. This leaves the dolomites 295 feet thick lying between the Maquoketa and the Kinderhook horizons to the Devonian-Silurian. Dolomites also characterize the strata below the Kinderhook at Rockwell City.

AUDUBON

(Altitude 1325 feet, C. & N. W. Ry.)

The city well at Audubon was drilled in 1912 by the J. P. Miller Artesian Well Company of Chicago. Much water was found in quicksand from 26 to 31 feet and was cased off. At 1510 feet in "blue limestone" above the Maquoketa shale water stood 240 feet below the curb and tested 120 gallons per minute with a six-inch pump. Some more water with the same head is reported at 1584 feet in argillaceous dolomite below the main body of Maquoketa shale. Below this depth more water was found but at what levels is not stated. On completion the well pumped 208 gallons per minute and the static level had risen to 225 feet from the curb.

Record of strata in city well, Audubon, with driller's log to 1040 feet

	DEPTH IN FEET
Pleistocene and Recent (252 feet thick; top 1300 feet above sea level):	
"Clay	0–26
"Quicksand	26–31
"Clay	31–250
"Rock, perhaps a boulder	250–251
"Clay, yellow	251–252
Pennsylvanian (323 feet thick; top 1048 feet above sea level):	
"Shale	252–377
"Coal and sulphur	377
"Shale, gray	377–475
"Shale, black	475–480
"Shale, light colored	480–575
Mississippian (520 feet thick; top 745 feet above sea level):	
"Streaks of lime and shale	575–610
"Sandy lime 7, green shale	610–630
"Sand	630–636
"Lime, clear, brown	636–653
"Streaks of lime and shale with some spar	653–654
"Shale, sandy	654–657
"Shale, green	657–660
"Lime with quartz in it	660–725
"Shale, green	725–736

"Lime"	736–745
"Streaks of lime and shale"	745–790
"Lime, clear, white"	790-820
"Shale"	820–860
"Marl, yellow"	860–865
"Lime, gray, full of quartz"	865–1040
Shale, highly calcareous, blue gray, in friable concreted masses; 5 samples	895–935
Limestone, light yellow-gray, soft, earthy, rapid effervescence in cold dilute HCl; green shale, chalcedonic silica	945
Chert, blue-gray, and limestone	955
Dolomite or magnesian limestone, light brown, crystalline-granular, slow effervescence, large chips of blue shale	965
Limestone, gray, rapid effervescence, cherty	975
Chert, blue	985
Limestone, gray, rapid; blue chert	995
Limestone and shale, limestone gray, rapid effervescence, much chert; in friable concreted masses	1005–1015
Limestone, blue-gray and yellow, oölitic, rapid, some blue chert	1025
Shale, light blue and greenish, calcareous, in chips and concreted masses; 6 samples (Kinderhook)	1035–1085
Devonion (?), Silurian (445 feet thick; top 205 feet above sea level):	
Dolomite, light blue-gray, argillaceous; 5 samples	1095–1135
"Shale, green"	1140–1143
Dolomite, light yellow-gray, blue-gray and whitish, some chips in cuttings with rather brisk effervescence, some gray shale; 11 samples	1145–1390
Dolomite, light buff, crystalline, in sand	1435
"White lime"	1440–1480
"Lime, bluish"	1480–1485
"Shale"	1485–1489
"Lime, bluish"	1489-1540
Ordovician:	
Maquoketa shale (90 feet thick; top 240 feet below sea level)—	
"Green shale"	1540–1557
Dolomite, blue-gray, earthy, argillaceous, some green shale; 2 samples	1540, 1600
Galena and Platteville (335 feet thick; top 330 feet below sea level)—	
"Lime, flinty at 1740 and 1791, white shale at 1865 to"	1980
"Shale"	1980–2015
"Shale, green"	2015–2052
Dolomite, light gray, light buff	1630, 1665
Dolomite, whitish, argillaceous, in concreted masses	1675, 1685
Dolomite, light gray, in fine sand and small chips; 3 samples	1695–1715
Chert and dolomite, white	1725, 1735
Dolomite, in whitish flour and concreted masses, highly argillaceous, or dolomitic shale	1745
Chert and dolomite; 3 samples	1755–1775
Dolomite, light yellow and whitish, cherty; 4 samples	1785–1815
Dolomite, whitish, highly argillaceous, in flour and concreted masses; 3 samples	1825–1845
Dolomite, blue-gray and buff and drab, in sand, cherty at 1885–1905, argillaceous at 1915 to 1935; 11 samples	1855–1955
Glenwood (80 feet thick)—	
Shale, bright blue-green, in flaky chips	1965, 1975
Shale, light blue-gray, highly calcareous, nonplastic; 3 samples	1985–2005
Shale, bright blue-green, plastic, in flakes and concreted masses; 3 samples	2015–2035
Saint Peter sandstone (60 feet thick; top 715 feet below sea level)—	
Sandstone, whitish, fine, rounded grains; considerable green shale; 5 samples	2045–2085
Sandstone, highly argillaceous, calciferous, grains fine, some with secondary enlargements; in concreted masses	2095

Prairie du Chien (penetrated 295 feet; top 805 feet below sea level)—	
Dolomite, buff, highly arenaceous, in fine sand of dolomite, crystalline and cryptocrystalline quartz	2105-2110
Dolomite, gray	2125
Dolomite, brownish gray, highly vesicular with minute spheroidal cavities as if from the removal of oölite grains; in large chips	2135
Dolomite, buff in mass, much fine quartz sand	2145
Dolomite, gray	2155–2165
Dolomite, highly arenaceous, or sandstone; cuttings in buff sand of dolomite and rounded grains of quartz (New Richmond? Jordan?)	2175–2185

Notes.—In the above section, the carefully kept driller's log fills out the first 895 feet, of which no samples of the cuttings were taken, and also bridges an occasional gap below that depth and inserts thin beds of which the samples taken at wider intervals give no evidence.

The base of the Mississippian is drawn with considerable uncertainty at the bottom of the 50 foot bed of shale struck at 1035 feet, since this bed seems to represent the Kinderhook shale of southeastern Iowa.

The shale and argillaceous dolomite at 1540 feet hold about the position at which the Maquoketa might be expected. If this identification of the Maquoketa is correct the dolomites above it are probably largely, if not wholly, Silurian, and those beneath it are Galena and Platteville, together with the basal shales (the Glenwood) immediately overlying the Saint Peter.

Whether the calciferous sandstone at 2095 feet belongs with the Saint Peter as a basal transition bed or with the Prairie du Chien is a matter of doubt, but the dolomites beneath it are clearly the latter in both place and facies.

Driller's log of Audubon deep well, below 1040 feet

	DEPTH IN FEET
Green shale	1040–1103
Lime, chalky, with little white balls at 1115	1103–1140
Shale	1140–1182
Lime, at 1193 hard and soft streaks of chalky lime	1182–1405
Crevice of 8 inches at	1405
Brown lime	1405–1440
White lime	1440–1480
Bluish lime	1480–1485
Shale	1485–1489
Bluish lime	1489–1540
Green shale	1540–1557
Lime, flinty at 1740 and 1791, streak of white shale at 1865	1557–1980
Shale	1980–2015
Green shale	2015–2052
Sand	2077–2105
Lime	2105–2400

*Chemical analysis of water of Audubon city well**

Acids and Bases (Parts per 100,000)			Probable Combination in the Water (Grains per U. S. gallon)		
Sodium Oxide	Na_2O	35.61	Calcium Carbonate	$CaCO_3$	11.37
Calcium Oxide	CaO	23.97	Calcium Sulphate	$CaSO_4$	18.49
Magnesium Oxide	MgO	9.92	Magnesium Sulphate	$MgSO_4$	17.36
Iron Oxide	Fe_2O_3		Iron Oxide	Fe_2O_3	
Alumina	Al_2O_3	0.16	Alumina	Al_2O_3	0.09
Silica	SiO_2	0.84	Silica	SiO_2	0.49
Sulphuric Acid	SO_3	61.40	Suspended Matter		0.74
Chlorine	Cl	20.45			
			Incrusting Solids		48.54
Hardness, Etc.			Sodium Sulphate	Na_2SO_4	23.74
Hardness		69.00	Sodium Chloride	$NaCl$	19.65
Alkalinity		19.5			
Metacidity		1.7	Non-Incrusting solids		43.39
			Free Carbon Dioxide	CO_2	0.44
			Half Bound Carbon Dioxide	CO_2	5.00
			Volatile Matter		5.44

AYRSHIRE, PALO ALTO COUNTY

(Altitude 1315 feet, M. & St. L. R. R.)

A well 878 feet deep was drilled for the town of Ayrshire in 1921 by Bert Sharff, artesian well contractor of Oelwein. The diameters are 10 inches to 346 feet, 8 inches to 800 feet, and 6 inches to 878 feet. Water stands at 116 feet from the surface of the ground. The capacity as measured by a 24 hour test with the pump 46 feet below the surface of the water was 120 gallons per minute. As the well is cased to the Saint Peter sandstone at 852 feet, it is assumed that the supply tested was entirely from that formation. A flow of 22 gallons was found at 360 feet in "sand" and a flow untested but apparently much larger was found at 650 feet.

Driller's Log

Formation	Depth in Feet	Formation	Depth in Feet
Soil	0–3	Brown lime, very hard	694–702
Clay, yellow	3–13	Gray rock	702–711
Gravel, coarse	13–15	Blue shale	711–714
Clay, blue	15–100	Lime rock	714–732
Sand	100–105	Green shale	732–734
Clay, blue and brown	105–295	Lime, brown	734–740
Sand	295–346	Shale, bluish	740–753
Sandrock	346–352	Rock	753–756
Sand	352–370	Blue shale	756–840
Shale, brown	370–378	Black shale	840–846
Sand, very fine	378–515	Hard rock	846–848
Limestone	515–560	Blue shale	848–852
Blue shale and shelly rock	560–640	Saint Peter sandrock	852–878
Dakota sandstone	640–694	Shale	878

* L. M. Booth Co., Engineering Dept., Jersey City, 1917.

Notes.—The above log was evidently taken with care, and to a considerable extent the rocks described can be referred to their respective geological formations with assurance, although no samples of the cuttings were saved. The workmen were familiar with the Saint Peter sandstone from their experience in eastern Iowa and their identification of the sandstone at 852 feet (463 feet above sea level) may be taken as correct. A forecast for Ayrshire had given the depth of the Saint Peter as 400 feet above sea level. As at Algona and Emmetsburg to the northeast and Hartley to the northwest, the very heavy shales above the Saint Peter are referred to the Glenwood and perhaps include the Platteville and Decorah. As far up as the brown limestone at 694 feet (621 feet above sea level) we have evidently the Galena limestone. But the 54 feet of "Dakota sandstone" from 640 to 694 feet is difficult to interpret. No such sandstone occurs at this horizon at Emmetsburg and Algona. Comparing the Ayrshire section with the Emmetsburg section the summit of the Saint Peter occurs at Ayrshire 33 feet lower than at Emmetsburg and the summit of the Glenwood-Decorah is some 16 feet lower. But if the sandstone whose base is at 694 feet (621 feet above sea level) is the Dakota, then that sandstone declines from Emmetsburg to Ayrshire the extraordinary amount of 297 feet. And if the sandstone in question is Dakota, the 125 feet of "limestone," "blue shale and shelly rock" immediately overlying it are left quite in air. Under these circumstances, the possibility must be considered that the fine sand to which Galena dolomite often cuts has been mistaken for true sandstone, a mistake often made, and that, unaccustomed, perhaps, to the Dakota sandstone of western Iowa, the drillers labelled the formation as Dakota. If the Galena extends upward, then, to 640 feet, the "blue shale and shelly rock" above it may represent in part the Maquoketa.

The "sandstone, very fine" from 378 to 515 feet is pretty surely Cretaceous and its base at 800 feet above sea level is 118 feet lower than the base of sandstone of the Dakota at Emmetsburg. The drift probably extends to the base of the "blue and brown clay," which is here taken to be till, giving it a thickness of 295 feet, and may also include the "sand" beneath, which would make the total depth 346 feet.

*Mineral Content of City Well, Ayrshire**

	P.P.M.
Bicarbonate	383.1
Chloride	12.
Sulfate	572.9
Silica	15.6
$Fe_2O_3+Al_2O_3$	5.2
Calcium	133.4
Magnesium	66.3
Na + K as Na	105.7
Total solids	1103.0

BANCROFT, KOSSUTH COUNTY
(Altitude 1174 feet)

The city well of Bancroft, drilled in 1928 by Bert Sharff of Oelwein, is 626 feet deep. Rock was struck at 165 feet and was "shelly" to 275 feet. The Saint Peter sandstone was not reached, but according to the gradient between Algona and Blue Earth, Minnesota, it should be encountered at about 675 feet from the surface. The static level of the well is 24 feet below the surface, with a draw down of five feet after a 24 hour test pumping of 150 g.p.m.

BAYARD, GUTHRIE COUNTY
(Altitude of curb about 1080 feet)

In the autumn of 1926 a group of Guthrie Center citizens organized the Central Oil and Gas Company and began drilling an oil prospect near Bayard. Sample drillings were sent to the Survey by the driller, Mr. Calvin Reed of Bowling Green, Kentucky. The record of the drillings follows, with interpretations by Dr. James H. Lees, Assistant State Geologist. Work on this prospect was discontinued at 1320 feet, in August, 1927, but was resumed in January, 1929, with G. H. Rose and Son of Maryville, Missouri, as drillers.

Samples from Bayard Well

	DEPTH IN FEET
Pleistocene:	
Till, glacial, with pebbles	20–30
Gravel, glacial, pebbles up to one-half inch diameter; "flowing water"	30–50
Sand, very fine, uniform, gray	50–100
Same as above; "gas at 110 feet"	100–150
Clay, probably glacial, gray, fine-textured, a few pebbles	150–155
Sand and gravel, rather fine, probably glacial	155–170
Sand, fine, uniform, light gray, a few specks probably mica	170–180

* Analysis by Harry F. Lewis, Chemical Laboratory, Cornell College, Mount Vernon, 1927.

Clay, fine, uniform, brownish gray, probably glacial	180–205
Clay, black, very fine, some siliceous pebbles	205–220
Des Moines:	
Shale, very fine, smooth feel, gray, probably Des Moines	220–300
Sand, fine, uniform, light gray; "Water"	300–312
Shale, fine, dark gray	312–330
St. Louis and Osage:	
Limestone, gray, fine-grained	330–340
Limestone, gray, with fragments of dark chert	340–350
Limestone, finely sandy, gray	350–358
Sandstone, limy, fine-textured, dark gray	358–368
Limestone, gray, fine-grained	368–375
Limestone, dark gray	375–385
Limestone, similar to above, with lighter fragments	385–395
Limestone, dark gray, with fragments of fine-grained sandstone and clayey sand	395–400
Limestone, dark gray, fine-grained, with large amount of sand in rather coarse white grains	400–410
Limestone, dark gray, similar to above; blue chert	410–420
Sandstone, fine-grained, much chert and lime	420–425
Limestone, dark gray, some fine-grained, some coarser	425–440
Limestone, similar to above, some chert and quartz grains	440–450
Sandstone, fine, dark, some lime, probably as matrix. "Water"	450–453
Limestone, dark gray, in coarse chips, sugary texture, much chert and quartz	453–460
Limestone, dark gray; chert, gray to white; shale, black	460–470
Limestone in chips and powder, the former responding slowly to acid at first, more briskly later; shale, black; some chert, white and gray	470–480
Limestone, gray; chert, bluish white and gray; all in small angular chips. A little dark shale	480–490
Limestone, etc., similar to above	490–500
Limestone, gray, some fine sand, much gray to white chert in fragments	500–510
Shale, dark gray, very fine-textured, calcareous	510–520
Shale, similar to above, and fragments of limestone and of flint which contain some lime as shown by reaction	520–530
Limestone and chert, gray, in fine grains and powder	530–540
Same as above	540–550
Limestone, dark gray, in small chips, with chert and some shale	550–560
Limestone, light gray, with much chert, in fine grains	560–570
Same as above	570–580
Limestone, light gray, in fine powder, ready effervescence in acid	580–590
Limestone, gray, in fine grains, with much chert and clear quartz grains	590–600
Same as above	600–610
Limestone, light tan color, in fine grains, a little chert	610–620
Limestone, gray, in small flakes and grains, very finely granular, some grains and powder of chert	620–625
Limestone, dark gray, in small grains, some chert	625–630
Limestone, light gray, chips and powder, vigorous effervescence, considerable residue. Fragments of limestone are made up of small rounded grains with fine matrix	630–640
Limestone, similar to above	640–650
Same as above	650–660
Limestone, similar to above, some chert and pyrite	660–670
Limestone, gray, in angular chips, which are almost entirely soluble in acid. Some grains of chert	670–680
Limestone, similar to above but more chert	680–690
Limestone, with much chert	690–700
Same as above	700–710
Limestone, dark gray, in fine grains; some chert and a good deal of fine sand	710–715
Limestone, similar to above, only in larger grains; finely granular texture, mostly soluble in acid	715–720

Similar to above, some chert	720–730
Limestone, dark gray, finely sugary texture, rather slow reaction to acid, probably dolomitic; some gray chert	730–735
Limestone, similar to above but with more fine sand, which is insoluble in acid	735–740
Limestone, similar to above, but with less sand	740–745
Kinderhook:	
Shale, fine-textured, gray-green, some lime present	745–775
Shale, very finely gritty, blue-green, somewhat limy	775–800
Shale, very finely gritty, light gray, calcareous	800–825
Shale, dark green when damp, very fine-textured, little lime present; some harder nodules with calcareous matrix	825–835
Devonian and Silurian (?):	
Limestone, dark gray, sugary texture, in small chips and granules; almost entirely though slowly soluble in acid	835–840
Limestone, light tan, finely crystalline with sparkling facets; almost entirely soluble in acid. Some darker chips	840–845
Limestone, light tan, very similar to above	845–850
Limestone, gray, similar to above, except for slightly darker color. Some chips of shale may be from above. Driller says rock below Kinderhook shale drilled as if there were streaks of shale a foot or so thick, but that Kinderhook was caving, so could not be sure	850–860
Limestone, very light tan, somewhat sugary texture, but finer grained than samples above. In chips one-fourth to three-fourths inch in diameter. A few of these show pyrite	860–865
Limestone, similar to above, but in smaller chips and grains; a little pyrite; some shale. Responds readily to acid and is almost entirely soluble	865–870
Limestone, a little darker and more coarsely crystalline than sample above. Some fragments of calcite and some shale	870–880
Limestone, in small crystalline grains, mostly gray, some white and some transparent. Responds rather slowly to cold acid, more strongly to hot acid; entirely soluble	880–885
Limestone, similar to above, in uniformly small gray granules; evidently dolomitic, but entirely soluble	885–890
Limestone, dark gray, in chips and coarse powder. Effervesces rapidly in cold acid—finely granular	890–895
Limestone, similar to above; considerable shale	895–905
Limestone, similar to above, but somewhat more definitely crystalline; in fine grains; much shale	905–910
Limestone, gray, finely granular and sugary, strong response to acid, a little very fine siliceous residue. Considerable shale in bluish chips, very fine-textured, very slightly limy	910–915
Limestone, similar to above, but with somewhat coarser sugary texture. Much shale as above	915–920
Limestone and shale, as above	920–925
Limestone, light bluish gray, finely crystalline, slow response to acid, but almost complete solution. Not much shale	925–930
Limestone, light gray, similar to above sample	930–935
Limestone, dark gray, very finely granular, slow response to acid, with a little whitish residue. Some shale	935–945
Limestone, similar to above	945–950
Limestone, similar to above	950–960
Limestone, light gray, very fine-grained, readily and almost completely soluble in acid	960–965
Limestone, rather dark gray, distinctly sugary texture, a little fine-grained shale	965–970
Limestone, similar to above. Numerous shale chips	970–980
Limestone, similar to above but finer in texture—not much shale	980–985
Limestone, rather dark gray, finely to coarsely crystalline	985–990
Limestone, similar to above. Some shale	990–995
Limestone, similar to above	995–1000

Limestone, rather dark gray, in fine gritty powder. Reaction of acid is rather slow at first, considerable residue of fine clear quartz sand grains 1000–1010
Limestone, similar to above but in larger grains; some sand grains 1010–1020
Limestone, similar to above. The rock has a fine sugary texture and this and its slow response to acid probably indicate that it is magnesian 1020–1030
Limestone, similar to above, but again in rather fine powder with much fine clear sand 1030–1040
Limestone, similar to above, coarser grains. Some quartz sand and some fragments of clear calcite 1040–1050
Limestone, similar to above 1050–1060
Limestone, similar to above 1060–1070
Limestone, somewhat lighter gray than samples above, otherwise similar 1070–1080
Limestone, similar to above. Ready response to acid. Considerable quartz in small grains 1080–1090
Limestone, similar to above, only finer grains 1090–1100
Limestone, gray, evidently dolomitic, action with acid slow but long continued, with almost complete solution of the sample. In very fine grains, very little silica 1100–1120
Limestone, like that above 1120–1140
Limestone, or dolomite, gray, in grains and fine powder, finely granular, slow response with acid, but nearly complete solution 1140–1180
Limestone, darker gray, in medium sized, finely granular grains; response with acid rather more brisk than sample above, few sand grains but otherwise material is almost entirely soluble 1180–1190
Limestone, dark gray, in coarse grains, some white calcareous material in fine powder. Nearly all soluble. Much blue noncalcareous shale in small chips and powder. Driller says the shale seems to be in layers six to twelve inches thick and two to five feet apart 1190–1195
Limestone and shale, similar to above 1195–1200
Limestone, similar to above but shale less abundant 1200–1210
Limestone, similar to above sample, in fine grains, some white calcite, some shale 1210–1220
Limestone, dark gray, in coarse grains, rapid reaction with acid. Much shale 1220–1235
Limestone, like above 1235–1240
Limestone, very dark gray, in coarse grains and chips, ready response with acid. Perhaps one-fourth shale 1240–1245
Limestone, and shale as above but in smaller fragments 1245–1250
Limestone and shale, similar to above, cuttings fine 1250–1260
Limestone, dark gray, in fine crystalline granules; shale, dark blue-green in small chips, constitutes perhaps one-fourth of mass. Fairly brisk response to acid, solution of limestone nearly complete 1260–1270
Limestone and shale, similar to above 1270–1280
Limestone and shale, similar to above 1280–1290
Limestone, gray, some very fine-grained, some rather finely granular. Very little shale. Considerable cherty residue 1290–1300
Limestone, similar to above 1300–1315
Limestone, gray, granular, and shale, blue-green. Both are in fine powder to small chips, up to one-fourth inch diameter. Response to acid very brisk, much residue of shale and chert. A few chips from 1320 feet are dark gray hard noncalcareous shale 1315–1320
Limestone, brownish gray, in fine sand, dolomitic, some residue of very fine siliceous material and small chips of chert; shale, blue-green, brittle, in small chips 1338–1342
Limestone, similar to above but in finer more uniform crystalline sand; response to cold acid fairly brisk; residue very finely divided silica; no shale present; 2 samples 1340–1343
Limestone, similar to above but in somewhat coarser fragments; numerous smoothly rounded clear grains of quartz 1346–1355

Limestone, light gray and grayish tan, in fine crystalline sparkling granules which dissolve rather readily in cold acid and leave a residue of very fine siliceous material; 4 samples....1355–1380
Limestone, medium gray, coarse to fine granules, sugary texture, response in cold acid fairly brisk, more rapid in hot acid, long continued, residue small 1385
Limestone, light gray, in very fine powder of crystalline granules of rather slow response to cold acid; 4 samples 1390–1405
Dolomite, dark tan, small angular chips of chert and fewer rounded, rather clear dolomitic grains. Response to acid not very brisk, residue large 1408
Dolomite, similar to above but in coarser fragments; chert, gray, comprising greater part of sample, some white, chalcedonic; 2 samples..1415, 1420
Dolomite, bluish gray at 1425 and 1435, dark gray at 1445 and 1448, in powder and chips, response to hot acid somewhat more ready than in two preceding samples; abundant gray chert; 4 samples 1425–1448

Notes.—The driller notes: Struck gas in a "sea mud" at 110 feet. This formation was real soft and would heave up the hole from 30 to 40 feet. I had to drive the casing ahead of the tools in order to drill the well. The last ten feet of (Kinderhook) shale seemed to be harder and there may be quite a lot of lime in it, but it was about the same color as the shale. The strata seemed to change at about 1160 or 1180 feet as if the drill were passing from Devonian to Silurian strata.

BETTENDORF, SCOTT COUNTY

(*Altitude 572 feet*)

WELL NO. 2 OF THE BETTENDORF WATER COMPANY

The first deep well of the Bettendorf Water Company was sunk by the Bettendorf Improvement Company, and was described in the report of 1912 on the Underground Water Resources of Iowa. The second well was drilled in 1925 by Thorpe Brothers Well Company of Des Moines. The depth is 2122 feet; the diameters are from 20 to 10 inches. Water was found from 1505 to 1565 feet in the Jordan sandstone, when a distinct fall of the static level was noted, the water dropping in the tube to 30 feet below the curb. The advice of this office was asked as to going deeper and the company was strongly urged to not stop the work until the water bed of the Dresbach had been tapped. A higher head from this Cambrian aquifer was also predicted. The main supply of the well was reported in the Dresbach sandstone from 1868 to 1990 feet and water was found also at 2100 feet in the Eau Claire. The pumping capacity of the well is 1000 gallons per minute, and the natural flow is 200 gallons per minute.

The relations of the two wells 100 feet apart are of special interest. Well no. 1, 1650 feet deep, taps no water beds below the Jordan sandstone. In well no. 2 the Saint Peter is cased out. Yet the amount of leakage from well no. 2 into well no. 1 is so great that for some time it was not necessary to install a pump in well no. 2. "On pumping no. 1 at the rate of about 600 gallons per minute the draw-down is about 12 feet. The draw-down on no. 2 while pumping no. 1 is about 5 feet. Pumping out of no. 2 at the rate of 1000 gallons per minute, the draw-down was about 15 feet. The draw-down on no. 1 while pumping no. 2 is nothing. Pumping both wells at the same time does not change the draw-downs as stated above, that is, 15 feet on no. 2 and 12 feet on no. 1."

These facts illustrate the well known law that the water of a lower aquifer discharges laterally into any higher aquifer whose water is under less pressure. At Clinton in well no. 6 of the Waterworks Company, the strong flow from the Mount Simon horizon of the Cambrian had such an enormous leakage that according to the officials of the company it lifted some 3 feet the head of other artesian wells within an area extending 2000 and 3000 feet from the well. At Bettendorf the company fortunately is able to retrieve a portion of the leakage through well no. 1.

The drill hole is cased with 20 inch cast iron casing to 120 feet, 12 inch from 391 to 644 feet, 10 inch from 946 feet to 1127 feet, and 10 inch from 1573 to 1855 feet. The cost of the well was $26,000. The data as to the well and as to several wells at Davenport were supplied by Mr. W. Z. Schneider, general manager of the company, who also donated to the Survey an exceptionally complete set of samples of the cuttings.

Record of Strata of Well No. 2 of the Bettendorf Water Company

	Depth in Feet
Pleistocene and Recent (35 feet thick; top 586 feet above sea level):	
Soil, dark	10
Sand, lighter, some grains of limestone	20
Sand as above, some particles of gray sandstone	30
Devonian:	
Wapsipinicon limestone, Lower Davenport beds (35 feet thick; top 551 feet above sea level)—	
Limestone, whitish, rapid effervescence in cold dilute HCl; 3 samples	40–60

Silurian:	
Niagaran (350 feet thick; top 516 feet above sea level)—	
Dolomite, cream-gray and light blue-gray, compact, slow effervescence	70, 80
Dolomite as above, some buff and brown; 5 samples	90–130
Dolomite, light gray, in small chips and whitish powder, in larger chips and vesicular from 260 down; with some white flint at 350 and 360; with much white flint from 370 to 410; 28 samples	140–410
Ordovician:	
Maquoketa shale (200 feet thick; top 166 feet above sea level)—	
Shale, bluish, highly calcareous, with microscopic quartzose particles, in small chips, with some dolomite; 3 samples	420–440
Shale, blue, in powder, with chips of hard dark argillaceous limestone	450
Shale, in powder and chips; 3 samples	460–480
Limestone, dark drab, argillaceous, in small chips	490, 500
Shale, blue, in powder and chips; 7 samples	510–570
Shale, olive green	580
Shale, light brown, fissile, feebly inflammable	590
Shale, brown, strongly inflammable	600, 610
Galena and Platteville limestones and Glenwood shales (365 feet thick; top 34 feet below sea level)—	
Dolomite, light brown, vesicular, in small chips	620
Dolomite, gray and buff; 10 samples	630–720
Dolomite, brown and buff, much white chert; 6 samples	730–780
Dolomite, gray, some chert; 3 samples	790–810
Dolomite, brown, cherty	820
Dolomite, blue-gray, cherty	830
Dolomite, brown, cherty; 4 samples	840–870
Limestone, in large flakes, earthy, rapid effervescence; some bright green shale in flakes	880
Limestone, blue-gray and whitish, in sand, rapid effervescence, earthy	890
Dolomite, light buff, cherty (misplaced ?)	900
Limestone, as at 890; 4 samples	910–940
Glenwood formation—	
Sandstone, white, fine, grains well rounded, some limestone	950
Sandstone, white, clean, as above	960
Shale, dark green, pyritiferous, noncalcareous, in flakes and concreted masses	970
Shale, dark green, in splintery flakes; and white sandstone, coarser than at 950	980
Saint Peter sandstone (75 feet thick; top 399 feet below sea level)—	
Sandstone, white rounded grains, with small friable whitish masses of sand of minute angular grains with calcareous cement; shale in dark green flakes; laminated greenish argillaceous sandstone	990
Sandstone, white, clean, St. Peter facies, larger grains at 1050 1 mm. in diameter; 6 samples	1000–1050
Prairie du Chien (440 feet thick; top 474 feet below sea level)—	
Dolomite, whitish to light brownish gray; with siliceous oölite at 1240, 1250, 1260; with chert at 1130, 1300-1390, 1410, and 1470; with considerable quartz sand at 1250, 1260 and 1290; with some quartz sand in cuttings at 1130, 1170, 1240, 1250, 1290; 44 samples	1060–1490
Cambrian:	
Jordan sandstone (80 feet thick; top 914 feet below sea level)—	
Sandstone, white, calciferous, rounded grains, in chips, with whitish dolomite and much siliceous oölite	1500, 1510
Sandstone, white, fine, larger grains rounded; with dolomite and chert	1520–1530

Dolomite, gray, in small chips, with much quartz sand	1540
Chert; gray siliceous dolomite; sandstone, fine, in chips; and much quartz sand, rounded	1550–1560
Sandstone, in small chips, showing dolomitic cement; grains rounded	1570
Saint Lawrence:	
Trempealeau beds (170 feet thick; top 994 feet below sea level)—	
Dolomite, blue-gray and drab; in fine chips and powder; 16 samples	1580–1740
Franconia beds (110 feet thick; top 1164 feet below sea level)—	
Dolomite, dark buff in mass, quartzose and slightly glauconitic, some purplish shale as below	1750
Shale, purplish, highly arenaceous with minute angular quartzose particles, highly calcareous; some glauconite	
Shale, green-gray, highly arenaceous, with finest angular particles, glauconitic, calcareous	1760
Shale, green-gray, highly arenaceous, calcareous, glauconitic (or sandstone, of finest angular grains); 3 samples	1770–1790
Dolomite, gray, minutely arenaceous, sparingly glauconitic; with green shale	1800–1810
Sandstone, gray, dolomitic, of minute grains, sparingly glauconitic	1820
Dolomite, as at 1800	1830
Sandstone, gray, of minute angular particles, dolomitic, glauconitic	1850
Dresbach sandstone (140 feet thick; top 1274 feet below sea level)—	
Sandstone, cream-colored in mass, larger grains well rounded	1860
Sandstone as above, coarser, in chips and loose grains	1870
Sandstone, white, fine, rounded grains, in loose sand; and minute chips of microscopic angular particles in dolomitic cement	1880
Sandstone, cream white, fine, larger grains well rounded; some particles of coal at 1970 and 1980; 11 samples	1890–1990
Eau Claire beds (penetrated 122 feet; top 1414 feet below sea level)—	
Sandstone, green-gray, in small chips, microscopic angular particles, dolomitic, slightly argillaceous; some glauconite; considerable brownish cryptocrystalline silica	2000
Sandstone, fine, larger grains rounded, some green pyritiferous shale	2010
Sandstone, gray, fine, dolomitic, in chips	2020
Sandstone, gray, fine, grains poorly rounded, a little glauconite	2030
Sandstone, light buff, very fine angular grains, a little glauconite	2040
Sandstone, gray, in chips, grains minute; dolomitic, glauconitic; some green shale; much shale at 2090; 5 samples	2050–2090
Sandstone, light buff, of minute angular particles, dolomitic, glauconitic	2100, 2110
Shale, drab, plastic, in difficultly friable masses, microscopically quartzose, dolomitic	2122

Driller's Log of Bettendorf Water Company Well No. 2

	Depth in Feet
Black soil	0–10
White fine sand	10–25
Broken lime and light colored shale	25–40
Hard gray lime	40–400
Blue shale	400–480
Hard gray lime	480–530
Blue shale	530–600
Hard white lime	600–945
Sand and shale	945–960
Light green shale	960–985
Sandstone, white fine sand	985–995
Saint Peter sandstone. Soft white fine sand	995–1045

Shale and sand	1045–1055
Lime and red shale	1055–1085
Very hard white lime	1085–1505
White hard sand	1505–1565
White limestone, medium hard	1565–1732
Red lime and shale	1732–1765
Sand, gray lime and shale	1765–1780
Sand and gray lime, very hard	1780–1868
White fine soft sand	1868–2018
White fine sand with black specks	2018–2045
White fine sand and shale	2045–2068
Mixture, sand, shale and black specks	2068–2100
Gray limestone	2100–2120
Red shale	2120–2122

BRIGHTON, WASHINGTON COUNTY

(Altitude 740 feet, C., B. & Q. R. R.)

In 1923 a deep well was drilled for the town of Brighton by Floyd Alspach, contractor, of Nowata, Oklahoma. The depth is 1815 feet and the diameters may be inferred in part from the casings, of which a 12 inch pipe is set at 97 feet, an 8 inch pipe at 209 feet and a 6 inch pipe at 1492 feet. Water was found in Meramec sandstone at 120 feet; at 655 and 775 feet in Devonian limestone; from 1260 to 1265 feet in a sandstone stratum of the Glenwood; in the Saint Peter sandstone, 1287 to 1322 feet; in arenaceous dolomite of the Shapokee and New Richmond; and in the Oneota dolomite, from 1500 to 1530, from 1550 to 1650 and from 1665 to 1685 feet.

On completion, water stood 90 feet below the surface.

Record of Strata

	Depth in Feet
Pleistocene and Recent (90 feet thick; top 748 feet above sea level):	
Sand, yellow, clayey	30
Clay, yellow, sandy	40
Clay, yellow	50
Clay, yellow, sandy	60
Sand, gray, grains irregular, moderately fine, mostly of clear quartz, also black, yellow and purplish	70, 80
Mississippian:	
Meramec, Osage and Upper Kinderhook beds (290 feet thick; top 658 feet above sea level):	
Shale, gray, unctuous; some sand	90
Sandstone, light gray, clear quartz, fine, irregular grains, calcareous matrix at 100, noncalcareous at 110, with some limestone particles at 120, argillaceous and calcareous at 130	100–130
Limestone, light blue-gray, slow effervescence in cold dilute HCl, siliceous with minute particles of clear quartz and some grains of quartz sand; pyritiferous; in sand	140
Chert, dark gray and white, some banded, bands up to 4 mm. wide; sandstone, gray, fine, with sporadic coarse grains; calciferous	150
Sandstone, blue-gray, highly argillaceous, grains very fine, irregular; in friable masses	160

Shale, blue-gray, calcareous	170
Limestone, blue-gray, macrocrystalline-earthy, rapid effervescence, soft, friable, in large chips	180
Shale, blue-gray, calcareous, in concreted masses	190, 200
Shale, highly calcareous, blue-gray, in chips; chalcedonic silica	210
Limestone, whitish, rapid effervescence, macrocrystalline-earthy; in large chips	220
Limestone, light gray, rapid effervescence, earthy, with some greenish specks of included shale; much white chert	230, 240
Limestone, whitish, fine granular-crystalline, rapid effervescence, hard; much white chert	250, 260
Chert, white; limestone, light yellow-gray, fine granular, rapid effervescence, in sand	270, 280
Limestone, light gray, moderately rapid and rapid reaction to acid; chert, chalcedony; blue gray shale	290, 300
Limestone, light yellow-gray, rapid effervescence; brown limestone, with rather slow reaction	310
Limestone, brown-gray, fossiliferous, rapid effervescence, fine crystalline-granular; white chert	320
Limestone, brown and yellow-gray, rapid effervescence, cherty	330, 340
Sandstone, drab, minute angular grains, argillaceous, calcareous	350
Shale, blue, calcareous	360
Sandstone, as at 350	370
Kinderhook shale (280 feet thick; top 368 feet above sea level):	
Shale, blue, plastic, calcareous	380, 390
Shale, blue, in powder and small highly siliceous chips, calcareous and composed largely of microscopic particles of quartz	400
Shale, blue, plastic; 6 samples	410–450
Shale, brown, in flakes and powder, noninflammable, empyreumatic ordor on heating	460
Shale, brown, as above, and blue	470
Shale, drab, plastic; 3 samples	480–500
Shale, blue-gray, plastic; 8 samples	510–580
Shale, drab	590, 600
Shale, blue-gray, plastic; 5 samples	610–650
Devonian (140 feet thick; top 88 feet above sea level):	
Limestone, blue-gray, earthy, rapid reaction, argillaceous, in chips	660, 670
Shale, chocolate-brown, burns white but noninflammable, noncalcareous	680
Shale, blue, plastic	690, 700
Limestone, brownish buff, finely mottled, fine crystalline-granular, rapid effervescence	710
Limestone, buff, rapid and slow response to acid	720
Limestone, blue-gray, earthy, fossiliferous at 730, rapid reaction	730, 740
Limestone, light gray, rapid effervescence, cherty at 760 and 770; 4 samples	750–780
Limestone, buff-gray, moderately slow reaction, considerable residue of particles of cryptocrystalline silica and a few fine grains of clear quartz	790
Silurian (100 feet thick; top 52 feet below sea level):	
Gypsum, in white hard tough concreted mass with limestone	800
Gypsum, in hard concreted gray-white mass, with some yellow limestone of rapid effervescence	810
Chert; limestone, some rapid effervescence; gypsum; a few grains of clear quartz; yellow-gray in mass	830
Limestone, light blue-gray, rapid reaction, with gypsum, some chips of limestone and gypsum together; some gray shale in chips	840, 850
Dolomite, brown-gray, compact, subcrystalline	860, 870
Dolomite, green-gray, highly argillaceous, a little fine rounded quartz sand imbedded	880
Dolomite, blue-gray, in fine meal; much gypsum in meal and larger grains	890

Ordovician:	
Maquoketa shale (110 feet thick; top 152 feet below sea level):	
Shale, dark blue-gray, hard, dolomitic, in chips	900
Shale, red, plastic	910
Shale, drab	920, 930
Shale, light blue-gray; 4 samples	940–970
Shale, brown-gray; with chips of dolomite, soft, buff, argillaceous	980
Shale, light gray, plastic	990
Shale, light brown-gray, dolomitic with microscopic crystals	1000
Galena to Glenwood inclusive (280 feet thick; top 262 feet below sea level):	
Dolomite, brown-gray, with light yellow-gray limestone at 1020, 1030; 3 samples	1010–1030
Limestone, light gray, rapid effervescence; dolomite, brown-gray	1040
Dolomite, brownish or buff; limestone, gray, rapid reaction; cherty at 1090; 5 samples	1050–1090
Limestone, light blue-gray, rapid; mottled brown, showing under microscope crystals of dolomite in matrix of brown, rapidly effervescing limestone; green shale in flakes; white chert	1100
Dolomite; chert; limestone; 3 samples	1110–1140
Dolomite, buff	1150
Limestone, moderately rapid and rapid effervescence, buff and light yellow	1160
Limestone, light gray and light brown-gray, rapid effervescence, highly cherty at 1180	1170, 1180
Dolomite, buff; limestone, light gray, rapid reaction; chert	1190
Dolomite, buff, a little cryptocrystalline silica and fine irregular grains of clear quartz; a little limestone	1200
Limestone, light gray, rapid response; some dolomite	1210
Limestone, chocolate-brown, rapid effervescence, inflammable	1220
Dolomite, gray; some limestone showing rapid reaction with acid; some quartz sand in fine well rounded grains	1230
Limestone, gray, earthy, rapid reaction, in small chips	1250
Dolomite, gray, in fine meal	1260
Sandstone (Glenwood beds), fine grains well rounded and frosted; much limestone and dolomite in small chips	1270
Shale (Glenwood), dark gray-green, pyritiferous	1280
Saint Peter sandstone (40 feet thick; top 542 feet below sea level):	
Sandstone, white, grains up to 1 mm. in diameter, usual facies of Saint Peter; dark fissile shale from above	1290
Sandstone, as above, very fine at 1300; at 1320 fine and coarser up to 0.8 mm. in diameter; with some chert	1300–1320
Prairie du Chien:	
Shakopee (210 feet thick; top 582 feet below sea level)—	
Dolomite, gray	1330
Dolomite, yellow-gray; a little quartz sand and white chert	1340
Dolomite, with more or less quartz sand; oölitic at 1410, cherty at 1390, 1410-1450, 1500; 16 samples	1360–1530
New Richmond (100 feet thick; top 792 feet below sea level)—	
Dolomite, yellow gray, cherty, siliceous-oölitic, with much quartz sand, 5 samples	1540–1580
Dolomite, gray, much quartz sand	1590
Sandstone, fine, secondary enlargements; gray dolomite with imbedded grains of quartz	1600
Dolomite, buff, highly arenaceous, secondary enlargements	1610
Sandstone, buff, secondary enlargements, with some dolomite	1620
Dolomite, highly arenaceous, imbedded grains	1630
Oneota (penetrated 170 feet; top 842 feet below sea level):	
Dolomite, gray, much cryptocrystalline silica in minute translucent flakes; a little fine quartz sand; all in fine meal	1640
Dolomite, light gray, cherty at 1750, 1760, 1780; usually some residue of cryptocrystalline silica and sand of clear quartz; 14 samples	1650–1810

Driller's Log

	Depth in Feet		Depth in Feet
Clay	0–30	Lime, gray	880–895
Blue mud	30–37	Lime, gray	895–905
Quicksand	37–60	Red mud	905–910
Sandy mud	60–90	Shale, blue	910–930
Blue mud	90–97	Shale, brown	930–1005
Lime	97–120	Lime, brown	1005–1015
Sand	120–123	Lime, gray	1015–1040
Shale	123–125	Lime, brown	1040–1100
Lime	125–127	Lime, gray	1100–1216
Shale	127–165	Lime, red	1216–1222
Blue mud	165–180	Shale, blue	1222–1224
Shale, white	180–215	Lime, red	1224–1229
Lime, gray	215–230	Lime, gray	1229–1260
Lime, soft	230–350	Sand, gray	1260–1265
Shale, blue	350–365	Lime	1265–1271
Sand, soft	365–371	Shale, blue	1271–1287
Shale, blue	371–385	Sand, St. Peter	1287–1322
Shale, brown	385–400	Lime, gray	1322–1475
Shale, white	400–600	Sand	1475–1482
Shale, brown	600–605	Lime, brown	1482–1500
Shale, white	605–655	Sand, white	1500–1530
Lime, broken	655–675	Lime, sandy	1530–1550
Shale, white	675–702	Sand	1550–1650
Lime, white	702–775	Lime, white	1650–1665
Sand, white	775–780	Sand, white	1665–1685
Lime, brown	780–800	Sand and lime	1685–1785
Lime, white	800–865	Lime, brown	1785–1798
Lime, brown	865–880	Lime, brown	1798–1815

*Mineral Content of City Well, Brighton**

	P.P.M.
Bicarbonate	300.1
Chloride	69.
Sulfate	470.8
Silica	12.8
$Fe_2O_3+Al_2O_3$	7.1
Calcium	64.3
Magnesium	37.9
Na + K as Na	156.5
Total solids	968.8

BURLINGTON

(Altitude 530 feet, C., R. I. & P. Ry.)

WELL OF THE HOTEL BURLINGTON

This deep well was drilled in 1924 by E. F. Jones of Burlington. The depth is 585 feet and the diameter 5 inches. The head is 25 feet above the curb. Casing is driven about 150 feet into rock, The water is used only for the coils of an ice-making machine. The cost of the well was about $1100.

* Analysis by Harry F. Lewis, Chemical Laboratory, Cornell College, Mount Vernon, 1927.

WELL OF THE BURLINGTON FRUIT COMPANY

In 1924 a well was completed for this company by E. F. Jones. The depth is 675 feet and the diameter 5 inches. The principal supply was found at about 300 feet. The head is stated to be 50 to 60 feet above the curb. The well is cased to above 250 feet; its total cost was $1350.

WELL OF THE JOHN BLAUL'S SONS COMPANY

This well, 613 feet deep and 5 inches in diameter, was drilled by E. F. Jones in 1924. Water was found at 550 feet. The original head was 18 feet above the curb and in 1926 it was 14 feet. The flow per minute is 25 gallons. The cost of the well was $1200.

Chemical Analysis of Water by Dearborn Chemical Co., Peoria, Ill.

Mineral	Grains per gallon
Silica	.991
Oxides of iron and aluminum	.070
Carbonate of lime	trace
Sulphate of lime	61.451
Carbonate of magnesia	11.220
Sulphate of magnesia	19.432
Sodium and potassium sulphates	80.258
Sodium and potassium chlorides	23.800
Total mineral solids	197.392
Total incrusting solids	73.732
Total nonincrusting solids	123.660

The directing chemist of the Dearborn Company reports that the water is very difficult to handle from a scale-forming and also a foaming standpoint, and is not recommended for boiler purposes under any conditions.

BURT, KOSSUTH COUNTY

(Altitude 1177 feet)

CITY WELL NO. 1

This well was drilled in 1916 and is 517 feet deep. The diameters are 8 and 6 inches. A little water was encountered at 95 and 165 feet, but the principal supply was found at 517 feet. The static level on completion was 24 feet below the surface, where it still remains. The pumping capacity is 95 gallons per minute—two and one-half times the maximum consumption of the town. The casing is 8 inches to 184 feet and 6 inch casing to rock at 264 feet.

CALIFORNIA, HARRISON COUNTY

OIL PROSPECT OF H. R. COULTHARD

This drill hole was sunk about a quarter mile north of the station on the Missouri river flood plain at an elevation of about 1010 feet above sea level. The upper strata represented by the samples are evidently Mississippian. The Saint Peter sandstone was not reached, but the lowest dolomites may belong to the Galena.

Record of Strata

	Depth in Feet
No samples	0–360
Limestone, light yellow-gray, oölitic, brisk effervescence in cold dilute HCl; in sand	360–365
Limestone, light gray, earthy, rapid effervescence, with imbedded calcite crystals; in rather large chips	464–481
Limestone, light yellow-gray, oölitic (?), rapid effervescence; in sand	595–614
Dolomite, light buff in mass, in fine sparkling crystalline sand	614–628
Dolomite, or magnesian limestone, buff, in fine crystalline sand, rather slow effervescence	655
Dolomite, brown, fine crystalline-granular; much white chert	662
Dolomite, buff, in fine sparkling sand; limestone, drab, fine crystalline-granular, argillaceous, rather rapid reaction in acid, with sporadic calcite crystals, in chips	692
Shale, blue; limestone, blue-gray, and yellow-gray, rather slow effervescence; some flint and chalcedonic silica; all in chips	780
Shale, blue-gray, calcareous	780–790
Dolomite, light gray, in fine crystalline sand	810–816
Dolomite, light gray, crystalline-granular, soft, cherty, somewhat more rapid effervescence than LeClaire dolomite; 2 samples	967, 978
Dolomite, buff, in coarse sand, some grains of rapid effervescence	970–1045
Limestone, drab and yellow-gray, rapid effervescence, much bright green shale in waterworn chips	1145–1150
Dolomite, light gray, in sand, with shale as above	1150–1190
Dolomite as above, and shale as above	1209–1228
Dolomite, gray, much white chert, some chalcedonic silica	1228–1300
Chert, white; dolomite, light gray	1360–1460

CALMAR, WINNESHIEK COUNTY

(Altitude 1258 feet)

In 1922 a well 398 feet deep was completed for the Chicago, Milwaukee and Saint Paul Railway Company by James Kushar of Plymouth, Iowa.

The static level is 77 feet below the surface of the ground, and is lowered 11 feet when the well is pumped at its capacity of 165 gallons per minute. At 376 feet a test was made which showed a static head of 84 feet with a draw down of 34 feet, when the well was pumped at the rate of 160 gallons per minute. At 177 feet the well was tested at 25 gallons per minute and the static level of 85 feet was lowered within 2 feet of the bottom.

Driller's Log

	Depth in Feet
Pleistocene (64 feet thick):	
Yellow clay	0–30
Blue clay	30–64
Maquoketa (123 feet thick):	
Limestone	64–110
Lime and soapstone mixed	110–120
Brown limestone	120–132
Brown lime and sandstone	132–141
Limestone	141–148
Shale and limestone	148–177
Limestone and a little shale	177–187
Galena and Platteville (penetrated 221 feet):	
Hard limestone	187–248
Limestone and shale in layers	248–268
Hard limestone	268–276
Hard limestone and a few layers of shale	276–308
Hard brown limestone and some shale	308–318
Hard brown limestone	318–378
Soft porous brown limestone	378–395
Hard brown limestone	395–398

Notes.—Comparing the above section with those of wells nos. 1 and 2 of the railway company at Calmar[43] it will be seen that the thickness of the Maquoketa in wells nos. 2 and 3 is precisely the same and is 23 feet less than that recorded for well no. 1.

The interval from 248 to 310 feet is reported in well no. 2 as "shale," in well no. 1 as "limestone," and in well no. 3 more accurately, no doubt, as "limestone and shale in layers," "limestone and a few layers of shale" and "limestone and some shale."

Well no. 1, drilled to the depth of 1223 feet, found the Saint Peter at 608 feet, the Prairie du Chien at 675, the Jordan at 1000 and the Trempealeau dolomite of the Saint Lawrence at 1120 feet.

CEDAR RAPIDS

(*Altitude 725 feet*)

WELL OF T. M. SINCLAIR COMPANY

This well was drilled by the J. P. Miller Artesian Well Company of Chicago in 1911. The depth is 1471 feet, the diameters are 12 inches to 415 feet, 10¼ inches to 682 feet and 8 inches to the bottom.

At 301 feet (Niagaran limestone) water stood 4 feet below the surface and yielded 200 gallons per minute.

43 Underground Water Resources of Iowa, vol. XXI, Ann. Rept.: Iowa Geol. Survey, pp. 414-15.

At 410 feet (Niagaran limestone), the static level remaining the same, a tee was placed 9 feet from the surface and the water flowed 50 gallons per minute into the reservoir. At 1130 feet (Prairie du Chien) an additional supply was struck and at 1225 (Prairie du Chien) the flow into the reservoir was 85 gallons per minute. At 1300 feet the flow measured 125 gallons, and at 1330 feet 260 gallons. Crevices were encountered at 1370 feet with an increase in flow to 300 gallons per minute. At 1430 (Jordan) the flow decreased to 200 gallons per minute and remained unchanged to the completion of the well. The well was later found to have a pumping capacity of 900 g.p.m.

Temperature of Water

At 301 feet	54° Fahr.
At 875 feet	59° Fahr.
At 1225 feet	59½° Fahr.
At 1330 feet	60½° Fahr.

Driller's Log

	Depth in Feet
River sand deposit, quicksand on rock	0–70
Lime rock, gray-blue (Devonian and Silurian)	70–420
Shale (Maquoketa)	420–680
Lime, white, with trace of shale at 910	680–925
Quartz and iron pyrite, at	925
Lime, grayish	925–985
Sand (Saint Peter)	985–1015
Lime (Shakopee)	1015–1050
Sandy lime (New Richmond included)	1050–1225
Lime (Oneota)	1225–1400
Sand (Jordan)	1400–1471

WELL OF PENICK AND FORD, LTD.

This well is one of several of about the same depth which have been drilled in the business district of Cedar Rapids and which tap the waters of the Niagaran limestone.

The well, 430 feet deep and 6 inches in diameter, was drilled by Chas. D. Nolan of Cedar Rapids in 1924. The principal supply was found at 400 feet "above Maquoketa shale", and other viens were struck at 65, 145 and 240 feet. The static level is 7 feet below the curb; the pumping capacity under air is 110 g.p.m. The cost of the well was $1290.

CHARLES CITY

(Altitude 1011 feet)

CITY WELL OF 1928

The first artesian well of this city was drilled in 1906 and is described in the report on the Underground Water Resources of Iowa. The natural flow on completion was 200 g.p.m. and the discharge under a vacuum of 7 pounds 900 g.p.m. In 1928 the discharge is reported as 250 g.p.m. under a centrifugal pump.

Increased consumption as well as the decreased yield of the old well made a new well necessary. The second well was drilled 1540 feet from well no. 1 in order to prevent interference as far as conveniently possible. It was completed in 1928 by the McCarthy Well Co. of St. Paul and Minneapolis. The depth is 1385 feet, 202 feet less than that of well no. 1, which penetrated the St. Lawrence formation to the depth of 337 feet, at least 187 feet of which were the dry Franconia beds. The diameters are 20 inches to 70 feet, 16 inches to 122 feet, 13 inches to 593 feet, and 10 inches to bottom. The principal supply was found at 1190 feet in the Jordan sandstone. Another water bed was struck at 718 feet near the top of the Saint Peter sandstone.

The static level is 13 feet below the surface. The pumping capacity is 300 g.p.m. with a draw down to 100 feet below the surface of the ground with a turbine pump set at 120 feet. The head of the Jordan sandstone water is lower than that of the Saint Peter sandstone, as the well flowed after a day's shut down, when it had reached the depth of 735 feet. The well is cased with 70 feet of 20 inch pipe outside the 16 inch pipe which extends from the surface to 122 feet. A 10 inch liner extends from 593 to 787 feet.

Record of strata of City well no. 2, Charles City

	DEPTH IN FEET
No samples	0–70
Devonian (114 feet thick, first sample at 941 feet above sea level):	
Limestone, yellow, fine-grained, earthy, slow effervescence in cold dilute HCl	70
Limestone, light brown-gray, crystalline, rapid effervescence	80
Limestone, gray and dark drab, fine crystalline-granular, rapid effervescence	90
Limestone, gray, earthy, rather slow effervescence, some rapid	100
Shale, light blue-gray, calcareous, in friable masses	109
Shale, blue-gray, plastic, in hard concreted masses, calcareous	114
Dolomite, yellow-gray, soft, fine-granular, compact	124
Dolomite, gray, fine crystalline-granular, slightly porous, soft, some blackish spots	134

Limestone, magnesian or dolomite, fine crystalline-granular, porous, moderately slow effervescence	144
Limestone, blue-gray, argillaceous, obscurely fossiliferous with calcite casts, rather slow effervescence; some chert	154
Dolomite, fine crystalline-granular, gray	164
Limestone, light and dark gray, argillaceous, earthy, moderately rapid effervescence	174
Ordovician:	
Maquoketa (90 feet thick; top 827 feet above sea level)—	
Shale, light gray, calcareous, in friable masses; considerable fine sand of clear quartz in irregular grains and a few crystals	184, 194
Dolomite, gray, porous; and light blue, highly argillaceous	204
Dolomite, gray, argillaceous at 224, drab at 244 feet; 4 samples	214–244
Dolomite, light brownish drab, some vesicular, argillaceous	254
Sandstone, blue-gray, argillaceous, dolomitic, in chips, grains fine, fairly well rounded	264
Galena-Platteville (361 feet thick; top 737 feet above sea level)—	
Limestone, gray and brown-gray, soft, argillaceous, fine-granular, rather slow effervescence, obscurely fossiliferous in white calcite	274
Limestone, in mass yellow-gray, rapid effervescence; much white chert; fine rounded grains of quartz sand; all concreted in friable masses	284, 294
Limestone, light yellow-gray, granular, rapid effervescence	304
Limestone, light and darker gray, argillaceous, rather coarse-granular, rapid effervescence, in concreted masses	324
Shale, gray, in rather difficultly friable masses concreting gray limestone and white chert	334
Limestone, gray, earthy, fine-grained, rapid effervescence, in chips; 3 samples	344–364
Limestone, gray, earthy, in large flakes, fossiliferous, rapid effervescence	374, 384
Limestone, gray and light yellow-gray, rapid effervescence, fossiliferous at 404, gray flint at 494 and 504; 20 samples	394–584
Limestone, light yellow-gray, earthy, rapid effervescence, in sand concreted with argillo-calcareous powder; 5 samples	594–634
Glenwood shale (73 feet thick; top 376 feet above sea level)—	
Shale, in light blue-gray concreted mass, highly calcareous with grains of limestone; residue of fine grains of quartz sand, larger ones rounded; chert; pyrite	635
Shale, light gray, in concreted mass with some light gray limestone	645
Shale, dark brownish drab and greenish gray, unctuous, hard	665
Shale, brown-gray in mass, some greenish flakes	675
Limestone, yellow-gray, earthy, rapid effervescence, with some flakes of dark shale, all concreted with argillo-calcareous powder into tough mass	685
Shale, rather dark blue-green and drab, slightly calcareous, with some quartz grains at 705; in tough masses	695, 705
Saint Peter sandstone (68 feet thick; top 303 feet above sea level)—	
Sandstone, grains of Saint Peter facies, larger ones 1 mm. diameter, concreted in sample with powder of shale in blue-gray mass	708
Sandstone, as above, but a little finer, concreted with argillo-calcareous powder in light gray, rather difficultly friable mass at 718, blue-gray at 728, a little green shale at 738; 3 samples	718–738
Sandstone, light gray in mass, larger grains less than 0.5 mm. in diameter, some concreting powder but easily friable	758, 768
Prairie du Chien (404 feet thick; top 235 feet above sea level)—	
Dolomite, brown-gray, in chips, with much quartz sand	776
Dolomite, brown-gray, in chips	786
No sample	796
Dolomite, gray, in small chips; some quartz sand and shale	806

No sample	816
Dolomite, gray; 4 samples	826–856
Sandstone, fine rounded grains of clear quartz; some dolomite with imbedded grains	862
Sandstone, highly dolomitic, pyritic	872
Dolomite, gray, in clean chips	874
Dolomite, with quartz sand concreted with powder of light green shale	884
Dolomite, gray	894, 904
Dolomite, gray, with quartz sand and powder of shale concreted in rather difficultly friable light gray mass; a little white chert	914, 924
Dolomite, gray, in chips	934
Sandstone, grains rounded, with dolomite chips showing imbedded grains	940
Dolomite, gray, showing minute round holes as from removal of oölites; considerable quartz sand, larger grains about 1 mm. in diameter	950
Dolomite, gray, imbedded grains of quartz sand; siliceous oölite; much loose quartz sand; powder of shale; all in hard light-gray concreted mass	960
Dolomite, gray	970
Sandstone, larger grains 1.5 mm. diameter, with much gray dolomite	980
Sandstone, with gray dolomite; some white chert	990
Dolomite, gray, blue-gray, yellow-gray, whitish; cherty at 1010, 1020, 1070, 1080; considerable quartz sand at 1030, 1050, 1150, 1170; 18 samples	1000–1170
Cambrian:	
Jordan sandstone (90 feet thick; top 169 feet below sea level)—	
Sandstone, grains of clear quartz, rounded, frosted, larger grains slightly over 1 mm. diameter; some chips of dolomite	1180
Sandstone, white, grains as above	1190, 1200
Sandstone, white, some chips of fine blue-gray sandstone with dolomitic cement	1210, 1220
Sandstone, dolomitic	1230
Sandstone, in loose grains; some chips of fine sandstone, dolomitic	1240, 1260
Saint Lawrence (Trempealeau formation) (penetrated 20 feet; top 259 feet below sea level)—	
Dolomite, whitish, blue-gray and gray, pyritic, arenaceous	1270
Shale, light blue-gray, in hard concreted masses, inclosing much quartz sand and particles of dolomite, some with imbedded grains; perhaps a highly argillaceous, arenaceous dolomite	1280, 1290

Notes.—The limits of the formations for the first 274 feet in the above section are highly uncertain and are rendered more problematic by some grave disagreements between the samples of the first and second city wells. The Devonian clearly extends at least as far down as 109 feet, and the Galena-Platteville clearly begins as high up as 284 feet. But as basal layers of the Devonian may be dolomitized, the magnesian beds from 124 to 164 feet inclusive are assigned to that formation, since the underlying stratum of limestone appears too slightly magnesian for either the Niagaran or the Maquoketa.

At Waverly the Niagaran has thinned to 50 feet at most. At

Charles City it appears to have feathered out, leaving the Devonian to rest directly on the Maquoketa, as in the counties to the east. And as to the east the Maquoketa may be expected to have lost in part its clayey shales and to have become much more calcareo-magnesian. The argillaceous sandstone at 264 feet is an unusual feature, but better placed at the base of the Maquoketa than with the Galena-Platteville.

The Galena-Platteville is left with a normal thickness of 361 feet and is undolomitized, as in the well-sections of Bremer county.

The shales referred to the Glenwood are abnormal in thickness when compared with the Glenwood to the south and east, but lack nearly 20 feet of the thickness they hold at Mason City. At Osage they are 45 feet thick. At Charles City they embrace not only the usual dark blue-green shale at base, but also gray, blue-gray, drab and brownish shales with two seams of limestone. They extend upward to the horizon of the Decorah shales of the counties to the east, but their arenaceous content at top seems to link them rather to the Glenwood.

The Saint Peter sandstone is of special interest because of the clayey content (evident in the unwashed samples) of the upper layers. This clay appears as a cement concreting the contents of the slush bucket when dry into tolerably tenaceous light gray or blue-gray masses, and is to be distinguished from the flakes of greenish shale, fallen from the Glenwood, common at this horizon in any well. In the first city well these argillaceous sandstones were placed by the writer with the Glenwood and the contour line of the Saint Peter in Floyd county in the report of 1912 was thus given a local convexity to the northeast, interrupting its normal curve. The cuttings now available lead to a correction and show clearly, as the cuttings of the first well did not, that the dolomites of the Prairie du Chien begin at 776 feet.

The Jordan sandstone was struck at about the same level in both wells and was found to be of about the same thickness.

The Saint Lawrence beds were penetrated but 20 feet in well no. 2. The drill of well no. 1 had explored them to a depth of 337 feet, of which the lower 187 feet at least is referable to the Franconia. A gap of 120 feet in the sample cuttings made it impossible to demark the Trempealeau and the Franconia. As at Waverly and Sumner the Saint Lawrence, so far as cuttings show, is here composed mainly of shales.

CHURDAN, GREENE COUNTY

(*Altitude 1121 feet*)

Log of Wm. Becker, driller

	DEPTH IN FEET
Soil	0–18
Sand and a little water	18–23
Blue clay	23–186
Rock	186–200
Shale and slate and a little water	200–412
Cap rock, very hard	412–440
Lime rock and more water	440–495
Brown rock almost as hard as granite	495–640
Sand rock with more water; head 70 or 80 feet below curb	640–705
Gray rock, more water; head 65 feet below curb	705–773

This well was drilled a year or two previous to 1915. Its diameters were 9 to 6 inches and it was cased to 413 feet. It failed to yield a satisfactory supply and two wells 160 feet deep, with diameters, one of 4 inches, the other of 8 inches, were drilled later. These wells end in sand and yield an abundant supply. The town has nearly a mile of mains.

CLARINDA

(*Altitude, 1012 feet*)

On Nevember 5, 1928, Iowa's First Oil Developing Company of Clarinda began the drilling of Wilson no. 1 oil prospect hole. It is on the bottom lands of Nodaway river four miles south of Clarinda, on the Wilson farm, in the southeast quarter, southeast quarter, section 24, T. 68 N., R. 37 W., in Page county. The drillers were G. H. Rose and Son of Maryville, Missouri. The well was begun with a diameter of 15½ inches and was lined with 15½ inch casing to 25 feet. Thence the hole is 12½ inches in diameter to 506 feet and is cased with 12½ inch pipe to that depth. Below this point the diameter is 10 inches to 912 feet with 10 inch casing. At 912 feet the well was reduced to 8 inches with casing of the same size and was still at this size at 1530 feet.

Record of strata of Wilson No. 1 oil prospect of Iowa's First Oil Developing Co., Clarinda

	DEPTH IN FEET
Pleistocene and Recent (25 feet thick; top about 988 feet above sea level):	
Glacial clay, yellow, sandy, noncalcareous	0–10

Pennsylvanian: Missouri series (690 feet thick; top 963 feet above sea level):

Limestone, gray, fine-textured, in light gray powder and chips, responds readily to acid; 25 to 31 and	33–36
Shale, blue, gray, drab, sandy	36–40
Shale, dark gray, calcareous, some small clear specks may be selenite (gypsum)	51–60
Limestone, light gray, finely crystalline	70–80
Limestone, dark gray, finely granular, some Fusulina	80–83
Limestone, or limy shale, in fine strongly calcareous concreted powder, light gray, some sand grains which may be from above	83–94
Limestone, light gray, fine-grained	94–102
Shale, bluish gray, very fine-grained, very slightly calcareous	102–140
Limestone, dark gray, very finely granular	140–144
Limestone, light gray, finely sugary, many small specks of pyrite	144–150
Shale, very smooth feel, rather light gray, noncalcareous	150–160
Limestone, light gray, finely sugary	160–165
Shale, dark gray, very finely gritty, limy; 2 samples	340, 349
Limestone, dark gray, very fine-grained	353
Shale, bluish, purplish, fine-grained, limy; 4 samples	355–372
Limestone, gray, in fine powder and grains. Label says "salt water". Sample of water is decidedly salty	385–392
Shale, gray, limy, chips of limestone at 435; some bluish and whitish at 450; 6 samples	418–450
Limestone, light gray, finely sugary, some darker flakes are hard shale like that at 440; "top of lime below No. 27"	450
Shale, light and dark gray, finely gritty, limy; 3 samples	452–460
Limestone, dark gray, soft, very fine-grained, much very fine dark clay residue	462–465
Shale, dark gray, fine-textured, very little lime	465–467
Limestone, light gray, finely sugary	467–470
Limestone, white and light gray, in fine powder which is almost entirely soluble in cold acid	470–473
Limestone, gray, sugary texture; 2 samples	473–477
Limestone, blue-gray, fine texture	477–480
Limestone, gray, finely sugary texture	480–484
Limestone, dark gray, almost black when wet, finely sugary texture, some shale; 2 samples	484–493
Shale, finely gritty, dark gray, limy; sand grains 495-499; 3 samples	493–499
Shale, light gray, very finely gritty, limy; 2 samples	499–504
Limestone, light gray, in coarse powder, effervesces very freely in cold acid, some residue probably siliceous	504–505
Shale, limy, dark gray, soft, very smooth feel, also dark green, very finely granular, hard	505–510
Shale, light gray, finely gritty, limy	510–515
Limestone, light gray, in chips and powder, briskly effervescent, a very little light colored residue	515–519
Limestone, light gray, in grains and chips, packed with Fusulina and spines	519–523
Shale, dark gray, gritty with very fine sand; grains of limestone mingled in shale	523–530
Limestone, dark gray, somewhat shaly, granular, several specimens of Fusulina	530–535
Shale, dark gray, very finely gritty, quite limy	535–540
Limestone, dark gray, crystalline-granular	540–545
Limestone, dark gray, fragments oölitic, strong effervescence, some dark residue	545–550
Limestone, light gray, crystalline-granular, in grains and chips, some of which contain Fusulina and other light colored masses, numerous black specks, 565-571: 4 samples	550–571
Shale, dark gray, finely gritty, limy	571–577

Limestone, dark gray, in small chips; some black fragments which do not respond to acid probably are black shale........ 577–581
Limestone, light gray, granular, ready effervescence, darker gray, 594-604; 4 samples 581–604
Shale, black, hard, laminated, numerous specks, probably mica, on parting planes 604–610
Shale, very limy, or limestone, shaly, dark gray, ready response to acid but much dark very finely divided residue 610–615
Limestone, light gray, fine-grained 615–621
Limestone, light gray, sugary texture 621–627
Limestone, similar to above, and shale, black, hard, very fine-textured, mica specks 627–634
Shale, black, similar to above, noncalcareous, some reaction from mingled limy matter 634–640
Shale, light gray, noncalcareous, finely gritty, hard 640–645
Limestone, light gray, crystalline; 2 samples 645–652
Shale, gray, hard, finely gritty, nonlaminated 652–655
Limestone, light gray, similar to that at 645-652 655–660
Shale, gray, noncalcareous, hard, some effervescence from powder in sample 660–665
Limestone, brown, crystalline, briskly effervescent; a little dark residue perhaps silica 665–670
Limestone, brown, with large clay content; and shale, greenish, fine-textured, limy, hard; much of sample is in powder concreted to hard masses; 2 samples 670–680
Limestone and shale, greenish gray, limestone subcrystalline, shale finely gritty, rather hard 680–685
Shale, gray, fairly hard, very fine-textured, very small lime content; some gray powder is briskly effervescent 685–691
Limestone, dark gray, fine-grained, with large clay content 691–695
Limestone, gray, and shale, dark gray and brown, slightly calcareous 695–702
Limestone, in white and gray crystalline granules very freely responsive to cold HCl; shale, blue-gray, chocolate-colored, hard, not limy; pyrite; 2 samples 702–712
Limestone, some clayey, some granular, readily soluble in cold HCl, light to dark gray; much shale, soft, greenish, reddish, gray, limy 712–715

Pennsylvanian: Des Moines series (penetrated 725 feet; top 273 feet above sea level)—

Shale, gray and chocolate-colored, finely gritty, somewhat calcareous; samples contain some fragments of bright shiny brittle coal at 735-741 (bag says "Hit coal at 738-743, no cap rock") and at 741-745; 4 samples 715–745
Limestone, gray, clayey, fine-grained, in angular chips and flakes, brisk effervescence; shale, gray, finely gritty, perhaps one-fourth of sample 745-748, one-half of samples 748-750 and 750-755, some dark gray and brown in second sample; 3 samples 745–755
Shale, black and dark gray, laminated, strongly calcareous above, less below; 5 samples 755–785
Shale, dark brown, hard, slightly limy; some fragments of hard gray finely granular limestone 785–791
Limestone, light gray, fine-grained, very brisk effervescence, slight residue; shale, dark gray, limy, carbon streaks, mica specks; 4 samples 791–804
Shale, light gray, soft, calcareous, some flakes of dark gray limestone 804–808
Limestone, dark gray, hard; shale, dark gray, hard, limy; darker 822-827; probably some differences were detected by the driller, as noted in his log, but the samples are very similar; 7 samples 808–841
Shale, light and dark gray, some calcareous, some not, very fine-textured; 5 samples 841–876
Shale, similar to above, noncalcareous; sandstone, fine, light gray, noncalcareous; 2 samples 876–885

Shale, black, finely laminated, noncalcareous, some in large flakes; limestone, light gray, fine-textured	885–894
Shale, gray, very fine-textured, mostly noncalcareous; calcareous with some dark brown noncalcareous 904-906, mostly dark brown, noncalcareous 906-915, some gray limestone 915-920, somewhat calcareous 924-928, almost black 928-955, a few fragments limestone and sandstone 955-964; 18 samples	894–990
Sandstone, medium gray, composed of fine subangular clear grains of quartz, numerous white mica specks; shale, very dark gray, fine-grained, a few large chips 990-1000, abundant small chips 1000-1005, 1010-1018; 5 samples	990–1021
Sandstone, like that of sample above; shale, a few dark gray flakes, noncalcareous, but mostly in concreted masses of light gray, limy, fine-textured material	1021–1025
Shale, light and dark as above but noncalcareous; a few grains of quartz sand, perhaps from above	1025–1034
Shale, light tan to light bluish, gritty, calcareous; limestone, some small light gray chips	1034–1044
Limestone, light gray, fine-grained, briskly effervescent in cold HCl; shale, light and dark gray, very fine-textured, noncalcareous; residue fine, hard, whitish grains probably chert	1044–1050
Shale, black, very fine-textured; a few fragments of bright coal (log says "Coal, very inferior, 1044-1057"); powder of sample gives some reaction with acid, residue includes chert	1050–1057
Shale, as above; sandstone, gray, fine-grained, in grains and small pebbles; a few grains of limestone	1057–1065
Shale, light to dark gray, finely gritty, calcareous 1065-1075, mostly noncalcareous below; some sandstone 1113-1119; thin films and lenses of limestone 1119-1125; concreted calcareous masses 1130-1140, quartz sand 1145-1170, 1193-1206; nearly black 1206-1245; 25 samples	1065–1245
Sandstone, medium gray, composed of fine subangular clear quartz grains; some bluish black shale, nearly gritless	1245–1251
Shale and sandstone as above, in approximately equal amounts	1251–1265
Shale, dark gray, similar to above, no sandstone; calcareous 1287-1292; some samples concreted into hard masses, some in small chips; powder slightly calcareous 1320-1330, strongly so 1340-1350, but chips noncalcareous; black 1345-1350, dark tan 1350-1357, mixed black and tan 1364-1371, tan 1371-1377; 20 samples	1265–1384
Shale, gray and black, former finely gritty, latter almost gritless, all noncalcareous; sandstone, similar to those above, nearly equal to shale in amount; powder contains some effervescent particles; 4 samples	1384–1410
Shale, very dark gray, finely gritty, noncalcareous, pyrite, a few small chips of coal 1417-1422; in small chips and grains, with some sand in fine rounded to subangular grains 1422-1427; more sandstone, in small gray pebbles 1427-1433; 4 samples	1410–1433
Sandstone, gray, grains fine to very fine, subangular to rounded, clear to translucent, a few white; a very little black shale 1433-1435; tan, grains more even in size 1435-1461; somewhat calcareous 1468-1474; some black shale and pyrite 1490-1495; 8 samples	1433–1495
Shale, black and dark gray, in small chips, almost noncalcareous, some pyrite; sandstone, grains similar to those in sandstones above, small amounts 1495-1503, equal to shale 1503-1512; mostly black shale, with much pyrite 1512-1530; 4 samples	1495–1530

Driller's log, Wilson No. 1 oil prospect

Character	Thickness, feet	Depth, feet
Soil	10	0–10
Sand and gravel, lots of water	15	10–25
Lime	6	25–31
Shale, dark	2	31–33
Lime	3	33–36
Shale, dark	4	36–40
Shale, light	3	40–43
Shale, blue	3	43–46
Lime	5	46–51
Shale, gray	19	51–70
Lime	10	70–80
Coal and shale (inferior coal)	3	80–83
Light shale	11	83–94
Lime	8	94–102
Black shale	38	102–140
Limy shale	4	140–144
Lime	6	144–150
Dark shale	10	150–160
Lime	5	160–165
Shale	1	165–166
Lime	6	166–172
Shale, gray and black	8	172–180
Lime	28	180–208
Dark shale	16	208–224
White lime	4	224–228
Light shale	8	228–236
Red rock	14	236–250
Light shale	70	250–320
Brown shale	20	320–340
Dark sandy shale	9	340–349
Lime and shale, broken	7	349–356
Brown shale	19	356–375
Lime	10	375–385
Water sand, salty	12	385–397
Black shale	8	397–405
Blue shale	4	405–409
Brown shale	4	409–413
Blue shale	31	413–444
White shale	1	444–445
Broken white lime	2	445–447
White hard lime	4	447–451
Dark shale	11	451–462
Black lime	7	462–469
White shale	4	469–473
Hard lime (white to gray to black to brown)	15	473–488
Shale, light and sticky	11	488–499
Shale, light and sticky	5	499–504
White lime	6	504–510
Light shale	4	510–514
White lime	10	514–524
Dark shale	14	524–538
Lime	36	538–574
Dark shale	4	574–578
White lime	30	578–608
Dark shale	8	608–616
White lime	18	616–634
White shale	12	634–646
Lime	14	646–660
Dark shale	10	660–670

Light shale	10	670–680
White lime	10	680–690
Light shale	12	690–702
Shale, brown and red	23	702–725
Shale, light blue	10	725–735
Shale, blue	3	735–738
Coal	5	738–743
Lime	2	743–745
Shale	2	745–747
Hard lime	8	747–755
Black shale	25	755–780
Blue shale	5	780–785
White lime	17	785–802
Light gray shale	20	802–822
Lime shale and dark shale	8	822–830
Lime (water enough to drill with)	22	830–852
Light shale	53	852–905
Dark shale	7	905–912
White lime	6	912–918
Shale, light to dark	77	918–995
Water sand (salty)	25	995–1020
White shale	14	1020–1034
Dark shale	4	1034–1038
Soft sandy lime	4	1038–1042
Light shale	2	1042–1044
Coal (very inferior)	13	1044–1057
Dark shale	188	1057–1245
Water sand (break in the middle)	15	1245–1260
Dark shale	65	1260–1325
Lime shell	2	1325–1327
Black shale	64	1327–1391
Lime shell	1	1391–1392
Dark shale	18	1392–1410
Light sandy shale	10	1410–1420
Coal	2	1420–1422
Dark shale	13	1422–1435
Water sand (show of oil in top of sand)	42	1435–1477
Black shale	2	1477–1479
Water sand	3	1479–1482
Brown shale	2	1482–1484
Water sand	46	1484–1530

Notes.—The driller's log shows that the Missouri series begins at a depth of 25 feet below the surface. The top of the Des Moines series is placed at 715 feet on the shale which seems to have some of the features of Des Moines shale, such as color and the presence of coal. The coal at 80 to 83 feet doubtless is the Nodaway bed, as its elevation corresponds quite well with that in the mines at Clarinda—900 to 920 feet above sea level. Salt water was encountered at 385 to 397 feet and again in the sandstones at 995 to 1020 and 1245 to 1260 feet. The driller says of the coal logged at 738 to 743 feet: "It drilled very fast and while it showed some coal I rather think it was just a small streak." The same was true of the coal recorded between 1044 and 1057 feet. A shale at 670 to 680 feet caused much trouble and delay by repeatedly squeezing into the hole. Finally the 10 inch casing was driven past it. The well caved a little also between 1340 and 1410. The sandstone between 1245 and 1260 feet showed enough gas to be detected by the odor.

Drilling was still being prosecuted in February, 1929, when this report went to press.

CLINTON

(Altitude 590 feet)

WELL OF THE WESTERN ICE COMPANY

In 1927 C. W. Varner of Dubuque completed a well for this company, the first deep well drilled in the city since 1912. The depth is 1500 feet, the diameters 17, 12, 10 and 8 inches. The discharge is approximately 300 g.p.m. The static level is 10 feet above the surface. The well started to flow at 1060 feet and continued to increase to about 1330 feet. Below this level no further increase was noticed. The following casing was inserted: 12 inches to 90 feet, 10 inches from 83 to 403 feet, 8 inches apparently from 710 to 750 feet, casing out the shales above the Saint Peter.

Driller's Log

	DEPTH IN FEET
Soil	0–3
Niagaran limestone	3–173
Maquoketa shale	173–495
Galena lime	495–730
Shale (Glenwood)	730–740
Saint Peter sandstone	740–780

"The rest of the formation is about the same as at the American Sugar Beet Company's well."

COLLINS, STORY COUNTY

(Altitude 1007 feet)

Previous to 1926 Collins had been supplied from a well 180 feet in depth. A second well was drilled in that year by E. A. Ford of Marshalltown. The depth is 384 feet. The drill passed through 278 feet of clay, with thin streaks of shale at bottom and it foots in rock at the depth mentioned. The capacity of the well is 40 g.p.m.

CONRAD, GRUNDY COUNTY

(*Altitude 992 feet*)

CITY WELL NO. 1

The depth of this well is 606 feet and its diameters are 10 and 8 inches. It was completed in 1915 by Edgar Ford of Marshalltown. Water was found at 125 feet and the principal supply came from 606 feet. Water stands at about 160 feet from the surface. The pumping capacity with the cylinder hung at 240 feet is 40,000 g.p.d.; the consumption of the town averages 5,000 g.p.d., with a maximum of 10,000 g.p.d. The water can not be used in boilers.

Driller's Log

	Depth in Feet
Clay	0–22
Sand	22–172
Shale and rock	172–322
Rock	322–606

CORYDON

(*Altitude 1083 feet*)

In 1911 a well was sunk by the city of Corydon to a depth of 1240 feet, when the work was abandoned as the yield was but 20 gallons per minute. The log and some further description of the drill hole was published in the report of 1912 on the Underground Water Resources of Iowa, but since that time a set of cuttings has been received, which may be described as follows:

Record of Strata

	Depth in Feet
Pleistocene, Pennsylvanian (top 1110 feet above sea level):	
No record, no samples	0–610
"Shale, sandy"	610–663
"Sandstone, some water"	663–731
Mississippian (444 feet thick; top 379 feet above sea level):	
Sandstone, light yellow-gray in mass, grains fine, of clear quartz, poorly rounded; limestone whitish, rapid effervescence in cold dilute HCl	742–748
Chert, white, in large chips; limestone, light gray, rapid effervescence, in sand; chalcedonic silica	770
Limestone, dark buff, crystalline-earthy, moderately rapid reaction, in large flakes	810
Limestone, whitish, rapid effervescence, calcite	821–831
Limestone, blue-gray, soft, rapid reaction, in small flakes	835–841
Limestone, blue-gray, crystalline-earthy, soft, rapid effervescence, in flakes; cherty at 875	854, 875
Shale, blackish; chert, brown; limestone, argillaceous	895–898
Limestone, whitish and bluish gray, macrocrystalline; white chert ..906,	918–925
Limestone, light cream colored, macrocrystalline, rapid effervescence; chalcedonic silica and limpid quartz	925–928

Chert, white; limestone as above 928–930
Chert, white, chalcedonic silica; limestone whitish and light yellow gray, rapid effervescence 950–953
Limestone, light gray, cherty 970–975
Dolomite, or magnesian limestone, brownish gray, moderately slow effervescence; some cryptocrystalline silica 1000
Dolomite, as above, in fine sand; white chert; chalcedonic silica; chips of clear quartz; pyrite; 3 samples 1018–1036
Limestone, blue-gray, rapid reaction, in fine sand; blue flint 1036-1039
Chert, white and blue-gray; limestone, light gray; some dolomite, brownish gray; some grains of clear quartz; pyrite; 3 samples 1039–1056
Limestone, gray, rapid response to acid; white chert; chips of crystalline quartz 1056–1077
Limestone, light blue-gray, macrocrystalline-earthy, in flaky chips 1077–1088
Shale, bluish drab, calcareous, plastic, in concreted masses, 4 samples (Kinderhook) 1088–1145
Limestone, light brown-gray, earthy, rapid effervescence 1145–1160
Shale, blue, plastic, calcareous 1160–1175

Devonian (penetrated 55 feet; top 65 feet below sea level):
Limestone, dark blue-gray, rapid reaction, in fine sand; much blue fissile shale in flakes probably from above; some flint and pyrite; 2 samples 1175–1183
Limestone, gray, rapid effervescence, in sand 1183–1210
Limestone, light gray, rapid response 1210–1220
Limestone, light gray and whitish, rapid reaction 1220–1230

COUNCIL BLUFFS

WELL NO. 3, IOWA SCHOOL FOR THE DEAF

A well 1012 feet in depth was drilled for this school in 1885 and a second well, 1100 feet deep, in 1889. In July, 1927, a third well was completed by Thorpe Brothers Well Company of Des Moines. The depth is 2155 feet, the diameters from 16 to 5 and 5/16 inches. Water was found at 55 feet and the main supply at 1585 feet. Small veins were struck at 707, 1815 and 1900 feet. Water rises within 59 feet of the surface. On test pumping with the pumping cylinder at 370 feet 150 gallons per minute were delivered, with a draw down to 360 feet below the surface. The well is cased throughout, with the exception of 500 feet of the lower 525 of the well. The cost of the well was $20,000 and of the pumping machinery $3500.

Chemical analysis of water of Well no. 3, Iowa School of the Deaf

An analysis made by William T. Bailey shows the following mineral content:

	Parts per million (p.p.m.)	Grains per U. S. Gallon (gr. per gal.)
Residue on evaporation	1389	81.705
Volatile matter	122	7.176

Calcium (Ca)	81.17	4.770
Magnesium (Mg)	95.33	5.607
Sodium & potassium (Na+K)	197.10	11.594
Iron (Fe)	2.00	.117
Aluminum (Al)	18.17	1.068
Silica (SiO_2)	41.6	2.447
Chlorine (Cl)	85.0	5.000
Normal carbonate (CO_3)	28.0	1.647
Bicarbonate (HCO_3)	283.04	16.636
Sulfate (SO_4)	658.25	38.720
Nitrates (NO_3)	0.30	.017
Total	1489.96	87.623

Hypothetical Combinations:

Calculated	p.p.m.	gr. per gal.
Sodium nitrate ($NaNO_3$)	.41	.024
Sodium chloride (NaCl)	127.52	7.501
Sodium sulfate (Na_2SO_4)	452.45	26.615
Magnesium sulfate ($MgSO_4$)	440.59	25.917
Magnesium carbonate ($MgCO_3$)	21.83	1.284
Calcium carbonate ($CaCO_3$) equivalent to 328.19 p.p.m. or 19.306 gr. per gal. calcium bicarbonate	202.58	11.917
	1245.28	73.258

Determined:	p.p.m.	gr. per gal.
Silica (SiO_2)	41.6	2.447
Iron oxide (Fe_2O_3)	5.72	.336
Aluminum oxide (Al_2O_3)	34.28	2.016
Total calculated	1326.98	78.057
Residue on evaporation	1389.00	81.705
Excess residue above calculated & determined	62.02	3.648

Record of strata, Well no. 3, Iowa School for the Deaf

	Depth in Feet
Pleistocene and Recent (55 feet thick; top 1010 feet above sea level):	
Soil, dark, pulverulent	0–6
Loess-like silt, buff, calcareous	6–20
Silt, bright buff, slightly calcareous, a little coarser than above, in friable masses, ''muddy quicksand'' of log, almost impalpable grain; 2 samples	20–40
Sand and gravel, yellow-gray, some grains of pink quartzite; 2 samples	40–55
Pennsylvanian (675 feet thick; top 955 feet above sea level):	
Limestone, gray and buff, rapid effervescence in cold dilute HCl; much quartz sand	55–65
Shale, black, in hard concreted masses with fragments of gray limestone included	65–75
Limestone, blue-gray, rapid effervescence; gray chert	75–88
Shale, drab and dark drab	88–90
Shale, blue	90–95
Shale, red	95–100
Limestone, light gray, macrocrystalline-earthy, rapid effervescence	100–109
Shale, blue	109–113
Limestone, dark gray, fine-grained, crystalline-earthy, minute yellowish calcite nests, in large chips	113–120
Limestone, drab, earthy, fossiliferous; fragments of bryozoa, cyathophylloids, crinoid stems, brachiopods	120–130
Shale, blue	130–142

Limestone, gray, earthy	142–150
Shale, blue-gray	150–155
Limestone, blue-gray, minutely fossiliferous	155–160
Limestone, gray, earthy, siliceous	160–166
Shale, drab, fossiliferous	166–170
Shale, blue-gray	170–172
Limestone, gray and whitish	172–181
Shale, black, inflammable, and blue	181–191
Limestone, light gray and whitish, earthy, fossiliferous with fragments of brachiopods and crinoid stems; some gray flint	191–200
Limestone, light gray, earthy, soft; 2 samples	200–220
Shale, black, coaly, inflammable; shale, drab	220–229
Limestone, gray and light gray, some soft, some harder with irregular fracture; 3 samples	229–243
Shale, green-gray	243–248
Limestone, light gray, soft, earthy, laminated, in flakes	248–261
Shale, cinnamon red; 3 samples	261–290
Limestone, gray, earthy, rather soft	290–303
Sandstone, blue-gray, argillaceous, calcareous, micaceous, grains minute; 2 samples	303–320
Shale, red	320–335
Limestone, gray, laminated, earthy	335–344
Sandstone, as at 303	344–355
Shale, black, inflammable	355–364
Limestone, gray, earthy	364–366
Shale, drab, in concreted masses	366–375
Limestone, gray and drab, earthy	375–380
Limestone, yellow-gray, earthy, some speckled; 3 samples	380–404
Shale, blue-gray, in concreted masses	404–410
Shale, drab and black, in chips	410–420
Shale, drab and blue-gray; 5 samples	420–461
Limestone, gray, earthy; 2 samples	461–472
Shale, red	472–480
Shale, red, buff, blue	480–490
Sandstone, gray, fine, irregular grains; 4 samples	490–525
Shale, red, some drab at 540 and 570; 8 samples	525–600
Shale, drab or blue with some red; caving at 630; 4 samples	600–640
Shale, blue	640–648
Shale, sandy, brown; some limestone	648–650
Shale, sandy	650–653
Shale, blue	653–658
Shale, black; 3 samples	658–680
Shale, drab and gray	680–690
Shale, blackish; 2 samples	690–707
Sandstone, gray, fine irregular grains; much pyrite; some limestone, gray and drab, rapid effervescence; 3 samples	707–730
Mississippian (430 feet thick; top 280 feet above sea level):	
Limestone, light gray, rapid reaction in sand; some white opaque chert and quartz sand; some shale	730–740
Limestone, whitish and light gray, soft, crystalline-earthy, rapid effervescence, in flakes; 2 samples	740–760
Limestone, brown, slow effervescence, argillaceous, microscopically arenaceous	760–770
Limestone, gray, some of moderately slow response, some with rapid; fine crystalline	770–780
Limestone, gray, rapid reaction, much light blue-gray chert; and hard very fine-grained sandstone	780–790
Limestone, brown, moderately slow effervescence; whitish and brown chert; chalcedonic silica, some grains of quartz sand; 4 samples	790–826
Shale, blue, plastic, calcareous	826–829
Limestone, buff and gray, fine crystalline-granular, effervescence mod-	

erately slow, some white chalcedonic silica and brown chert; 2 samples	829–850
Limestone, gray, response rapid and moderately slow, much chert, chalcedonic silica, and vein quartz	850–860
Limestone, gray, rapid effervescence; silica, chert and quartz as above	860–870
Limestone, gray, fine crystalline-granular, and earthy, rapid reaction, in flakes	870–880
Limestone, whitish, highly siliceous or cherty	880–885
Shale, blue-gray	885–889
Chert, gray; chalcedonic silica; gray cherty limestone	889–900
Limestone, gray, yellow-gray and buff, rapid reaction, much chert and chalcedony as above; 4 samples	900–940
Limestone, light yellow-gray, crystalline-earthy, reaction rapid, in large flakes	940–950
Chert, light gray and whitish, granular, in chips, some large; limestone, light yellow-gray, rapid effervescence, in sand	950–960
Limestone, yellow-gray and light buff, oölitic, rapid reaction, in sand; 3 samples	960–990
Limestone, buff, response rapid; much white and gray chert, some chalcedonic silica	990–1000
Limestone, gray and buff, rapid effervescence, fine-granular; much blue gray chert	1000–1010
Limestone, dark brownish, reaction rapid and moderately rapid, fine crystalline-granular, some blue-gray chert	1010–1020
Limestone, buff-gray, rapid response, chert as above	1020–1030
Limestone, buff-gray and light gray, rapid reaction, fragments of brachiopods, gray chert; 2 samples	1030–1050
Limestone, mottled gray and whitish, response rapid, flaky chips	1050–1070
Limestone, yellow-gray, calcilutite, rapid effervescence; some white, soft, earthy	1070–1080
"Limestone, gray and white"	1080–1086
"Shale"	1086–1090
Shale, light blue, green-blue and drab, calcareous, plastic; 7 samples (Kinderhook)	1090–1160
Unassigned; below 1592 probably Ordovician (Galena) (thickness 995 feet, top 150 feet below sea level):	
Limestone, whitish and light gray, rapid reaction, in flaky chips, larger chips mottled; earthy-fine-crystalline, some macrocrystalline; 6 samples	1160–1220
Limestone, white and light yellow-gray, earthy-fine-crystalline; some shale in concreted masses	1220–1230
Limestone, gray and white, soft, rapid effervescence	1230–1233
Shale, dark gray, strongly calcareous; one large chip of finely crystalline, fragmental limestone	1233–1236
Limestone, brown-gray	1236–1240
Limestone, buff-gray, rather slow reaction, much shale, some in concreted masses	1240–1250
Limestone, buff, some with rapid reaction, some rather slow; much shale	1250–1260
Limestone, medium dark brown, response rather slow, some drab shale; 2 samples	1260–1280
Chert, white and light blue-gray, in large flakes; chalcedonic silica, limestone and shale	1280–1290
Shale, blue-gray, calcareous, plastic; 2 samples	1290–1310
Shale, drab, in large flakes	1310–1320
Limestone, brown, rather slow effervescence; gray, rapid; large chips of blue shale from above	1320–1330
Limestone, drab, fine-grained, somewhat clayey, response rather slow	1330–1340
Limestone, brown, rapid effervescence	1340–1350
Limestone, light buff and light yellow-gray, rapid reaction	1350–1360
Limestone, drab and buff, rather slow response	1360–1370
Limestone, drab, fine-grained, rather rapid response	1370–1380
Limestone, buff, hard, fine crystalline-granular, rapid reaction	1380–1390

Limestone, buff, earthy, soft, argillaceous, reaction rather rapid	1390–1400
Limestone, brown and buff, fine crystalline-granular, effervescence rather slow; 5 samples	1400–1445
Limestone, dark blue-gray, compact, in fine chips, rapid effervescence; a little shale	1445–1455
Limestone, brown and buff; much shale; 2 samples	1455–1480
Limestone, buff, soft, argillaceous, fine crystalline-granular, reaction rather slow, disintegrating under weak HCl into fine flour; shale in chips from above	1480–1490
Dolomite or magnesian limestone, buff, in fine chips, much shale in fine chips; driller's log: "1455-1490 shaly lime"	1490–1500
Limestone, buff, crystalline, compact, rapid effervescence	1500–1501
Shale, blue-green, hard, feebly calcareous, in concreted masses	1501–1510
Limestone, brown, compact, reaction rapid; with shale	1510–1520
Limestone, buff-gray, some light gray, reaction rather slow; much white chert at 1520 and at 1540; 3 samples	1520–1550
Limestone, buff-gray, soft, rather slow response, disintegrating into fine flour under weak HCl, earthy; 2 samples	1550–1570
Dolomite, buff-gray	1570–1580
Dolomite, light gray; some whitish limestone of rapid effervescence	1580–1585
Sandstone, fine grains ill-rounded, larger about 0.7 mm., some secondary enlargements, some grains pinkish	1585–1592
Dolomite, light gray and whitish, some imbedded quartz grains; loose quartz sand fine and poorly rounded; some whitish rapidly effervescing limestone; much gray and white chert and some chalcedonic silica	1592–1600
Limestone, light gray, very fine-grained, reaction rather rapid, in flaky chips; dolomite, gray, in small chips; a little shale and quartz sand	1600–1610
Dolomite, light gray and gray, considerable chert; 5 samples	1610–1660
Dolomite, gray; a little chert; 4 samples	1660–1700
Dolomite, light blue-gray, in small chips, white chert, a little translucent chalcedonic silica and fine ill-rounded grains of quartz sand; 2 samples	1700–1720
Dolomite, light brownish gray and yellow-gray; white chert, chalcedonic silica, ill-rounded grains of quartz sand, pyrite, much light blue shale in concreted masses inclosing chips and grains of the other materials; 2 samples	1720–1740
Dolomite, gray and yellow-gray, chert, pyrite and silica as above; a little blue and greenish shale in small chips	1740–1750
Dolomite, light gray, a little white chert, quartz sand and blue shale; 4 samples	1750–1790
Dolomite, light gray and gray, in fine chips and sand, a few chips of decayed chert, some blue shale; a little whitish limestone	1790–1800
Dolomite, gray and light yellow-gray and whitish, in fine crystalline sand, cherty at 1810, 1890, 1910, 1920; 13 samples	1800–1930
Chert, gray and white, in chips, with gray dolomite in fine sand; 3 samples	1930–1960
Dolomite, whitish; much white chert	1960–1970
Chert, gray and white, with some dolomite in fine sand	1970–1980
Dolomite, light gray; much gray and white chert	1980–1990
Dolomite, light gray; a little chert; all in fine sand	1990–2000
Dolomite, light buff, in fine crystalline sand, with some fine angular particles of quartz; 2 samples	2000–2020
Dolomite, light buff and yellow, hardly any quartz sand; 3 samples	2020–2050
Dolomite, light buff and light gray, in fine sand and powder, somewhat arenaceous with minute angular particles of quartz; pyrite; some hard fissile shale, blue-green, in flakes; 3 samples	2050–2080
Dolomite, light gray, highly arenaceous with minute angular particles of quartz; much pyrite in microscopic crystals; hard fissile shale in small flakes	2080–2090
Dolomite, buff and light gray, in fine crystalline sand; a little limestone of rapid effervescence; 2 samples	2090–2110

Shale, dark blue-green, fissile, slightly calcareous, in flakes	2110–2120
Shale, medium light blue-green, hard, in minute flakes	2120–2122
Dolomite, gray, in fine sand; some limestone, of rather rapid reaction, coarser	2122–2130
Shale, medium light blue-green, unctuous, slightly calcareous, pyritiferous	2130–2135
Dolomite, gray, in fine sparkling crystalline sand; quartz in broken particles and some ill-rounded grains, some with secondary enlargements; cryptocrystalline silica in grains containing microscopic crystals of pyrite; much pyrite in fine opaque particles; some minute lumps of blue shale pyritiferous; 3 samples	2135–2155

Notes.—In the above section at Council Bluffs the base of the Pennsylvanian is pretty clearly determined at 280 feet above tide. This is 264 feet higher than the Pennsylvanian floor at Oakland, but according to the driller's log is 177 feet lower than the same horizon at Walnut. South from Council Bluffs the Pennsylvanian floor sinks to 148 feet below tide at Glenwood, a fall of 428 feet. But in the short distance from the School for the Deaf at Council Bluffs to Miller Park, Omaha, and Fort Crook there is a sharp ascent, for at these points the floor of the Coal Measures occurs respectively at 532 and 550 feet above sea level, or at Fort Crook 270 feet higher than at the School for the Deaf.[44]

Assuming this strong eastward dip we may correlate the thick shale at Council Bluffs which we have assigned to the Kinderhook with the thin shale at 212 feet above sea level at Fort Crook. And perhaps the hard green shale 150 feet below sea level at Fort Crook is the same as the shale found at Council Bluffs at 491 feet below sea level.

The dolomites below this horizon are much the same in both wells, crushing under the drill to finest sparkling sand, and strongly suggest the horizon of the Galena. If this reference is correct, the shales near the bottom of the Council Bluffs well, at 2110-2120 and 2130-2135 feet, are probably the Decorah or Glenwood, and the Saint Peter sandstone lies not far below the footing of the well. It will be recalled that at Nebraska City the shales above the Saint Peter with their distinctive fossils were found at 2754 feet, 1824 feet below sea level, and the Saint Peter sandstone was struck at 2783 feet.

44 Norton, Iowa Geological Survey, vol. XXI, pp. 1172-75.

CRAWFORDSVILLE, WASHINGTON COUNTY

(Altitude 731 feet)

Crawfordsville, Washington county, population 340, is supplied by two wells, one 240 feet in depth and capable of furnishing 15,000 g.p.d. and the other 695 feet deep and capable of furnishing 20,000 g.p.d. The latter well was drilled in 1915 by Edward Fass. The principal supply was found at 145 feet in rock and no other water bed of importance was encountered. The depth of the cylinder is 160 feet and the pumping capacity is 14 g.p.m.

CRESCO

(Altitude 1300 feet)

In 1924 a well 670 feet deep was completed for the city of Cresco by the Sewell Well Company of Saint Louis. Sixteen inch casing extends to a depth of 258 feet, where it is bedded in a concrete seal 15 inches thick poured when the well had reached that depth. This casing cuts off any cave from the drift sands and from the Maquoketa shales. The diameter of the drill hole is 15¼ inches from 258 feet to 597 feet, where it is constricted to 12½ inches. Casing of 12¼ inches diameter is inserted from 494 to 597 feet, cutting off the Decorah and Glenwood shales.

A strong flow was struck at 415 feet in the Galena limestone and another in the Saint Peter sandstone. The static level is 151 feet below the surface and the tested capacity is 250 gallons per minute with a draw down of 49 feet, below which it could not be lowered. On stopping the pump the static level was recovered in 20 minutes.

Record of strata of the Cresco city well of 1924

	Depth in Feet
Pleistocene and Recent (30 feet thick; top 1300 feet above sea level):	
Clay, brownish yellow, very sandy, in hard moulded masses	0–10
Sand, gray, and gravel, greenstones abundant	10–20
Sand, yellow, and gravel	20–30
Devonian (50 feet thick; top 1270 feet above sea level):	
Limestone, yellow, soft, earthy, rapid effervescence in cold dilute HCl	30–40
Limestone, yellow, earthy, black specks of manganese oxide and ferruginous stains and crusts, in large chips, rapid effervescence, fossiliferous	40–50
Limestone, light yellow-gray and buff, crystalline-granular and earthy, rapid reaction; 3 samples	50–80
Maquoketa (120 feet thick; top 1220 feet above sea level):	
Dolomite, light brown-gray and yellow-gray, very fine grain, conchoidal fracture, sparsely vesicular; shale, blue-green, hard, dolomitic, in small chips; 2 samples	80–100

Limestone, whitish, fine crystalline-granular, rapid and moderately rapid effervescence	100–110
Dolomite, light brown-gray, drab and gray, fine grained, vesicular, earthy, response rather slow; 4 samples	110–150
Shale, blue, hard, calcareous, in large chips and concreted masses; much dolomite gray and yellow-gray; in sand; 2 samples	150–170
Shale, light blue-gray, calcareous, minutely arenaceous, in friable concreted masses; some selenite	170–180
Dolomite, brown, soft, fine crystalline-granular, large argillaceous residue, empyreumatic odor on heating; 2 samples	180–200
Galena (310 feet thick; top 1100 feet above sea level):	
Limestone, brownish, drab and gray, earthy, in flaky chips, effervescence rapid; 10 samples	200–300
Limestone, light yellow-gray and gray, earthy, rapid reaction, 21 samples	300–510
Decorah (50 feet thick):	
Shale, olive; limestone; in moulded masses	510–520
Shale, blue-gray and greenish, calcareous, in moulded masses; 4 samples	520–560
Platteville (20 feet thick):	
Limestone, gray, rapid reaction	560–570
Limestone, as above, a few flakes of green calcareous fissile shale	570–580
Glenwood (10 feet thick):	
Shale, in hard moulded masses, some in flakes, gray-green, fissile, non-calcareous; some quartz sand of St. Peter facies	580–590
Saint Peter (70 feet thick, top 710 feet above sea level):	
Sandstone, light gray in mass, grains rounded and frosted, up to 1 mm. in diameter, some grains cemented; some shale in gray-green flakes, non-calcareous, fissile	590–600
Sandstone, light gray in mass, finer than above	600–610
Sandstone, white, medium to fine; some flakes of shale; 5 samples	610–660
Shakopee (top 640 feet above sea level):	
Dolomite, gray (some limestone of rapid effervescence), cuttings mostly of Saint Peter sand	660–670

Driller's log, Cresco city well, 1924

	Depth in Feet
Surface solution	0–5
Clay, gravel and sand	5–15
Blue mud	15–25
Yellow clay and boulders	25–80
Shale and limestone	80–89
Limestone	89–170
Shale	170–180
Limestone and some shale	180–195
Limestone	195–255
Limestone, water at 280	255–520
Shale and limestone, water at 415	520–525
Shale	525–557
Limestone	557–582
Shale	582–592
Sandy shale	592–597
St. Peter sandstone	597–667
Limestone	667–670

*Mineral analysis of water from Cresco city well**

	Parts per million
Nitrate (NO_3)	21.3
Chlorine (Cl)	29.0
Sulfate (SO_4)	50.0

* Dr. E. W. Bartow, State University, Iowa City, Oct. 20,1924.

Bicarbonate (HCO_3)	314.8
Sodium (Na) (Calc'd)	36.3
Magnesium (Mg) (Calc'd)	36.0
Calcium (Ca) (Calc'd)	56.6
Iron (Fe)	Trace

Hypothetical combinations	Parts per million	Grains per gallon
Sodium nitrate ($NaNO_3$)	29.2	.71
Sodium chloride (NaCl)	48.8	2.85
Sodium sulphate (Na_2SO_4)	28.5	1.67
Magnesium sulfate ($MgSO_4$)	38.5	2.25
Magnesium carbonate ($MgCO_3$)	97.8	5.72
Calcium carbonate ($CaCO_3$)	142.0	8.30
Undetermined	21.2	1.24

Notes on the Cresco section.—Comparing the log of the driller with the depths given on the samples of the cuttings it will be seen that in several instances the former is more precise, and the thickness and position of some of the formations may be accordingly corrected.

The deposits of the drift represented by the cuttings do not agree entirely with the log, as the "blue mud" of the log is not confirmed by any samples. Taken by itself the log would lead to the inference of a deposit of yellow clay (till) with boulders extending from 25 to 80 feet. The cuttings, however prove that this deposit is limestone and the impression of the drill working in a boulder bed may have been given by the condition of the strata: deformation, crushing, close and irregular joints and pitching courses, such as Calvin records at the local quarry.[45] The Maquoketa shales outcrop in the valley of Silver creek northeast of Cresco, so that with the gentle dip of the rocks in this area no great thickness of the Devonian is to be expected, unless the Maquoketa is cut away owing to erosion before the deposit of the Devonian.

The Maquoketa section in the vicinity of Cresco was found by Calvin to embrace shales and calcareo-magnesian beds in alternating layers, crystalline dolomites, light yellow magnesian shales, and non-magnesian, fossiliferous limestones. Owing to the absence of the heavy beds of plastic shales which make up the larger part of the Maquoketa in the area of outcrop to the southeast, the entire thickness of the formation in this county is estimated by Calvin at not to exceed 100 feet.[46]

45 Calvin, S., Geol. of Howard Co., Iowa Geol. Survey, vol. XIII, p. 59, Des Moines, 1903.
46 Op. cit., pp. 48, 49.

In accordance with these field determinations the upper bed of the Maquoketa is taken to be the dolomite and shale at 80 feet. A thickness of 120 feet brings the formation to the horizon where a brown argillaceous dolomite gives place at 200 feet to heavy nonmagnesian earthy limestone, evidently Galena limestone which has escaped dolomitization, a common feature of the Galena of this area.

DALLAS CENTER, DALLAS COUNTY

(*Altitude 1073 feet*)

CITY WELL OF DALLAS CENTER

This well was drilled by Thorpe Brothers Well Company of Des Moines and is a little over 2000 feet deep. Its diameters range from 12 to 6 inches. It is cased with 12 inch pipe to 131 feet, with 10 inch pipe to 498 feet, with 8 inch pipe from 469 to 1048 feet and with 6 inch pipe from 960 to 1900 feet.

The formations encountered by the drill were glacial drift to 130 feet and shale to 840 feet, where limestone, presumably of the Mississippian system, was reached. The top of the Saint Peter sandstone is reported as approximately 1941 feet below the curb, or about 868 feet below sea level.

An analysis of water from this well was made recently by Howard C. Maffitt of Des Moines and the results are given below.

Analysis of water from the present town well at Dallas Center

Constituents	Parts per million by weight	Grains per U. S. gallon
Sodium and potassium	316.0	18.3
Calcium (as Ca)	537.0	31.2
Magnesium (as Mg)	138.0	8.0
Iron (as Fe)	5.6	0.32
Aluminum (as Al)	3.7	0.21
Manganese	none	
Sulphate (as SO_4)	2251.0	131.0
Nitrate	none	
Phosphate	none	
Bicarbonate (as HCO_3)	216.0	12.5
Chloride (as Cl)	177.0	10.3
Silica (as SiO_2)	30.0	1.74
Hypothetical Combinations	P.P.M.	
Sodium chloride	292.0	
Sodium sulphate	622.0	
Magnesium sulphate	683.0	
Calcium sulphate	1818.0	
Calcium bicarbonate	8.0	

The iron had precipitated from the water before the sample was received.

WELL OF MINNEAPOLIS AND SAINT LOUIS RAILROAD

This well was drilled by the McCarthy Well Company of Minneapolis. It is approximately 900 feet deep, but very little else is known about it. Little use is made of the water on account of its high mineral content, as is true also of the city well. The analyses of these two well waters were furnished by Messrs. W. E. Buell and Company, Municipal Engineers of Sioux City, who suggested that possibly the similarity in the analyses may be due to a break in the casing of the city well permitting the influx of sulphate waters from the Coal Measures, which probably supply the railroad well.

*Analysis of water from the M. & St. L. Railroad well at Dallas Center**

Constituents	P.P.M.	Gr. per Gal.
Total solids	3495.0	204.5
Silica (SiO_2)	11.0	.64
Iron and aluminum oxides	7.5	.44
Calcium (Ca)	568.0	33.20
Magnesium (Mg)	109.8	6.32
Alkalinity (as $CaCO_3$)	175.6	10.27
Chlorides (Cl)	166.2	9.73
Sulphates (SO_4)	2015.0	117.70
Hypothetical Combinations		
Sodium chloride (NaCl)	275.5	16.10
Sodium sulfate (Na_2SO_4)	568.0	33.20
Magnesium sulfate ($MgSO_4$)	541.8	31.65
Calcium sulfate ($CaSO_4$)	1698.0	99.35
Calcium carbonate ($CaCO_3$)	175.2	10.24

No determination of iron alone could be made since by the time water reached the laboratory the iron had all settled out.

DAVENPORT

(Altitude C., M., St. P. & P. R. R. Sta. 560 feet, U. S. G. S.)

WELL OF CITY OF DAVENPORT

In 1922 a well 1905 feet deep was completed for the municipal swimming pool at Davenport by the McCarthy Well Co. of Minneapolis and Saint Paul.

The diameters are from 12½ to 10 inches. The well is a flow-

* Made by the State Chemical Laboratory of the State of South Dakota.

ing well with a natural discharge of approximately 200 g.p.m. The log of the well is as follows:[47]

	Depth in Feet		Depth in Feet
Drift	0–28	Shale	1752–1768
Limerock	28–400	Shale and lime	1768–1780
Shale	400–625	Limerock	1780–1785
Limerock	625–950	Shale and lime	1785–1790
Shale	950–970	Limerock	1790–1798
Sandrock	970–1150	Lime and shale	1798–1808
Shale and rock	1150–1200	Limerock	1808–1817
Limerock	1200–1460	Shale and lime	1817–1821
Sandrock	1460–1471	Limerock	1821–1845
Limerock	1471–1476	Lime and shale	1845–1851
Sandrock	1476–1532	Limerock	1851–1880
Limerock	1532–1752	Sandrock	1880–1905

The log permits the following assignment to formations:

	Thickness	Depth in Feet
Pleistocene	28	0–28
Devonian and Silurian	372	28–400
Maquoketa	225	400–625
Galena-Platteville	325	625–950
Glenwood	20	950–970
St. Peter (and upper Shakopee)	180	970–1150
Prairie du Chien	310	1150–1460
Jordan	72	1460–1532
Trempealeau	220	1532–1752
Franconia	128	1752–1880
Dresbach, penetrated	25	1880–1905

DAVIS CITY, DECATUR COUNTY

(Altitude 913 feet)

The city well of Davis City was drilled by the Thorpe Bros. Well Co. of Des Moines about 1914 and is reported to be 950 feet deep. The diameters are from 10 to 5 inches. Water stands within 200 feet of the surface. No other facts as to the well are now obtainable.

DECORAH

DRILL HOLE OF THE PIONEER OIL AND GAS COMPANY

This well is on Bakke no. 1 lease, Twp. 98 N. R. 7 W. Se. qr. of sw. qr. Sec. 30 Glenwood township, Winneshiek county. (Altitude about 1100 feet.)

47 Lindly, J. M., Proceedings Iowa Acad. of Science, vol. XXXIV, p. 247.

Driller's log, with assignment to formations

	Depth in Feet
Pleistocene and Recent (28 feet thick):	
Mud, soft	0–28
Galena limestone (222 feet thick):	
Lime, hard	28–250
Decorah shale (38 feet thick):	
Shale	250–260
Sandy shale (water)	260–275
Shale, blue	275–288
Platteville limestone (22 fect thick):	
Lime	288–310
Glenwood shale (5 feet thick):	
Mud	310–315
Saint Peter sandstone (90 feet thick):	
Saint Peter sandstone (water)	315–405
Prairie du Chien (290 feet thick):	
Blue mud	405–408
White lime	408–465
Sand (water)	465–470
Hard lime	470–500
Shale	500–505
Lime sand	505–695
Jordan sandstone (105 feet thick):	
White sand	695–800
Saint Lawrence dolomite and shales (218 feet thick):	
Black lime and sand	800–830
White sand	830–835
Lime	835–845
Shale	845–850
Lime	850–860
Sand	860–870
Lime	870–890
Sand	890–910
Blue shale	910–920
Sand	920–950
Shale	950–1018
Dresbach sandstone (137 feet thick):	
Sand	1018–1155
Eau Claire beds (85 feet thick):	
Shale	1155–1165
Sand shale	1165–1195
Mud	1195–1205
Sand shale	1205–1240
Mount Simon beds (410 feet thick):	
Sand	1240–1650
Red clastics (70 feet thick):	
Mud (red bed)	1650–1720
Archean, dark igneous or metamorphic rocks (penetrated 1580 feet):	
Black lime	1720–2512
Black lime	2512–3000
Salt water lime	3000–3300
Black lime	3300
Black sand in place of lime	

Remarks.—The Decorah oil prospect has several claims to distinction. Among them is the fact that it is the deepest drill hole in the state both stratigraphically and by measurement in feet. No oil or gas was found, and shooting the well in the summer of

1926 with 80 quarts of explosive at 3300 feet and with 160 quarts at 2560 feet did not bring to light any evidence that the Archean rocks of Iowa are more petroliferous than the Archean of other areas.

No samples of the cuttings were obtainable above the Archean, but the driller's log falls in rather easily with the normal geologic section to be expected in northeastern Iowa. Samples of the cuttings of the "black lime" were submitted, and have been examined petrologically by Professor J. R. Van Pelt, Jr., of Cornell College.

Minerals present	Depth of Sample in Feet
Quartz (35 to 45 per cent), oligoclase (35 to 45 per cent), magnetite (10 to 15 per cent), biotite (trace)	2990
Quartz, plagioclase, probably albite or oligoclase; calcite (from a higher horizon?); magnetite; hematite	3000
Material much finer-grained than other samples; nearly every grain deeply iron-strained; quartz, feldspar, minor amount of biotite	3140
Similar to preceding sample but coarser; both notable for deep brown rust color. Quartz abundant, fine; biotite 5 to 10 per cent, in flakes up to 2 mm.; small amount of fine-grained magnetite	3200
Quartz; plagioclase (much of it twinned on the albite law); biotite; magnetite; a light green translucent mineral unidentified	3300

None of the fragments in the samples was large enough to show the texture of the rock.

DELMAR, CLINTON COUNTY

WELL OF CHICAGO, MILWAUKEE AND SAINT PAUL RAILWAY

This well was drilled in 1917 by W. H. Gray and Brothers of Milwaukee. The depth is 1216 feet; the diameters are from 16 to 6 inches. The static level is 80 feet below the surface. The pumping capacity is 200 gallons per minute and with the pumping cylinder at 140 feet the water is lowered but slightly when pumped at the rate of 108 gallons per minute. The well is cased to top of rock and from 763 to 861 feet.

*Water Analysis**

	Grains per U. S. Gallon
Oxides	1.00
Calcium carbonate	10.88
Magnesium carbonate	7.01
Alkali sulphate	.71
Alkali chloride	.64
Total	20.75

* H. W. Ostrom, Railway Chief Chemist.

Driller's Log

	Depth in Feet
Pleistocene and Recent (57 feet thick; top 810 feet above sea level):	
Yellow clay	0–30
Blue clay	30–50
Gravel	50–57
Niagaran limestone (163 feet thick; top 753 feet above sea level):	
Yellow limestone	57–145
White limestone	145–220
Maquoketa shale (225 feet thick; top 590 feet above sea level):	
Hard sandy shale	220–445
Galena limestone, Glenwood shale and St. Peter formation (416 feet thick; top 365 feet above sea level):	
Limestone, very hard	445–763
Shale	763–771
Sandy shale	771–800
Medium sandy shale	800–807
Hard shale	807–830
Caving shale	830–861
Prairie du Chien (368 feet thick; top 3 feet above sea level):	
Limestone	861–1006
Streaks of lime and sandstone	1006–1175
Jordan sandstone (35 feet thick; top 365 feet below sea level):	
Sandstone, water bearing	1175–1210
Saint Lawrence, Trempealeau dolomite (penetrated 6 feet; top 400 feet below sea level):	
Limestone, to bottom of the well	1210–1216

Notes.—The shale at 220 feet is doubtless the Maquoketa, altho it is quite exceptional to have this "mud rock" shale described either as "hard" or "sandy." The run of limestone from 445 to 763 feet seems to include both the Galena and the Platteville, and the Decorah is not distinguished. The Glenwood shale appears at 771 feet, but its thickness and base are somewhat uncertain.

DELMAR WATERWORKS WELL, 1927

This well, 1592 feet deep, was completed in 1927 by the Gray Well Drilling Company of Milwaukee and Chicago. The diameters are from 13 to 8 inches. The well is cased with a 12½ inch drive pipe to rock, and a 10 inch casing extends from the surface to 458 feet, casing out Niagaran and drift waters and preventing caving from the Maquoketa shale. An 8 inch liner is inserted from 745 feet 8 inches to 875 feet, shutting out caving shales both above and below the Saint Peter sandstone.

The original contract provided for a well 1250 feet deep, sufficient to tap not only the Saint Peter and other Ordovician aquifers, but also the Jordan sandstone of the Cambrian. At this depth, however, the well was found to yield but 75 g.p.m. and the drilling was continued through the Dresbach sandstone. On completion at 1592 feet the well delivered on test 100 g.p.m. with the pumping cylinder at 278 feet.

Until after passing the Jordan sandstone the static level stood abnormally high. At 1250 feet it was 70 feet (with a draw down to 140 feet). The head, therefore, of the Jordan and higher water beds was 737 feet above sea level. This may be compared with the original head at Sabula from the Jordan, 658 feet above tide, Green Island 665 feet, Clinton water works no. 1 632 feet, and of more recent wells, Clinton water works well no. 5 (1902) 602 feet and De Witt city well (1923) 617 feet. On continuing the drilling the static level had fallen to 170 feet (637 feet above sea level) at 1309 feet, in the Trempealeau dolomite, and to 190 feet (617 feet above tide) at 1380 feet, in the Franconia beds. After piercing the Dresbach sandstone the static level stood on the completion of the well at 196 feet (611 feet above sea level) or at about the present static level of the De Witt and Clinton wells.

Record of strata, Delmar waterworks well, 1927

	Depth in Feet
Pleistocene and Recent (54 feet thick; top 807 feet above sea level):	
Clay, yellow, sandy, noncalcareous, in hard masses; 2 samples	0–30
Till, blue-gray, calcareous; 3 samples	30–54
Niagaran dolomite (158 feet thick; top 753 feet above sea level):	
Dolomite, buff, large chips; 3 samples	54–85
Dolomite, bright buff, in sand and powder, argillaceous	85–95
Dolomite, bright buff, large chips	95–105
Dolomite, bright buff; at 115 also some dark olive-gray clay, unctuous, noncalcareous; at 125 feet fragment of cast of *Halysites catenulatus ?*; 3 samples	105–135
Dolomite, very light gray or whitish, crystalline-granular, some slightly vesicular; at 135 considerable clay or shale as at 105; from 175 to 195 much white chert; 6 samples	135–195
Dolomite, blue-gray, cryptocrystalline, cherty	195–205
Dolomite, blue-gray, argillaceous, some siliceous with microscopic particles of quartz; some blue gray shale	205–212
Maquoketa shale (228 feet thick; top 595 feet above sea level):	
Shale, blue, hard, dolomitic, pyritic, some laminated, in chips; some light colored dolomite	212–220
Shale, blue, plastic	220–230
Shale, blue-gray, in chips and concreted masses	230–240
Shale, blue, dolomitic, plastic; 16 samples	240–410
Shale, drab, in concreted masses; included chips brownish drab	410–420
Shale, dark brown, inflammable, in chips	420–430
Shale, brown and drab	430–440
Galena-Platteville limestones; Glenwood shale (325 feet thick; top 367 feet above sea level):	
Dolomite, drab and light brown-gray, argillaceous, pyritic, crystalline-earthy, compact; in flaky chips; much brown inflammable shale	440–445
Dolomite, gray and yellow-gray, crystalline, in chips; 2 samples	445–460
Dolomite, light gray, in sand and fine chips; 5 samples	460–510
Limestone, rapid effervescence in cold dilute HCl, white, soft, earthy, fossiliferous, in flaky chips; most of sample dolomite as above	510–520

Limestone, whitish and buff, in chips and powder, effervescence rapid; 5 samples	520–570
Limestone, as above; dolomite, buff	570–580
Dolomite, yellow-gray; white chert; 2 samples	580–600
Dolomite, brown and buff, cherty; 2 samples	600–620
Dolomite, buff; limestone, light yellow and whitish, earthy, effervescence rapid, in large flakes; 2 samples	620–640
Limestone, yellow gray and whitish, some mottled, earthy, response moderately rapid; some buff dolomite; 3 samples	640–670
Limestone, brown, rapid effervescence	670–680
Shale, brown, highly inflammable, calcareous, hard, in chips; much whitish limestone	680–690
Limestone, buff and gray, effervescence rapid, moderately rapid and slow	690–696
Shale, green, hard; chips of limestone	696–701
Limestone, buff and whitish, response rapid; shale, brown, inflammable; shale, bright green	701–710
Limestone, drab and gray, response rapid; 5 samples	710–755
Shale, greenish, in concreted masses; inclosed chips of limestone	755–765
Saint Peter sandstone (95 feet thick, top 42 feet above sea level):	
Sandstone, yellow in mass from rusted grains (magnetic iron from drill in cuttings), grains well rounded and frosted, larger grains up to 1 mm. in diameter; some hard green shale in flakes	765–775
Sandstone, white, finer	775–785
Sandstone, light yellow-gray; whitish clayey powder feebly calcareous	785–795
Sandstone, whitish; 2 samples	795–815
Sandstone, rusted light yellow, secondary enlargements	815–825
Sandstone, yellow-gray in mass; siliceous chips white, with imbedded transparent grains of quartz; some whitish shale	825–835
Sandstone, white; shale, light green, fissile, noncalcareous	835–845
Shale, light bright green, noncalcareous, concretionary structures; concreted masses of white dolomitic powder; a few chips of gray dolomite and of light greenish gray dolomite argillaceous and siliceous; white unctuous clay with microscopic particles of white chert; two chips of yellow jasper with minute globular structures, oölitic or fossiliferous	845–855
Shale, light bright green; one large chip indurated, light greenish gray, apparently concretionary	855–860
Prairie du Chien dolomites (295 feet thick; top 53 feet below sea level):	
Dolomite, light yellow-gray, fine-grained, compact, soft; chert, white; much green shale	860–870
Dolomite, light yellow-gray and brown; shale, green	870–880
Dolomite, gray, in small chips; whitish from 970 to 1030; 14 samples	880–1030
Dolomite, blue-gray	1030–1040
Dolomite, as above, cherty; 2 samples	1040–1060
Dolomite, blue-gray; 4 samples	1060–1100
Dolomite, buff, cherty	1100–1105
Dolomite, light yellow-gray, highly cherty, arenaceous	1105–1115
Dolomite, light gray	1115–1125
Dolomite, whitish, arenaceous, a little hard green fissile shale; a little fine-grained sandstone	1125–1135
Dolomite, buff; 2 samples	1135–1155
Jordan sandstone (30 feet thick; top 348 feet below sea level):	
Sandstone, light yellow in mass, fine, well-rounded grains, some crystalline enlargements, considerable dolomite with embedded grains; some dark brown argillaceous sandstone with buff flint at 1165; 3 samples	1155–1185
Saint Lawrence, Trempealeau dolomite (145 feet thick; top 378 feet below sea level):	
Dolomite, whitish, in fine sand, a very little quartz, some drusy	1185–1195
Dolomite, whitish	1195–1205
Dolomite, light gray, crystalline; a very little quartz sand; 2 samples	1205–1225

Dolomite, light gray, much sand in fairly well rounded grains but no imbedded grains found in dolomite chips; 2 samples 1225–1245
Dolomite, light gray, some quartz sand; some chert; 2 samples 1245–1260
Dolomite, buff in mass, in fine sand; 2 samples 1260–1280
Dolomite, whitish, in very fine sand 1280–1290
Dolomite, gray, cherty 1290–1300
Dolomite, gray; a little quartz sand 1300–1310
Dolomite, light red-brown, rusted by iron from drill; some quartz sand; 2 samples 1310–1330

Saint Lawrence, Franconia beds (100 feet thick; top 523 feet below sea level):
Dolomite, brown in mass, minutely arenaceous, glauconitic 1330–1340
Sandstone, reddish gray, minute grains, glauconitic; shale, purplish and green, hard, fissile 1340–1350
Sandstone, gray, grains minute, speckled with glauconite 1350–1360
Shale, green, highly arenaceous, grains minute; glauconitic, dolomitic; 2 samples 1360–1380
Sandstone, gray, of minute grains, speckled with glauconite, dolomitic cement; green shale; 3 samples 1380–1410
Sandstone, gray, minute grains, slightly glauconitic; gray shale; 2 samples 1410–1430

Dresbach sandstone (110 feet thick; top 623 feet below sea level):
Sandstone, clean, white, diverse in size of grains, maximum up to 1.2 mm. diameter, grains well rounded, frosted; 2 samples 1430–1450
Sandstone, 2 samples, one as above; the other, argillaceous, crystalline enlargements of grains 1450–1460
Sandstone, white, some rusted buff, medium to fine, at 1520 largest grains reach 1.3 mm.; 8 samples 1460–1540

Eau Claire sandstone (penetrated 52 feet; top 733 feet below sea level):
Sandstone, gray, argillaceous, fine, grains rounded, feebly dolomitic; 2 samples 1540–1560
Sandstone, greenish gray, fine, glauconitic, feebly dolomitic; 2 samples..1560–1580
Sandstone, greenish gray, fine to medium, glauconitic, grains rounded ..1580–1592

Notes.—It will be noted that thin transition beds, argillaceous dolomites, occur both above and below the Maquoketa shales. As in some other deep well sections a brown inflammable shale is found at the base of the formation.

The upper 70 feet of the Galena-Platteville are typical dolomites. The lower 245 feet are undolomitized with the exception of a 40 foot bed of dolomite well up the column. Within 75 feet of the base occurs a layer of brown inflammable shale and a few feet below is 5 feet of green shale.

The Glenwood shale is thin, rests directly on the Saint Peter sandstone and contributes by caving to the first cuttings of the sandstone.

At the base of the Saint Peter occurs anomalously a caving shale, 15 feet thick, which may be compared to the shales and conglomerate found at this horizon at Maquoketa, Preston and De Witt. The cuttings at Delmar do not clearly indicate a conglomerate as at the towns just mentioned, but they strongly suggest such an origin by the mingling of shale, dolomite, chert, decayed chert and jasper.

The Prairie du Chien has its normal thickness for northeastern Iowa but does not here carry a well defined medial sandstone, the New Richmond.

The Jordan is exceptionally thin and its texture as evidenced by the cuttings shows the reason for its scanty yield.

The underlying Trempealeau dolomite is in places somewhat sandy. Possibly the Jordan might be mistaken for the New Richmond, the Trempealeau for the Oneota of the Prairie du Chien and the Dresbach for the Jordan, were it not for the typical glauconitic shaly dolomitic sandstones so easily and clearly identified as the Franconia.

The Dresbach sandstone, 100 feet thick, gives cuttings which suggest a more generous yield than the tests on completion proved. It rests on typical Eau Claire beds.

DENISON

(Altitude 1170 feet)

The deep well at Denison, completed for the city in 1916 by W. H. Gray and Brother of Chicago, is 1810 feet in depth, with diameters from 14 to 8 inches. The pumping capacity is 200 g.p.m. and is sufficient for the normal demand. Two dug wells, yielding 60,000 g.p.d. are in reserve. The static level is 88 feet with a draw down to 170 feet. The main supply comes from the Saint Peter and the Prairie du Chien, from 1680 feet and below, the lower beds furnishing the larger amounts.

The upper casing, 14 inch, is 262 feet in length. A 10 inch casing 261 feet long is bedded at 500 feet. The shales above the Saint Peter sandstone are cased out with 8 inch casing, 46½ feet long, bedded at 1665 feet.

The cost of the well was $6613.

Driller's Log

	Depth in Feet
Struck shale at	245
Drift and shale	245–485
Brown limerock	485–950
Lime rock with traces of shale	950–1600
Shale and rock, caved and had to be cased out	1600–1665
Lime rock	1665–1680
Sandstone	1680–1730
Brown lime	1730–1810

Below the sandstone there seemed to be many crevices, as we drilled 35 feet, from 1740 to 1775 feet, without being able to get a sample.

Record of strata in City well no. 1, Denison

	Depth in Feet
Pleistocene and Recent (210 feet thick; top 1170 feet above sea level):	
Alluvium, silts, clay, sand and glacial tills; 20 samples	10–200
Pennsylvanian (170 feet thick; top 960 feet above sea level):	
Shales, gray, brown, black; 17 samples	210–370
Mississippian, Devonian (?), Silurian (780 feet thick; top 790 feet above sea level):	
Limestone, whitish and light yellow-gray, crystalline-earthy, rapid effervescence in cold dilute HCl, in flaky chips; with some chips of black shale	380
Flint, yellowish; limestone of same color; a little shale	390
Limestone, buff and gray, fine-grained, effervescence moderately slow	400, 410
Shale, gray, calcareous, in concreted masses	420, 430
Chert, white; limestone, gray; some brown ferruginous limestone; shale in concreting powder	440
Shale, gray; with some limestone, white crystalline-granular and light yellowish, cryptocrystalline, rapid effervescence; white chert	450
Shale, gray; limestone, white, gray and buff, reaction rapid; chert, chalcedonic silica, and quartz sand in fine irregular grains; 3 samples	460–480
Limestone, gray, fine crystalline-granular, much blue-gray flint	485
Flint, blue-gray; and limestone, yellow-gray and whitish, crystalline-granular, rapid reaction	490
Limestone, whitish and yellow-gray, rusted buff, encrinital, rapid response to acid	500
Limestone, blue-gray and whitish, subcrystalline and earthy, reaction rapid; at 520 laminated and with chips of vein or geodic quartz; 4 samples	510–540
Limestone, light yellow-gray, calcilutite, and buff, fine crystalline-granular	550
Limestone, light yellow-gray, whitish and gray, crystalline-earthy and fine crystalline-granular, oölitic at 580, cherty at 570 and 690, rapid effervescence, with considerable quartz sand in cuttings at 610 and 630, and some in all; 14 samples	560–690
Limestone, light yellow-gray, slow reaction, some rapid	700
Limestone as above, cherty; 3 samples	710–730
Limestone, light yellow-gray, fine grained, rapid effervescence; light gray chert	740
Limestone, drab, cherty, argillaceous, rapid response	750
Limestone, light buff, fine crystalline-granular, rapid effervescence; cherty	760
Limestone, buff, rather slow response to acid	770
Limestone, light gray, rather rapid reaction	780
Dolomite, light blue-gray, fine crystalline-granular, in fine sand; 4 samples	790–820
Limestone, gray, earthy, rather rapid reaction, some chips slow	830
Dolomite, light blue-gray; 3 samples	840–860
Dolomite as above, with some limestone chips of rapid effervescence	870
Dolomite, light yellow-gray, fine crystalline-granular, with some chips of rapid effervescence; 5 samples	880–920
Dolomite, light gray, somewhat argillaceous	930
Limestone, whitish and blue gray, earthy, in flaky chips, reaction rapid; some dark gray, finely laminated, highly argillaceous; some green shale, fissile, calcareous	940
Dolomite, light buff	950
Shale, blue-gray, highly calcareous, in hard concreted masses	960
Dolomite, light yellow-gray, unwashed cuttings in friable concreted masses, washed cuttings in crystalline sand	970, 980
Dolomite and shale; dolomite, light yellow gray in sand; shale, blue-gray	990, 1000

Dolomite as above, some flakes of gray-green shale; in hard concreted masses	1010
Dolomite and shale; dolomite, light yellow-gray, in sand; shale in concreting powder	1020
Dolomite, in light buff sand; 4 samples	1030–1060
Dolomite, light yellow-gray and buff, crystalline-granular, effervescence somewhat more rapid than LeClaire dolomite; at 1100 majority of grains of cuttings show rapid effervescence; 9 samples	1070–1150
Ordovician:	
Maquoketa shale (40 feet thick, top 10 feet above sea level)—	
Dolomite, blue-gray, earthy, moderately slow effervescence	1160
Dolomite and shale, dolomite dark blue-gray, moderately slow reaction, in sand; shale in powder, considerable pyrite	1170
Shale, light drab, in hard concreted masses gritty with fine limestone particles	1180, 1190
Galena and Platteville (480 feet thick; top 30 feet below sea level)—	
Dolomite, buff, subcrystalline, considerable pyrite at 1220; 3 samples	1200–1220
Chert, white, gray and blackish, mottled; and dolomite	1230
Dolomite and chert, as above	1240
Chert and dolomite, light gray	1250
Dolomite and chert	1260
Dolomite, light gray; 3 samples	1270–1290
Dolomite, gray, vesicular, crystalline-granular, rough, cherty	1300
Dolomite, gray and dark gray, subcrystalline and white, cherty; some cuttings with pepper and salt appearance; 8 samples	1310–1380
Dolomite, gray, argillaceous; cherty	1390, 1400
Dolomite, light gray, with flint of same color	1410
Dolomite, whitish, in flour, argillaceous, cherty; with particles of crystalline quartz too minute to polarize in strong colors	1420
Dolomite, gray and buff, mostly in fine crystalline sand, cherty at 1440-1470, 1510-1540; 15 samples	1430–1570
Limestone, blue-gray and yellow-gray, in small chips, rapid reaction	1580
Shale, light blue-gray, highly calcareous, in hard concreted masses, quartzose with minute grains and angular particles; 3 samples	1590–1610
Limestone, light yellow-gray, earthy, soft, rapid response, in flaky chips; and chips of green-gray, fissile calcareous shale	1620
Shale, blue-gray, green-gray and drab, calcareous; 4 samples	1630–1660
Limestone, light gray, reaction rapid; pyrite; chips of gray shales	1670
Saint Peter sandstone (60 feet thick; top 510 feet below sea level)—	
Sandstone, white, fine, grains well rounded, frosted; a few chips of limestone of brisk effervescence at 1680; a little green shale in chips at 1710-1720; 5 samples	1680–1720
Sandstone, minute ill-rounded grains of pure quartz, some stained with iron; chert; much pyrite	1730
Prairie du Chien (penetrated 70 feet, top 570 feet below sea level)—	
Dolomite, whitish, light yellow-gray and pink, somewhat rusted, sparsely arenaceous with imbedded grains; cuttings in coarse sand with considerable quartz sand and green shale	1740
"Drillings washed away"	1750, 1760
Dolomite, light gray and oölitic chert	1775
Dolomite, light yellow-gray, in sand, arenaceous, particles of dolomite largely in excess of quartz grains	1785
Dolomite as above, some quartz grains with secondary enlargements	1795–1805
Dolomite, as above, arenaceous, grains of quartz sand, rounded, coarser and more numerous than above; considerable chert	1810

Notes.—In the Denison section the Coal Measures may seem exceptionally thin, but it must be taken into account that their base lies 45 feet higher than at Audubon, for example, of points southeast, while the preglacial surface stands 88 feet lower.

The base of the Mississippian is undetermined. If it lies at about the same distance above the top of the Saint Peter as at Audubon, it may occur at 790 feet (380 feet above sea level) where dolomites or magnesian limestones begin in heavy beds.

The thickness of the Silurian at Stuart, where it is believed to be marked by gypsiferous beds, leads to the inference that the dolomites at Denison from 790 to 1160 feet may belong to that system. The shales and argillaceous limestones at the latter depth seem to correspond stratigraphically with the Maquoketa at Stuart. The underlying dolomites and limestones and basal shales to the Saint Peter sandstone at 1680 feet are thus assigned to the Galena and Platteville and to the Glenwood.

The Saint Peter is here too fine of grain to be a bountiful water-bed. The main supply comes from the creviced dolomites and sandy layers of the Prairie du Chien. The upper beds of these dolomites, and perhaps all of them, belong to the Shakopee, but possibly the highly arenaceous stratum struck at 1810 represents the New Richmond sandstone.

It may be added that the cuttings were unwashed. The colors given are those of the individual chips after washing and are thus different from the color of the cuttings in mass, which was pretty uniformly a gray.

*Chemical Analyses of Cuttings from deep well at Denison**

Depth in Feet	720	780	790	870	1070	1300	1540	1580
Fe_2O_3	7.24	.92	1.31	1.59	.90	.63	2.26	4.82
Al_2O_3	.44	.62	0.00	.49	.34	1.51	.57	.53
$CaCO_3$	52.30	60.80	57.34	61.01	64.40	56.52	57.02	80.10
$MgCO_3$	40.23	37.57	41.63	37.27	34.43	41.77	40.20	14.60
Total	100.21	99.91	100.28	100.16	100.07	100.43	100.06	100.05

DES MOINES

WELL OF NORTHLAND MILK AND ICE CREAM COMPANY, EAST 6TH AND DES MOINES STREETS

This well was drilled in 1925 by Thorpe Bros. of Des Moines. The flow over the top, when the well was completed, was approximately 100 g.p.m.

* Silica omitted, because of chert and quartz sand in cuttings.

*Record of strata**

	Depth in Feet
Pleistocene and Recent (26 feet thick; top 833 feet above sea level):	
"Yellow clay"	0–26
Pennsylvanian (209 feet thick; top 807 feet above sea level):	
"Gray shale"	26–60
"Brown shale"	60–70
"Light shale, seep water"	70–95
"Black shale"	95–105
"Light shale"	105–115
"Dark blue shale"	115–170
"Light blue shale"	170–213
"Dark shale"	213–217
"Light blue shale"	217–222
"Sandstone, shaly"	222–230
"Light shale"	230–235
Mississippian:	
Meramec, Osage and Upper beds of the Kinderhook (400 feet thick; top 598 feet above sea level)—	
"Limestone"	235–275
"Shale, blue"	275–280
"Limestone"	280–295
"Brown shale"	295–335
"Limestone"	335–345
"Shale, with lime streaks"	345–365
"Limestone"	365–380
"Lime, with shale streaks"	380–410
"Limestone"	410–460
"Shale, blue"	460–470
"Limestone"	470–510
Limestone, with large amounts of chert	505
Limestone with sand, limestone dark gray, in fine chips ranging up to one-fourth inch in diameter, finely granular, responds rather slowly to acid; residue quite large, very fine-textured, gritty; chips of white granular quartz	515, 530
Limestone, similar to above, more ready response to acid, residue cherty, only a little sand	540, 550
Limestone, as above, more dolomitic; white flint	560
Limestone, shaly, gray, in friable concreted lumps; response to acid very brisk; residue abundant, of exceedingly fine white sand grains and clay	570
Limestone, light gray, in concreted lumps which break up readily into fine powder and small chips, response to acid very ready; cherty; a little very fine sand; 3 samples	580–600
Limestone, lighter gray than above, very readily soluble	610, 620
Kinderhook shale (185 feet thick; top 198 feet above sea level)—	
Shale, gray, red, chocolate colored, etc., soft; fine; somewhat limy	635
Shale, gray, soft, very limy; some finely gritty; 9 samples	640–720
Shale, light tan, soft, very limy, finely gritty; 3 samples	730–740
Shale, similar to above, more gritty with chips of gray limestone and blue gray shale	750
Shale, light tan, limy, finely gritty, and with small chips of light gray and dark gray limestone, very responsive to acid, finely crystalline	755, 760
Shale, tan, limy, finely gritty, noncalcareous; flakes of limestone, dark gray, fairly ready response to acid; flakes of selenite	770
Shale, brownish tan, and dark blue, soft, only slightly gritty, noncalcareous	775
Shale, as at 770	790
Shale, brownish, in rather coarse powder; flakes of selenite; dark	

* By Dr. James H. Lees, Assistant State Geologist.

sand grains; yellowish calcite. A small chip disintegrates in acid leaving abundant sand	800
Devonian (120 feet thick; top 13 feet above sea level):	
Limestone, light gray, in flakes, grains and powder, noncrystalline; effervesces freely in acid; considerable fine siliceous residue; dark round flat masses like flax seed which probably are ironstone	820
Shale, very light gray, readily effervescent, finely gritty; very fine grains of silica, some dull, some sparkling	830
Limestone, dark gray, very fine-grained; calcite; crystalline fragments of quartz; ironstone concretions as above; flakes of white chert; little clay present in the limestone but much silica in fine grains in addition to the flint. Another sample marked 840 is a light gray, highly calcareous, very fine powder and evidently represents a streak of limy, finely siliceous shale	840, 850
Limestone, gray, in powder and small grains, very ready response to acid; some transparent granules of quartz; considerable sandy residue	860, 870
Limestone, light tan, in fine gritty powder, highly calcareous, some sandy residue	880
Limestone, light gray, dolomitic, in very fine grains, which under the glass are seen to be almost white and translucent with many small shining fragments of calcite	890
Limestone, gray, crystalline, as above, but somewhat more responsive to cold acid	900
Limestone, darker gray, crystalline, responds vigorously to cold acid	910, 920
Limestone, as at 900	930
Silurian (penetrated 414 feet; top 107 feet below sea level):	
Limestone, a little darker than above, readily soluble; with insoluble white subcrystalline flakes of the hardness of anhydrite	940
Limestone, light gray, in grains and small chips; flakes of white fibrous selenite three-fourths inch long	950
Limestone, gray, in grains and chips, noncrystalline, some crystalline, effervesces freely in cold acid; (at 980 in very small grains, white to dark brown, action in acid brisk); large clayey and sandy residue; 4 samples	960–990
Limestone, gray, in fine sugary grains, free effervescence in acid; 6 samples	1000–1060
Limestone, as above; large residue of gypsum or anhydrite	1070
Limestone, light gray; large admixture of gypsum, some in flakes one-fourth inch in diameter; response to cold acid slow at first but increasing	1080–1090
Limestone, darker gray than above, response to acid fairly ready, residue small; some gypsum	1100
Limestone as above, action in acid brisk	1110
Limestone, dark gray, sugary texture, action in acid slow at first; some flakes of selenite	1120
Limestone, dark gray	1130
Limestone, light gray, in fine powder concreted into masses	1140
No samples, "lime" of driller's log	1140–1210
Limestone, gray, sugary texture, action in acid brisk; 7 samples	1210–1270
Limestone, gray, action in acid starts rather slowly	1280
Limestone, gray, sugary, dolomitic, solution nearly complete	1290
Limestone, as above, sandy residue	1300
Limestone, yellowish, in fine sugary grains, moderate response to acid; residue fine clear grains of sand and fragments of gypsum	1310
Limestone, as above. Another sample taken from the drill bit at 1320 feet is shale, red, yellowish, blue, purple, etc., slightly limy, somewhat gritty. Just above the shale is a thin bed of sand which runs very freely and gave the drillers a good deal of trouble. Sample effervesces freely; large residue of clear quartz grains	1320
Shale, like that in sample above	1330
Limestone, light gray, in small grains and larger chips ranging up to	

one-fourth inch in diameter, effervesces readily; numerous flakes of bluish shale; flint, pink and white; clear grains of quartz which may come in part from bed above	1340
Dolomite, light gray, sugary; much quartz sand in small clear well-rounded grains, with some white and pink flint. The quartz composes probably two-thirds the entire mass	1350

Driller's Log

	Depth in Feet
Given above in *Record of strata*	0–510
Lime, sandy	510–555
Limestone	555–630
Shale	630–748
Limestone	748–775
Lime, white, medium hard	780–860
Hard gray lime	860–888
Hard sandstone	888–890
Hard sand and lime	890–907
Hard lime	907–990
Broken lime, some salt water overflowed at surface	990–1010
Hard lime	1010–1020
Broken lime	1020–1080
Lime	1080–1222
Lime streaked with shale	1222–1272
Hard lime	1272–1310
Yellow shale with sand	1310–1320
Red shale	1320–1325
Light shale	1325–1336
Sand and lime mixed, strong flow of water	1336–1355

Analysis of water by Dearborn Chemical Co., Chicago, D. K. French, Chemical Director.

Mineral Analysis

Hypothetical combinations	Grains per U. S. Gallon of 231 cu. in.
Silica	1.168
Oxides of Iron and Aluminum	.116
Carbonate of Lime	Trace
Sulphate of Lime	94.196
Carbonate of Magnesia	11.550
Sulphate of Magnesia	7.674
Sodium and Potassium Sulphates	119.435
Sodium and Potassium Chlorides	12.240
Sodium and Potassium Nitrates	Trace
Loss, etc.	.069
Total Soluble Mineral Solids	246.448
Organic Matter	Trace
Suspended Matter	2.336
Total Soluble Incrusting Solids	107.030
Total Soluble Nonincrusting Solids	139.418

Pounds Soluble Incrusting Solids per 1000 U. S. gallons 15.29
Pounds Soluble Nonincrusting Solids per 1000 U. S. gallons 19.92

DEEP WELL OF WOOD BROTHERS, DES MOINES

This well was drilled by Thorpe Brothers Well Company in 1926. On completion it tested 250 gallons per minute and during this test of between three and four days the water, which had stood at 67 feet below the curb at the beginning of the test, lowered but 11 feet. The elevation of the curb is 840 feet above sea level.

*Driller's log of well of Wood Brothers**

	Depth in Feet
Pleistocene and Recent (85 feet thick; top 840 feet above sea level):	
Soil	0–15
Sea mud and sand	15–85
Pennsylvanian (145 feet thick; top 755 feet above sea level):	
Shale, yellow	85–230
Mississippian above Kinderhook shale (390 feet thick, top 610 feet above sea level):	
Lime	230–300
Shale, green	300–330
Lime	330–405
Shale, green	405–425
Lime	425–485
Shale, light	485–490
Lime	490–620
Kinderhook shale (65 feet thick; top 220 feet above sea level):	
Shale, green	620–645
Lime	645–660
Shale, green	660–685
Devonian and Silurian (665 feet thick; top 155 feet above sea level):	
Lime	685–1295
Shale, red	1295–1315
Sandy lime, sharp (Hoing sands of Silurian)	1315–1350
Maquoketa shale (100 feet thick, top 510 feet below sea level):	
Shale, red	1350–1375
Shale, blue	1375–1450
Galena, Decorah, Platteville, Glenwood (455 feet thick; top 610 feet below sea level):	
Lime shale	1450–1555
Sand shale	1555–1575
Lime	1575–1850
Shale, green (Decorah)	1850–1860
Lime (Platteville)	1860–1890
Shale, green (Glenwood)	1890–1905
Saint Peter (25 feet thick; top 1065 feet below sea level):	
Sand, soft, white	1905–1930
Prairie du Chien, 430 feet thick; top 1090 feet below sea level):	
Lime	1930–2085
Sandy lime	2085–2140
Sand, white	2140–2185
Lime	2185–2360
Jordan (penetrated 63 feet; top 1520 feet below sea level):	
Sand, brown and white	2360–2395
Sand, soft, white	2395–2423

Notes.—Comparing the sections of the two wells described above and that of the deeper well at Greenwood Park[48] it will be

* Assignment to formations by W. H. Norton.

48 Norton, W. H., Iowa Geol. Survey, vol. XXI, pp. 893-894.

seen that at the park well the Coal Measures are much thicker than at the others, while the Mississippian is correspondingly thinner.

The gypsum found by Lees at Silurian horizons in the Northland well, like that found at the same levels in the Park well, is referred to the Salina rather than the Niagaran.

The Hoing sands at the bottom of the Northland well may be the same as the arenaceous dolomite occurring 21 feet higher in the Park well and overlying 55 feet of cherty dolomite. In the Wood Brothers' well, the Hoing is apparently represented by the "sandy lime, sharp" at 1315 feet, immediately above the shales assigned to the Maquoketa.

The top of the Maquoketa appears 63 feet higher in the Wood Brothers' well than in that of Greenwood Park and the formation is 67 feet thicker, the base of the shales in both being at about the same elevation. In both wells the Galena, Decorah, Platteville and Glenwood are well made out. The thickness assigned to the underlying formations is as close as is to be expected, and the top of the Jordan is but 26 feet higher at Greenwood Park than in the well of Wood Brothers.

DE WITT, CLINTON COUNTY

(Altitude 719 feet, C., M. & St. P. Ry)

Previous to 1923 the city supply of De Witt was drawn from two wells, 274 and 524 feet deep. In the first water was obtained from the Niagaran limestone immediately above the floor of the Maquoketa shale; in the second from the Galena limestone immediately below the ceiling formed by the base of the same impervious shale, with a yield of 50 gallons per minute.

In January, 1923, a well 1646 feet deep was completed by the F. M. Gray, Jr., Well Company of Milwaukee. The diameters are 12½ inches to 70 feet, 12 inches to 283 feet, 10 inches to 1256 feet and 8 inches to bottom. The well is cased to 70 feet, from 283 to 526 feet, casing out the Maquoketa shales, and from 877 to 1256 feet.

The chief supply was found in the Dresbach sandstone at 1646 feet. The Saint Peter also was water bearing at 1100 feet.

The static level is 101 feet below the surface. At the test, pumping 225 gallons per minute gave a draw down of but one foot. The cost of the well was $10,000 and of the pumping machinery $5,000.

Record of Strata

	Depth in Feet
Pleistocene and Recent (30 feet thick; 718 feet above sea level):	
"Clay and drift"	0–30
Niagaran (295 feet thick; top 688 feet above sea level):	
Dolomite, bright buff and yellow, pale cream color at 220; slightly cherty at 220 and 240, very cherty at 260; 14 samples	30–280
Dolomite, blue-gray	280–295
Maquoketa (201 feet thick; top 423 feet above sea level):	
Dolomite, blue-gray, crystalline; greenish drab, earthy, argillaceous; in chips; shale, light blue and drab, calcareous	295–305
Dolomite, blue-gray, crystalline in chips; shale, light blue	305–325
Shale, blue, plastic; 5 samples	325–425
Shale, gray; 2 samples	425–465
Shale, brownish gray	465–485
Shale, blue	485–496
Galena-Platteville (333 feet thick; top 222 feet above sea level):	
Dolomite, pale brownish gray and dark gray, crystalline, in clean chips; 4 samples	496–525
Dolomite, light buff-gray, in fine sand; an occasional well rounded grain of fine quartz sand	525–535
Dolomite, light brown-gray	535–555
Dolomite, buff and brown-gray, in fine sand, and chips; 3 samples	555–600
Dolomite, brown in mass, crystalline	600–620
Clay, yellow, slightly calcareous, very fine-grained; a little white sandstone of microscopic angular particles of clear quartz	620–625
Limestone, light gray and brownish gray, brisk effervescence in cold dilute HCl; a little brown dolomite; some white chert; 3 samples	625–680
Limestone, whitish and brownish gray, rapid effervescence, cherty; 3 samples	700–755
Shale, green, fossiliferous; pyrite; impure limestone (Decorah)	755–760
Limestone, drab and gray, finely laminated and fossiliferous at 760; 3 samples	760–820
Limestone, medium dark blue-gray	820–829
Glenwood (13 feet thick):	
Sandstone, whitish gray in mass, grains well rounded, some with secondary enlargements; a little brown inflammable shale	829–833
Shale, green, fissile, feebly effervescent	833–842
Saint Peter sandstone (223 feet thick, top 124 feet below sea level):	
Sandstone, whitish gray in mass, grains rounded, frosted, up to 0.8 mm. diameter; some green shale; on one chip sandstone and shale in apposition	842–850
Sandstone, white, clean, very fine	850–860
Sandstone, white, medium; 4 samples	860–915
Sandstone, white, some rusted grains; 4 samples	915–970
Sandstone, light gray and cream colored; 3 samples	970–1015
No samples, "sandstone"	1015–1050
Sandstone, light yellow from iron stained grains; secondary enlargements	1050–1065
Basal beds of the Saint Peter formation: conglomerates, shales and sandstones (295 feet thick; top 347 feet below sea level):	
Sandstone, light pink, fine to medium, some secondary enlargements, color due to pinkish and reddish grains and remains after boiling in acid	1065–1070

Sandstone, yellow, some grains rusted; some secondary enlargements, a very little dolomite, "chert pebbles" (Thwaites) 1070–1080
Shale, dark purplish red, hard, fine-grained, noncalcareous; a little shale light greenish, noncalcareous; chert pebbles up to 1 cm. diameter, surfaces softer than interior 1080–1140
Shale, dark purplish red, noncalcareous, nonarenaceous except for a small amount of minute angular quartzose matter; shale light greenish, noncalcareous, nonarenaceous; pebbles of chert; some whitish aggregates of quartz sand and particles of cryptocrystalline silica 1120–1135
Dolomite, gray, in fine chips; a little shale green and purplish red as above, in small rounded chips as if water-worn in the well; chert, white; much gray sand of rounded medium fine grains; one fragment of black coal at 1135; two samples 1135–1161
Shale, light blue-green, in moulded masses including rounded quartz sand and chips of chert 1161–1173
Chert, white and brownish gray, white, in large angular chips, some decayed; some rounded fragments of green and red shale; quartz sand 1173–1190
Chert, in small chips, quartz sand; much water-worn green and red shale 1190–1200
Chert, white and gray, some brownish gray; shale as above 1200–1210
Chert, white, and some quartz sand; much rusted; an occasional grain of dolomite; some white soft masses of decayed chert; very little shale 1210–1220
Chert and sand as above, some soft decayed chert; considerable dolomite, gray, in sand; green shale, at 1220 very abundant and in large flakes; 2 samples 1220–1240
Chert, oölitic, arenaceous, some pyrite; sand as above; considerable green shale; some dolomite; 2 samples 1240–1260
Sandstone, in rounded grains, secondary enlargements; chips of fine noncalciferous white sandstone; oölitic chert, white, brown, yellow, purplish; whitish dolomite in sand; some green shale; 2 samples 1260–1280
Sandstone, as above, chips of hard fine sandstone abundant; chert; dolomite; shale 1280–1290
Sandstone, as above, coarse, grains up to 1 mm. diameter, secondary enlargements; grains much broken; chips of fine sandstone; chert; pyrite; some light green shale and a little red shale in small chips..1290–1300
Dolomite, light purplish; sandstone as above but finer; some green shale in small rounded chips; pyrite 1300–1310
Sandstone, fine, gray, as above; dolomite, gray, highly siliceous with microscopic quartzose particles; shale and pyrite as above 1310–1320
Dolomite; sandstone, gray in mass; all in fine grains; shale as above; pyrite; a cinder 1320–1340
Dolomite, yellow-gray, minutely siliceous with crystalline and cryptocrystalline quartz; much sandstone in grains, some sandstone with cherty material; some chips of chert; much green and red shale; two large bits of coal 1340–1360

Trempealeau (80 feet thick; top 642 feet below sea level):
Dolomite, buff, arenaceous with fine rounded grains; clean, in fine sand; 3 samples 1360–1400
Dolomite, whitish, in fine flour; siliceous with minute particles of clear and crytocrystalline quartz; slightly argillaceous 1400–1410
Dolomite, gray and yellow-gray, in chips and sand, highly siliceous as above; 3 samples 1410–1440

Franconia (100 feet thick; top 722 feet below sea level):
Sandstone, gray, of minute quartzose particles, dolomitic, glauconitic....1440–1450
Sandstone, gray, very fine-grained but coarser than above, dolomitic, glauconitic; 6 samples 1450–1520
Sandstone, brown in mass, from medium fine rounded grains to minute quartzose particles, highly glauconitic, dolomitic 1520–1530
Sandstone, light gray in mass, grains up to 0.8 mm. diameter; some

grains of dolomite with quartz grains imbedded; a little glauconite 1530–1540

Dresbach (105 feet thick; top 822 feet below sea level):

Sandstone, yellow, clean, a little finer than above; some glauconite 1540–1545

Sandstone, yellow in mass; grains white, frosted, rounded, larger grains up to 1 mm. diameter, mass color due to slight iron stain 1545–1555

Sandstone, light yellow, finer than above; 2 samples 1555–1575

Sandstone, light yellow-gray in mass, medium, in grains and chips, dolomitic; much fine material in cuttings 1575–1605

Sandstone, light yellow-gray, medium, rounded grains; 3 samples 1605–1645

Eau Claire (penetrated 1 foot; top 927 feet below sea level):

Dolomite, buff, in chips, siliceous with minute particles of quartz; much quartz sand in cuttings 1645–1646

Notes on the De Witt section.—The samples of Niagaran dolomite show the characteristic colors and textures of the Hopkinton stage and the cherty beds at the base which are so well exhibited in the outcrops at Clinton.

The dolomite and shale at the summit of the Maquoketa may represent interbedded transitional layers.

In the Glenwood, the presence is to be noted of a thin top layer of sandstone, separated from the Saint Peter sands by the usual green fissile shale. There is some doubt whether the sandstone from 842 to 850 feet should not go with the Glenwood, as it is placed by Dr. F. T. Thwaites of the Wisconsin Geological Survey, who has examined these samples for the drilling company. On the whole, however, it seems preferable to regard the green shale of the cuttings as derived from the shale above, and this is also the interpretation of the driller's log.

Between the clean Saint Peter sandstone ending at 1065 feet and the clean samples of dolomite of the Trempealeau which begin at 1360 feet, the rocks in which the drill was working are represented by anomalous and somewhat ambiguous samples which are taken by both Thwaites and the writer to represent conglomerates and shales with some sandstone. As will be noted from the detailed description given above, the samples consist of shales of various colors, chert, much of it decayed, dolomite chipped to fine sand, and sandstone either in loose sand or chips. The conglomeratic nature of much of this rock is confirmed by the characteristic caving of it, a feature often noted in other wells. In the driller's log as given on the blue print of the consulting engineer the rock from 1080 to 1256 is set down as "176 feet caving dolomite, brown and gray in various shades." The Gray Well Drilling Company writes "We underreamed this well from the 1100 ft. point to the point where the casing now rests" (1256 feet). "This was due to the fact that it was impossible for us to make any headway due to the bad caving nature of the formation." The casing referred to is an 8 inch pipe bedded at 1256 feet and extending to 877 feet, high up in the Saint Peter sandstone. It is on account of this extensive and continued caving that the interpretation of the cuttings is difficult both for drillers and geologists.

There is no doubt that the Saint Peter sandstone, with 15 feet of transitional sandstone, is underlain by 55 feet of shale, dark purplish red and light green, with chert pebbles, some with surfaces decayed. As the chert is unstained, and for other reasons, the pebbles are held to occur in distinct beds and not sporadically.

The samples between this shale and the clean dolomite at 1360 feet show much intermingling of material. From 1135 feet, the base of the shale referred to, to 1161 feet, the samples consist of shale, water-worn and probably largely due to caving, chert, quartz sand and dolomite. It is assumed that the drill here was working in a conglomerate of pebbles of chert and dolomite set in a sandstone matrix, perhaps with seams of shale. But we can not be sure that in part the drill was not working in dolomite and that the presence of shale, chert, and sand is not due to extensive caving. From 1161 to 1173 feet, a 12 foot bed of light blue-green shale is represented by a fairly clean sample.

The samples from 1173 to 1260 feet are heterogeneous, composed of the same ingredients as are those taken to represent the conglomerate above. They are given the same interpretation.

From 1260 to 1360 feet the samples continue heterogeneous and ambiguous. It is to be supposed that the casing bedded at 1256 feet cut off all caving from above. If, then, all the materials of the samples are native it may be assumed that the drill was still working in conglomerate. The presence of sandstone, here in chips, shows that the matrix of the conglomerate was more indurated than that at higher levels. However, the possibility is not to be excluded from consideration that sandstone and dolomite were supplied from bedded layers instead of from matrix and included pebbles. The explanation of shale in the samples below the footing of the casing offered by the drilling firm is "that after the 8 inch pipe was set at 1256 feet depth several streaks of shale weren't counted and did cave a little, thereby causing these shale cavings to appear in these samples."

The upper limit of the Franconia is drawn where the siliceous dolomites of the Trempealeau give place to minutely quartzose glauconitic sandstones. The Franconia is less argillaceous than in many localities. The base is difficult to define. A gradual increase in coarseness of grain is shown as the Dresbach is approached. The sandstone from 1530 to 1540 is included on account of the dolomite present, and the sandstone from 1540 to 1545 is placed with the Dresbach, although glauconite is a constituent.

*Mineral Content of City Well, De Witt**

	P.P.M.
Bicarbonate	336.7
Chloride	39.
Sulfate	37.0
Silica	34.2
$Fe_2O_3+Al_2O_3$	4.2
Calcium	92.2
Magnesium	33.5
Na + K as Na	21.4
Total solids	429.8

DEXTER, DALLAS COUNTY
(*Altitude 1148 feet*)

The well of this city was started July 10, 1928, and finished December 10, 1928. It is specially noteworthy from the fact that an abundance of water was found at a moderate depth in an area where, as at Stuart, the deepest wells in the state are necessary to tap the dependable water beds. The Dexter well is 1245 feet deep and does not reach the Ordovician. Water was found in strata which apparently belong to the upper beds of the Silurian. The diameters of the well are from 16 to 8 inches. The well is cased throughout. Water was found at 1240 feet in limestone and yielded under test of 36 hours 200 g.p.m. with a draw down of but 15 feet. The static level is 242 feet below the curb, or about 902 feet above sea level. The static level of the St. Peter

* Analysis by Dr. Harry F. Lewis, Chemical Laboratory, Cornell College, Mount Vernon, 1927.

water at Stuart, we may state for comparison, was found to be 325 feet below the curb, or about 880 feet above sea level, while the static level of the deeper water beds was 20 feet lower. The well was drilled by the Thorpe Bros. Well Co. of Des Moines. It cost over $12,000 and pumping equipment will cost about $3000 additional.

Driller's log

	Depth in Feet
Yellow clay	0–20
Yellow clay and gravel	20–40
Blue clay	40–190
Red shale	190–210
Brown shale	210–265
Blue and red shale	265–285
Gray shale	285–335
Blue shale	335–355
Black shale	355–498
Blue shale	498–520
Shale and lime rock	520–565
Lime rock	565–670
Shale	670–680
Lime rock	680–820
Shale	820–826
Lime rock	826–1015
Shale	1015–1060
Lime rock	1060–1140
Sand rock, some water	1140–1160
Shale	1160–1166
Lime rock and shale	1166–1240
Lime rock, broken, took cuttings, water	1240–1245

Record of strata, Dexter City well

	Depth, feet
Pleistocene and Pennsylvanian (680 feet thick; top 1144 feet above sea level):	
No samples, see log	0–680
Mississippian (370 feet thick; top 464 feet above sea level):	
No samples, see log	680–700
Limestone, drab and brownish, argillaceous, rapid effervescence in cold dilute HCl; gray and brown chert and whitish chalcedony; some clear quartz in fine irregular grains; much drab and blackish shale	700–710
Limestone, gray and brown, argillaceous, moderately rapid effervescence; gray chert; 2 samples	710–730
Limestone, gray, fine crystalline-granular, rapid effervescence; much gray chert	730–740
Limestone, gray, argillaceous, moderately rapid effervescence; much gray and brownish chert	740–750
Chert, gray and brownish, chalcedonic silica; limestone, gray; 2 samples	750–770
Limestone, gray, earthy, argillaceous, moderately rapid effervescence; gray and brownish chert and conspicuous white chalcedonic silica; 2 samples	770–790
Limestone, yellow-gray and gray, rapid and moderately rapid effervescence; gray chert, some mottled; 3 samples	790–820
Limestone, gray and yellow-gray, mottled, soft, macrocrystalline-earthy, in large flakes, rapid effervescence; some chert	820–830
Chert, light gray and gray, some limestone and whitish chalcedony; 3 samples	830–860
Limestone, gray, moderately rapid effervescence	860–870
Chert, gray; some gray limestone	870–880
Limestone, gray and yellow-gray, rapid effervescence; a little gray chert and chalcedony at 880; 2 samples	880–900
Chert; whitish chalcedony; gray limestone	900–910
Limestone, light yellow-gray, oölitic, rapid effervescence; 4 samples	910–960

Limestone, yellow-gray and brown, moderately rapid effervescence, fine crystalline-granular	960–970
Limestone, light and dark gray mottled, soft, in large flakes, macro-crystalline, encrinital, rapid effervescence	970–980
Limestone, drab, rather slow; whitish and gray chert	980–990
Limestone, gray, fine crystalline-granular, rather slow effervescence	990–1000
Shale (Kinderhook) light blue, in concreted masses, calcareous	1000–1010
Limestone, buff, rapid effervescence, in fine sand	1010–1020
Shale, light blue-gray, in chips strongly calcareous	1020–1030
No samples, "shale" in log	1030–1050
Devonian (150 feet thick; top 94 feet above sea level):	
Limestone, gray, fine crystalline-granular and calcilutite, rapid effervescence; 4 samples	1050–1090
Limestone, light yellow-gray, fine texture, rapid effervescence	1090–1100
Limestone, whitish, in fine sand, rapid effervescence; 2 samples	1100–1120
Limestone, light yellow-gray, somewhat rusted, rapid effervescence	1120–1130
Limestone, light gray, rapid effervescence	1130–1140
Shale, drab, calcareous, in tough concreted masses	1140–1150
Limestone, gray, rapid effervescence, some large chips of laminated light brownish calcilutite; much powder of shale	1150–1160
Limestone, light yellow-gray and dark gray, rapid effervescence	1160–1170
Dolomite, buff and brown	1170–1180
Dolomite, yellow-gray, rather slow effervescence	1180–1190
Dolomite, light yellow-gray, earthy, soft, rather slow effervescence	1190–1200
Silurian (penetrated 45 feet; top 56 feet below sea level):	
Shale, light blue-gray, in concreted masses inclosing chips of gray dolomite	1200–1210
Dolomite, gray and greenish gray, fine crystalline-granular	1210–1220
Shale, very light gray or whitish, quartzose; some minute grains of quartz sand; chips of light gray dolomite	1220–1230
No samples	1230–1245

Notes.—The upper strata assigned to the Mississippian are characteristic in their cherty argillaceous limestones and beds of cherts, and in the presence of chalcedonic silica. There is considerable shale in the samples, in part blackish and red or pink and evidently fallen from above, in part gray and less clayey and very possibly from layers in which the drill was working.

Equally characteristic of the lower strata of the Mississippian are the oölitic limestones beginning at 910 feet. The shales beginning at 1000 feet are taken to be Kinderhook.

The beds assigned to the Devonian are characteristic limestones of rapid effervescence including calcilutites, with some dolomitic beds at base which perhaps should go to the Silurian.

The shales at 1200 feet are taken to mark the top of the Silurian and may be compared with the gypseous shales and limestones of the Silurian at Stuart, although at Dexter they carry no gypsum. With these assignments of the Kinderhook and the Silurian, the Devonian at both Stuart and Dexter is given a thickness of about 150 feet.

The towns of Dexter and Stuart are less than six miles apart, so that the geologic sections of their logs should be closely parallel.

No samples of the cuttings of the Stuart well were saved above 1185 feet, and for this distance the samples at Dexter may be used for the interpretation and reinterpretation of the Stuart log, remembering that the town of Stuart is 61 feet higher than Dexter.

In the light of the Dexter cuttings, the "shale, light colored, calcareous" of the Stuart log from 765 to 815 feet may well be Mississippian instead of Pennsylvanian as assigned (p. 333), although the Mississippian floor on which the Pennsylvanian was laid is known to be one of rather large relief.

The shales referred to the Kinderhook at both Dexter and Stuart are about 50 feet thick, and as stated an equally close agreement is obtained for the Devonian. However, the top of the Kinderhook at Dexter is 144 feet above sea level, while at Stuart it is but 28 feet above the same datum. The same difference in level is found at top of the Silurian.

DONNELLSON, LEE COUNTY
(Altitude 708 feet)

A deep well was drilled for this town in 1925 by J. M. Schlicher, who furnished the facts given together with samples of the cuttings. The depth is 1095 feet, the diameters are 8¼, 7⅝, 6 and 4½ inches. The chief water bed is the Saint Peter sandstone. Water was found also at 136 feet in Mississippian sandstone and at 720 feet in Silurian or Devonian limestone. The lower 50 feet of the Galena and Platteville limestones are also water bearing.

The water struck at 720 feet had a static level of 150 feet below the curb. At 990 feet water began to rise in the drill hole, and the water from the Saint Peter sandstone lifted the level to 80 feet below the surface of the ground.

The well is cased with 8¼ inch casing to 67 feet, 6 inch to 285 feet, and 4½ inch to 708 feet.

The discharge is equal to the capacity of the pump, viz. 80 gallons per minute. This drill hole was put down in an old well 275 feet deep, at a cost of $3226. The casing cost $1137 in addition.

Chemical analysis

PROBABLE COMBINATIONS	GRAINS PER U. S. GALLON
Silica	0.607
Oxides of iron and aluminum	0.186
Calcium carbonate	2.350
Calcium sulphate	54.783
Magnesium carbonate	18.880
Sodium and potassium sulphate	33.099
Sodium and potassium chlorides	1.020
Total solids	110.960

Record of Strata

	DEPTH IN FEET
Pleistocene and Recent (67 feet thick; top 696 feet above sea level):	
"Clay"	0–61
"Sand"	61–67
Mississippian:	
Meramec and Keokuk (208 feet thick; top 629 feet above sea level)—	
"Limestone"	67–136
"Sandstone"	136–138
"Limestone"	138–150
"Shale, blue"	150–275
Burlington group (93 feet thick; top 421 feet above sea level)—	
Limestone, whitish, macrocrystalline, soft, in large flakes	275–290
Limestone, whitish, crystalline-earthy; much blue-gray chert and chalcedonic silica	306
Chert; earthy whitish limestone; some gray shale	320
Chert, blue-gray	330
Limestone, whitish and blue-gray, macrocrystalline-earthy, in large thin chips	348, 360
Kinderhook shale (325 feet thick; top 328 feet above sea level)—	
Shale, greenish and blue, calcareous, in concreted masses	368, 380
Sandstone, gray, argillaceous, slightly calcareous, grains largely microscopic, in small chips	392, 400
Shale, bluish, in concreted masses	408
Sandstone, as at 392	419, 430
Shale, bluish, in concreted masses	440
Shale, blue-gray, calcareous, highly quartzose	448, 460
Shale, blue, in concreted masses; 6 samples	465–515
Shale, brownish drab, burns white with slight empyreumatic odor	520
Shale, drab, fissile	530
Shale, blue-gray	540
Shale, drab	550
Shale, blue; 10 samples	560–650
Shale, brownish drab, with pyrite	660
Shale, blue-gray	670–680
Devonian (and Silurian ?) (140 feet thick; top 3 feet above sea level):	
Limestone, blue-gray, highly argillaceous and arenaceous, grains minute, ill-rounded, in chips	693
Limestone, as above, somewhat arenaceous; pyrite	700
Limestone, yellow-gray, brisk effervescence in cold dilute HCl, in fine sand	711
Shale, blue, in chips; some limestone	720
Limestone, blue, argillaceous, soft, crystalline-earthy, rapid effervescence, in small flakes	730, 740

Limestone, blue-gray, calcilutite, laminated, some surfaces of laminæ dark brown, effervescence rapid, in flaky chips, with powder of blue shale	745
Limestone, as above, yellow-gray, but with no brown surface films	750, 760
Limestone, blue-gray, calcilutite, some dark and irregularly surfaced laminæ, reaction rapid, some chocolate brown shale	770, 780
Limestone, mottled brown-gray, in thin flakes, rapid response, fossiliferous, crystalline-earthy, some dark surfaces as above	790
Limestone, light yellow-gray, fine-grained, rapid reaction; 4 samples	800-830
Ordovician:	
Maquoketa shale (5 feet thick, top 137 feet below sea level)—	
Shale, light green-gray and blue-gray, fissile, somewhat calcareous, in chips and concreted masses	833–838
Galena and Platteville (202 feet thick; top 142 feet below sea level)—	
Dolomite, gray, crystalline, in small chips	840, 850
Dolomite, light buff and gray in crystalline sand; 14 samples	860–990
Dolomite, as above, with brown flint	996,1000
Dolomite, or magnesian limestone, buff and light brown, in crystalline sand and small chips, not so slow effervescence as LeClaire dolomite; 3 samples	1010–1030
Saint Peter sandstone (55 feet thick; top 344 feet below sea level)—	
Dolomite, buff, highly arenaceous, with imbedded grains fine, moderately well rounded, some showing secondary enlargements	1040
Sandstone, light yellow in mass, grains as above but without secondary enlargements, wide range in size; a little buff dolomite	1050
Sandstone, as above, clean, larger grains up to 0.7 mm. in diameter; 4 samples	1060–1090
Prairie du Chien (Shakopee dolomite, entered at 399 feet below sea level)—	1095

Notes.—The Kinderhook shales are present at Donnellson in great force, as at Burlington, Fort Madison and Mount Clara. Their summit shows a fall of 141 feet from Mount Pleasant, and of 247 feet from Burlington, and a continued fall to Keokuk of 50 feet, while it is about the same level as the top of the Kinderhook at Fort Madison.

The laminated calcilutite limestones with dark surfaces struck at 745 feet are of a rather rare type, and at once suggest the Otis horizon of the Wapsipinicon stage of the Devonian.

The shale at 833 feet is assigned to the Maquoketa with much uncertainty although its position is that of the shale, also thin, placed with the Maquoketa at Fort Madison, and that of the much thicker shales of the same stratigraphical position at Burlington and Mount Pleasant.

The Galena-Platteville has its usual facies, but the basal shale which so commonly rests upon the Saint Peter sandstone is absent as at Mount Pleasant and Keokuk.

The sandstone at 1040 feet is assigned with considerable confidence to the Saint Peter, as it agrees closely in position with the sandstones referred to that formation in the deep well sections of southeastern Iowa. On a cross section from Burlington to Baring, Missouri, the gradient of the Saint Peter intersects at Donnellson the location of the sandstone in question. Lithologically, however, it departs somewhat from type.

DUBUQUE

(Altitude 608 feet)

The city of Dubuque has long been one of the best developed local artesian fields of Iowa. In 1912 nineteen artesian wells were in service including four belonging to the city, while one had been abandoned. Since that date twelve deep wells have been drilled within the city limits. In 1910 our knowledge of the geologic section at Dubuque and therefore of artesian conditions was very incomplete. Now it is fairly adequate, through the careful efforts of Mr. C. W. Varner, artesian well contractor, who has preserved samples of the cuttings of several recent wells. The wells drilled since the compilation of the report on the Underground Water Resources of Iowa are as follows:

The well of the Fisher Ice Company, drilled in 1912, is 1325 feet deep.

The well of Swift and Company, drilled in 1922 by V. Garvey of Dubuque, is 1335 feet deep, with a diameter of 8 inches. It delivers 54 gallons per minute.

The well of the T. J. Mulgrew Ice Company, drilled in 1922, is 900 feet deep, discharges 300 gallons per minute and maintains a static level of 4 feet above the curb.

The Sanitary Milk Company's well, drilled in 1925 by C. W. Varner of Dubuque, is 515 feet deep, diameter 8 inches, discharge 150 gallons per minute, and head 12 feet below the curb.

The Consumers Ice Company's well, drilled in 1925 by C. W. Varner, is 1300 feet deep and discharges 225 gallons per minute. A 10 inch drive pipe extends to 165 feet, below which the well is uncased with these diameters: 10 inches to 414 feet, 8 inches to 503 feet, and 6 inches to the bottom.

The Farley and Loetscher Company's well, completed in 1926 by C. W. Varner, is 1438 feet deep, diameters: 12 inches to 500 feet, 10 inches to 1025 feet, 8 inches to bottom. Twelve inch casing extends to 193 feet. The discharge is from 700 to 800 gallons per minute when pumped down to 28 feet below the curb.

The following water levels were recorded as the well was drilled, showing the increase of height of head with depth:

DEPTH OF WELL IN FEET	DEPTH OF STATIC LEVEL BELOW CURB IN FEET
340	28
390	22
525	18
800	13½
1380	3
1400	flowed

As the height of the water did not increase between 1180 and 1280 feet the driller considers these beds dry.

Wells have also been drilled for the Iowa Dairy Company, the A. Y. McDonald Mfg. Company and the Brunswick Balke Collander Company, but no information regarding them can be obtained.

Since 1910 the city has added three deep wells to its Eagle Point equipment, making five deep wells now in service there.

Wells nos. 3 and 4 were drilled in 1919, depths 1460 and 1458 feet. Their diameters are each from 12 to 6 inches. Number 4 is cased with 12 inch casing to 136 feet, 10 inch 374 to 430 feet, 8 inch 550 to 593, and 6 inch 868 to 968 feet. Their static level is estimated at about 658 feet.

Well no. 5, drilled in 1924 by C. W. Varner, is 1500 feet deep, diameters 16 to 10 inches with 16 inch casing to 130 feet to shut out alluvial sands and 125 feet of 12 inch casing to protect from caving shales which occur in places between 390 and 445 feet. The location of water beds is indicated by the variations in static level and discharge as the drilling progressed.

At 420 feet, Jordan sandstone, water raised 2 or 3 feet.
At 550 feet, Trempealeau dolomite, water raised 7 or 8 feet.
At 700 feet, Dresbach sandstone, water raised within 8 feet of surface.
At 780 feet, Dresbach sandstone, water started to overflow.
At 1165 feet, Mount Simon sandstone, flow of 154 gallons per minute.
At 1350 feet, Mount Simon sandstone, flow of 240 gallons per minute.
At 1500 feet, Mount Simon sandstone, flow of 267 gallons per minute.

The average daily consumption of the city of Dubuque from the public supply is 3,000,000 gallons. The pumping capacity of the five artesian wells at Eagle Point under air lift of 128 feet is about 6,500,000 gallons and shallow sand wells can supply an additional 1,500,000 gallons. The water is pumped by electricity to a high level reservoir whose capacity is 7,500,000 gallons and a very low rate is obtained, as the pumping is done at off-peak periods except in emergencies.

Static level.—With the drilling of an increasing number of deep wells and the installation of powerful pumps, the static level has progressively lowered. The deeper wells drilled in the '80s and early '90s had a static level of more than 700 feet above tide. (Butchers' Association well, 1887, head 740 feet. Linwood cemetery well no. 2, 1891, 742 feet.) In 1908 the head of the Dubuque wells had generally sunk to levels not exceeding 625 feet. The initial head of the city wells at Eagle Point (1899) was reported at 649 feet and the measurement of the head of well no. 5 indicates that that head is still maintained. This is particularly gratifying in view of the large decline from the earliest levels to those of 1908 and especially in view of the large loss from disused wells. Yet the recommendations of our report of 1912 must be repeated with emphasis. Wells in this area should be kept effectively cased wherever permeable upper beds allow the lateral escape of the waters rising under high pressure from the deeper aquifers, and disused wells should be plugged above the Dresbach sandstone, i. e. in the Franconia or the Trempealeau beds of the Saint Lawrence.

Little information is obtainable as to the present condition of the Dubuque wells. Seven wells have been abandoned since 1912 for various reasons, among them the cheapness of the city water as compared with the cost of pumping. These wells are the two wells of Linwood cemetery and those of the Cushing factory, the Consumer's Steam Heating Company, Schmidt's brewery, and the wells of the city at 6th Avenue and at 8th Street.

In part the loss of head and of discharge has been due to leakage owing to defective casing rather than to any general overdraft. Thus the well of James Beach and Sons, 940 feet deep, with an initial head (1897) of 34.5 feet above the curb, now heads below curb owing to defective casing. In 1925 the well of the Bank and Insurance Building was repaired by C. W. Varner, the pumping capacity was increased 35 per cent, to 150 gallons per minute, and the initial head of 1894, 648 feet above tide, was restored.

Record of Strata in City well no. 5, Dubuque

	Depth in Feet
Pleistocene and Recent (118 feet thick; top 625 feet above sea level):	
Sand, alluvial, brown and buff; 4 samples	10–60
Sand, reddish, fine, with clay, in friable masses	60–75
Sand, brown, coarser, with clay	75–90
Clay, light buff	90–103
Sand, buff, coarse, of rocks of the drift, much of yellow chert and dolomite	103–118
Saint Peter sandstone (139 feet thick; top 507 feet above sea level):	
Sandstone, grains of clear quartz, well rounded, moderately fine, with some chips of yellow chert	118–127
Sandstone, white, light yellow-gray and buff, rounded grains; 9 samples, all in loose sand	127–249
Sandstone, yellow, fine, not friable, and red, friable, both in chips	250–257
Prairie du Chien (Oneota dolomite, 93 feet thick; top 368 feet above sea level):	
Shale, dark red, hard; and dolomite, light gray, both in chips	257–260
Dolomite, light gray, with some red shale and green shale	260–265
Dolomite, light gray, small residue of minute quartz particles and grains	265–280
Sandstone, fine, with some chips of dolomite and red shale	293
Dolomite, light brownish gray	293–308
Dolomite, gray, pinkish chert, considerable quartz sand	308–315
Dolomite, gray	315–325
Dolomite, gray, some highly arenaceous, with much gray chert	325–340
Cambrian:	
Jordan sandstone (95 feet thick; top 275 feet above sea level)—	
Sandstone, buff, hard, in chips	350
Sandstone, fine, light reddish, larger grains well rounded, in loose sand	363
Chert, white, large chips stained pinkish	370
Chert, with much red shale, in small chips	385–388
Dolomite, highly arenaceous with thickly imbedded grains, in large chips	388–395
Sandstone, fine, pinkish from surface stains	395–405
Sandstone, yellow, moderately coarse	407–415
Sandstone, pinkish, fine; 2 samples	415–445
Saint Lawrence (Trempealeau dolomite, 120 feet thick; top 180 feet above sea level)—	
Dolomite, gray and brown; 7 samples	445–550
Dolomite, purplish brown, arenaceous	560–565
Saint Lawrence (Franconia beds, 90 feet thick)—	
Sandstone, buff and reddish, fine grained, calciferous, glauconitic, in chips; with shale, green, arenaceous, glauconitic	565–580
Sandstone, gray, of minute grains and particles, calciferous, argillaceous, glauconitic, with some green shale, glauconitic and minutely arenaceous; 4 samples	580–640
Sandstone, moderately coarse grains, with highly arenaceous dolomite, glauconitic	640–655
Dresbach sandstone (195 feet thick; top 30 feet below sea level)—	
Sandstone, white and gray, of clean quartz sand, grains well rounded, frosted, maximum diameter about 1 mm.; 11 samples	655–850
Eau Claire beds (100 feet thick; top 225 feet below sea level)—	
Sandstone, gray, very fine irregular grains, calciferous, glauconitic, micaceous, in friable chips	850–865

Sandstone, light buff, fine 865–880
Shale, green-gray 880–895
Sandstone, red, of minute angular grains, some dark red shale 900–905
Sandstone, buff, fine-grained 905–920
Sandstone, reddish and buff, very fine irregular grains, slightly calciferous, sparsely glauconitic, in small chips 920–935
Sandstone, as above, with a little white chert 935–950

Mount Simon beds (penetrated 550 feet; top 130 feet below sea level)—
Sandstone, whitish, fine-grained, maximum up to 0.7 mm. in diameter, larger grains rounded (light pinkish at 980); 8 samples 950–1079
Sandstone, buff, grains up to 1 mm. diameter; 5 samples 1079–1147
Sandstone, reddish brown cuttings, grains irregular, secondary enlargements, heavily stained and cemented with ferruginous material with some magnetic iron; 3 samples 1147-1187
Sandstone, cuttings blackish, coatings dissolve in hot HCl, leaving sand white, larger grains rounded, some secondary enlargements, a little flint 1187–1201
Sandstone, light reddish buff, fine 1201–1214
Sandstone, cuttings brown, much magnetic iron, a little flint, secondary enlargement of grains, surface of some fragments of cemented grains smooth and shining, as if developed in contact with surface of glass receptacle; 2 samples 1214–1241
Sandstone, buff, somewhat rusted, secondary enlargements; 2 samples 1241–1270
Sandstone, cuttings brown, heavily rusted, secondary enlargements.. 1270–1285
Sandstone, buff, somewhat rusted, secondary enlargements, chips of sandstone of minute grains, argillaceous, well cemented at 1300 feet; 4 samples 1285–1335
Sandstone, cuttings brown, deeply rusted, in detached grains, some chips of well cemented sandstone of minute grains, and some mottled sandy shale 1335–1350
Sandstone, buff, moderately coarse, and chips of cream yellow friable fine-grained sandstone with secondary enlargements 1350–1355
Sandstone, light reddish buff 1355–1370
Sandstone, fine and very coarse, with some gravel of clear quartz up to 6 mm. diameter, fine grains show secondary enlargements.... 1375–1380
Sandstone, light pinkish, fine-grained, many grains broken, crystalline enlargements 1390–1395
Sandstone, light reddish brown, grains imperfectly rounded 1405–1410
Sandstone, fine, with chips of reddish argillaceous sandstone of very fine grain 1410–1414
Sandstone, light yellow and light pink, grains ill-assorted, some up to 2 mm. diameter; 2 samples 1425–1445
Sandstone, reddish buff, fine; 3 samples 1445–1490
Sandstone, pinkish, ill-assorted, grains up to 2.2 mm. diameter, some chips of unrusted sandstone, light yellow, friable, imperfectly rounded ill sorted grains 1500

Record of Strata in Farley and Loetscher's well, 8th and White Streets, Dubuque

Pleistocene and Recent (193 feet thick; top 639 feet above sea level):
"To bed rock" 0–193

Ordovician:

Saint Peter sandstone (top 446 feet above sea level)—
"Sandstone, small amount; shale, 3 feet below sandstone" ....

Prairie du Chien (270 feet thick; top 439 feet above sea level)—
Dolomite, light blue-gray, crystalline, rather soft in chips, with some green shale 200–210
"Limestone"; no samples 210–260
Dolomite, light blue-gray, hard, subcrystalline, white chert and some siliceous oölite, some with imbedded grains of quartz sand, some pyrite 260–270

Dolomite, light gray, macrocrystalline, vesicular	300–310
Chert, light gray, some dolomite; 4 samples	330–375
Dolomite, gray, cherty; 2 samples	375–390
Dolomite, gray	390–400
Dolomite, gray, some sparse imbedded grains of quartz	400–410
Dolomite, light yellow-gray; 2 samples	410–450
Dolomite, light yellow-gray, subcrystalline, cherty, arenaceous, in chips	450–460
Dolomite, light yellow-gray, cuttings in sand, arenaceous	460–470
Cambrian:	
Jordan sandstone (70 feet thick; top 169 feet above sea level)—	
Sandstone, calciferous, light gray, in small chips and sand, grains rounded; 2 samples	470–520
Sandstone, whitish, fine-grained, calciferous, argillaceous, secondary enlargements	520–530
Marl, whitish, highly arenaceous, calcareous, argillaceous, quartz grains rounded, but some with secondary enlargements; in friable concreted masses	530–540
Saint Lawrence (Trempealeau dolomite, 60 feet thick; top 99 feet above sea level)—	
Dolomite, light yellow-gray and brown, fine crystalline granular; 6 samples	540–600
Saint Lawrence (Franconia beds, 160 feet thick; top 39 feet above sea level)—	
Marl, pink, calciferous, and red, argillaceous, highly arenaceous, glauconitic, grains of quartz sand fine and ill-rounded with much material of angular quartz particles, in friable concreted masses; 6 samples	600–660
Marl, as above, green, highly glauconitic	660–670
Shale, gray and greenish and brown, calcareous, glauconitic and highly arenaceous, in hard concreted masses; 5 samples	670–720
Shale, red, calcareous and highly arenaceous	720–730
Sandstone, gray and yellow, calciferous, argillaceous, glauconitic, rounded grains up to 1 mm. diameter; 2 samples	740–760
Dresbach sandstone (180 feet thick; top 121 feet below sea level)—	
Sandstone, light yellow and white, clean, grains up to 1 mm. diameter; 2 samples	760–790
Sandstone, light yellow, in chips and sand, a few chips of drab arenaceous dolomite	790–800
Sandstone, light yellow and white, in clean quartz sand, grains well rounded, very diverse in size up to 1 mm. diameter; 10 samples	800–900
Sandstone, gray, in chips, very fine of grain, some argillaceous and calciferous, with much coarse whitish sand	900–910
Eau Claire beds (100 feet thick; top 301 feet below sea level)—	
Shale, blue, noncalcareous, in concreted masses, with considerable buff quartz sand and chips of fine calciferous, glauconitic sandstone; 2 samples	940–960
Sandstone, yellow-gray, in chips, some large and thin, fine-grained	970–980
Sandstone, gray, in sand, fine-grained	980–990
Sandstone, red, argillaceous, calciferous, grains minute, in friable concreted masses; 2 samples	990–1010
Sandstone, buff, of minute grains and particles	1010–1020
Sandstone, gray, glauconitic, some grains rounded, some with secondary enlargements, some pink and yellow	1020–1030
Mount Simon beds (penetrated 398 feet; top 401 feet below sea level)—	
Sandstone, light buff, rounded grains up to 0.8 and 1 mm. in diameter, many rusted; 3 samples	1040–1070
Sandstone, buff, grains much rusted, coarser than above, some chips of blue-gray calciferous sandstone	1070–1080
Sandstone, as at 1040	1080–1090
Sandstone, as at 1070	1090–1100

Sandstone, light yellow, white and red, grains rounded, largest up to 0.8 mm. or less, at 1220 feet up to 2 mm. diameter, deeply rusted at 1100; 24 samples	1110–1350
Shale, red, in hard concreted mass	1350–1355
Sandstone, as at 1100; 8 samples	1355–1438

Record of strata in well of the Consumer's Ice Company

	Depth in Feet
Pleistocene and Recent:	
Sandy clay and humus	12–15
River sand, gray, moderately fine, fragments of shells	15–30
Gravel and coarse sand, up to 1¾ inches diameter	30–45
Clay, red, plastic	45
Sand, yellow	75–105
Clay, drab, sandy	145–165
Prairie du Chien:	
Dolomite, light yellow-gray, arenaceous, cherty; 3 samples	170–195
Chert, white, and dolomite, whitish	345–360
Dolomite, yellow-gray, oölitic	400–450
Jordan:	
Sandstone, well rounded grains, calciferous, in chips	450–470
Sandstone, light buff, fine, calciferous	500–525
Saint Lawrence (Trempealeau dolomite):	
Dolomite, light yellow-gray, in chips, considerable quartz sand in cuttings	525–540
Dolomite, light buff and pink; 3 samples	540–620
Saint Lawrence (Franconia beds):	
Sandstone, red, in powder and concreted friable masses, grains minute, argillaceous, calciferous, with some glauconite; some chips of pink dolomite	620–650
Sandstone, drab and red, as above, no dolomite chips	650–690
Sandstone, bluish, as at 650	690–730
Dresbach sandstone:	
Sandstone, white, in clean loose sand, grains rounded, maximum diameter 1 mm.; 9 samples	730–930
Eau Claire sandstone:	
Sandstone, drab, argillaceous, of fine quartz particles, glauconiferous; some blue shale; some loose rounded grains of quartz; 2 samples	930–970
Sandstone, light pink, clean, of fine grains	970–1000
Mount Simon sandstone:	
Sandstone, buff, rather coarse, rounded grains	1235
Sandstone, white and buff (rusted), grains up to 1.2 mm. at 1255 feet, rounded; 3 samples	1235–1300

Notes.—The three wells whose logs are given above are sunk in the fill of an ancient channel of Mississippi river. Its maximum depth as here disclosed is about 160 feet below the present water surface. It will be noted that the fill consists of river deposits only—no glacial till is present.

By this ancient erosion channel, the Galena and Platteville limestones are entirely cut away, and the Saint Peter also in the Ice Company's well; while only a trace remains in the well at 8th and White Streets. In the Eagle Point well, the Saint Peter is 139 feet thick. Here the ancient channel is more shallow, and the highly irregular bed of the sandstone descends 70 feet below its level at Eighth and White Streets. In the well at Schmidt Brewery[49] the the Saint Peter was struck at about its level in the Eagle Point city wells, and was found to be overlain by 66 feet of limestone and dolomite of the Platteville, while the base of the sandstone was approximately at the same level as in the Eighth and White Streets well.

In the Eagle Point well the unconformity at the base of the Saint Peter cuts deep into the Prairie du Chien, leaving it here but 93 feet thick.

It is of special interest that the Jordan sandstone, one of the chief aquifers of the Upper Mississippi artesian field, is here fine of grain, largely calciferous, and yields little or no water.

The Saint Lawrence runs true to type, presenting first the body of dolomite, which the Wisconsin Geological Survey has called the Trempealeau, and second the body of shales and shaly sandstones of finest grain, in many instances glauconitic, designated by the same Survey as the Franconia.

In strong contrast to these beds is the clean, water-bearing Dresbach sandstone which underlies them.

Until now the Iowa Cambrian beds beneath the Dresbach have been undifferentiated, but we may follow again the Wisconsin geologists in designating the beds present in the Dubuque wells as the Eau Claire and the Mount Simon. The Eau Claire consists here of shaly sandstones and sandy shales overlying the clean sandstones of coarser grain of the Mount Simon. The same succession obtains widely in northeastern Iowa, in the well-sections of McGregor, Manchester, Anamosa, Clinton and Tipton, and in southern Minnesota also.

In City well no. 5 the cuttings from 1147 to 1350 feet are deeply rusted. Magnetic iron, doubtless from the drill, bespeaks special wear by some hard substance. The contractor reports especially slow drilling here and that more time was taken in drilling this distance of 203 feet than in drilling all the remainder of the well. The steel bit became deeply grooved. The cuttings show little flint, and this brittle though hard substance rarely gives much trouble. Pyrite, the only other common hard mineral

49 Iowa Geol. Survey, vol. XXI, p. 384.

to be expected, is suggested by the presence of iron oxide in large amount, since grains of iron sulphide, especially if in the form of marcasite, might be altered to limonite under the conditions which obtained, since the cuttings taken from the slush bucket were kept wet for months in glass jars. No pyrite is found now in the samples of the cuttings, but the blue print made by the engineer in charge records between the depths mentioned "intermittent thin layers of iron pyrites imbedded in flint."

It is the belief of the contractor, however, that some hard substance was struck which followed the tools down, grooving the tempered edge of the bit when in the right position at the bottom of the well, a mass which did not change its shape or wear out, but at last was pounded into the walls of the drill hole.

Pyritiferous beds "in which pellets and crystals of iron sulphide constitute a considerable portion of the material" are reported from the Eau Claire horizon in southern Minnesota.[50]

DYSART, TAMA COUNTY

(Altitude 973 feet)

The city well of Dysart was drilled about 1917 and is 1600 feet in depth, with a diameter from top to bottom of 10 inches. On completion the static level was 120 feet below the surface and the pumping capacity 60 g.p.m. Both have remained unchanged to the present time. There is no draw down under continuous pumping. The quality of the water is reported as soft. No log has been preserved of the well. At Dysart the Saint Peter sandstone is to be expected at about 300 feet below sea level, or 1275 feet in round numbers below the level of the railway station. The well probably draws on the Prairie du Chien as well as the Saint Peter, and possibly enters the Jordan sandstone.

ELKADER

WELL OF TOWN OF ELKADER, 1927

This well, 659 feet deep, was drilled by C. W. Varner, Dubuque. The diameters are from 15 to 10 inches. The main supply was found from 350 to 400 feet, and other water beds were struck at 175, 350 and 550 feet. The static level was estimated to be about

50 Hall, Meinzer and Fuller, U. S. Geological Survey, Water Supply Paper no. 256, p. 48.

20 feet above the curb. The well discharges under natural flow 190 g.p.m. This and the two wells of the town already in use discharge into a surface reservoir about 300,000 gallons in 24 hours. The well is cased with 65 feet of 12 inch pipe and 216 feet of 10 inch pipe, "separating the flow from the Saint Peter sandstone."

The cost of the well was $5,950.

Record of strata, Elkader well, 1927

	Depth in Feet
Soil	0–5
Galena limestone (60 feet thick, top 733 feet above sea level):	
Limestone, yellow-gray, rapid effervescence in cold dilute HCl	5–50
Limestone, blue-gray, rapid effervescence	50–65
Decorah shale (25 feet thick):	
Shale, light blue-gray, in concreted masses; limestone, yellow-gray, reaction rapid; gray chert; pyrite	65–90
Platteville limestone (48 feet thick):	
Limestone, blue-gray, rapid effervescence, fossiliferous, in flaky chips	90–138
Glenwood shale (7 feet thick):	
Shale, hard, green-gray, laminated	138–145
Saint Peter sandstone (30 feet thick, top 593 feet above sea level):	
Sandstone, white, grains well rounded, frosted, up to 1 mm. diameter; much fine material of broken grains	145–175
Prairie du Chien (315 feet thick; top 563 feet above sea level):	
Dolomite, yellow-gray, cherty at 200 feet; 3 samples	175–215
Dolomite, gray, some closely and minutely vesicular, considerable quartz sand in cuttings	215–230
Dolomite, brown	230–250
Dolomite, yellow-gray, cherty	250–270
Dolomite, whitish, some quartz sand	270–300
Dolomite, gray, cherty at 360; 4 samples	300–380
Dolomite, brown, cherty	380–400
Dolomite, yellow-gray, buff at 470, slightly cherty at 400, considerable quartz sand at 450; 4 samples	400–490
Jordan sandstone (40 feet thick; top 248 feet above sea level):	
Sandstone, white, grains rounded, frosted, larger up to 1 mm. diameter, most of material fine or broken grains	490–500
Sandstone, rusted to light yellow, very fine, "hard"	500–510
Sandstone, light yellow, very fine, irregular grains, dolomitic cement; in chips and sand	510–530
Saint Lawrence, Trempealeau dolomite (penetrated 80 feet or more; top 208 feet above sea level):	
Dolomite, gray, in chips; quartz sand in cuttings	530–550
Shale, gray, in friable concreted masses, dolomitic, highly arenaceous with minute angular grains of quartz	550–570
Dolomite, yellow-gray, in clean chips; 2 samples	570–610
No samples, reported to be no change in material	610–659

*Mineral Content of City Well, Elkader**

	P.P.M.
Bicarbonate	319.6
Chloride	4.
Sulfate	47.4
Silica	8.4

* Analysis by Dr. Harry F. Lewis, Chemical Laboratory, Cornell College, Mount Vernon, 1927.

$Fe_2O_3+Al_2O_3$	2.6
Calcium	66.4
Magnesium	42.6
Na + K as Na	14.8
Total solids	346.0

FAIRFIELD

(Altitude 766 feet)

WELL OF JEFFERSON COUNTY GAS, OIL AND MINERAL COMPANY

This well was sunk in 1910 about one-quarter mile east of the business center of Fairfield by J. D. Shaw of Davenport. The depth is 1685 feet or more and the diameters are from 12 to 8 inches. The main flow was struck at 1135 feet and other water beds were found at 200 and 500 feet. The head of water is 88 feet from the surface (680 feet above sea level).

A few samples of the cuttings were obtained and are described as follows:

Record of Strata

	Depth in Feet
Mississippian, Meramec, Osage and Upper Kinderhook:	
Limestone, blue-gray in mass, fine-grained, earthy, rapid effervescence in cold dilute HCl	150
Chert, white and blue; chalcedonic silica; some limestone as above	210
Limestone, light blue and yellow-gray, macrocrystalline, rapid effervescence; limestone, magnesian, buff, fine crystalline-granular, rather slow effervescence; much bluish chert	275
Chert and limestone, whitish	310, 345
Kinderhook shale (250 feet thick; top 180 feet above sea level, bottom 70 feet below sea level):	
No samples except the following	600–850
Limestone, blue-gray, earthy, argillaceous, siliceous, reaction rapid	815
Silurian:	
Limestone, light brownish gray, compact; gypsum plentiful, in white chips	940
Limestone and gypsum as above; gypsum in small amount	1000
Galena-Platteville:	
Dolomite, light yellow-gray and blue-gray, in chips	1100
Dolomite, buff, in fine sand	1135
Dolomite, yellow-gray, in fine chips	1400
Glenwood:	
Shale, bluish green and drab, in flakes and moulded masses	1450
Saint Peter, sample, 714 feet below sea level:	
Sandstone, white, fine, Saint Peter facies	1480
Prairie du Chien:	
Dolomite, gray, cherty; some fissile shale	1530, 1680
Dolomite, light yellow-gray, cherty; considerable quartz sand of rounded grains	1685

WELL OF THE FAIRFIELD PURE ICE COMPANY

This well, 1325 feet deep, was completed in 1912 by J. E. Foss of Washington, Iowa. The diameters are from 10 to 6 inches. The chief supply was found at 1275 feet in "sandstone" unusually soft and easily drilled. The capacity of the well under an air compressor was found to be 100 gallons per minute maintained for 18 hours without lowering the water below its static level of 116 feet from the surface of the ground.

Samples of the cuttings were taken by the company "when we met with different formations" and the following description of them is furnished by the manager.

"No. 1, 500 feet, Gray limestone
No. 2, 550 feet, Brown limestone
No. 3, 575 feet, Gray limestone
No. 4, 600 feet, Blue shale
No. 5, 725 feet, Black shale
No. 6, 760 feet, Blue shale
No. 7, 800 feet, Black shale
No. 8, 825 feet, Blue shale
No. 9, 850 feet, Brown limestone
No. 10, 900 feet, White limestone, continuing to
No. 11, 1125 feet, St. Peter sandstone, from 1125 to 1325 feet."

FORT DODGE

(Altitude 1111 feet, C. G. W. R. R.)

*Record of Strata of City Well No. 4**

Located on Duck Island in Des Moines river. Altitude of city well is about 6 feet above river level or about 976 feet above sea level.

	Depth in Feet
Sand and cobbles, size of walnut to baseball	0–20
Blue clay	20–35
Red shale or clay, called fire clay by driller	35–70
White shale	75–105
Lime rock, gray or brown	105–125
Lime rock, brown	125–220
Sand rock	220–328
Limestone, in fine powder, gray-buff, effervescence very ready with cold HCl; considerable residue	357–360
Limestone, gray, in coarse powder and small chips which show granular, sugary surfaces; effervescence slight in cold HCl, rapid in hot acid	365
Limestone, in gray powder, sugary fracture, response with cold HCl fairly ready, more so with hot HCl	370
Limestone in fine light gray powder, some clear, translucent sand grains present. Responds very readily to cold HCl	375
Limestone, in coarse dark gray powder and fragments, fractured faces dull, lusterless, a few small sparkling fragments of calcite. Response to cold acid fairly ready, considerably accelerated on slight application of heat. One lump of light gray dolomite enclosed	380
Sample similar to that at 380, with some small fragments of light gray limestone	385

* By Dr. James H. Lees, Assistant State Geologist.

Limestone in light gray, fine powder, responds to acid very readily after slight heating. Small concreted masses readily friable. Powder almost entirely soluble	390
Limestone, powder slightly darker than at 390, effervescence slightly less ready	395
Very similar to 390, small insoluble residue of sand grains	400

*Record of Strata of City Well No. 5**

	Depth in Feet
Shale, dark gray, very finely gritty, no response to acid; at 30 feet contains some small rounded pebbles which evidently are of foreign origin; 3 samples	0–30
Limestone, gray, in small chips, easily attacked by acid; much fine residue apparently of quartz, together with some larger grains	30–40
Shale, dark gray, very finely gritty, some slightly calcareous, a few fragments of limestone at 70 and 120 feet; 8 samples	40–120
Limestone, gray, powder reddened by iron rust. Ready effervescence	120–125
Shale, light gray, limy; 2 samples	125–140
Limestone, dark and light gray, in fine chips, grains and powder, pyrite, ready effervescence, magnesian 400 to 450 feet, chert at 410, clayey residue at 468; 33 samples	140–468
Shale, blue-gray, very slightly calcareous, finely gritty; 3 samples	468–490
Limestone, drab and blue-gray, in small chips; almost no response to cold acid, vigorous effervescence in hot acid; 2 samples	490–510
Limestone, bluish gray, rapid effervescence; 4 samples	510–550
Limestone, light gray, subcrystalline, strongly magnesian, in small sand, fragments present many glistening facets	550–560
Limestone, light gray, bluish at 590, in very fine sparkling sand, freely effervescing; 3 samples	560–590
Limestone, like the preceding, but quite magnesian; 2 samples	590–610
Limestone, medium dark to bluish gray, fine powder, free effervescence; 2 samples	610–624

Drillers' Log, City Well No. 6

	Depth in Feet
Surface	0–16½
Shell rock	16½–18
Soft shale	18–78
Lime rock, small amount of water	78–110
Shale and slate, cavy	110–167
Sandstone	167–188
Red shale	188–224
Lime rock	224–227
Shale	227–252
Lime rock	252–257
Sand rock	257–264
Lime rock	264–283
Shale, entered at	283

Driller's Log, City Well No. 7

	Depth in Feet
Surface	0 – 19
Red shale	19 – 33
Lime rock	33 – 37
Red and blue shale	37 – 62
Lime rock	62 – 73
Sand rock, small flow	73 – 80
Lime rock	80 –123

* By Dr. James H. Lees, Assistant State Geologist.

Shale	123 –126
Soft limestone	126 –163
Very hard lime rock	163 –200
Limestone	200 –299½
Rock, very difficult drilling	299½–309
Limestone	309 –315½
Sandrock (increased flow)	315½–427
Blue limestone	427 –448
Blue limestone	448 –468
Limestone	468 –473
Limestone (increased flow)	473 –485
Blue shale	485 –498

Record of Strata, City Well No. 8

	Depth in Feet
Mississippian:	
Dolomite, buff, limestone, buff and light gray; shale	53
Shale, drab and purplish; a very little limestone; "mixed with cave;" 3 samples (Pella beds?)	150–170
Shale, light greenish yellow; limestone, rapid effervescence in cold dilute HCl	180
Shale, light greenish gray; much finely divided cryptocrystalline silica; pyrite; a flake or so of selenite	190
Limestone, dolomite, buff, slow effervescence; limestone, lighter colored, rapid effervescence	200
Limestone, gray, oölitic, rapid effervescence; shale	210
Limestone, gray; much finely divided cryptocrystalline silica; pyrite; shale	220
Limestone, buff, rather rapid reaction, crystalline-granular, in coarse chips	230
Limestone, gray, rapid reaction, in fine meal; sandstone, fine, grains ill-rounded; quartz crystals; much cryptocrystalline silica	240
Limestone, light buff and light gray, rapid response; 3 samples	250–270
Shale, greenish	280
Limestone, light cream colored, oölitic, rapid effervescence	290, 300
Limestone, light yellow-gray; macrocrystalline, rapid reaction	310
Dolomite, buff, in fine sand; some light yellow-gray limestone of rapid effervescence, in larger chips	320, 330
Limestone, gray and buff, fine-grained, rapid reaction	340, 350
Limestone, buff, dolomitic, response slow and rather slow; some rapid	360, 370
Limestone, light gray, rapid reaction	380
Limestone, drab, fine-grained, rather slow reaction	390
Limestone, buff and light yellow-gray, fine-grained, rapid response	400, 410
Limestone, light yellow-gray, rather rapid effervescence	420
Dolomite, brown gray, fine crystalline-granular; gray chert; 3 samples	430–450
Chert and limestone, gray	460
Limestone, brown, fine-grained, earthy	470
Limestone, light yellow-gray	480
Shale, blue-gray, calcareous, in hard moulded masses	490
Limestone, light yellow, reaction rapid, in sand concreted with shale	500
Shale, yellow-gray, in concreted masses	510
Dolomite, light buff, in fine crystalline sand, with much shale	520
No samples	530, 540
Devonian and Silurian (360 feet thick; top 456 feet above sea level):	
Limestone, gray and buff; some chips of shale; 3 samples	550–570
Dolomite, light buff, subcrystalline	580, 590
Dolomite, whitish and light blue-gray, crystalline; 4 samples	600–630
Limestone, blue and yellow-gray, crystalline, rapid reaction, large flakes	640, 650
Limestone, buff, gray and brown, rapid effervescence	660
Dolomite, gray, fine crystalline-granular, soft	670, 680
Shale, greenish, slightly calcareous; whitish masses of powdered limestone	690

Dolomite, blue-gray, some laminated, compact, argillaceous 700
Dolomite, yellow-gray, crystalline 710
Shale, blue-green, fissile, with small chips of crystalline dolomite 720
Dolomite, blue and yellow-gray, fine crystalline; much blue-green shale 730, 740
Dolomite, buff and blue-gray, in sand; some blackish inflammable shale in fine grains 750, 760
Dolomite, gray 770
Dolomite, gray, some blackish inflammable shale 780, 790
Limestone, magnesian or dolomite, gray-buff, rather slow effervescence 800
Limestone, gray and buff, rapid effervescence 810
Limestone, magnesian, or dolomite, drab, buff and gray, rather slow reaction; some limestone, response rapid; 4 samples 820–850
Dolomite, gray, in fine sand; speckled with grains of blackish shale, non-inflammable, but giving distillate of oil 860
Dolomite, buff and light blue-gray; some limestone 870
Limestone, buff and light yellow-gray, rapid effervescence; some rounded grains of quartz sand 880

Ordovician:

Maquoketa shale (210 feet thick; top 96 feet above sea level)—
- Shale, blue and blue-green, calcareous, laminated; 4 samples 890–920
- Limestone, buff, crystalline, argillaceous, rapid reaction; considerable shale in powder 930, 940
- Dolomite, brown 950
- Dolomite, buff and blue-gray, in sand; some whitish limestone; considerable shale in flakes; 3 samples 960–980
- Shale, greenish blue, soft, in flakes 990
- Shale as above, with some sand of dolomite and white chert 1000, 1010
- Dolomite, buff, in sand; some shale 1020
- Shale, greenish, in flakes, sand of buff dolomite; whitish limestone; cinders 1030
- Shale, drab 1040
- Shale, drab; buff dolomite, effervescence rather slow, in sand 1050
- Dolomite, rather slow reaction, buff 1060
- Dolomite, gray, much white and gray chert; shale, dark drab and gray; quartz sand in rounded, corroded grains 1070
- Dolomite, light buff 1080
- Shale, greenish drab, plastic; white decayed chert 1090

Galena-Platteville (240 feet thick; top 114 feet below sea level)—
- Dolomite, blue-gray, cherty; 7 samples 1100–1160
- Shale, drab, calcareous, with dolomite and chert, in sand 1170
- Dolomite, blue-gray, cherty 1180
- No samples 1190, 1200
- Dolomite, blue-gray 1210, 1220
- Dolomite, gray; much chert; some whitish limestone 1230, 1240
- Dolomite, rusted brown, in sand, a little chert 1250
- Dolomite, buff; some whitish limestone 1260
- Dolomite, heavily rusted; 4 samples 1270–1300
- Dolomite, light buff and gray, in sand 1310
- Dolomite, blue-gray; white chert 1320
- Dolomite, buff, in crystalline sand; a very few rounded grains of quartz 1330

Glenwood shales (40 feet thick; top 354 feet below sea level)—
- Shale, blue-green, in hard moulded masses and flakes; with some chips of blue-gray subcrystalline laminated dolomite; 3 samples 1340–1370

Saint Peter sandstone (penetrated 30 feet; top 394 feet below sea level)—
- Sandstone, Saint Peter facies, rusted; chips of hard blue-green shale 1380, 1390
- Sandstone, clean, light yellow in mass, larger grains up to 0.7 mm. in diameter 1400, 1410

*Record of Strata from Well No. 1 of Beaver Products Company, Fort Dodge**
Well at Mill. (Altitude about 1115 feet)

	Depth in Feet
Clay, gray, pebbly, calcareous, glacial till; 4 samples	0–40
Sand, light gray, medium fine-grained, concreted into lumps; noncalcareous. Some of the grains appear to be of gypsum	40–50
Sand, light gray, fine powder to grains ⅛ inch in diameter, concreted by calcareous powder. Some grains appear to be of gypsum. Some are too dark	50–60
Clay or shale, reddish or pale wine color, fine textured, but with minute sand grains and mica specks; noncalcareous	60–70
Shale, black, fine textured, smooth feel, somewhat calcareous	70–80
Shale, limy, or limestone, in grains most of which are black, a smaller number white. Some of the latter are strongly effervescent while others are not. Evidently the sample represents black shale with white streaks and with some bands of limestone. The white grains are not gypsum. Some of the black grains are concreted by a calcareous powder	80–90
Shale, black and gray, smooth textured, slightly calcareous	90–100
Shale, dark gray, gritty, calcareous; some black grains and some white ones, these latter noncalcareous; 2 samples	100–120
Shale, dark gray, reddish at 150 to 190, smooth textured, strongly calcareous, grains of limestone at 170; 7 samples	120–190
Limestone, gray, with some red and some black grains; strongly calcareous	190–200
Sandstone, reddish, very fine-grained	200–210
Limestone, gray in washed sample, reddish tinge perhaps due to shale above; mostly soluble in acid; a fragment of blue-gray, calcareous shale in sample at 240; 3 samples	210–240
Sandstone, reddish gray; fragments of limestone and red calcareous shale	240–250
Shale, red, or shaly limestone, in flakes and grains; some fragments of gray limestone and shale; all calcareous; 4 samples	250–290
Limestone, gray, in powder, fine grains, small chips and angular fragments; many granules of white or translucent chert at 320 feet, some at 360 feet and below; 11 samples	290–400
Sandstone, gray, fine-grained, some calcareous cement; 2 samples	400–416

WELL NO. 2 OF BEAVER PRODUCTS COMPANY

This well was drilled by Thorpe Bros. Well Co. of Des Moines in 1924. The depth is 450 feet, the diameters are 12 to 6 inches. Water was found at 100 and 400 feet, the latter being the principal supply. Water rises within 80 feet of the surface. The pumping capacity is about 25 gallons per minute, with the pumping cylinder set at a depth of 250 feet. The water is softened for boiler use.

WELL NO. 3 OF BEAVER PRODUCTS COMPANY

This well was completed in July, 1925, and was drilled by Thorpe Brothers of Des Moines. The elevation of the curb is 1114 feet above sea level. The diameter is 12 inches at the top and 6 inches at the bottom. Twelve inch casing extends to 205

* By Dr. James H. Lees, Assistant State Geologist, from samples submitted by the driller, J. J. Becker of Garner.

feet, 10 inch from 194 feet to 365 feet, 8 inch from 590 feet to 688 feet, and from 1434 feet to 1510 feet, 6 inch from 1485 to 1580 feet. Packing is set at 688 feet and at 1535 feet.

The principal supply of water was found in the Saint Peter sandstone from 1525 to 1586 feet. Water was found also in the Shakopee dolomite and the New Richmond sandstone.

On completion the water stood 62 feet below the curb, a static level which it has maintained to date. Before the Saint Peter aquifer was struck the water in the well headed about 50 feet below the surface.

The pumping capacity of the well is 275 gallons per minute with the cylinder set 132 feet below the surface. Continuous pumping does not draw down the head.

The temperature is 56° Fahr. The water is reported to have no bad effects on boilers. The cost of the well was $13,000.

*Analysis of Water**

	Grains per U. S. Gallon
Volatile and organic matter	.25
Silica	1.55
Oxides of Iron and Aluminum	trace
Calcium oxide	8.96
Magnesium oxide	4.44
Sodium oxide	4.03
Sulphuric anhydride	10.24
Carbonic anhydride (fixed)	8.93
Chlorine	.35
Hardness as $CaCO_3$	27.10
Suspended matter (mostly iron)	.35
Alkalinity as $CaCO_3$	20.30
Probable combinations	
Volatile and organic matter	.25
Silica	1.55
Calcium carbonate	16.00
Magnesium carbonate	3.61
Magnesium sulphate	8.16
Sodium sulphate	8.52
Sodium chloride	.58
Total solids	38.67

Record of Strata of Well No. 3 of Beaver Products Company

	Depth in Feet
Pleistocene and Recent (45 feet thick; top 1114 feet above sea level):	
Till, drab with a light yellowish tinge, predominantly clayey; 4 samples	10-40
Permian, Fort Dodge beds ("45 to 61 feet"):	
Gypsum, white and gray; limestone, buff; blue shale; much varicolored quartz sand, pebbles of drift	50, 60

* By Wm. B. Scaife & Sons Co.

Pennsylvanian, Des Moines series (89 feet thick; top 1053 feet above sea level):	
Shale, dark blue, some red, plastic, noncalcareous	70
Shale, black, turns gray before the blowpipe; 2 samples	80, 90
Shale, dark gray	100
Shale, blackish; 4 samples	110–140
Mississippian (520 feet thick; top 964 feet above sea level):	
Pella beds (60 feet thick)—	
Shale, reddish and gray; and limestone, gray, rapid effervescence, in chips and powder; with a little coal	150
Shale, red, plastic; 4 samples	160–190
Shale, red with other colors, with limestone in chips	200
St. Louis beds (120 feet thick)—	
Limestone, white, earthy, rapid effervescence in cold dilute HCl, in flaky chips	210
Limestone, light buff, fine-grained, compact, argillaceous, moderately slow reaction, some rapid; with bluish chert, and some gray argillaceous sandstone of fine grain; 3 samples	220–240
Limestone, as at 210	250
Limestone, blue-gray, crystalline-earthy, argillaceous, reaction rapid	260
Limestone, yellow-gray and buff, fine-grained, earthy, or crystalline-granular, response moderately slow; 3 samples	270–290
Limestone, light blue, argillaceous, crystalline-earthy, rapid effervescence, with considerable pale yellow crystalline quartz	300
Limestone, gray, soft, earthy, rapid effervescence; 2 samples	310, 320
Kinderhook stage (340 feet thick)—	
Limestone, blue-gray, fossiliferous, rapid reaction, in flaky chips with considerable chalcedony and crystalline quartz intercrystallized with calcite	330
Limestone, calcilutite, light yellow-gray	340
Limestone, whitish, macrocrystalline, in large flaky chips, rapid effervescence, with some oölite	350
Limestone, whitish or light yellow-gray, fine crystalline-granular, rapid reaction, in flaky chips; 5 samples	360–400
Limestone, light yellow-gray, macrocrystalline-earthy, rapid response	410
Shale, blue, in flakes; and sandstone, gray, fine, ill-rounded grains, argillaceous, calciferous, pyritiferous; some limestone	420
Limestone, light yellow-gray, effervescence rapid; with white cryptocrystalline silica and grains of quartz sand; some pyrite	430, 440
Limestone, blue-gray, macrocrystalline, pyritiferous, rapid effervescence; and shale	450, 460
Limestone, white, soft, earthy, rapid reaction, in large flaky chips, gray, macrocrystalline at 490 and 500; 4 samples	470–500
Limestone, gray, crystalline-granular, some rapid, some slow effervescing; in sand and small chips; 2 samples	510, 520
Limestone, yellow-gray, soft, earthy, rapid response, flaky chips; 2 samples	530, 540
Limestone, gray, a calcilutite, rapid effervescence, large chips	550
Limestone, buff, rapid reaction; with white chert	560
Limestone, gray, fine granular, moderately slow reaction; with much white chert; 3 samples	570–590
Limestone, gray, rapid response; some white chert	600
Limestone as above, gray shale, much pyrite, a little quartz sand in fine grains, cuttings in sand	610
Shale, blue, plastic, calcareous; 2 samples	620,630
Limestone, blue-gray, reaction slow; and shale, greenish and drab, some blackish, with pyrite; 2 samples	640, 650
Shale, blue-green, plastic, calcareous	660
Devonian (190 feet thick; top 444 feet above sea level):	

Limestone, light yellow-gray, crystalline-granular, slow reaction, in chips	670
Limestone, buff, rapid effervescence, in sand and small chips	680
Limestone, buff and blue-gray, moderately slow	690
Limestone, blue-gray and light yellow-gray, crystalline-granular, moderately slow reaction, some buff and rapid	700
Limestone blue-gray, coarse-granular, moderately slow response	710
Limestone, blue-gray, coarse-granular, rapid reaction; 2 samples	720, 730
Dolomite or magnesian limestone, blue-gray or light yellow-gray, much in crystalline sand; 7 samples	740–810
Limestone, blue (at 850 light yellow-gray), moderately slow response, crystalline-granular; and much highly argillaceous limestone, hard, dark bluish, in small chips; 3 samples	830–850
Silurian (140 feet thick; top 254 feet above sea level):	
Limestone, light yellow-gray, fine crystalline-granular, effervescence moderately slow; 2 samples	860, 870
Dolomite, brown or buff, cherty at 930 and 940, in sand; 11 samples	880–980
Limestone, yellow-gray and brown, in small chips and sand, rapid reaction	990
Ordovician:	
Maquoketa shale (190 feet thick; top 114 feet above sea level)—	
Limestone, dark blue with moderately slow effervescence and light brown with rapid reaction; and shale, drab, hard, in chips; 2 samples	1000–1010
Limestone, drab and light gray, some mottled, earthy, some macro-crystalline-earthy, rapid response, in large thin chips; 4 samples	1020–1050
Limestone, brown, rapid effervescence	1060
Limestone, brown, some rapid reaction, mostly moderately slow, in sand	1070
Limestone, light yellow-gray, earthy, moderately slow response, in small chips	1080
Limestone, blue, argillaceous, moderately slow response, in small chips	1090
Limestone, light buff, earthy, moderately slow reaction, with some light greenish shale	1100
Limestone, light drab, earthy, moderately slow effervescence, hard, in small chips and sand; 6 samples	1110–1160
Shale, greenish, with a little brown inflammable and drab limestone as above	1180
Galena and Platteville limestones (thickness 310 feet, top 76 feet below sea level)—	
Dolomite, brown, subcrystalline, in small chips, with much white chert	1190
Dolomite, as above, with considerable greenish shale	1200
Dolomite, drab, cherty, with some powder of shale; 2 samples	1210, 1220
Dolomite, buff, in sand and meal, with some powder of shale	1230
Dolomite, buff and gray, cherty at 1240, 1330, 1340; argillaceous at 1270; 16 samples	1240–1390
Limestone, gray, rapid response, in small chips; 2 samples	1400, 1410
Limestone, gray, with some shale	1420
Shale, green, plastic, with some argillaceous limestone	1430
Limestone, brown, fossiliferous, crystalline-granular, some green shale	1440
Limestone, yellow-gray, rapid effervescence	1450
Shale, bright green, plastic	1464–1478
Limestone, whitish, fossiliferous, soft, earthy, rapid effervescence, in flaky chips; with much green shale; 2 samples	1480, 1490
Glenwood shale (20 feet thick; top 386 feet below sea level)—	
Shale, green, some brown at 1510; 2 samples	1500, 1510

Saint Peter sandstone (75 feet thick; top 406 feet below sea level)—
Sandstone, moderately fine, of usual Saint Peter facies, white except as rusted in container, with much green shale at 1520, 1580 and 1595; 8 samples 1520-1595
Shakopee dolomite (55 feet thick; top 486 feet below sea level)—
Dolomite, no samples, cuttings washed away 1600–1665
New Richmond sandstone—
Sandstone, white, moderately fine, rounded grains of pure quartz, to bottom of well 1665–1669

Driller's Log, Well No. 3, Beaver Products Company

Formation	Thickness feet	Depth feet
Dirt and clay	45	45
Gypsum rock	16	61
Shale	77	138
Limestone	17	155
Red shale	28	183
Limestone	3	186
Red shale	18	204
Limestone	86	290
Shaly limestone	35	325
Limestone	283	608
Shale	32	640
Limestone	15	655
Shale	10	665
Limestone	799	1464
Shale	12	1476
Limestone	18	1494
Shale	30	1524
Saint Peter sandstone	62	1586
Limestone	9	1595
No samples, open limestone	60	1655
New Richmond sandstone	14	1669

Notes.—This well on the upland penetrates higher beds than the city wells located on the Des Moines valley floor. The Pleistocene till is probably underlain by thin glacial sands and gravels not represented in the samples of the cuttings nor in the driller's log, but furnishing drift sand and gravel to the underlying cuttings at 50 and 60 feet. Some of the white sand of the cuttings of the Fort Dodge beds may be derived from an incoherent sandstone of that formation.

The section through the Coal measures and the Pella beds conforms to that of the local outcrops.

The characteristics of the Saint Louis beds are pretty clearly exhibited from 210 to 250 feet, and the argillaceous limestones from 300 to 320 feet are included in this formation with less evidence. This is also a distinctly argillaceous horizon in city well no. 1.

The upper limestones referred to the Kinderhook, some of them oölitic, perhaps represent the Alden beds. The base of the Kinderhook and the summit of the Devonian might be expected to be marked by distinct and heavy shales. Such, however, are reached only in shales and shaly limestones from 610 to 670 feet. This is also a particularly well marked horizon in city wells no. 1, no. 7 and no. 8. If this is taken as the base of the Mississippian it gives it an extravagant thickness. It may be assumed that these shaly beds represent the Sheffield shale of Franklin county, which, it must be remembered, while provisionally referred to the Kinderhook, may be shown by more thorough investigation in the field to be Devonian. Lithologically the limestones above this shale as high as 604 feet above sea level might also be Devonian. But if the Devonian begins at this height (510 feet deep) the shales from 610 to 670 feet are left in the middle of the Devonian instead of at either top or bottom where they should be expected.

The underlying dolomites, with some limestones, correspond stratigraphically with the beds at Webster City, which are pretty clearly defined as Silurian by their gypsum content.

The Maquoketa shale probably is represented by the earthy, argillaceous limestones with some shale occurring from 1000 to 1190 feet, although the samples afford no "mud rock shale," pounded into plastic clay under the drill, and the driller's log reports no shale between these limits. The lower limit of the Maquoketa is uncertain, as the upper beds of the Galena may be argillaceous. The unwashed samples from city well no. 1, described in the Report on the Underground Waters of Iowa, 1912, and the samples of well no. 8, show this horizon much more clearly. The underlying formations are plainly demarked.

The driller's log, which no doubt gives closer measurements than the sample cuttings, states that the Saint Peter is 62 feet thick and the subjacent limestone, the Shakopee, is 69 feet thick.

WELLS OF L. E. ARMSTRONG

In May, 1927, Mr. Armstrong had drilled on his farm in section 31, Cooper township, about a mile west of Fort Dodge, a well 407 feet deep. Water rose within 125 feet of the curb, which is about 1120 feet above sea level. The driller was J. J. Becker of Garner. In October, 1927, Mr. Becker drilled a second well for Mr. Armstrong, in the north half of the northeast quarter of section 35, Douglas township, two miles west of well no. 1. This well is 216 feet deep and water rises within 119 feet of the top, which is about 1130 feet above sea. In the following record samples from both wells are combined as indicated.

*Record of Armstrong Wells Nos. 1 and 2**

	Depth in Feet
Clay, gray, limy, probably glacial till (No. 2)	50
Shale, red with light blue streaks, limy, Coal Measures (No. 2)	80
Shale, similar to above (No. 2)	110
Shale, black, some fragments of coal (No. 1 ?)	125
Shale, red, like that at 80 feet (No. 2)	130
Shale, like that above (No. 2)	150
Shale, like above	165
Shale, like above	180
Shale, like above	190
Shale, light pinkish tan, limy	200
Shale, light tan, similar to above	205
Sandstone, fine-grained, with some shale	215
Sandstone, fine, white grains, red shale. Last sample marked "No. 2"	216
Shale, dark gray	225
Shale, black, very fine, marked "thickness 2 feet"	240
Shale, dark gray to black, numerous pebbles of various kinds which look like glacial gravel	260
Shale, red, limy, with mixture of pebbles as above	270
Shale, red as above	290
Shale, red like above but few pebbles	310
Shale, red, similar to above	320
Shale, similar to above	330
Sandstone, very fine colorless grains, pinkish from iron stain or shale	340
Sandstone, like above	350
Sandstone, like above, but tan color	360
Sandstone, like above	370
Sandstone, like above	380
Limestone, gray, powder to rather coarse crystalline grains which respond readily to acid. Some sand	390
Limestone, similar to above	400
Limestone, similar to above. These last three samples are St. Louis limestone	407

WELL OF FREDERIC LARRABEE

In May, 1927, Mr. Larrabee had drilled by Mr. J. J. Becker a well on his farm in the northwest quarter of section 13, Douglas township, two miles northwest of Fort Dodge. The well is 315 feet deep, the altitude about 1100 feet and water stands 100 feet below curb. The description of the samples follows. Probably all below the first one represent St. Louis limestone.

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* By Dr. James H. Lees, Assistant State Geologist.

*Samples from well of Frederic Larrabee**

	Depth in Feet
Gravel or coarse sand, clean, gray, with fine sand mixed	90
Limestone, dark gray, fine-grained to sugary texture	100
Sandstone, fine-grained, gray, with abundant limestone, perhaps as cement	110
Sandstone, coarse to fine, light gray; limestone in chips and powder, gray	120
Sandstone, very fine-grained, light gray; much limestone, also fine powder	130
Sandstone, similar to above	140
Shale, gray, almost gritless, somewhat limy	150
Sandstone, dark gray, rather fine-grained, much limestone in fine powder	160
Limestone, in powder and chips, light gray; considerable sand in small grains	170
Limestone, similar to above, a little sand and some clay	180
Limestone, dark gray, powder to chips, fine-grained for most part, some finely crystalline	190
Shale, dark gray, very finely gritty, limy	200
Limestone, dark gray, with some clay and chert	210
Limestone, light gray, fine-grained; some darker limy shale	220
Limestone, gray, very finely sugary; very ready effervescence in acid, nearly all soluble. Some shale, may be from above	230
Limestone, very shaly, dark gray, in soft powder and chips; ready action in acid but much residue	240
Limestone, light gray, in finely gritty powder, nearly all soluble in acid	250
Lmestone similar to above but in coarser grains. A little residue of clear grains, probably chert	260
Limestone and shale, gray, limestone in finely gritty powder, shale in chips	270
Limestone, light gray, entirely soluble in acid. In small fragments	280
Limestone, similar to above	290
Limestone, similar to above; some shale	300
Limestone, in nearly white, very finely gritty powder	310
Limestone, similar to above	315

GARRISON, BENTON COUNTY

(Altitude 863 feet)

WELL OF IOWA CANNING COMPANY

In 1926 a well at least 1435 feet deep was completed for this company by Charles D. Nolan of Cedar Rapids. The principal supply was found from 1375 to 1435 feet. During the drilling of the well, it is said, water stood about 12 feet below the curb until the main water bed was reached when it fell to 21 feet below the same level.

On testing the well yielded to the capacity of the pump, 125 gallons per minute, with the pumping cylinder set 80 feet below the curb and the draw down to 42 feet below the curb.

49 feet of 12 inch casing is set to rock, and 191 feet of 8 inch casing through the Maquoketa shales. The cost of the well was $8610.

* By Dr. James H. Lees, Assistant State Geologist.

Description of samples of cuttings from well of Iowa Canning Company, Garrison

	Depth in Feet
Dolomite, in fine buff sand	450
Shale, blue, calcareous (Maquoketa)	529, 545, 595
Limestone, nonmagnesian, Galena facies; 14 samples	690– 975
Dolomite, Prairie du Chien facies, some rounded grains of quartz sand, chert at 1095	1090–1095
Dolomite and sand, as above; some blue-green shale, slightly calcareous	1150
Shale, in light blue-gray concreted masses, highly dolomitic with minute crystals of dolomite; some fine quartz sand and flakes of blue-green shale	1225, 1235, 1255
Dolomite, some grains of quartz sand	1315, 1340
Dolomite and chert, oölitic, Prairie du Chien facies	1400

GLADBROOK, TAMA COUNTY

(Altitude 850 feet)

The city well of Gladbrook was completed in 1914 by E. A. Ford of Marshalltown. The depth is 828 feet and the diameters are 10 and 8 inches. The capacity of the well is 125 g.p.m. The well is cased with 10 inch pipe to 168 feet and with 8 inch pipe from 160 to 412 feet.

Driller's Log

	Depth, feet
Wisconsin and Kansan drift	0–168
Mississippian lime, solid	168–258
Mississippian lime and shale	258–400
Devonian lime	400–685
Silurian lime	685–828

GLENWOOD

(Altitude 1031 feet)

CITY WELL NO. 2

In April, 1925, a well now about 2200 feet deep was begun by the Layne-Bowler Chicago Company of Chicago. The diameters are from 16 to 6 inches. The city officials state that the official test of the well, when 1990 feet in depth, showed that the well could produce about 60 g.p.m., about the present yield of each of the two deep wells at Glenwood, the city well and that of the Institution for the Feeble-Minded. As the contractors had agreed to bring in a well producing 200 g.p.m., the city refused to accept the well and brought suit to recover $14,000 advanced to the company. The company later drilled some 200 feet deeper, without success, so far as known, and it is stated that no appreciable work has been done since 1926.

This instance illustrates the unwisdom of contracts guaranteeing a certain supply, even "where a geologist would be reluctant to assume any financial risk in the case."[51]

Even in well exploited artesian fields the utmost which the contractor should guarantee is good materials and workmanship. Any guarantee of a specific amount of water is specially unwise and should never be asked in areas whose deep geology and water resources are little known. The best that can be said of such contracts is that they tend to distribute the cost of occasional failures to the entire clientele.

The following data as to water were supplied by the late Seth Dean, city engineer.

Water Beds in City Well No. 2, Glenwood

Depth	Formation	Capacity, g.p.m.	Head below curb, feet	Draw down, feet
15	Blue clay		15	
75–80	Sand and gravel	29	38	26
525	Shale (Pennsylvanian), cased out	....	.....	....
630–640	Sandstone (Pennsylvanian), cased out	33	200	....
1065	Sandy limestone, cased out	....	125	....
1090	Sandy limestone, salt water rose from 165 to	....	140	....
1150	Hard limestone	....	133	....
1305	Mississippian	....	120	....
1345	Limestone	....	115	....
1600	Sandy limestone	....	75	....
1670	Sandy limestone	85	67	93

In the above table the formations are assigned on the basis of the section of the first deep well of Glenwood drilled in 1891.[52] In this well the Mississippian, reached at 1235 feet, extended probably at least to the base of a heavy shale at 1644 feet. The remainder of the well, 2000 feet deep, was attributed to the Silurian, because of the presence of gypsum from 1941 feet to the bottom, with the possible exception of some upper limestone which may be Devonian.

GOWRIE, WEBSTER COUNTY

(Altitude 1137 feet)

A deep well for the town of Gowrie was completed in March, 1926, by the Thorpe Brothers Well Company of Des Moines.

[51] Norton, W. H., Artesian wells of Iowa, Iowa Geol. Survey, vol. VI, p. 418.

[52] Underground Water Resources of Iowa, Iowa Geol. Survey, vol. XXI, pp. 1139, 1140, Pl. XVIII.

The depth is 1842 feet and the diameters range from 16 to 8 inches. Water was found from 500 to 600 feet in Mississippian limestones but the principal supply was struck from 1700 to 1785 feet in the Saint Peter and Upper Shakopee and at the bottom of the well. The static level is 81 feet from the surface. With the pumping cylinder set at 150 feet the pumping capacity is 300 gallons per minute. The cost of the well was $16,673.

Casing

Diameter in inches	Length in feet	Depth of bottom in feet
16	182	182
12	210	385
10	106	860
8	226	1300 (1st line) and 1678 (2nd line)
6	20	1693

Record of Strata

	Depth in Feet
Pleistocene and Recent (160 feet thick; top 1139 feet above sea level):	
Clay, brownish yellow, sandy, noncalcareous, with pebbles of drift, grass roots at 80 feet; 13 samples	0–130
Clay, as above, some masses of soft, decayed, buff limestone	140, 150
Pennsylvanian (230 feet thick; top 984 feet above sea level):	
Shale, hard, blackish, coaly on surface, 3 large chips	160
Shale, blackish and drab; 13 samples	170–310
Shale, blue and light blue-gray, calcareous, in moulded masses; at 350 feet when washed gives chips of soft, gray, earthy, argillaceous limestone; fine-grained sandstone; gray flint; pyrite; and some coarse grains of reddish silica 2 to 3 mm. in diameter; 7 samples	320–380
Mississippian (420 feet thick; top 749 feet above sea level):	
Limestone, light yellow-gray, very soft and friable, macrocrystalline-earthy, in large flakes; rapid effervescence in cold dilute HCl	390
Chert, blue-gray, in large chips; some limestone, gray, fine-grained, rapid effervescence	400
Limestone, buff, rapid effervescence, hard, fine-grained; shale, olive colored, noncalcareous, large chips	410
Limestone, as above	420
Limestone, light yellow-gray, encrinital; some limestone, hard, blue-gray	430
Limestone, cream colored, soft, earthy; limestone, gray, earthy, speckled, hard, pyritiferous; chalcedony, blue-gray	440
Limestone, yellow-gray, soft, earthy, with sporadic calcite crystals; some oölitic limestone; some yellow gray calcilutite; some shale	450
Limestone, buff, finely crystalline; yellow-gray calcilutite; gray chalcedonic silica	460
Chert, blue-gray; chalcedonic silica, gray; limestone, light yellow-gray, crystalline	470, 480
Limestone, blue-gray, light yellow-gray and mottled, soft, macrocrystalline	490
Limestone, whitish, macrocrystalline-earthy, soft, large flakes	500
Shale, drab; limestone, yellow-gray, mottled; white chalcedonic silica	510
Limestone, light yellow-gray, soft, coarsely crystalline	520
Limestone, light yellow-gray, fine-crystalline, rather slow reaction; some as above, rapid reaction	530, 540

Limestone, whitish, oölitic, response rapid, in large flakes	550
Chert, blue-gray; some yellow-gray limestone of rapid effervescence	560
Limestone, light yellow-gray and whitish, coarse crystalline-granular, some oölitic at 570; 3 samples	570–590
Limestone, yellow-gray, fine crystalline-granular, rapid effervescence	600, 610
Limestone, light yellow-gray, coarse crystalline-granular, some oölite	620
Limestone, light yellow-gray, cherty	630
Limestone, light yellow-gray and brownish, finely granular	640
Limestone, light yellow-gray and whitish, macrocrystalline-earthy, oölitic in large chips	650
Limestone, yellow and blue-gray, in sand	660
Limestone, light yellow-gray and whitish, oölitic; some drab shale	670
Limestone, light yellow-gray, finely granular; some large chips of coarse grained limestone	680
Dolomite or magnesian limestone, yellow-gray, fine crystalline, slow effervescence, in medium sized chips	690
Limestone, light yellow-gray and whitish, coarsely crystalline, rapid reaction	700
Limestone, light blue-gray and yellow-gray, finely crystalline-granular, rapid effervescence, in coarse sand	710
Limestone, blue-gray and yellow-gray, crystalline, rapid reaction, with considerable clayey powder; 3 samples	720–740
Limestone, as above, some fine quartz sand and flint	750
Shale, light blue, plastic, calcareous; 5 samples	760–800
Devonian to Galena-Platteville inclusive (850 feet thick; top 329 feet above sea level):	
Limestone, blue-gray, finely crystalline; some yellow limestone of slow effervescence; mottled flint; argillaceous powder	810
Limestone, blue-gray, rather rapid reaction	830
Limestone, buff and light blue-gray, crystalline-granular, rather slow reaction, cherty	840
Limestone, blue-gray, fine-grained, rather rapid response to acid	850, 860
Limestone, light buff-gray, coarser grained than above, rapid reaction	870
Limestone, light buff-gray, fine-grained, rather rapid effervescence; some chert	880
Limestone, gray, fine-grained, effervescence rather rapid; gray flint	890, 900
Limestone, yellow and blue-gray	910
Limestone, magnesian, or dolomite, light and dark gray, slow effervescence, some rather rapid; 4 samples	920–950
Limestone, light gray and buff, mostly of rapid effervescence; much argillaceous powder	960
Limestone, light gray and olive gray, very fine-grained, rather slow reaction; yellow gray, rapid effervescence; some shale, light blue-green, calcareous	970, 980
Limestone, gray, rapid response, some bright yellow, very fine-grained, slow; shale, drab and blue	990
Limestone, yellow-gray and drab, mostly rapid reaction; blue and blackish shale; cinders at 1030; 6 samples	1000-1050
Limestone, light gray and yellow, compact, fine-grained, rapid response; some white chert; some limestone in smaller chips of rather slow effervescence; argillaceous powder concreting whole into rather difficultly friable masses	1060, 1070
Chert, gray and whitish; some limestone of slow response; 3 samples	1080–1100
Limestone, light gray, both slow and rapid effervescence	1110, 1120
Chert, blue-gray; some limestone, slow reaction	1130
Limestone, blue-gray, argillaceous, rapid response to acid, highly arenaceous, grains fine, ill-rounded	1140
Limestone, blue-gray, argillaceous, rapid effervescence	1150
Limestone, blue-gray, some whitish, response rapid; some dolomitic	1160
Chert, gray; some dolomite, light gray, a little limestone	1170, 1180
Limestone, blue-gray, encrinital, rapid response; some light blue shale	1190
Limestone, finely crystalline, rapid effervescence	1200

Limestone, buff-gray, fine-grained, rapid reaction, some whitish, coarser, crystalline, rather slow; some light blue shale, pyritiferous; 3 samples	1210–1230
Limestone, light buff-gray and whitish, crystalline-granular, reaction rapid; some light blue shale; 3 samples	1240–1260
Limestone, light yellow-gray and whitish, crystalline, rather rapid effervescence; limestone, blue-gray, macrocrystalline, argillaceous	1270
Limestone, light yellow-gray, response rather slow; and blue-gray limestone of rapid reaction	1280, 1290
Limestone, whitish, crystalline, rather slow reaction, some gray and rapid, some blue-gray, finely laminated, siliceous; considerable shale	1300
Limestone, yellow, rather rapid effervescence; whitish, rapid, and blue gray, rather slow reaction	1310
Limestone, gray of various tints, some rapid reaction, some slow in same sample; 12 samples	1320–1430
Chert and dolomite, gray	1440
Dolomite, light yellow-gray; some limestone of rapid response, in larger chips	1450, 1460
Limestones, gray, rapid and slow response	1470, 1480
Dolomite, light gray, compact, fine-grained, in small chips; some chert; some gray limestone of moderately slow reaction; 17 samples	1490–1650
Glenwood shale (40 feet thick; top 521 feet below sea level)—	
Shale, blue-green, some drab, fissile, in moulded masses; 4 samples	1660–1690
Saint Peter sandstone (60 feet thick; top 561 feet below sea level)—	
Sandstone, white, clean, rounded and frosted grains up to 0.8 mm. diameter; some fissile green shale; 6 samples	1700–1750
Shakopee dolomite (penetrated 30 feet)—	
Dolomite, gray, much quartz sand and shale as above; 4 samples	1760–1790
No samples, to bottom of well	1800–1842

Driller's Log

	DEPTH IN FEET
Yellow clay	0–62
Sand	62–66
Yellow clay	66–155
Red shale	155–166
Black shale	166–175
Gray shale	175–310
Shale and lime	310–385
Lime	385–750
Gray shale	750–790
Lime	790–1200
Broken lime	1200–1203
Lime	1203–1280
Shale	1280–1284
Lime	1284–1650
Blue shale	1650–1685
Sand	1685–1735
Lime and sand	1735–1785
Sand	1785–1842

Notes.—It is quite possible that the boundary between the Pennsylvanian and the Mississippian should be drawn at the top of the blue shales from 320 to 380 feet, instead of at their base.

The shale from 760 to 800 feet is assumed to define the frontier between the Mississippian and the Devonian.

The limestones which extend almost without a break from the top of the Devonian at 800 feet to the Glenwood at 1650 feet present no clear formational characteristics. The shale of the driller's log at 1280 and the siliceous limestone at 1300 are probably to be included in the Maquoketa, which here, as at Fort Dodge, seems to be represented largely by limestones instead of shales. Probably the lower 220 feet, at least, of this run of limestone is Galena-Platteville.

The mixture of limestones of various reactions to acid, and the presence of shale in limestone cuttings probably is due to falls.

The elevation of the Saint Peter sandstone, 561 feet below sea level, is somewhat above that of the forecast of the report of 1912 (Map, Plate I), which placed it at a little more than 600 feet below this datum.

*Mineral Content of City Well, Gowrie**

	P.P.M.
Bicarbonate	427.0
Chloride	14.
Sulfate	208.1
Silica	15.8
$Fe_2O_3+Al_2O_3$	3.6
Calcium	93.6
Magnesium	53.2
Na + K as Na	52.0
Total solids	653.7

GRAND JUNCTION, GREENE COUNTY

(Altitude 1039 feet)

The city well at Grand Junction was drilled by Thorpe Brothers Well Co., of Des Moines, being completed December 26, 1925. It is 320 feet deep and is cased with 12 inch pipe to 105 feet and with 10 inch pipe from 100 feet to 250 feet, 6 inches. Static level of the water is 15 feet below the surface. In testing the well the pump was set 40 feet below the surface and it pumped 150 gallons per minute for 24 hours.

Driller's Log

	Thickness feet	Depth feet
Clay	47	47
Sand, fine and mixed	53	100
Shale, mixed	150	250
Rock	24	274
Sand rock	46	320

* Analysis by Dr. Harry F. Lewis, Chemical Laboratory, Cornell College, Mount Vernon, 1927.

GREENFIELD

(Altitude 1370 feet)

The deep well of the city of Greenfield at the close of 1928 had been drilled by Layne-Bowler Chicago Co. to the depth of 2505 feet. The diameters are from 20 to 8 inches. The static level is 505 feet from the surface, which may be compared with the head of the Stuart deep well, 350 feet. Some water was found in the sandstone near the base of the Pennsylvanian and also at about 1600 feet in Mississippian limestone. At 2130 feet, in the Silurian, according to press reports at the time, a water sandstone was reached. "From all appearances the sand resembles the St. Peters sandstone, which is supposed to be one of the best water bearing strata of sand. The sand is a solid formation and requires no casing. It is fine in texture and white in color and was found after a stratum of very hard rock was penetrated by the drill. When first taken from the well it resembles sugar sand in texture and color but gets darker after it is exposed to the air." The samples submitted to this office, however, were almost wholly of dolomite with some gypsum and showed no particular resemblance to the Saint Peter. They were referred to the same horizon—Silurian—which yields a supply for the Des Moines deep wells. The Saint Peter was not reached after 375 feet of deeper drilling and probably lies about 750 feet below the rock mistaken for it. The yield of this stratum does not seem to have been measured accurately, but to quote again from current press reports "This sandstone contains a large quantity of good water as test by the bailer revealed. The water coming up with the bailer was clear and suitable for drinking purposes. The water in the well "cleared" when this vein of sand was penetrated, showing a good inflow of water. * * * The striking of this stratum did not, however, raise the water level in the well, which still remains within 500 feet of the top."

Tests made after drilling was stopped at 2505 feet showed a capacity of 65 g.p.m. with the pumping cylinder at 600 feet. The report by city officials stated that it "pumps down to the cylinder and remains there if not more than 60 g.p.m. is pumped".

Casing was placed as follows: from the surface 20 inch to 207 feet, 16 inch to 285 feet, 12 inch to 980 feet and 10 inch to 1260 feet; from 1534 feet 8 inch to 1780 feet. The 8 inch casing was inserted to case out the Kinderhook shale and some of the overlying limestone and shale.

The latest report from Greenfield (Dec. 31, 1928) states that "the well is not completed and will probably be drilled to 3500 feet."

Mineral analysis (water believed to be entering well at 1600 feet)

	Grains per Gallon
Silica	0.700
Oxides of iron and aluminum	0.116
Carbonate of lime	15.611
Sulphate of lime	9.622
Carbonate of magnesia	5.839
Sodium and Potassium sulphates	82.195
Sodium and Potassium chlorides	6.800
Loss, etc.	0.005
Total mineral solids	120.888

Record of strata, Greenfield city well.

	Depth in Feet
Pleistocene and Recent (200 feet thick; top 1370 feet above sea level):	
Till, yellow, clayey, sand and pebbles of drift, in hard lumps; 5 samples	20–120
Peat, blackish and dark brown, inflammable, some fossil wood	120–140
Till, gray, calcareous, in hard lumps	140–160
Till, blue-gray, as above	160–180
Gravel, pebbles of drift up to 3 cm. diameter, with yellow clay sufficient to bind	180–200
Pennsylvanian (1130 feet thick; top 1170 feet above sea level):	
Limestone, yellow-gray, crystalline-earthy, rapid effervescence in cold dilute HCl; some drab flint; in chips	200–220
Shale, drab and blackish	220–230
Shale, dark gray, red and bluish gray; 3 samples	230–290
Limestone, drab, fossiliferous, in flaky chips, "lime shell 306-310"	290–310
Shale, red and gray	310–330
Limestone, drab and gray, hard, fine-grained, fossiliferous, argillaceous, somewhat siliceous	330–340
Limestone, gray; drab shale	340–360
Shale, blue-gray and red, drab, greenish gray; 3 samples	360–425
Limestone, gray, earthy, fossiliferous; 2 samples	425–460
Shale, drab; chips of light gray limestone	460–465
Limestone, light gray and whitish, some coarse granular, some calcilutite	465–475
Shale, drab, with chips of light gray limestone	475–500
Limestone, very light gray, macrocrystalline-earthy, soft	500–515
Shale, gray and blackish	515–525
Limestone, light yellow-gray, earthy	525–542
Shale, red; 2 samples	542–580
Shale, blue-gray, with chips of argillaceous drab limestone	580–600
Shale, red and blue-gray; 2 samples	600–640
Limestone, light brownish gray, rather hard, fossiliferous	640–645
Shale, blue-gray and drab	645–665
Shale, blue-gray; limestone	665–685
Shale, gray and drab; 4 samples	685–750

Limestone, gray, earthy, argillaceous	750–755
Shale, drab; some coal; 2 samples	755–800
Shale, blue-gray and drab; 5 samples	800–895
Limestone, yellow-gray, argillaceous, siliceous	895–905
Shale, gray and drab; 4 samples	905–965
Shale, blackish	965–985
Shale, drab	985–995
Sandstone, gray, fine, grains of clear quartz, highly irregular	995–1005
Shale, gray and drab; 5 samples	1005–1100
Shale, blackish; 2 samples	1100–1138
Sandstone, gray, irregular grains of clear quartz, larger about 0.5 mm. diameter; 2 samples	1138–1163
Shale, drab and blackish; 4 samples	1163–1235
Sandstone, as at 1138	1235–1250
Shale, gray, finely arenaceous, noncalcareous; some white chert; pyrite	1285
Mississippian (450 feet thick; top 40 feet above sea level):	
Limestone, drab and gray, slow effervescence, argillaceous, slightly arenaceous; considerable gray and white chert; sandstone, drab, very finely arenaceous, calcareous	1330
Limestone, light gray, crystalline-earthy, soft, in flaky chips	1350
Shale, medium blue-gray, micaceous, pyritic, in hard lumps	1390
Chert, brown and white; some limestone	1468
Shale, medium blue-gray, in hard lumps	1510
Chert, white and brown; chalcedonic silica; some limestone; 3 samples	1525–1590
Shale, medium blue-gray, in hard lumps	1600
Limestone, blue-gray and yellow-gray, rather slow effervescence; light gray chert; blue-gray shale; all in chips; 3 samples	1600–1640
Limestone, yellow-gray, rapid effervescence; 2 samples	1680, 1700
Shales (Kinderhook), light blue-gray, some brown at 1770; 6 samples	1720–1775
Devonian (125 feet (?) thick; top 410 feet below sea level):	
Limestone, light yellow-gray, rapid effervescence; 6 samples	1780–1860
Silurian (and underlying formations ?):	
Dolomite, brown, in sand, a little quartz sand and chert; a flake or so of selenite or gypsum	1905
Limestone, buff in mass, rather slow effervescence, some rapid; a little gypsum	1925
Limestone, buff, rather slow reaction, some rapid, in sand; considerable gray shale; 2 samples	1950, 1980
Dolomite, gray and buff-gray; 3 samples	2000–2060
Dolomite, brown, in sand; 3 samples	2070–2100
Dolomite, light brown and gray, in finer sand, considerable residue of gypsum; pyrite; gray chert; white clay; a little quartz sand; 2 samples	2120–2140
Dolomite as above, a little gypsum, some cryptocrystalline silica	2160, 2180
Dolomite, drab and gray; some gypsum; pyrite	2200
Dolomite, brownish; gypsum	2220
Dolomite, brownish and gray; gypsum in whitish grains; gypseous clay; 2 samples	2240, 2280
Dolomite or magnesian limestone, rather slow effervescence, soft, disintegrating under weak acid into crystalline finest grains, argillaceous residue; whitish gypseous calcareous clay in soft chips	2340
Dolomite or magnesian limestone, rusted, disintegrating under weak acid into finest crystalline sand; whitish gypseous clay	2355
Dolomite, gray, much quartz sand, fine grains rounded, some secondary enlargements	2380
Limestone, light gray, crystalline-earthy, rapid effervescence, argillaceous	2400
Shale, reddish, in concreted masses; white masses of limestone in powder with fine quartzose residue, and a little gypsum	2420
Chert, white, and chalcedonic silica, considerable quartz sand in fine rounded grains; a little limestone of rapid effervescence	2440

Dolomite, light gray and whitish; whitish cryptocrystalline silica, sandstone, fine, calcareous, larger grains well rounded	2455
No samples	2455–2505

Notes.—The gray sandstones occurring at or near the base of the Coal Measures (1138 to 1163 feet and 1235 to 1250 feet) may be compared with the similar sandstone found at the same horizon at Lamoni, Atlantic, Bedford and Glenwood. This sandstone furnished more or less of the meager yield of the well, as the casing was perforated from 1138 to 1168 feet.

The cuttings at 1285 are rather ambiguous and might be classed as Mississippian. But as the log records a black shale 15 feet thick at 1298, the top of the Mississippian is placed at 1330 feet, the depth of the first sample of typical Mississippian facies.

The samples of shale from 1720 to 1775 feet are Kinderhook in aspect and stratigraphically. With these assignments the thickness of the Mississippian foots up 450 feet, with which may be compared the thickness of the Mississippian at Lamoni, 453 feet, and at Des Moines (Wood Bros. well) 450 feet, at Atlantic probably at least 420 feet, and 405 feet at Stuart.

The limestones from 1780 to 1905 feet thus fall to the Devonian. The dolomites and limestones from 1905 to 2455 feet may be referred with plausibility to the Silurian on account of their position and their gypseous content. The thickness given the Silurian—it carries through to 2455 feet—is thus 550 feet, something less than at Bedford, where it shows much more gypsum, and a little thicker than at Des Moines.

Drilling was stopped at 2505 feet on account, in part at least, of mechanical difficulties arising from the loss of tools at the bottom of the drill hole.

The Saint Peter sandstone, it is inferred, was still several hundred feet below. At Stuart the distance from the top of the Mississippian to the top of the Saint Peter sandstone is 1561 feet, at Nebraska City 1763 feet; at Council Bluffs the Saint Peter had not been reached 1425 feet below the same datum. On the scale of the Stuart well the Saint Peter would be found at Greenfield at 2891 feet from the surface, 1521 feet below sea level, and on the scale of the Nebraska City well about 200 feet deeper. If the last sample is at or near the base of the Silurian, and the thickness of the Ordovician above the Saint Peter sandstone be given a minimum of 300 feet, the Saint Peter sandstone would lie at 2755 feet from the surface or 1385 feet below sea level.

Driller's log

	Depth in Feet
Yellow clay	0–120
Black mud	120–140
Blue shale	140–180
Yellow clay	180–200
White limestone, medium soft	200–220
Black shale	220–230
Mottled clay	230–250
Red shale	250–270
Blue shale	270–290
Blue shale and lime-shells, soft	290–310
Red shale	310–330
White limestone	330–340
Blue shale	340–380
Gray shale	380–425
Gray limestone	425–460
Green shale	460–465
White limestone	465–475
Blue shale	475–500
White limestone	500–515
Black shale	515–525
White limestone	525–542
Black shale	542–545
Red shale	545–580
Blue shale	580–600
Red shale	600–620
Blue shale	620–640
Limestone	640–645
Blue shale	645–700
Mottled shale	700–750
Gray limestone	750–755
Mottled shale	755–780
Blue shale	780–820
Gray shale	820–875
Mottled shale	875–895
Limestone	895–905
Gray shale	905–920
Mottled shale	920–1020
Gray shale	1020–1080
Pink shale	1080–1100
Black shale	1100–1138
Sandstone	1138–1163
Black shale	1163–1235
Sandstone, soft	1235–1265
Black shale	1265–1280
Soft sandstone	1280–1295
Black shale	1295–1310
Shale and sand	1310–1330
Lime	1330–1350
Gray shale	1350–1390
Lime	1390–1395
Sandy shale	1395–1465
Lime	1465–1500
Shale	1500–1510
Lime	1510–1570
Gray shale	1570–1640
Lime	1640–1720
Shale	1720–1785
Brown lime	1785–1790
Shale	1790–1800
Hard lime	1800–1880
Lime	1880–1890
Sandy lime	1890–1900
Brown lime	1900–1930
Hard lime	1930–2080
Brown lime	2080–2108
No record, except about 4 feet of shale at 2445	2108–2505

GRINNELL

(Altitude 1007 feet, C., R. I. & P. Ry)

CITY WELL NO. 5

This well, drilled in 1920 by the Thorpe Brothers Well Company of Des Moines, is 2000 feet deep and its diameters are from 16 to 8 inches. The principal supply was found at 1800 feet in the Shakopee dolomite; other water beds were encountered at 1500 feet in the Galena and at 1900 feet in the New Richmond.

The static level is 250 feet below the surface. The capacity under the air lift is 120 gallons per minute but continuous pump-ness of the Ordovician above the Saint Peter sandstone be given a minimum of 300 feet, the Saint Peter sandstone would lie at 2755 feet from the surface or 1385 feet below sea level.

Driller's log

	Depth in Feet		Depth in Feet
Yellow clay	0–120	Limestone	895–905
Black mud	120–140	Gray shale	905–920
Blue shale	140–180	Mottled shale	920–1020
Yellow clay	180–200	Gray shale	1020–1080
White limestone, medium soft	200–220	Pink shale	1080–1100
Black shale	220–230	Black shale	1100–1138
Mottled clay	230–250	Sandstone	1138–1163
Red shale	250–270	Black shale	1163–1235
Blue shale	270–290	Sandstone, soft	1235–1265
Blue shale and lime-shells, soft	290–310	Black shale	1265–1280
Red shale	310–330	Soft sandstone	1280–1295
White limestone	330–340	Black shale	1295–1310
Blue shale	340–380	Shale and sand	1310–1330
Gray shale	380–425	Lime	1330–1350
Gray limestone	425–460	Gray shale	1350–1390
Green shale	460–465	Lime	1390–1395
White limestone	465–475	Sandy shale	1395–1465
Blue shale	475–500	Lime	1465–1500
White limestone	500–515	Shale	1500–1510
Black shale	515–525	Lime	1510–1570
White limestone	525–542	Gray shale	1570–1640
Black shale	542–545	Lime	1640–1720
Red shale	545–580	Shale	1720–1785
Blue shale	580–600	Brown lime	1785–1790
Red shale	600–620	Shale	1790–1800
Blue shale	620–640	Hard lime	1800–1880
Limestone	640–645	Lime	1880–1890
Blue shale	645–700	Sandy lime	1890–1900
Mottled shale	700–750	Brown lime	1900–1930
Gray limestone	750–755	Hard lime	1930–2080
Mottled shale	755–780	Brown lime	2080–2108
Blue shale	780–820	No record, except about 4 feet of shale at 2445	2108–2505
Gray shale	820–875		
Mottled shale	875–895		

GRINNELL

(Altitude 1007 feet, C., R. I. & P. Ry)

CITY WELL NO. 5

This well, drilled in 1920 by the Thorpe Brothers Well Company of Des Moines, is 2000 feet deep and its diameters are from 16 to 8 inches. The principal supply was found at 1800 feet in the Shakopee dolomite; other water beds were encountered at 1500 feet in the Galena and at 1900 feet in the New Richmond.

The static level is 250 feet below the surface. The capacity under the air lift is 120 gallons per minute but continuous pumping draws down the head 100 feet. The cost of the well was $32,692.

Samples of the cuttings were carefully saved and the following description by Lees (somewhat abridged) corroborates the records of the earlier city wells.[53]

Record of Strata

	Depth in Feet
Pleistocene:	
Sand and gravel, some limestone fragments, to one-half inch diameter; some quartz and greenstone grains. Possibly represents both glacial gravel and bed rock	200–210
Mississippian:	
Saint Louis limestone and Osage shale—	
Limestone, gray, in fine powder concreted in sample; some clayey residue; 2 samples	210–230
Limestone, light gray, finely crystalline, sugary texture	230–240
Limestone, dark gray, in fragments and powder	240–250
Limestone, dark gray, in fragments and powder, some dark clay	250–260
Limestone, similar to above; 5 samples	260–310
Limestone, fragments of both light and dark gray, finely sugary texture	310–320
Limestone, medium and light gray, in fine powder (at 370 also in small chips); 7 samples	320–390
Kinderhook shale—	
Shale, limy, darker gray than sample above, in very fine powder concreted into lumps	390–400
Shale, in finely gritty blue-gray powder, ready response to acid, but large residue of clay; 5 samples	400–450
Shale, darker gray, in powder and chips	450–460
Shale, rather dark gray, hard, very little or no response to HCl; 9 samples	460–540
Shale, limy, or shaly limestone, medium dark gray, ready response to acid, but large clay residue	550–560
Shale, medium dark gray, no response to acid	560–570
Devonian:	
Limestone, medium dark gray, shaly, finely gritty, large clayey residue; 4 samples	570–610
Limestone, shaly, gritty, dark bluish gray, brisk response to acid, some clayey residue; 8 samples	610–690
Limestone, dark gray, some hard chips, response to acid more brisk than above	690, 700
Limestone, dark gray, in coarse powder and hard, fine-grained chips; 9 samples (in finer powder at 770)	700–790
Silurian:	
Limestone, light gray, in fine gritty powder, concreted	790–800
Limestone, rather dark gray, in coarse powder; 8 samples (some chips at 810, 860 and 870, some fine powder at 840)	800–880
Limestone, gray, small chips, coarse powder; 3 samples	880–920
Limestone, similar to above; some soft white grains; 6 samples	920–980
Limestone, dark gray, some light gray chips; 3 samples	980–1010
Limestone, lighter gray, much powder; gypsum in light blue-gray chips	1010–1020
Limestone, light gray, rather fine powder, and small chips; gypsum in light blue-gray chips	1020–1030
Limestone, light gray, in fine powder, concreted, brisk effervescence in cold acid; some small grains of white and bluish chert	1030–1040

53 Underground Water Resources of Iowa, Iowa Geol. Survey, vol. XXI, pp. 580-582.

Limestone, similar to above, powder quite fine 1040–1050
Limestone, similar to above, considerable clayey residue 1050–1060
Limestone, light gray, with some chips of dark green shale, sample chiefly small chips; 5 samples 1060–1110
Limestone, reddish, very fine-grained, much residue 1110–1120
Limestone, mixed light and dark gray chips, not so much reaction with acid 1120–1130
Limestone, similar to above, brisk reaction to acid; 3 samples 1130–1160
Limestone, dolomitic, fragments light gray, finely crystalline; 3 samples 1160–1190

Ordovician:
- Maquoketa shale—
  - Shale, dark gray, slightly limy; 24 samples (small fragments of pyrite at 1210, no response to acid at 1260, 1270, 1340, 1360, very limy at 1430, with lighter gray lime fragments at 1400-1420) 1190–1430
- Galena-Platteville limestone—
  - Limestone, dolomitic, brownish gray, finely granular powder, almost completely soluble in hot acid; 6 samples 1430–1490
  - Limestone, ready response to acid, light brownish gray and medium gray; 3 samples 1490–1520
  - Limestone, gray, dolomitic, considerable residue; 4 samples 1520–1560
  - Limestone, medium gray, ready response to cold acid; 3 samples 1560–1590
  - Limestone or dolomite, no response in cold acid 1590–1600
  - Limestone, dolomitic, similar to above 1600–1610
  - Limestone, dolomitic, gray, granular texture 1610–1620
  - Limestone, mingled light and dark fragments, fairly ready response to cold acid 1620–1630
  - Limestone, dark gray, in small chips and powder, very ready effervescence in cold acid 1630–1640
  - Shale, greenish, limy, fairly fine texture; some pyrite grains 1640–1650
  - Limestone, dark gray, in small chips and powder, ready response to acid; 2 samples 1650–1670
  - Limestone, lighter gray, finer texture than above 1670–1680
  - Limestone, similar to above, powder a little more gritty 1680–1690
  - Shale, green, not limy, fine texture 1690–1700
  - Limestone, gray, in rather fine powder, ready effervescence in cold acid 1700–1710
- Saint Peter sandstone—
  - Sandstone, light gray, almost white, very fine grains, reaction with acid slight, not increased with boiling; 2 samples 1710–1730
- Prairie du Chien—
  - Shakopee dolomite—
    - Limestone, dolomitic, dark gray, slight reaction in cold acid, vigorous in hot acid; 5 samples 1730–1780
    - Limestone. dolomitic, light gray, very fine-grained, considerable fine sandy residue; 4 samples 1780–1820
    - Limestone, dolomitic, light gray, fine powder; 5 samples 1820–1870
    - Limestone, dolomitic, medium gray, coarser grained than above, considerable white sandy residue, sample in subrounded sparkling granules; 2 samples 1870–1890
    - Limestone, light gray, ready effervescence in cold acid, large sandy residue 1890–1900
- New Richmond sandstone—
  - Sandstone, coarser and somewhat darker than sample above 1900–1910
  - Limestone, cream colored, ready response to cold acid; sample similar to 1890-1900 1910–1920
  - Sandstone, similar to sample at 1900 (*This and the last sample may be reversed*) 1920–1930
  - Sandstone, small light gray sparkling grains 1930–1940
  - Sandstone, in fine sparkling grains, mixed light and dark gray; 2 samples 1940–1960

Sandstone, light gray, larger grains than above	1960–1970
Limestone, dolomitic, sandy, lighter colored than sample above; no response to cold acid; some fine sandy residue after treating with hot acid	1970–1980
Oneota dolomite—	
Limestone, darker gray than sample above, fine sparkling grains, considerable response to cold acid, increased on heating, some sandy residue	1980–1990
Limestone, similar to sample at 1970-1980, small sandy residue	1990–2006

*Driller's Log**

	Depth in Feet
Pleistocene:	
Black soil	0–2
Yellow clay	2–25
Blue clay	25–41
Yellow sandy clay	41–90
Blue clay, some gravel	90–180
Yellow clay and sand	180–209
Mississippian:	
Saint Louis and Osage—	
Broken limestone	209–214
Shaly limestone	214–240
Limestone, harder	240–246
Shale	246–248
Limestone	248–256
Shale	256–268
Hard limestone	268–400
Limestone, sandy	400–411
Shale	411–425
Kinderhook shale—	
Light blue shale	425–490
Shale, darker	490–530
Shale, light green	530–567
Devonian:	
Limestone, and shale streak	567–594
Shale	594–601
Limestone	601–630
Shale, streak of lime	630–698
Limestone	698–713
Shale and lime	713–734
Hard lime	734–750
Very hard lime	750–774
Hard shale and lime	774–792
Silurian:	
Limestone, light color	792–862
Limestone, brown	862–875
Limestone, light color	875–889
Sandy shale, mixed lime	889–915
Limestone	915–1112
Shale, reddish	1112–1120
Limestone, sandy	1120–1151
Limestone	1151–1197
Ordovician:	
Maquoketa shale—	
Green shale	1197–1220
Shale, light	1220–1233
Chocolate shale	1233–1260
Lime, dark	1260–1263
Shale, dark	1263–1283

* Geological interpretation by Dr. James H. Lees, Asst. State Geologist.

Lime, black	1283–1289
Lime rock, shale streak	1289–1350
Shale and lime	1350–1361
Limestone, some shale	1361–1407
Galena-Platteville—	
Limestone	1407–1560
Limestone, sandy, cuttings washed	1560–1595
Limestone	1595–1649
Shale, green	1649–1652
Limestone, sandy	1652–1690
Shale, green	1690–1696
Sandy lime	1696–1698
Saint Peter—	
Sandstone	1698–1730
Prairie du Chien—	
Shakopee—	
Hard lime, sandy, cutting washed away	1730–1769
Limestone	1769–1839
Sandy lime and sandstone	1839–1860
Sandstone, cuttings washed away	1860–1868
Limestone	1868–1902
New Richmond—	
Sandstone	1902–1979
Oneota—	
Limestone, sandy	1979–1982
Sandstone	1982–1986
Sandy limestone	1986–2006

CITY WELL NO. 6, GRINNELL

This well was completed in 1926 by Thorpe Bros. of Des Moines. The depth is 2500 feet, the diameters from 16 to 10 inches, the latter diameter carried from 444 feet. The principal supply was found at 1700 feet and other water beds were struck at 1900 and 2190 feet. The static level is 258 feet below the curb. Continuous pumping with the air line at 635 feet lowers the water 35 feet. The capacity of the well is 500 gallons or more per minute. Casing is placed as follows: 16 inch to 300 feet, 12 inch from 300 to 444 feet, 9 inch from 444 feet to 1700 feet. The cost of the well was about $50,000.

Record of strata, City well no. 6, Grinnell

As the section of this well parallels that of well no. 5, given above, to the depth of 2006 feet, the footing of the latter well, only the cuttings below that depth are described.

	Depth in Feet
Oneota (120 feet thick; top (at 1970 feet) 942 feet below sea level):	
Dolomite, light cream color, vesicular, in chips	2000–2010
Dolomite, whitish, in fine meal	2010–2020
Dolomite, light cream color, in chips	2020–2030
Dolomite, brown, gray, yellow-gray and buff, cherty; 4 samples	2030–2080

Dolomite, light gray and light buff, in meal, cherty at 2080, and from 2110 to 2150; 10 samples	2080–2190
Jordan sandstone (60 feet thick; top 1162 feet below sea level):	
Sandstone, white, moderately well rounded grains, up to 0.7 mm. diameter, with considerable dolomitic meal	2190–2200
Sandstone, light yellow-gray, dolomitic cement, larger grains 1 mm. diameter; in chips and sand	2200–2210
Sandstone, white, larger grains 1.3 mm. diameter, well rounded, dolomitic cement	2210–2220
Sandstone, light yellow-gray, dolomitic cement, fine, rounded grains	2220–2230
Sandstone, whitish, fine, grains well rounded	2230–2240
Sandstone, whitish, somewhat dolomitic, grains minute, ill-rounded, larger grains well rounded	2240–2248
Sandstone, gray, dolomitic, finely arenaceous and quartzose; some rounded grains in cuttings, perhaps from above	2248–2250
Saint Lawrence, Trempealeau beds (110 feet thick; top 1222 feet below sea level):	
Dolomite, whitish, soft, minutely arenaceous and quartzose; some fine grains of well rounded quartz sand perhaps from above	2250–2254
Dolomite, as above; dolomite, brown, hard, minutely quartzose	2254–2261
Dolomite, whitish, soft and gray; minutely quartzose	2261–2263
Dolomite, brown in mass, rusted; some highly arenaceous with fine well rounded imbedded grains	2260–2270
Sandstone, dark gray, minute, ill-rounded grains, dolomitic, argillaceous, pyritiferous, in chips	2280–2290
Dolomite, light yellow-gray, in fine sand	2290–2300
Sandstone, gray, minute grains, dolomitic, in chips	2310–2320
Dolomite, light yellow-gray, in powder and meal, minutely arenaceous and quartzose, with some larger grains, argillaceous	2330–2340
No samples	2340–2350
Saint Lawrence, Franconia beds (penetrated 140 feet; top 1332 feet below sea level):	
Dolomite, gray, minutely quartzose; sandstone, gray, glauconitic, dolomitic	2350–2360
Dolomite, yellow-gray and whitish, minutely quartzose, glauconitic; 2 samples	2370–2390
Marl, light blue-green, dolomitic, argillaceous, highly quartzose, some fine ill-rounded grains, some with secondary enlargements, glauconitic	2390–2400
Dolomite, gray and whitish, in small chips, minutely quartzose, glauconitic at 2410; 2 samples	2400–2420
Dolomite, buff, minutely quartzose, quartz grains, as those of samples above, too small generally to polarize in strong colors	2420–2430
Dolomite, gray, finely arenaceous, glauconitic	2430–2440
Sandstone, minutely quartzose, dolomitic, glauconitic; shale light green, noncalcareous	2460–2470
Sandstone, drab and gray in mass, minutely quartzose, dolomitic, glauconitic, argillaceous at 2495; 4 samples	2470–2500

Driller's log, City well no. 6, Grinnell

	DEPTH IN FEET
Soil and clay	0–48
Sand	48–53
Clay, blue	53–197
Shale	197–199
Hard lime	199–220
Lime and shale	220–248
Shale, blue	248–258
Shale with lime	258–268
Lime rock	268–399
Lime and shale	399–414

Shale, light colored	414–490
Shale, dark	490–530
Shale, gray	530–566
Lime, some shale	566–592
Limestone	592–620
Shale with a little lime	620–706
Lime, hard	706–761
Shale	761–782
Lime, white	782–848
Lime, brown	848–863
Lime, white	863–873
Sand, shale and lime	873–903
Lime with small streaks of shale	903–1026
Shale, light	1026–1030
Lime, sharp	1030–1077
Shale, red	1077–1079
Lime with streaks of shale	1079–1108
Lime, sharp	1108–1169
Cherty lime, very hard	1169–1186
Shale, green and light	1186–1221
Shale, chocolate brown	1221–1264
Shale, light and real hard	1264–1321
Shale, chocolate brown	1321–1363
Shale, light and hard	1363–1391
Lime	1391–1638
Shale	1638–1643
Lime, hard	1643–1676
Shale	1676–1681
Sandstone	1681–1714
Lime, hard	1714–1768
Lime rock, some sand	1768–1914
Sandstone, New Richmond	1914–1968
Dolomite	1968–2181
Sandstone	2181–2233
Dolomite with streaks of shale	2233–2438
Shale, light	2438–2443
Dolomite	2443–2486

GRUNDY CENTER

(Altitude 983 feet)

A well 255 feet deep and 10 inches in diameter was completed for Grundy Center in 1917 by E. A. Ford of Marshalltown and pumped in 1922 80 g.p.m. The town also has installed an 8 inch well 360 feet in depth yielding 65,000 g.p.d.

Driller's Log

	Depth in Feet
Clay	0–161
Shale	161–171
Rock	171–255

GRUNDY COUNTY POOR FARM (Four miles southwest of Grundy Center)

In 1925 a well was drilled for this institution by E. A. Ford of Marshalltown and tested 25 g.p.m. The depth is 507 feet and the diameters are 8 and 6 inches.

Driller's Log

	Depth in Feet
Clay	0-253
Shale	253–353
Rock	353–507

GRUNDY CANNING COMPANY, GRUNDY CENTER

This well, 428 feet deep and 8 inches in diameter, was completed in 1919 by E. A. Ford of Marshalltown. The tested capacity of the well is 125 g.p.m. The cost was $1805.

Driller's Log

	Depth in Feet
Clay (Pleistocene)	0–113
Shale (Mississippian)	113–270
Rock (Devonian)	270–428

WELL OF H. F. SPRAGUE, GRUNDY CENTER

The well at the Sprague Ice Factory is 509 feet in depth, with diameters from 8 to 6 inches. It was completed in 1917 by E. A. Ford of Marshalltown. The principal supply was found at 506 feet. The well supplies 35 g.p.m. under the air lift. There are 156 feet of 8 inch casing and 175 feet of 6 inch. The cost of the well was $1313.

The owner states an interesting fact in the operation of the well. "I use the Sullivan air lift for pumping and we pump enough so that I have a small stream overflowing from the tank. But with the same air pressure and other conditions the same, if the wind blows from the southeast for about 24 hours there will be a smaller amount of water pumped, for the overflow will stop. As soon as the wind gets out of that quarter, we will have the overflow stream again. I have heard of this in shallow wells, but not in deep wells before."

The log of the city well, given in the water report of 1912, indicates that the well foots in the Devonian limestone, possibly reaching the Silurian.

HAMBURG, FREMONT COUNTY

(*Altitude of C., B. & Q. R. R. Sta., 911 feet*)

Driller's record of oil prospect on Spicer Farm, spudded in June 20, 1925. Located on the NE¼ of the NE¼ of section 3, township 67, range 42, Fremont county, three miles north and one-half mile east of Hamburg

	Thickness, feet	Depth, feet
Loess and glacial drift		90
Shale and gravel, light colored, soft	10	100

Shale, light colored, soft	100	200
Lime, white, hard	10	210
Shale, white, hard	80	290
Lime, white, hard	5	295
Slate, black, soft	135	430
Lime, white, hard	55	485
Shale, white, soft	10	495
Lime, white, hard	5	500
Red rock, soft	5	505
Shale, white, soft	90	595
Lime, white, firm	20	615
Shale, white, soft	5	620
Lime, white, hard	35	655
Shale, gray, soft	5	660
Lime	15	675
Shale, gray, soft	10	685
Lime	40	725
Slate, black	5	730
Lime, broken, firm	70	800
Slate, black	10	810
Lime	80	890
Shale, light	50	940
Shale, black	5	945
Shale, gray	5	950
Lime, white, hard	5	955
Shale, white	50	1005
Slate, black	5	1010
Slate, white, soft	50	1060
Slate, black	5	1065
Lime, white	5	1070

Some oil was found at the bottom of the well.

HAMPTON

(Altitude 1140, C. G. W. R. R.)

WATERWORKS WELL NO. 2, 1926

This well, 1700 feet deep, was completed in February, 1926, by the Thorpe Bros. Well Company of Des Moines. The diameters are from 20 inches to 8 inches. The principal supply was found at 1700 feet in the Jordan standstone. Water found in the Saint Peter sandstone at 1200 feet was cased out. The static level is 153 feet below the surface. With the cylinder at 200 feet the well delivers 1000 g.p.m. with a draw down of 23 feet. The cost of the well was $23,000 and of the pumping machinery $5,000.

The normal static level of well no. 1, drilled in 1900,[54] was 50 feet below the surface with a draw down to 160 feet. The static level is now the same as that of well no. 2, which is only 30 feet distant. The capacity originally was 160 g.p.m., but after well no. 2 was drilled it was reported at 366 g.p.m.

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54 Norton, Underground Water Resources of Iowa, Iowa Geol. Survey, vol. XXI, pp. 777-779.

Record of strata, Hampton city well no. 2

	Depth in Feet
Pleistocene and Recent:	
No samples	0–10
Mississippian, Kinderhook (140 feet thick, top 1106 feet above sea level):	
Limestone, ocher-yellow, effervescence in cold dilute HCl rather slow, much rusted and decayed	10
Sandstone, gray, argillaceous, highly calcareous, grains of quartz minute and ill-rounded; in easily friable masses	20, 30
Shale, gray, slightly calcareous, minutely arenaceous	40
Sandstone, as at 20 and 30 feet	50
Limestone, blue	60
Limestone, gray	70
Shale, blue; 7 samples	80–140
Devonian and Silurian (?) (450 feet thick, top 966 feet above sea level):	
Limestone, brown, crystalline-granular, effervescence moderately rapid, in large chips	150
Limestone, drab; powder of shale	160
Limestone, drab, fine crystalline-granular; whitish, same texture	170, 180
Shale, blue-green, in concreted masses	190
Limestone, varicolored	200
Shale, greenish gray, in concreted masses	210
Limestone, drab, fine crystalline-granular; calcite	220, 230
Shale, blue and green-gray; 6 samples	240–290
Limestone, whitish, in large chips	300, 310
Limestone, cream colored and gray, fine grained; 4 samples	320–350
Limestone, brown-drab	360
Limestone, cream color and gray, with much powder of shale	370
Limestone, gray, buff and brown, effervescence generally rather slow, some brisk; 11 samples	380–480
Limestone, light brown, compact, cryptocrystalline, slow effervescence	490
Limestone, whitish and light yellow-gray and buff, rapid reaction	500
Limestone, blue-gray and yellow-gray, reaction rather slow, some rapid; 5 samples	510–550
Limestone, yellow-gray, moderately rapid	560
Limestone, whitish, soft, response rapid; 3 samples	570–590
Maquoketa shale (140 feet thick; top 516 feet above sea level):	
Shale, light brown, calcareous	600, 610
Shale, light reddish brown; some greenish yellow	620
Shale, blue; 3 samples	630–650
Limestone, yellow-gray, slow effervescence	660
Chert, gray, and shale, some limestone; some red shale at 700; 4 samples	670–700
Shale, gray; 3 samples	710–730
Galena and Platteville limestones (400 feet thick; top 376 feet above sea level):	
Limestone, drab and light buff, reaction rapid; chips of shale	740, 750
Shale, blue-gray	760
Limestone, gray and yellow-gray, slow and moderately slow effervescence	770, 780
Limestone, whitish, rapid reaction	790, 800
Limestone, gray in mass; 25 samples	810–1050
Shale, blue-green	1060
Limestone, gray in mass; 7 samples	1070–1130
Glenwood shale (30 feet thick):	
Shale, hard, blue-green	1140
Shale, drab and brown	1150
Shale, green, fissile	1160
Saint Peter sandstone (70 feet thick; top 54 feet below sea level):	
Sandstone, whitish, of Saint Peter facies; with much yellow-gray limestone of rapid effervescence in small chips	1170

Sandstone, white, grains up three-fourths mm. in diameter; considerable shale in flakes	1180
Sandstone, white, clean except for a little shale	1190, 1200
Shale, blue-green, noncalcareous; a large chip of sandstone, dark gray, of well cemented rounded grains	1210
Sandstone, white, rusted yellow at 1230	1220, 1230
Prairie du Chien (410 feet thick; top 124 feet below sea level):	
Dolomite, light gray, in fine chips; most of sample consists of quartz sand	1240, 1250
Dolomite, gray, buff and whitish; highly arenaceous from 1300 to 1480, sandstone at 1460 (New Richmond); 37 samples	1260–1620
Dolomite, highly arenaceous	1630
Dolomite, clean of sand	1640
Jordan sandstone (penetrated 50 feet; top 534 feet below sea level):	
Sandstone, white, clean, grains well rounded, up to about 1 mm. diameter; 6 samples	1650–1700

HAWKEYE, FAYETTE COUNTY

(Altitude 1176 feet)

A well 835 feet deep and 8 and 6 inches in diameter was drilled for this town by Thomas James of Shullsberg, Wisconsin.

At 600 feet a water bed was struck, when the water in the well dropped to 90 feet from its previous head of 30 feet below the curb. The main supply was found at 835 feet, when the water fell to the static level of 265 feet.

The well now delivers 100 gallons per minute under air. The cost of the well was $5,200.

HOLSTEIN, IDA COUNTY

CITY WELL NO. 2, 1924

This well was drilled by Thorpe Brothers of Des Moines. Its depth is 2040 feet and the diameters are 12 inches to 6 inches. With the cylinder of the pump placed at 600 feet, the well has a pumping capacity of 200 gallons per minute.

The static level of the water is about 290 feet below the curb. The chief water beds reported are the Pleistocene at 275 feet, undifferentiated Paleozoic at 750 feet in dolomite and the Prairie du Chien at 1550 feet. Water is also said to have been found in the Cambrian at 1900 feet. The cost of the well was $34,000 and that of the pumping machinery $4,000. In city well no. 1 (1897) water was found in quicksand at 390 feet, at 1200 feet in Galena dolomite and "below 1500 feet", i.e. in the Prairie du Chien and possibly the subjacent beds.

Record of strata in City well no. 2, Holstein

	Depth in Feet
Pleistocene and Recent (420 feet thick; top 1457 feet above sea level):	
Till, drab, clayey, calcareous, small pebbles of dolomite	20
Clay, blue, gritty, calcareous	30
Clay, light greenish drab, hard, concreted, calcareous, gritty	40
Till, clayey, pale yellow, calcareous, small pebbles of igneous rocks and limestone	50
Clay, as at 40 feet	60
Till, drab, clayey, with small pebbles; 5 samples	70–110
Clay, as at 40 feet, gritty with coarse sand	120
Clay, drab, hard, noncalcareous, with rare grains of siliceous limestone	130
Clay, gray-buff, calcareous, gritty with coarse sand of quartz and some of limestone	140
Till, gray-buff, clayey, with small pebbles; 2 samples	150, 160
Till, drab, clayey, with small pebbles; 3 samples	180–200
Till, drab, sandy, friable, pebbly	210
Till, drab, clayey, with pebbles, many of chert and limestone, 7 samples	220–280
Clay, reddish buff, noncalcareous, with small ironstone brownish concretions	290
Till, light drab, clayey, gritty, calcareous	300
Clay, friable, sandy, brownish drab	310
Clay, as at 290	330
Clay, dark gray, noncalcareous, gritty; 4 samples	340–370
Till, clayey, dark gray, calcareous, gritty, with many pebbles of limestone, greenstone, quartz, etc.	380
Pennsylvanian (?) (170 feet thick; top 1037 feet above sea level):	
Shales, drab, gray and red, plastic, noncalcareous; 15 samples	420–580
Mississippian (140 (?) feet thick; top 867 feet above tide):	
Sandstone, light yellow-gray, grains imperfectly rounded, of pure quartz, largest up to 1 mm. and 1.5 mm. diameter; 3 samples	590–610
Limestone, light yellow-gray, crystalline-granular, rapid effervescence in cold dilute HCl	620
Sandstone, as at 590	630
Limestone, as at 620	640, 650
Limestone, as above, in thin chips, cherty; with much quartz sand of highly irregular grains; 3 samples	660–680
Limestone, drab, effervescence rapid; with a little quartz sand	690
Limestone, magnesian, or dolomite, light buff, fine crystalline-granular, moderately slow effervescence	700
Limestone, as above; with much white fossiliferous chert, and much quartz sand, irregular grains varying much in size, some pinkish	710
Limestone, gray and light yellow, compact, rapid reaction, with much sand as above	720
Undifferentiated Paleozoic, lower portion Galena and Platteville (700 feet thick; top 727 feet above tide):	
Shale, hard, blue-green, fissile; and sandstone, gray, fine, of pure quartz, moderately well rounded, apparently from horizon of Saint Peter, and out of place, as no like shale and sand appears in cuttings of immediately underlying beds	730
Dolomite, or magnesian limestone, blue-gray, and yellow-gray, earthy, laminated, in flaky chips	740, 750
Dolomite, drab, subcrystalline, hard, compact, in chips; with some large chips of buff limestone at 770; 3 samples	760–780
Dolomite, as above; with considerable quartz sand of vari-colored and ill-rounded grains probably from above	790
Dolomite, drab, chiefly in sand, some blue shale	800
Dolomite, blue, drab and light yellow-gray; with some blue and green hard fissile shale, and some irregular grains of quartz	810
Dolomite, blue and yellow-gray, pyritiferous; with much quartz sand of well rounded grains and dark green-gray hard, finely laminated shale	820

Dolomite, light gray, with a little green shale and sand 830, 840
Dolomite, drab, hard 850
Dolomite, light yellow-gray, in sand; with much green shale, some with *cone-in-cone* structure, and well rounded quartz sand up to 1 mm. diameter 860
Dolomite, gray and blue-gray, in crystalline sand and small chips, argillaceous, and with some blue shale at 1040-50, a little white chert at 1080-90, highly cherty 1100-30; 23 samples 900–1130
Shale, greenish drab, hard, fissile; and sandstone, rounded grains up to 1.3 mm. diameter; much white chert 1140
Dolomite, light gray and yellow-gray, cherty 1150, 1160
Dolomite, blue and yellow-gray, in crystalline sand, at 1170 dark drab in chips, cherty at 1250; 16 samples 1170–1310
Dolomite, yellow-gray, with some drab shale 1320, 1330
Dolomite, blue, argillaceous; with some sandstone, blue, argillaceous, of minute grains 1340
Shale, light green-gray, calcareous, arenaceous with minute grains 1350
Sandstone, rounded grains, a few reaching 1.8 mm. in diameter; much green fissile shale, a little gray dolomite 1360
Shale, bright green and blue-gray, calcareous; 3 samples 1370–1390
Limestone, response rapid, gray, with shale 1400
Shale, green and light brown 1410
Limestone, gray, rapid reaction, with much shale, all in small chips 1420

Ordovician:

Saint Peter sandstone (20 feet thick; top 27 feet above sea level)—
Sandstone, white, fine, grains well rounded, with some chips of green shale 1430, 1440

Prairie du Chien (180 feet thick; top 7 feet above sea level):
Dolomite, light yellow-gray 1450
Dolomite, drab, sparse floating grains of sand, oölitic, with much quartz sand and drab shale 1470
Sandstone, clean, white, well rounded grains up to about 0.5 mm. diameter; some green, fissile shale 1480
Dolomite, gray, in sand; much shale at 1510 1490–1510
Dolomite, gray, oölitic 1540
Dolomite, light yellow-gray, cherty (duplicate sample: sandstone, white, well rounded grains) 1550
Dolomite, gray and buff, in fine crystalline sand; 6 samples 1560–1620

Cambrian:

Jordan sandstone (?)
Sandstone, white, well rounded grains, up to 1.2 mm. diameter 1630

Saint Lawrence dolomite and shales and undifferentiated Cambrian (340 feet thick; top 183 feet below sea level)—
Dolomite, gray, highly arenaceous with minute quartz grains and particles, somewhat argillaceous; 5 samples 1640–1680
Shale, green-gray, calcareous, minutely quartzose, glauconitic, in powder and friable masses 1690
Dolomite, highly arenaceous, grains minute, at 1740 argillaceous; 4 samples 1700–1740
Shale, gray, highly calcareous, minutely quartzose 1750, 1760
Sandstone, grains minute, dolomitic, glauconitic 1770
Shale, green-gray, as at 1750 .... 1780, 1790
Sandstone, as at 1770 1800
Shale, as at 1780, in powder 1810
Sandstone, gray, calcareous, argillaceous 1820
Shale, greenish and blue-gray, plastic, hard, in splintery chips, slightly calcareous; 4 samples 1830–1880
Dolomite, buff, arenaceous, glauconitic 1890
Shale, greenish, in hard splintery chips 1900
Dolomite, gray, highly quartzose, glauconitic, in chips, with much shale 1910, 1920
Shale, drab, hard, noncalcareous, with dolomite as above 1930, 1940

Shale, calcarcous, quartzose	1950
Shale, hard, green gray, plastic	1960, 1970
Red Clastic beds (40 feet thick; top 523 feet below sea level):	
Sandstone, red, grains of clear uncolored quartz well rounded, little broken, with surface before washing reddened with ochreous interstitial material, with balls, dark red, ochreous, ellipsoidal and globular, up to 2.7 mm. diameter, concentric structure, outer coating dark red, inner reddish yellow, noncalcareous; 3 samples	1980–2000
Sandstone, cuttings flesh colored, grains of clear quartz with a light surface stain, grains well rounded, up to 1.5 mm. diameter, in sand; with some chips of flesh colored sandstone, noncalcareous, of minute grains of clear uncolored quartz	2010
Archean (?) (penetrated 20 feet; top 563 feet below sea level):	
Granite, pink; with much quartz sand in rounded grains and a little shale; components of granite; orthoclase feldspar, quartz in small grains, white mica (muscovite?), and a black ferro-magnesian mineral, yellow brown when pulverized, with no noticeable pleochroism; in chips and sand; 3 samples	2020–2040

Notes.—While the samples of the cuttings of this well, on the whole, have evidently been taken with care, yet some obvious misplacements have taken place. The city officials who packed them for shipment to this office called attention to this fact, and in copying labels other errors could happen. Thus a Pleistocene clay is labelled with a depth of 890 feet. The sandstone of Saint Peter facies at 730 feet also is very probably out of place.

The drift is of exceptional thickness, and the shales beneath it carry no very convincing evidence as to whether they are Cretaceous or Pennsylvanian. Comparing this section with that of the deep well at Cherokee, eighteen miles north, it will be seen that the nondolomitic limestones and sandstones assigned to the Mississippian have thinned greatly to the south, while the underlying dolomites have correspondingly thickened. Probably the larger portion of these dolomites belongs to the Galena and Platteville. The gray and blue-gray argillaceous and in part cherty dolomites from 900 to 1130 feet probably include the Maquoketa. A thin sandstone of Saint Peter facies occurs at Holstein, according to the samples, at 1360 feet and is associated with the green shale so common at this horizon. The top of the Saint Peter, however, is placed at 1430 feet, where a white sandstone occurs in greater thickness, at near the level of the Saint Peter in well no. 1, and where it is underlain by the usual dolomites of the Shakopee.

The white sandstone at 1630 feet is too thin to be assigned with any certainty to the Jordan, but the underlying thick series of dolomitic, argillaceous quartzose beds, in places glauconitic, with some shales, are typically Saint Lawrence and EauClaire. No well defined Cambrian water bearing sandstones, such as the Dresbach and Mount Simon of northeastern Iowa deep well sections, are found here below the Saint Lawrence—a fact of major importance in well drilling. The beds of the lithologic facies of the Franconia or EauClaire rest directly on a red ochreous sandstone, tentatively correlated with the Red Clastics of southern Minnesota, as its loosely cemented grains show no evidence that it had ever been quartzitic.

The importance of the granite floor reached at 2020 feet has been set forth by Lees,[55] who was consulted by the drillers and after visiting the town and examining the cuttings identified the rock as granite in which the drill was working and advised stopping the work immediately.

From Cherokee to Holstein the south dip of the Saint Peter sandstone is about sixteen feet per mile. The Cherokee well did not go below the Saint Peter, and while additional water might have been found in the Prairie du Chien, the Holstein section shows that it would have been unadvisable to enter the Saint Lawrence. Indeed, if the Archean surface is of slight relief and the Cambrian formations above it thicken to the south, it might easily have been reached at Cherokee from 300 to 500 feet below the bottom of the well.

It is worth remark that the red sandy, cherty, caving shale found in the first city well at Holstein at 1520 feet, not far below the base of the Saint Peter, where such residual formations are not uncommon, is entirely absent in the second well.

Mineral Content of City well, no. 2, Holstein[*]

	P.P.M.
Bicarbonate	236.7
Chloride	13.
Sulfate	757.8
Silica	24.4
$Fe_2O_3+Al_2O_3$	10.0
Calcium	139.5
Magnesium	77.8
Na + K as Na	109.6
Total solids	1250.4

55 Proc. Iowa Acad. Sci., vol. XXX, pp. 445-450.

* Analysis by Dr. Harry F. Lewis, Chemical Laboratory, Cornell College, Mount Vernon, 1927.

HUXLEY, STORY COUNTY

(*Altitude 1046 feet, Ft. D., D. M. & S. R. R.*)

The well which furnishes the public supply for Huxley is 892 feet deep and was completed in 1921 by Thorpe Brothers of Des Moines. The diameters are from 10 to 5 inches. The main supply was found at 891 feet and small veins were struck between 125 and 325 feet. The original static level of 125 feet below the curb and the pumping capacity of 75 g.p.m. are both maintained. The consumption of the village averages 5,000 g.p.d. with a maximum of twice that amount. The pumping cylinder is hung at 160 feet and continuous pumping has no effect on the level of the water. The water is reported as rather hard on boilers. The cost of the well was $10,000.

Driller's log of town well at Huxley

	Thickness, feet	Depth, feet
Black dirt	8	8
Yellow clay	40	48
Blue clay	72	120
Shale	120	240
Limerock	40	280
Shale	80	360
Limerock	60	420
Shale	120	540
Limerock	180	720
Shale	40	760
Lime	110	870
Shale	22	892

Hole started 10 inches in diameter. 8 inch pipe from surface to solid formation. 120 feet of 6 inch pipe from 500 feet to 620 feet, 4 inch pipe to bottom.

INWOOD, LYON COUNTY

(*Altitude 1466 feet*)

The city well of Inwood was drilled in 1917 by the McCarthy Well Company of Saint Paul. The depth is 914 feet; the diameters are 12 and 10 inches. The principal supply was found in the "fine sand" from 290 to 300 feet. A "light vein" was struck at 450 feet in the "shale" of the driller's log, yielding soft water. About 5 gallons per minute were obtained from the Sioux quartzite.

The static level is 275 feet below the curb and is not drawn down by pumping. The pumping capacity is named at 23 gallons of clear water. The pump, whose cylinder is set at 297 feet below the curb, will lift 60 gallons, but the water is then turbid.

The cost of the well was $10,000 and of the pumping machinery $2,000.

Driller's Log

	DEPTH IN FEET
Clay	0–290
Fine sand	290–300
Shale	300–475
Granite	475–915

A few samples of the cuttings of this well were obtained. The first, stated to represent the material from the surface to 300 feet, is a blue clay with pebbles of the northern drift. That labeled 300 to 475 feet is shale, drab, noncalcareous, with much quartz in fine angular particles. The sample at 475 feet and three others to and including 500 feet are of Sioux quartzite, in clear pinkish grains, coarse, up to 2.5 mm. in diameter, and at 500 feet showing greater induration by more complete fractures. The top of the Sioux quartzite lies about 1000 feet above sea level. The shale above it may be Cambrian. The fact that the drillers noticed no difference of material from 475 feet to 915 feet gives a shade of probability to the supposition that the quartzite extends to the bottom of the well.

While the drilling was in progress Assistant State Geologist Lees gave the advice not to drill into the quartzite "as it is in most places very hard and close-grained and yields very little water"—advice which if followed would have saved the town several thousand dollars.

*Mineral Content of City Well, Inwood**

	P.P.M.
Bicarbonate	380.6
Chloride	9.0
Sulfate	957.8
Silica	20.0
$Fe_2O_3+Al_2O_3$	10.1
Calcium	250.9
Magnesium	162.5
Na + K as Na	63.1
Total solids	1663.7

IOWA CITY

WELL OF THE STATE UNIVERSITY OF IOWA, 1927

This well is located just north of the east end of the Burlington Street bridge on the bank of Iowa river at an elevation above

* Analysis by Dr. Harry F. Lewis, Chemical Laboratory, Cornell College, Mount Vernon, 1927.

sea level of 672 feet. The depth of the well is 840 feet. A 10 inch pipe extends to 499 feet; an 8 inch pipe, from this point to the bottom, is perforated at the water beds. Flowing water was struck in the Galena limestone at 755 feet, with a natural discharge of 100 g.p.m.

The pumping capacity on completion was found to be 210 g.p.m. with a draw down of 20 feet. An air lift now raises 300 g.p.m. with a draw down of 70 feet. The well was drilled by the Thorpe Bros. Well Company of Des Moines at a cost of $9700.

Chemical analysis of water of University well, Iowa City, done by the Cochrane Engineering Co.

	Grains per U. S. Gallon
Magnesium carbonate	5.98
Magnesium sulphate	1.79
Calcium sulphate	10.85
Sodium sulphate	21.00
Sodium chloride	4.55
Silica	0.44
Iron oxide and alumina	0.02

Record of strata, State University well, Iowa City, 1927

	Depth in Feet
Cedar Valley limestone:	
Limestone, light cream yellow, soft, earthy, fine-grained, compact, laminated, rapid effervescence in cold dilute HCl, in thin flakes	55–65
Wapsipinicon limestone (140 feet thick):	
Limestone, light yellow-gray, soft, earthy, rapid reaction; chip of same texture shows fragment of small brachiopod shell with plications, another chip a fragment of a larger plicated brachiopod shell; some light gray limestone	65–75
Limestone, light yellow-gray, calcilutite, conchoidal fracture; also buff-gray, crystalline-earthy; buff, laminated; and buff with brown crusts	75–80
Limestone, light yellow-gray, and light gray, calcilutite; some chips show crystalline-earthy gray limestone inclosing minute fragments of calcilutite	80–90 (?)
No samples	90–110
Limestone, yellow-gray, earthy, argillaceous, rather slow effervescence	110–120
Limestone, dark buff, fine crystalline-granular, in large chips of rough surface and irregular fracture; slight quartzose and argillaceous residue	120–130
Limestone, gray, crystalline-earthy, soft, rapid effervescence; some buff dolomite or magnesian limestone, slow reaction; some silica, whitish, translucent	130–140
Shale, light gray, in clean large flaky dolomitic chips, and earthy argillaceous limestone of same color	148
Dolomite, gray, crystalline-granular, in chips	150–160
No samples	160–185
Dolomite, gray and yellow-gray, cryptocrystalline	185–190
Shale, dark greenish gray, noncalcareous, unctuous, pyritic, highly arenaceous, grains fine, of clear quartz and many of larger grains well rounded	201–205
Niagaran (150 feet thick; top 462 feet above sea level):	

Dolomite, light yellow-gray, cryptocrystalline, vesicular, rough fracture; 3 samples	210–240
Dolomite, light blue-gray and yellow-gray, cherty at 340; 12 samples; no samples from 280-320	240–360
Maquoketa (top 312 feet above sea level):	
Shale, light blue-gray and green-gray, plastic, dolomitic; 2 samples	360–380
No sample	380–390
Dolomite, blue-gray and yellow-gray, crystalline; shale, hard, drab	390–400
Shale, light blue-gray, plastic; 3 samples	400–430
Dolomite, gray, hard; much gray chert	430–440
Dolomite as above, earthy; some chert	440–450
Dolomite, gray, earthy	450–460
Shale, light blue-gray, plastic; 2 samples	460–478
Shale, hard, drab and greenish drab; gray shale, noncalcareous, arenaceous with fine well rounded grains of clear quartz; dolomite, greenish drab, earthy; lumps of decayed chert; 2 samples	478–490

Notes on this section will be found under Oakdale sanatorium well, 1928.

*Driller's log, well of State University of Iowa, 1927**

	Depth in Feet
Pleistocene and Recent (50 feet thick; top 672 feet above sea level):	
Soil and clay	0–15
Sand	15–50
Devonian limestones and shales (155 feet thick; top 622 feet above sea level):	
Sandy limestone	50–60
Limestone	60–95
Broken lime rock	95–105
Limestone; water, 25 g.p.m.	105–128
Shale	128–136
Lime	136–164
Shale	164–172
Lime	172–179
Shale	179–185
Limestone	185–201
Shale	201–205
Niagaran limestone (155 feet thick; top 467 feet above sea level):	
Lime	205–250
Lime	250–360
Maquoketa shale (193 feet thick; top 312 feet above sea level):	
Shale	360–390
Lime	390–406
Shale	406–432
Lime; more water	432–465
Shale	465–478
Lime	478–499
Lime	499–504
Shale	504–553
Galena-Platteville (287 feet thick; top 119 feet above sea level):	
Lime	553–563
Sand rock	563–568
Lime rock	568–580
Shale	580–585
Lime	585–755
Magnesia lime; more water	755–770
Magnesia lime	770–812
Hard lime	812–828
Green mud (Glenwood shale?)	828–835
Mud, blue (Glenwood shale?)	835–840

* Assignment of formations by W. H. Norton.

KEOKUK

(*Altitude 504 feet*)

WELL OF ELECTRO-METALS CO.

This well was drilled by S. B. Geiger and Co. of Chicago, and was completed in 1928. It is 888 feet in depth and from 12 to 8 inches in diameter. There are 40 feet of 12 inch casing at top and an 8 inch pipe from 245 to 470 feet cases out the Kinderhook shales.

The natural flow is 294 g.p.m. A small flow was obtained from the Galena-Platteville limestone at 625 feet and one of 125 g.p.m. at about 730 feet in the same formation. The Saint Peter gave a flow of 275 g.p.m. at about 820 feet and this had increased to 294 g.p.m. at the bottom of the well. The temperature of the water is 63° F. The curb is 513 feet above sea level.

Driller's log and record of strata

	DEPTH IN FEET
"Fill and white sand"	0–58
Clay, gray and buff, with a few pebbles, some rolled	10–37
Sand and gravel	37–40
Mississippian, undifferentiated (222 feet thick; top 475 feet above sea level):	
"White lime"	58–150
Limestone, white, soft, earthy, in flaky chips, rapid effervescence in cold dilute HCl	40–137
Limestone, dark gray and yellow-gray, soft, crystalline-earthy; in chips and argillaceous powder	137–150
"Shale"	150–155
Shale, blue-gray, somewhat calcareous; a little white chalcedonic silica	150–155
"Gray lime"	155–170
Sandstone, dark blue-gray, calcareous, highly argillaceous, grains irregular, microscopic; a little chalcedony	155–170
"Shale"	170–180
"White lime"	180–260
Limestone, yellow-gray, fine-grained, earthy, rapid effervescence	180–250
Limestone, drab, in sand, rapid effervescence	250–260
Kinderhook shale (200 feet thick; top 253 feet above sea level):	
"Shale"	260–460
Devonian? Silurian? Maquoketa? Galena-Platteville (322 feet thick; top 53 feet above sea level):	
"Brown lime"	460–590
"Sand"	590–755
Dolomite, light buff gray in mass; in sand	590–595
Dolomite, as above	595–605
Dolomite, brownish buff in mass, in coarser sand; a little white chert	605–625
"Lime"	755–782
Dolomite, grayish buff	755–782
St. Peter sandstone (106 feet penetrated; top 269 feet below sea level):	
"Sand"	782–888
Sandstone, white, fine, exceptional grains 1 mm. diameter, grains frosted, fairly well rounded, some secondary enlargements	782–850
Sandstone, white, finer than above, larger grains generally well rounded and frosted	850–888

Notes.—The following description of two samples of the cuttings is omitted from the above record as their labels are probably interchanged or otherwise misplaced.

Limestone, gray, in sand, rapid effervescence, some chips of brown, noninflammable shale	260–460
Shale, blue gray, in concreted mass, calcareous, some very feebly so	460–590

These samples, which contradict the log as to the place of the Kinderhook shale, contradict also the cuttings and logs of earlier wells at Keokuk.

The shales and sandstone at 150 feet are noted in the sections of the Y. M. C. A. and the Poultry Company's wells. In the above log the sandstone is called "gray lime;" as it occurs in chips and its arenaceous nature is not evident without test.

The "sand" of the driller's log from 590 to 755 feet is evidently the Galena-Platteville dolomite of the samples, a rock which, as is often noted, is apt to crush under the drill into sparkling crystalline dolomitic sand.

WELL OF THE KEOKUK PURE ICE CO.

This well, 701 feet in depth and 6 inches in diameter, was drilled in 1913 by T. J. Haggerty of Keokuk. The main supply was found at 680 feet. On completion the natural flow was 85 g.p.m. In 1914 the company, needing more water, put in a centrifugal pump with the pipe placed at about 40 feet and the supply was thus increased to 110 g.p.m. Two years later this amount became insufficient. The well was now cased for the first time, using 200 feet of 5 inch pipe, and an air lift was installed with the nozzle at 150 feet. The yield was now raised to 180 g.p.m. and later experiments with lowered nozzle and larger motor failed to increase it.

The natural flow gradually lessened until early in 1918 it probably was not more than 50 g.p.m. At this time two large wells (those of the J. C. Hubinger Bros. Co.) were put down one mile distant from the well and on ground 70 feet lower than the curb. In July it was found that, as an effect of interference, the static level had fallen to 6 feet below the curb and since that time it has fallen to 41 feet below that level. The delivery at present is 135 g.p.m., with the air lift nozzle at 150 feet. The temperature of the water is 62° F.

WELL NO. 1, J. C. HUBINGER BROS. CO.

In June, 1928, this well was completed by the S. B. Geiger Company of Chicago. The depth is 692 feet and the diameters are from 15½ to 10 inches. The main flow came from between 597 and 692 feet. On completion the flow was 890 g.p.m., but by December 1 of that year it had fallen to 705 g.p.m. The pressure or head was not taken. The temperature of the water is given as 64° F. The elevation of this well and that of well no. 2 are stated to be that of the Union station, or approximately 504 feet above sea level. There were placed 34 feet of 16 inch casing at the top of the well and 227 feet of 10 inch casing on the 459 foot level.

Driller's log

	Depth in Feet		Depth in Feet
Dirt and clay	0–33	Lime rock	564–597
Lime rock	33–243	Sand rock	597–650
Shale	243–564	Sand and lime	650–692

Record of strata

	Depth in Feet
Mississippian:	
Keokuk formation, Montrose cherts (top 471 feet above sea level)—	
Chert, white; limestone, light gray and whitish, rapid effervescence, only a little limestone at 100; Montrose cherts, 33-53 and	100
Burlington and Kinderhook limestones (121 feet thick; top 379 feet above sea level)—	
Limestone, white, soft, macrocrystalline	125
Limestone, light gray, crystalline-earthy	138
Shale, light blue-gray, in concreted masses with chips of gray and yellow-gray limestone	143
Sandstone, blue-gray, of microscopic grains of crystalline quartz, argillaceous, calcareous, in chips	148, 157
Shale, light blue-gray	165
Limestone, light gray, calcilutite, conchoidal fracture, somewhat siliceous, rapid effervescence as are all limestones above	172–175
Dolomite, brownish gray, fine-crystalline, some gray limestone	188
Limestone, light yellow-gray, fine-grained, rapid effervescence; some brown dolomite	200
Sandstone, blue-gray, argillaceous, calciferous, grains microscopic	232–237
Kinderhook shale (204 feet thick; top 258 feet above sea level)—	
Shale, blue-gray, siliceous, calcareous	246
Shale, blue	274
Shale, brown, some chips slightly inflammable	310
Shale, gray and light blue-gray	344, 350, 392, 400
Devonian (106 feet thick; top 54 feet above sea level):	
Limestone, light gray, some brown-gray, earthy, rapid effervescence	450
Limestone, gray and buff, hard, in coarse sand, rapid effervescence	502
Limestone, brown, mottled gray, in flaky chips, rapid effervescence	523

Limestone, light gray and yellow-gray, laminated, calcilutite, rapid effervescence	556
Ordovician:	
Unknown, no samples	556–580
Galena-Platteville (samples for 17 feet; top 76 feet below sea level)—	
Dolomite, light brownish, crystalline granular, in sparkling sand	580, 597

Notes.—No attempt is made to separate the Burlington from the Kinderhook limestones in the above section, although the dolomite and sandstone at 188 feet and below clearly belong to the latter both by place and by character. The Kinderhook shale has thinned both southward from Fort Madison, where it is 268 feet thick, and also eastward from Donnellson, where it is 325 feet thick. The Devonian limestones are characteristic and the calcilutite recurs which is found near the base at both Donnellson and Fort Madison. Nothing similar to the Niagaran dolomites occurs in this area. The Maquoketa shale also is wanting and it will be noted that at Donnellson it had thinned to five feet and was found but 18 feet thick at Fort Madison.

According to the samples of the Electro-Metals Company's well, the Galena dolomite extends to 269 feet below sea level, 81 feet below the footing of well no. 1 of the J. C. Hubinger Bros. Co. The log of this well thus makes the common mistake of confusing the sparkling dolomite sand of cuttings of the Galena with the quartz sand of the Saint Peter, where especially the former is water-bearing. The thickness of the Galena-Platteville is about the same as at Donnellson and about 50 feet thinner than at Burlington.

Although well no. 2 of this company is 45 feet deeper than well no. 1, reaching 233 feet below sea level, it still falls short of the horizon of the Saint Peter at 269 feet below sea level in the well of the Electro-Metals Co. The yield of well no. 2 also leads to the inference that the Saint Peter was not reached. Large as is the yield from the Galena it would appear that wells at Keokuk should be drilled to the base of the Saint Peter sandstone and that for certainty samples of the cuttings should be submitted to a competent geologist.

WELL NO. 2, J. C. HUBINGER BROS. CO.

On the 25th of July, 1928, S. B. Geiger completed a second deep well for the Hubinger Bros. Co. This is located 295 feet due west of well no. 1 and is of the same diameters. The depth is 737 feet. The main flow came from 630 feet to the bottom. Although this well is deeper than well no. 1, the discharge was much less—339 g.p.m. which later (December 1) had fallen to 310 g.p.m. Thirty-four feet of 16 inch casing was placed on the 34 foot level and 227 feet of 10 inch casing on the 459 foot level.

Driller's log

	Depth in feet
Dirt and clay	0–34
Lime rock	34–250
Shale	250–459
Lime rock	459–630
St. Peter's sand and rock	630–737

Mineral analysis of the J. C. Hubinger Bros. deep wells

	Parts per million	Grains per gallon
Total solids	3860	225.0
Potassium	115	6.7
Sodium	813	47.4
Magnesium	82	4.8
Calcium	187	10.9
Ammonium	4.3	0.3
Bicarbonate	301	17.6
Sulphate	1490	86.9
Chloride	690	34.2
Hypothetical Combinations		
Potassium chloride	220	12.8
Sodium chloride	966	56.4
Sodium sulphate	1341	78.2
Magnesium sulphate	406	23.7
Calcium sulphate	364	21.2
Calcium carbonate	212	12.4
Silica	26	1.5
Alumina and ferric oxide	20	1.1
Hydrogen sulphide	1.4	

KNOXVILLE

WELL NO. 2 OF THE STATE HOSPITAL FOR INEBRIATES

Record of strata

	Depth in feet
Pleistocene and Recent (25 feet thick):	
Clay, light buff, slightly calcareous	10
Des Moines:	
Shale, drab	25
Sandstone, gray, micaceous	33, 36
Limestone, gray, rapid effervescence in cold dilute HCl; powder of shale in cuttings	48
Shale, light blue-gray, fissile	60
Limestone, light gray, rapid effervescence, earthy, in large chips	70
Shale, dark gray	80

Limestone, as at 48 feet; powder of shale; pyrite	90
Limestone, white, rapid effervescence, in concreted fine sand and powder, highly arenaceous with small imperfectly rounded grains of quartz, which occasionally are seen imbedded	100
Sandstone, light gray, fine irregular grains	108
Shale, black, coaly	117
Shale, gray, hard	125
Shale, calcareous, cherty, pyritiferous, in powder and fine sand	130
Limestone, reddish, reaction rapid; chert; shale; all in coarse washed sand	142
Shale, dark and light gray, arenaceous, micaceous	150
Shale, dark gray; sandstone, light gray, of minute quartzose-angular grains, argillaceous, noncalcareous	159 and 161
Limestone, light gray, rapid reaction, with obscure minute structure as of foraminifers	170
Limestone, blackish, hard, argillaceous, response rapid, pyritiferous	175
Limestone, as at 170 feet	179
Shale, drab, fissile; 5 samples	190–225
Coal	225
Shale, light gray, highly siliceous	240
Limestone, gray, effervescence rapid, fossiliferous	250
Shale, blackish	260
Sandstone, gray, moderately fine, some secondary enlargements	270, 280
Sandstone, gray, coarser than above, soft, friable	290
Sandstone, light gray	300
Sandstone, light buff	310
Limestone, brown, mottled, earthy, rapid reaction	315
Sandstone, whitish, fine, grains imperfectly rounded, calcareous	320
Sandstone, rather fine	330
Limestone, blue-gray, rapid effervescence	340

LAKE MILLS, WINNEBAGO COUNTY

Lake Mills has two city wells, one 235 feet deep, 6 inches in diameter, with a pumping capacity of 80,000 g.p.d., the other 374 feet deep, 12 inches in diameter, with a pumping capacity of 250,000 g.p.d. The average town consumption is 40,000 g.p.d. and maximum 60,000 g.p.d. The record given below is of the deeper well.

Record of strata in the City well of Lake Mills

	Depth in Feet
Pleistocene and Recent (122 (?) feet thick; top 1266 feet above sea level):	
No samples	
Devonian and inferior Paleozoic terranes (penetrated 252 feet; top 1144 feet above sea level):	
Dolomite, bright buff in small chips and crystalline sand "rotten rock" of label	122, 134
Dolomite, gray, crystalline-granular, soft, in small chips; 4 samples	144–174
Dolomite, buff, fine-grained, large dark argillaceous residue	184–194
Limestone, drab, fine-grained, rapid effervescence in cold dilute HCl	204
Limestone, blue-gray, moderately rapid effervescence	214
Limestone, magnesian, blue-gray, reaction moderately slow, fine-grained	224
Limestone, grayish buff, fine-grained, some calcite, response moderately rapid. All the above from 184 feet have large argillaceous residue	234
Limestone, light blue and yellow-gray, fine-grained	244

Limestone, magnesian, or dolomite, gray and grayish buff, soft, fine-grained, earthy; 3 samples	254–274
Dolomite, gray, with chert at 284; 3 samples	284–304
Dolomite, light blue-gray, earthy, soft, fine and close-grained, large argillaceous and minutely quartzose residue	314
Limestone, light gray and white, soft, earthy, argillaceous with finely divided cryptocrystalline silica; rapid effervescence	324
Dolomite, gray-buff, fine crystalline-granular, much white chert, large drab argillaceous residue with finely divided white chert and minute grains of crystalline quartz	334
Dolomite, gray, fine crystalline-granular, soft, argillaceous	344
Dolomite, in fine buff crystalline sand	354, 364
Limestone, crystalline-earthy, disseminated calcite crystals, encrinital	374
"Shale and whitish clay, unable to get samples"	

Notes.—The shale reached at the bottom of the well, 892 feet above sea level, appears to correspond with the Maquoketa reached at Mason City at 824 feet above sea level. But with the gradient of the summit of the Saint Peter from Mason City to Blue Earth, Minnesota, the Maquoketa would be reached some 75 feet higher, provided that the Galena and Platteville maintained their thickness to the northwest from Mason City to Lake Mills. It is possible that the basal dolomites of the section belong to the Galena, which they much resemble lithologically and that the shale at 374 feet is the Glenwood.

*Mineral Content of City Well, Lake Mills**

	P.P.M.
Bicarbonate	456.
Chloride	2.
Sulfate	37.
Silica	43.8
$Fe_2O_3+Al_2O_3$	5.8
Calcium	99.7
Magnesium	34.5
Na + K as Na	23.6
Total solids	474.4

LAKE PARK, DICKINSON COUNTY

(Altitude 1469 feet)

WELL OF CHICAGO, ROCK ISLAND AND PACIFIC RAILWAY

The following account of this well is given by Meinzer in his report on the underground waters of Jackson county, Minnesota.[56] "At Lake Park, Iowa, * * * a well was drilled for the railway company to a depth of 804 feet. Stratified formations,

* Analysis by Harry F. Lewis, Chemical Laboratory, Cornell College, Mount Vernon, 1927.

56 Geology and Underground waters of Southern Minnesota, U. S. Geol. Survey Water Supply Paper 256, p. 213.

chiefly shale, sand, and sandstone, seem to make up about 550 feet of this depth. The upper portion is supposed to be Cretaceous in age, but the lower probably belongs to some Paleozoic formation. This well was tested with a large steam pump. The water is said to stand nearly 300 feet below the surface, or about 1200 feet above sea level. It is so hard that it is not used by the railway company."

LAMONI, DECATUR COUNTY

(Altitude 1123 feet)

The city well of Lamoni was drilled in 1927 by Thorpe Bros. Well Co. of Des Moines and is 2193 feet in depth. The diameters are from 16 to 6⅝ inches. The casing is as follows: 94 feet of 16 inch pipe from the surface; 552 feet of 12 inch pipe from the surface; 271 feet of 10 inch pipe from 510 feet to 781 feet; 500 feet of 8 inch pipe from 635 feet to 1135 feet; 561 feet of 6⅝ inch pipe from 1070 feet to 1631 feet.

The static level was found to be 340 feet below the surface of the ground, with a drawdown to 525 feet when pumped on test for 36 hours at the rate of 100 to 105 gallons per minute.

City well, Lamoni, Driller's log

	Depth in Feet		Depth in Feet
Clay and boulders	0–100	Fire clay	559–562
Sand	100–105	Black shale	562–590
Clay	105–150	Lime rock	590–600
Mixed shale	150–158	Soft light shale	600–611
Rock	158–160	Black shale	611–620
Rock, very hard	160–165	Light shale	620–642
Blue shale	165–169	Black shale	642–652
White shale	169–175	Gray shale	652–680
Lime rock	175–218	Gray sandy shale	680–770
Black shale	218–231	Sandstone, hard, cut very fine	770–780
Gray shale	231–237	Sand and lime, cut very fine	780–785
Lime rock	237–259	Sandstone, hard, cut very fine	785–839
Black shale	259–264	Hard black lime	839–842
Lime rock	264–291	Black shale	842–885
Black shale	291–302	Sandstone, hard and fine	885–955
Gray shale	302–322	Blue shale	955–1010
Lime rock	322–337	Black shale	1010–1015
Black shale	337–345	Gray sandy shale	1015–1070
Black shale streaked with rock	345–410	Lime rock	1070–1120
Black shale	410–430	Shale	1120–1180
Lime rock	430–442	Lime	1180–1185
Gray shale	442–464	Shale	1185–1195
Black shale	464–475	Light shale streaked with rock	1195–1223
Gray shale	475–543	Hard lime	1223–1363
Black shale	543–557	Light shale	1363–1367
Coal	557–559	Hard lime	1367–1481

Gray shale	1481–1523
Lime rock	1523–1543
Hard lime	1543–1870
Lime streaked with shale	1870–1876
Hard lime	1876–1920
Lime rock	1920–2020
Sand and lime, fine, hard, mostly sand	2020–2075
Lime rock	2075–2100
Sandstone, water-bearing	2100–2143
Flinty lime	2143–2193

Record of strata

	Depth in Feet
Sandstone, fine, highly irregular grains, rusted; pyrite	900
Sandstone, as above	940, 950
Shale, blackish	990
Sandstone, gray in mass, fine irregular grains, argillaceous, calcareous	1030
Limestone, white, earthy, in large flaky chips, rapid effervescence in cold dilute HCl; much quartz sand; some black shale	1070
Limestone, light gray, rusted, crystalline-earthy, rapid effervescence; chalcedonic silica in chips, sandstone in sand and calciferous chips	1090
Sandstone, in sand and chips, fine-grained, some cryptocrystalline silica	1110
Limestone, light gray, crystalline-earthy, rapid effervescence; shale, blue-gray	1120
Limestone, gray, very fine-grained, hard	1140
Limestone, yellow-gray, calcilutite; gray, softer and in some chips arenaceous and involving chips of chert; greenish shale	1150
Limestone, very light gray, soft, in thin flakes, rusted buff in mass	1170
Limestone, or dolomite, brown, hard, fine-crystalline, slow effervescence, in sand; limestone, gray, rapid effervescence	1190
Shale, light blue-gray, calciferous; 3 samples	1200–1220
Limestone, light gray, rapid effervescence, in sand; with light blue shale at 1240; 3 samples	1230–1250
Limestone, gray and yellow-gray, rapid effervescence; some light brown chert	1260
Limestone, gray and brown-gray, fossiliferous, rapid effervescence, in large chips	1270
Limestone, gray and drab, some mottled, rapid effervescence, in sand	1280
Limestone, gray, rapid effervescence, much brown and white chert, in sand	1290
Limestone, gray, light gray and whitish, rapid effervescence, in sand; chert, gray and white, and chalcedonic silica; 6 samples	1300–1350
Shale, light blue-gray, in friable masses, with minute quartz grains; some chalcedonic silica	1360
Limestone, light gray; milky white translucent silica	1370
Silica, chalcedonic, milky white, in small chips; whitish limestone, rapid effervescence; some shale; 5 samples	1380-1420
Limestone, gray and white, rapid effervescence; a little silica as above; considerable gray shale	1430
Chert, gray; shale, hard, blue-green, in flakes, calcareous; gray limestone; ''caving some''	1440
Limestone, gray and yellow-gray, rapid effervescence; chert; pyrite; shale	1470, 1480
Shale, light blue-gray, plastic, calcareous, some brown-gray; 4 samples	1490–1520
Limestone, gray, light gray, and whitish, rapid effervescence, fossiliferous at 1570; with more or less gray and drab shale and a little brown inflammable shale, in chips and powder; 8 samples	1530–1600

Notes.—As many of the labels of the cuttings taken above the depth of 900 feet have become illegible, the geologic section of this depth is best made out from the driller's log. This portion of the section clearly lies in the Pleistocene and the Pennsylvanian. The sandstone at the base of the Pennsylvanian may be compared with that found at the same horizon at Atlantic, Glenwood and Bedford. After passing this sandstone the well was tested —at 1080 feet—and was found to yield 55 g.p.m.

The cuttings below 1070 feet at least as far as 1523 feet, are typically Mississippian in the predominance of light gray and whitish limestone, nonmagnesian in its reaction to acid, milky white, more or less translucent cryptocrystalline silica, and considerable shale. The shale from 1481 to 1523 feet in the log (samples from 1490 to 1520 feet) is assigned to the Kinderhook. This gives a total thickness to the Mississippian of 453 feet, with its top at 53 feet above sea level and its base 400 feet below that datum. The map of the elevation of the top of the Mississippian published in our 1912 report gave this elevation at Lamoni at about 25 feet above sea level.

The limestone from 1523 to 1600 feet thus falls to the Devonian. Below this it is hardly safe without cuttings to assign the geological formations. Probably the water-bearing sandstone at 2100 feet is referable to the Silurian, corresponding to the Silurian water-bearing sandstone at Des Moines. At Des Moines the strata measure (Greenwood Park well) 947 feet from the base of the Coal Measures to the base of the Silurian. At Lamoni the distance from the base of the Coal Measures to the base of the water-bearing sandstone assigned to the Silurian measures somewhat more—1073 feet. It is hardly probable that this sandstone at 2100 feet (1077 feet below sea level) is the Saint Peter. In that case the Saint Peter would be actually higher at Lamoni than at either Des Moines (1114 feet below sea level) or Stuart (1176 feet below sea level), while the Saint Peter in the southwestern county of the state is shown by the deep boring at Nebraska City to reach at least 1853 feet below that level. The absence in the log of any shale referable to the Glenwood also makes against the placing of this sandstone with the Saint Peter.

LEON

(*Altitude 1019 feet*)

On May 23, 1923, Thorpe Bros. Well Co. finished a well for the town of Leon at the depth of 1103 feet. The well stood a pumping test of 35 gallons per minute. The static head was 380 feet below curb, the pumping head 490 feet. The altitude of the well is about 1100 feet above sea. Casing was inserted as follows:

Length, feet	Diameter, inches	Depth, feet
333	16	0 to 333
149 8 in.	12	310 to 462–8 in.
148 2 in.	10	442–8 to 590–10
344 10 in.	8	565–2 to 910
127 5 in.	6	872–7 to 1000

Driller's Log of Well at Leon

	Thickness feet	Depth feet
Yellow clay	55	55
Blue clay and stone	80	135
Blue clay and boulders	5	140
Yellow clay	23	163
Blue clay	22	185
Sand	1	186
Blue clay	40	226
Gravel	14	240
Blue clay	47	287
Clay and gravel	6	293
Blue clay	40	333
Limestone	2	335
Coal	2	337
Soapstone	7	344
Bluestone	10	354
Blue soapstone	23	377
Coal	1	378
White soapstone	62	440
Limestone	4	444
Black slate	6	450
Hard soapstone	20	470
Black slate	1	471
Coal	4	475
Blue soapstone	33	508
White limestone	7	515
White soapstone	6	521
Hard white soapstone	44	565
Coal	4	569
Blue soapstone	56	625
Sandrock, some water	15	640
Lime	10	650
Sandrock, some water	20	670
Shale	95	765
Sandy shale	20	785
Sand rock	10	795
Shale	5	800
Lime	10	810
Sandrock	5	815
Lime	7	822
Sand	8	830
Shale	5	835
Sandrock	5	840

Shale	20	860
Sandrock	10	870
Lime	20	890
Shale	4	894
Sandrock, some water	6	900
Lime rock	10	910
Shale	84	994
Lime	26	1020
Shale	83	1103

DECATUR COUNTY FARM WELL

Messrs Thorpe Brothers of Des Moines have furnished the following log of a well which they drilled for the Decatur County Farm near Leon. This well was finished in December, 1924, and is cased with 10 inch pipe to 287 feet, thence with 8 inch pipe to 343 feet, 6 inch pipe to 636 feet and 282 feet of 4 inch pipe at the bottom. The static head of the well is 380 feet below curb and the pumping head is 440 feet below curb. The well yielded 30 gallons per minute under a forty-eight hour pumping test.

Driller's log of well

	THICKNESS FEET	DEPTH FEET
To solid formation	343	343
Lime	5	348
Shale	288	636
Sand rock	30	666
Shale	42	708
Sand rock	45	753
Shale	167	920
Lime	5	925
Shale	17	942

LYTTON, SAC COUNTY

(*Altitude 1225 feet*)

The well from which Lytton draws its public supply is 1150 feet deep and 8 inches in diameter at top. It was completed in 1920 by Thorpe Brothers of Des Moines. Water was found in sandstone at the bottom of the drill hole. The static level is "about 75 to 100 feet". The cost of the well and pumping machinery combined was $10,000.

Log of Well at Lytton, Sac County

	THICKNESS FEET	DEPTH FEET
Black dirt	10	10
Yellow clay	30	40
Sand	10	50

Blue clay	110	160
Shale	60	220
Lime rock	30	250
Shale	80	330
Lime rock	190	520
Shale	40	560
Lime	200	760
Shale	20	780
Lime	285	1065
Sand rock	75	1140
Lime	10	1150

100 feet of 10 inch standard pipe. 8 inch pipe extends down 160 feet to solid formation, 6 inch pipe 420 feet, 4 inch pipe to the bottom.

MANSON, POCAHONTAS COUNTY

(Altitude 1237 feet)

CITY WELL NO. 2, 1928

This well was completed May 1, 1928, by the Thorpe Brothers Well Co. of Des Moines. The depth is 1211 feet and the diameters are 16 to 10 inches. The static level is 90 feet from the top of the curb. The well tested to 300 g.p.m. with a draw down of 2 feet on a 24 hour run. On a half hour test the yield was 360 g.p.m. with a draw dawn of 5½ feet. Besides 59 feet of temporary pipe the following casing was placed:

400 feet of 16 inch pipe from surface
616 feet of 12 inch pipe from 350 feet to 966 feet
191 feet of 10 inch pipe from 904 feet to 1105 feet

The cost of the well was $20,000.

Record of strata, Manson City well, 1928

	Depth in Feet
Pleistocene and Recent (230 feet thick; top 1232 feet above sea level):	
Till, blue-gray, calcareous	35
Sand and gravel, up to 1 cm. diameter, pebbles of drift; lumps of gray-blue clayey till. In one lump out of 15 pebbles 6 were limestone, 7 dolomite, 1 crystalline rock, 1 black shale. In the coarse sand of this lump out of 24 grains 11 were limestone and dolomite, 1 shale, 8 quartz, 4 other minerals of crystalline rocks	90
Till, yellow, calcareous	174
Clay, yellow, finely arenaceous, calcareous, in hard lumps	200
Cretaceous (?), Pennsylvanian (?):	
Shale, gray, in hard concreted masses inclosing pebbles of light gray and yellowish limestone, gray and buff dolomite, red sandstone, yellow jasper, one of red quartzite	230
Shale, blue-gray, few pebbles	250
Shale, drab, in hard concreted masses, inclosing many pebbles. Out of 37, 21 were of limestone, 8 of dolomite, 3 red clay-ironstone, 2 white quartz, 1 arkose; limestone and dolomites were of various textures and colors	270
Shale, drab, in hard masses inclosing much coarse material, mostly vari-colored limestones and dolomites; one pebble, 3½ cm. diameter,	

subangular smoothed, of light gray, fine calciferous sandstone; one decayed mass, 1 inch diameter, greenish gray, of crystalline rock with disintegrating particles of crystalline quartz and other minerals	280
Shale, drab, as above, nodule of drab feebly calcareous shale, large fragment of gray fine-grained crystalline limestone	290
Shale, drab, as above, included chips and pebbles mostly limestones and dolomites; some brick red finely arenaceous shale; some weathered feldspathic material. Of identified grains of included sand up to 3 mm. diameter 23 were limestone, 9 magnesian limestone, 13 silica or feldspar, 2 red shale, 1 red sandstone, 1 gray sandstone, 1 arkose	300
Shale, drab as above	310
Shale, drab, as above, included chips and pebbles examined were mostly limestone and dolomite, several of feldspar with or without associated ferromagnesian minerals	320
Shale, drab, as above	330
Limestone, light buff, soft, some crystalline, some earthy, rapid effervescence in cold dilute HCl	340
Shale, drab, in concreted masses, inclosed chips of shale, calcareous, with inclosed fragments of limestone, etc.; at 360 blackish, fine, hard, only microscopically arenaceous, pyritic; at 400 with fewer included pebbles: buff dolomite, drab limestone, red ochreous ironstone; arkose, red jasper; 13 samples	350–470
Shale, blackish, in concreted masses, inclosed chips of shale, noncalcareous	480
Shale, drab, in concreted masses. At 510 feet of 20 included fragments examined 6 were limestones, 2 dolomites, 2 calcite, 4 sandstone, 5 quartz of various colors, 1 feldspar-quartz aggregate. At 500 feet chips of shale noncalcareous; 5 samples	490–540
Sandstone, gray, coarse to fine, some pebbles up to 5 mm. diameter; grains subangular, mostly of clear quartz, some yellow, pink, and bright red; some white limestone; some feldspathic	550
Sandstone, as above; shale, chocolate brown and drab	560
Shale, drab and blackish	570
Sandstone, as at 550, concreted into friable masses with drab shale	580, 590
Shale and sandstone as above; coarse irregular grains, considerable arkose; fragment 2 cm. diameter of gray and red argillaceous arkosic sandstone, noncalcareous; pebble of gray siliceous rock of 15 mm. diameter with irregular pitted surfaces	600
Shale, ocher-red, concreted with much quartz sand; 4 samples	610–640
Sandstone, red, fine subangular grains, with much red shale	650
Shale, red, noncalcareous; 10 samples	660–750
Sandstone, fine to coarse, grains of clear quartz highly irregular, some yellow and pink; feldspathic material; chips of fine red argillaceous sandstone; all concreted in friable masses with red shale	760
Shale, blue-gray and red	770–780
Sandstone, fine to coarse, grains irregular; some yellow quartz; some of feldspathic rock; bluish sandstone very fine-grained; fine red sandstone; red and gray shale	790, 800
Shale, drab and red, plastic	810, 820
Sandstone, fine to coarse, grains irregular, some yellow and red quartz; a little feldspathic rock; in friable masses with red shale	830
Shale, red, some blue	840
Sandstone, irregular grains, fine to coarse, a little limestone and calcite; concreted in friable masses with gray shale	850
Shale, drab and blackish	860
Shale, blue-gray	870
Sandstone, coarse to fine, some grains rose-red and yellow, considerable feldspathic material, considerable limestone very light gray, of rapid effervescence, and yellow and blue-gray, of slow effervescence; fine red sandstone; chips of shale; fragment of "fine arkosic	

sandstone with quartz, altered feldspar, ferromagnesian and altered ferromagnesian minerals; some of the latter staining the surrounding grains''*	880
Shale, drab, some red	890
Sandstone, blue-gray in mass, fine irregular grains of clear quartz, secondary enlargements; feldspathic material, limestones, whitish, light yellow and gray, some of rapid effervescence, some of slow; concreted with much drab shale	900, 910
Shale, reddish gray, in lumps	920, 930
Sandstone, coarse to fine, irregular grains, some pink quartz; ''fragments of light gray feldspar, arkosic sandstone, and fine iron-cemented sandstone'';* limestone whitish and drab; much drab and red shale in chips and lumps	940, 950
Shale, drab with reddish tinge concreting quartz sand as above, arkose and limestone	960
Shale, drab, plastic, arenaceous	970
Shale, drab, some red, concreting much arkose, a little gray limestone; fragment 1.5 cm. diameter composed of ''fragments of white feldspar, quartz, and some ferromagnesian mineral altered to iron oxide. There are veinlets of clear calcite through the mass and what appear to be joint surfaces covered with a light green mineral 0.1 to 0.3 mm. thick''*	980
Shale, drab, in small chips and lumps, with much arkose and grains of fine and coarse quartz sand as above	990
Sandstone, arkosic, grains of quartz up to 1.5 mm. diameter, ill-rounded, some secondary enlargements; much drab shale, some red shale, in chips	1000
Arkose, in mass gray, speckled whitish; much feldspathic material in whitish chips up to 7 mm. diameter, some speckled with blackish mineral; quartz grains fine to coarse, irregular, some pink and yellow	1010
Shale, drab, in hard lumps, concreting coarse material as above	1020
Arkose as at 1010; whitish feldspathic grains up to 5 mm. diameter	1030
Arkose, purplish red in mass, speckled white; chips of shale and fine red sandstone; quartz sand grains up to 5 mm. diameter	1040
Arkose, as above, fragment of rolled pebble of yellow silica 12 mm. in diameter; red shale; one ''arkosic fragment 5 mm. diameter seems to be a single fragment of a ferromagnesian granite with probably augite as the carrier of the iron. Spots of pyrite in the ferromagnesian mineral. Ochreous spots between quartz and feldspar on some surfaces''*	1050
Arkose, drab, speckled white in mass; constituents as above, whitish feldspathic material, quartz sand, drab shale; 5 samples	1060-1100
Sandstone, coarse, up to 6 mm. diameter; rusted, rolled pebbles of limestone; chips of sandstone, feldspathic material, micaceous material, shale	1110, 1120
Arkose, as at 1060	1130
Arkose, gray, fine to coarse, much white feldspathic material. At 1160 one fragment 10 mm. in diameter ''of gneissic rock which has layers of quartz and feldspar separated by irregular layers of what seems to be chlorite to give greenish color and gneissic structure'';* 3 samples	1140–1160
No sample	1190
Arkose, light reddish brown in mass, in chips and sand. Reddish sandstone of microscopic grains of clear quartz, highly argillaceous and ferruginous; ''arkosic sandstone and fragments composed of feldspar and ferromagnesian minerals; somewhat less than one-half of the samples in bulk;''* 3 samples	1200–1211

* Determination by Dr. Earl T. Apfel of Syracuse University.

Driller's log, Manson City well, 1928

	Depth in Feet
Soil, yellow clay and boulders	0–20
Blue clay and gravel	20–52
Coarse gravel	52–58
Blue clay	58–92
Sand	92–102
Blue clay	102–145
Sand	145–154
Yellow clay	154–175
Blue clay	175–340
Blue shale, streaked with rock	340–385
Light blue shale, with rock	385–525
Rock	525–528
Red shale	528–530
Blue shale and rock	530–545
Hard rock	545–560
Rock (some sand running in from behind the pipe)	560–608
Red shale	608–683
Rock	683–692
Red shale	692–708
Rock	708–711
Red shale	711–750
Shaly rock	750–765
Red shale	765–767
Light blue shale	767–825
Flinty sandstone	825–850
Lime rock and shale	850–863
Blue shale	863–875
Rock	875–890
Rock and shale	890–920
Red shale	920–946
Lime rock	946–960
Blue shale	960–981
Rock	981–986
Red shale	986–996
Flinty rock	996–1004
Lime and sand rock	1004–1105
Sandstone (lighter in color and finer at 1140, with some water)	1105–1160
Hard white sandstone	1160–1207
Red sandy shale	1207–1211

Notes.—The Manson city wells are unique not only in the quality of their water but also in their geologic section. This is clearly seen if the Manson section is compared with the strata pierced by other deep wells of the area. If the strata between here and Fort Dodge, 19 miles east of Manson, were continuous, unchanged and horizontal between the two points, the drill at Manson would have entered the Saint Louis limestone at about 900 feet above sea level, 332 feet below the surface, and would have stopped in limestones of the Galena-Platteville. From the top of the Mississippian to the bottom of the well, it would have been predominantly in limestone. Instead, the drill did not reach the Mississippian or other limestone formations and below the drift is almost wholly in shale, sandstone and arkose, some of the rock with the appearance of conglomerate.

If the strata rose from Fort Dodge westward to Manson the Mississippian limestones would be struck at a still higher level and the abnormality of the well section would be still greater. As to the actual lie of the strata in this area, it is known that the Paleozoic formations dip westward as far as Webster City, as measured by the contours of the Saint Peter sandstone. From Webster City to Fort Dodge the Saint Peter sandstone is about on the level. From Fort Dodge the Saint Peter rises from 406 feet below sea level westward to 27 feet above sea level at Holstein, west-northwest to 323 feet above sea level at Cherokee, and west-southwest to 249 feet below sea level at Rockwell City. The elevation of the Saint Peter at Rockwell City seems to preclude any considerable downfold west of Fort Dodge in whose trough Manson might be located.

If we entertain the supposition that the Mississippian and other limestones have changed to shales and arkosic sandstones in the short distance west of Fort Dodge to Manson, we are met with the fact that they carry through still farther west to Cherokee and Holstein, as well as southwest to Rockwell City. Not only the surface exposures but also the deep wells of northern Iowa show that the Mississippian is there predominantly of limestone. If the rocks pierced by the drill at Manson belong in whole or part to the Mississippian they must have been deposited under abnormal conditions.

If the entire section at Manson below the drift be assigned to either the Pennsylvanian or the Cretaceous or both, it remains abnormal both in thickness and in facies. At Manson the combined thickness of the Pennsylvanian strata penetrated below the drift is 981 feet. At Fort Dodge (Beaver Products Co. well) the thickness of the Pennsylvanian is 70 feet, at Rockwell City 160 feet, at Somers at most 402 feet, at Gowrie 230 feet, at Holstein 170 feet, at Cherokee 495 feet, and at Herndon 100 feet.

The facies of the cuttings also is abnormal, especially in the appearance of conglomerate and in the large amount of arkosic material. In some aspects they are strikingly similar to those of the De Witt well below the Saint Peter sandstone, and to similar sections at Maquoketa and Preston, which the writer has interpreted as the fill of deep erosion channels cut in rocks of the Prairie du Chien during the interval preceding the deposit of the Saint Peter sandstone.

The exceptional character and thickness of the shales and arkose of the Manson well are explainable by a like hypothesis—the fill with continental deposits, and finally with marine sediments also, of a valley of erosion. The depth of the valley, 300 feet deeper than that of the Mississippi in northeastern Iowa, is notable. The arkosic material of the fill suggests that the headwaters of the river worked in the igneous rocks of the states bordering Iowa on the north.

The deposits themselves, so far as the cuttings reveal them, do not appear to offer conclusive evidence as to their age, whether they were laid at the close of the long erosion interval preceding the deposit of the Pennsylvanian or of that preceding the Cretaceous. The fact that Manson is located less than 5 miles west of the provisional eastern border of the Cretaceous would preclude the expectation of finding there any great thickness of normal marine sedimentary deposits of Cretaceous age, but not the fill of a deep pre-Cretaceous valley.

The character of the water, so far as that goes, would seem to favor the reference of the deposits to the Pennsylvanian. The water is of extraordinary softness, standing in strong contrast to that of the deep wells of north-central and northwestern Iowa, and especially to the heavily mineralized well waters of the Cretaceous. The water of well no. 2 has not been analyzed, but no doubt it is the same chemically as that of well no. 1, 1250 feet deep, analyzed by Hendrixson.* Hendrixson comments as fol-

	P.P.M.
Silica (SiO_2)	10.0
Iron (Fe)	0.2
Aluminum (Al)	0.8
Calcium (Ca)	16.0
Magnesium (Mg)	8.0
Sodium (Na) and Potassium (K)	221.0
Bicarbonate radicle (HCO_3)	4.0
Carbonate radicle (CO_3)	38.0
Sulphate radicle (SO_4)	162.0
Chlorine (Cl)	206.0
Total solids	651.0

lows:* "The well at Manson is the only deep well in the state whose water was found to contain normal carbonates; the magnesium and calcium in it are very low, the solids being mostly alkaline chlorides and sulphates. It may be questioned whether its comparatively soft water and its alkalinity may not be due to contamination by surface water owing to faulty casing."

This tentative suggestion by Hendrixson of surface contamination was as good an explanation as could then be made with the

* Hendrixson, W. S., Iowa Geol. Survey, vol. XXI, p. 178.
* *Ibid.* p. 174-5.

data at hand. The log of the well, no. 1, was also found "exceedingly peculiar" by Norton.† In the absence of cuttings little attempt was made toward its interpretation. The reference of the basal sandstone of the well to the Saint Peter by the driller and by citizens was controverted. The suggestion was made that the so-called "sandstone" was the Galena dolomite, "not infrequently called sand rock because of the sparkling crystalline sand to which it is crushed by the drill." This also was perhaps as good a suggestion as could be made with the data then at hand. Fortunately the complete set of samples of the cuttings saved by the Thorpe Bros. Well Co. points the way toward a solution of the dual mystery. The "exceeding peculiarity of the log" of well no. 1 is now seen to be due to the exceeding peculiarity of the formations it pretty faithfully records. The abnormal quality of the water is not due to surface contamination but to the abnormal arkosic aquifer and the absence of limestone in beds of any considerable thickness. The character and thickness of the deposits and the quality of the water are entirely normal in the continental deposits of the fill of a deep erosion channel, although such channels and fills are exceptional in Iowa deep wells.

The log of well no. 1 records "sandstone" from 1050 to 1220 feet, and "red shale" from 1220 to 1250 feet, at which depth "granite-like rock" was struck. According to the log of well no. 2 the "red shale, sandy" is penetrated four feet, from 1207 to 1211 feet. Apparently then the reddish sandstone and arkose extends some twenty feet, more or less, below the footing of well no. 2. The "granite-like rock" at the base of well no. 1 may have been a boulderet in a coarser conglomerate. It will be remembered that even in the field, as at Colorado Springs, arkose may have a strong superficial resemblance to the granite which is its source. The large content of crystalline rock in the lower cuttings of the Manson well indeed gave rise to the question whether the drill was working in decayed gneiss or granite. The quartz sand and limestone pebbles of the cuttings answered this question in the negative. The softness of the deposit is shown by the fact that the drill penetrated from 1110 to 1180 feet in somewhat less than four days.

† Norton, W. H., Iowa Geol. Survey, vol. XXI, p. 1017.

From the cuttings it is difficult to draw the line between glacial tills and shales on which they rest, although the distinction is usually perfectly obvious. Assuming that the driller's logs use the term "blue clay" only of till, the logs of the wells give the Pleistocene thicknesses of 310 and 340 feet. But on account of the close resemblance of the cuttings of shale below 340 feet, at which depth a thin bed of limestone was struck, and the samples of "blue clay" above it, it seems somewhat more probable that both above and below 340 feet the drill was working in shale and that the lower limit of the drift is 230 feet. In ease of drilling there was little if any difference between "blue clay" and "shale", the drill making 30 or 40 feet a day in each.

As the description shows, the cuttings of the gray and drab shales both above and below 340 feet are by no means of the texture of the cuttings of shales of the Pennsylvanian in central Iowa, as in the Nevada well (p. 273). While the argillaceous material at Manson concretes into tough masses, it is less unctuous and incloses much coarse material in the lumps. At 290 feet a nodule of pure shale was brought up, but for the most part the rock, as in cuttings of the Maquoketa shale, has been thoroughly crushed by the drill and affords few if any chips of pure shale. The source of the coarse material in these shales is not determined. A good deal probably came from the sand beds (92-102 and 145-154 feet of the log). Only the upper bed is represented by a sample and in this the large proportion of limestone and dolomite pebbles is noteworthy, a proportion which carries through the coarse material in the cuttings from the shales. The variety in texture and color of the limestone fragments of the shales is to be considered, since it proves that these fragments were not broken by the drill from limestone beds in place. In weak shales the upper casings could hardly be so firmly bedded as to prevent the inwash from water-bearing glacial sands and gravels, and it will be noted that the log states that at 560-608 feet "some sand was running in from behind the pipe."

But it seems possible that these sand beds are not the only source. The large amount of sand and pebbles and fragments of various rocks and minerals, including much feldspar, in many of the cuttings and especially the presence of arkosic sandstone in heavy beds at the base of the section point to the conclusion that some of the coarse material of the cuttings may be native to the strata in which the drill was working. It seems possible that the samples of shale mingled with more or less of sand and gravel and fragments of igneous rock come from lenses and layers of the coarser interbedded with the finer materials, the "shale with streaks of rock" of the log.

MARQUETTE (formerly North McGregor) CLAYTON COUNTY

(Altitude 628 feet)

The well of the Chicago, Milwaukee, St. Paul & Pacific Railroad, completed in 1917, is 450 feet deep and flows about 250 gallons per minute. A flow of 10 gallons per minute was had at 300 feet. At 420 feet the flow increased to about 200 gallons per minute, and reached its maximum at the bottom of the well. The diameters of the well are 20 inches to 90 feet, 14 inches to 125 feet, and 12 inches to the bottom. The curb is about 624 feet above sea level.

Record of Strata

	DEPTH IN FEET
Alluvium and rock, cuttings in concreted masses, light drab, of grains of quartz sand rounded and frosted, in slightly calcareous argillaceous powder; some chert	0–60
Saint Lawrence formation, Trempealeau beds:	
Shale, light yellow-green and drab, noncalcareous, coarsely fissile, in chips, with some chert and quartz sand	60–70
Dolomite, gray, earthy, microquartzose, with white and pinkish chert; and sandstone, cuttings chiefly quartz sand in well rounded grains	70–75
Chert, varicolored, with crystalline buff dolomite, and light yellow sandstone of minute particles; 3 samples	75–87
Sandstone, light yellow-gray, calciferous, of microscopic angular particles; 2 samples	87–100
Saint Lawrence formation, Franconia beds (190 feet thick; top 524 feet above sea level):	
Shale, calcareous and quartzose, light blue, quartz in fine angular particles; 4 samples	100–140
Dolomite, light gray, cuttings in sand; 2 samples	140–160
Dolomite, blue-gray, sporadic grains of glauconite and quartz particles	160–175
Sandstone, green-gray, argillaceous, dolomitic, glauconitic, in friable masses and occasional chips, quartz grains minute and fine, ill-rounded, highly dolomitic at 200, highly glauconitic at 210 feet; 11 samples	175–285
Sandstone, fine, grains moderately well rounded, glauconitic	285–290
Dresbach sandstone (penetrated 160 feet; top 334 feet above sea level):	
Sandstone, white, clean, fine to coarse; 15 samples	290–450

Notes.—In the above section the first sample is somewhat ambiguous, and its exact position is unknown. The second sample, at 564 feet above sea level, clearly represents the Saint

Lawrence formation and probably is taken at or near its summit, as the top of the Jordan sandstone outcropping in the McGregor bluffs is but 115 feet higher, a measure somewhat less than the total thickness of the Jordan exposed in the bluffs at Lansing.

It is therefore probable that the first sixty feet of the section belongs largely or wholly to the Jordan sandstone, here more or less cut out by the filled channel of Mississippi river.

The City well no. 4 at McGregor furnished samples of alluvial sands at 35 and 50 feet, while at 60 feet a sandstone was struck, perhaps the Jordan, and the Trempealeau dolomite was encountered at 74 feet. The Dresbach was entered at about the same depth as at Marquette.

The section of the deep well at Prairie du Chien[57] corroborates and extends the well sections of the west side of Mississippi river. The Saint Lawrence was found there 115 feet thick, and at 365 feet above sea level the drill passed into the Dresbach sandstone, which is 118 feet thick. Since at Marquette the Dresbach had been penetrated to a depth of 160 feet, it is probable that there the base of the formation was nearly reached. At 247 feet above sea level, at Prairie du Chien (73 feet above the footing of the Marquette well), the shaly beds of the upper Eau Claire appeared and extended to 38 feet above sea level, while the clean sands of the lower Eau Claire reached at least to 272 feet below that datum, where 45 feet of red sandstone was struck. This latter may perhaps be the equivalent of the Red Clastic beds of Minnesota.

Record of Strata in Aherns Bros. Farm well near Prairie du Chien, Wisconsin (Se. ¼, Sw. ¼ Sec. 18, Tp. 7, R. 6 W.)

The following record is added in corroboration of the Iowa sections through the courtesy of Dr. F. T. Thwaites, of the Wisconsin Geological Survey. The elevations above sea level are added.

	Depth in Feet
Surface deposits (77 feet thick; top about 650 feet above sea level):	
Sand, no samples	0–77
Trempealeau (123 feet thick; top about 573 feet above sea level):	
Dolomite, with some sandstone, no samples (Lodi "Shale")	77–130
Sandstone, yellow, very fine, dolomitic, hard (Lodi)	130–135
Dolomite, gray, sandy (St. Lawrence)	135–195

57 Geol. of Wisconsin, vol. IV, p. 61: Iowa Geol. Survey, vol. XXI, p. 353.

No sample	195–200
Franconia (115 feet thick; top 450 feet above sea level):	
Sandstone, fine to exceedingly fine, green, calcareous, glauconitic (no sample from 225-235)	200–285
Sandstone, exceedingly fine, gray, calcareous	285–295
Sandstone, like above, harder, glauconitic (shale)	295–305
Sandstone, coarse, gray, calcareous, glauconitic	305–315
Dresbach (150 feet thick; top 335 feet above sea level):	
Sandstone, coarse, white to light gray	315–450
Sandstone, fine to medium, white	450–465
Eau Claire (penetrated 287 feet; top 185 feet above sea level):	
Sandstone, fine to medium, gray, dolomitic, hard	465–475
Sandstone, fine to very fine, gray, calcareous, glauconitic	475–515
Sandstone, fine, gray and pink, calcareous, hard	515–545
Sandstone, very fine, gray, very calcareous	545–555
Shale, gray, slightly calcareous	555–565
Sandstone, fine, pink, calcareous	565–570
Sandstone, medium, gray; shale, gray, hard	570–580
Sandstone, medium, light gray, slightly calcareous	580–710
Sandstone, coarse to fine, light gray, flow	710–720
Sandstone, fine, light gray	720–730
Sandstone, very coarse to fine, light gray, main flow	730–752

MASON CITY

(Altitude 1125 feet)

WELL NO. 3 OF THE CHICAGO, MILWAUKEE & ST. PAUL RAILWAY

A well 1278 feet deep was completed for this company in 1913 by Jas. D. Shaw of Davenport. The diameters are 16 inches to 259 feet 6 inches, 12½ inches thence to 820 feet, and 10 inches to the bottom. Elevation of the curb is about 1125 feet.

The static level on completion and at present is 115 feet below the curb. With the pumping cylinder at 134 feet the capacity of the well is 266 gallons per minute. The casing is 41 feet of 16 inch pipe at the top, casing out the glacial drift deposits; 38 feet of 12 inch pipe from 221 feet 6 inches to 259 feet 6 inches; and 190 feet of 10 inch pipe from 629 feet 6 inches to 819 feet 6 inches, casing out the Saint Peter sandstone, the Glenwood shale and the basal portions of the Galena-Platteville.

Driller's log of well no. 3 of Chicago, Milwaukee & St. Paul Railway, 1913

	Depth in Feet
Clay	0–41
Limerock	41–689
Shale (Glenwood)	689–719
Saint Peter sandstone	719–779
Limestone (Prairie du Chien)	779–1149
Jordan sandstone	1149–1268
Sand and limestone mixed (Trempealeau)	1268–1278

Chemical analysis of water of well of Chicago, Milwaukee & St. Paul Railway, 1913

	Grains per U. S. gallon
Calcium carbonate	11.75
Magnesium carbonate	7.75
Calcium sulphate	2.61
Incrusting solids	22.11
Alkali sulphate	0.13
Alkali chloride	0.85
Non-incrusting solids	0.98
Total	23.09

WELL OF THE AMERICAN BEET SUGAR CORPORATION, MASON CITY

This well was drilled in 1924 by the McCarthy Well Company of St. Paul. The depth is 1347 feet, the diameters are 20 inches to 240 feet, 16 inches to 640 feet and 12 inches to the finish. The static level is 40 feet below the curb. The capacity of the well is about 650 gallons per minute with the cylinder set at 240 feet drawing through a pipe 20 feet in length. Eight hundred and fifteen feet of 12 inch casing are placed heading at 653 feet. The cost of the well was about $20,000.

Driller's log of well of American Beet Sugar Corporation

	Depth in Feet		Depth in Feet
Limerock	0–54	Hard rock (Prairie du Chien)	930–1145
Shale	54–68	Sandrock (Prairie du Chien)	1145–1195
Limerock	68–626	Shale (Prairie du Chien)	1195–1205
Shale	626–725	Sandrock (Jordan)	1205–1235
Hard rock	725–742	Hard rock (St. Lawrence)	1235–1275
Sandrock (Saint Peter)	742–930	Shale (St. Lawrence)	1275–1347

WELL NO. 2 OF J. E. DECKER AND SONS, MASON CITY

The first well drilled for this packing company was described in the author's report for 1912, and since that time has suffered no deterioration. A second well was drilled some years later with a depth of 1200 feet and diameters from 20 to 12 inches. The principal supply was found in the Jordan sandstone, in which the well foots. On completion water rose within 90 feet of the surface. The delivery on first tests was 450 gallons per minute, but on later installing larger pumps the delivery was increased to 650 gallons with the cylinder set at 140 feet. Continuous pumping produces a draw down of 20 feet.

MASON CITY WATERWORKS WELL NO. 8

This well, 1219 feet deep, was completed in 1912 by W. L. Thorne of Platteville, Wisconsin. The diameter is 16 inches to

200 feet, from 200 to 960 feet 13 inches, and 10 inches to the bottom.

The main supply was found in the Jordan sandstone, in which the well foots, and some water was obtained in the Saint Peter sandstone at 800 feet. On completion the static level was 82 feet below the curb. The present head is 123 feet below the surface, and with the air foot at 300 feet the well delivers about 1200 gallons per minute. The well was uncased except the first 20 feet, but later reports mention 200 feet of 14 inch casing at top, and 100 feet of 12 inch casing about 600 feet down, shutting out the shales above the Saint Peter. The cost of the well was $6295.

MASON CITY WATERWORKS WELL NO. 9

The ninth well drilled for Mason City was completed in 1913 by W. L. Thorne. The depth is 1200 feet. The diameters and casing are as follows:

24 inch diameter	0–55	feet.	20 inch casing with concrete fill
19 inch diameter	55–225	feet	
16 inch diameter	225–720	feet.	12 inch casing 540-720 feet
12 inch diameter	720–1200	feet	

During the drilling of the well water stood at the curb until the New Richmond sandstone was struck when it fell to 77 feet below the surface. The original draw down was about 7 feet and in 1919 it was reported as reaching to 140 feet, 56 feet lower. In 1919 the head was reported to be at 105 feet, and in 1925 it was stated to stand at 115 feet ''with no appreciable drop after draw down''.

The well delivers 1200 gallons per minute. The cost of this well was $10,000.

MASON CITY WATERWORKS WELLS NOS. 6 AND 7

These wells, whose original depths were 616 and 875 feet, were deepened about 1920 to 1218 and 1219 feet. Both wells reach the deeper water beds with eight inch holes. Under air the wells supply 700 and 800 gallons per minute.

WELL OF THE PEOPLE'S GAS AND ELECTRIC COMPANY, MASON CITY

This well, 1200 feet deep, was completed in 1915 by James Kutcher of Plymouth, Iowa. The diameters are 20 inches to 125 feet, 16 inches to 700 feet, 12 inches to 960 feet and 10⅝ inches to the bottom.

The main supply was found at 1182 feet (Jordan sandstone). The head is maintained up to the present at 50 feet below the curb. With the pumping cylinder at 125 feet the well delivers 800 gallons per minute with a draw down to 65 feet. Casing is set as follows: 20 inch to 100 feet; 12 inch from 625 to 700 feet; 10⅝ inch from 700 to 960 feet. The cost of the well was $15,000.

Driller's log of the well of the People's Gas and Electric Co.

	Depth in Feet
Limestone	0–636
Mixed limestone and shale	636–660
Shale (Glenwood)	660–682
Mixed limestone and shale (Glenwood)	682–688
Sandstone (St. Peter)	688–778
Limestone (Shakopee)	778–810
Sandstone (Shakopee)	810–816
Limestone (Shakopee)	816–917
Sandstone (New Richmond)	917–944
Limestone (Oneota)	944–1125
Sandstone (Jordan)	1125–1182
St. Lawrence formation	1182–1200

WELL NO. 1, OF NORTHWESTERN STATES PORTLAND CEMENT COMPANY

This well was commenced in 1923 and was completed July 6, 1924. It is 1281½ feet in depth and is 19 inches in diameter to 267 feet, 15 inches to 747 and 12 inches to the bottom. Casing with a length of 87.5 feet was inserted at the foot of the 15 inch section of the well to prevent caving of the shale at that depth. The well yields 1500 gallons per minute when pumped with air. The water has a temperature under these conditions of 56° F.

Following is the log of the well as furnished by Mr. W. J. Maytham, consulting engineer.

	Thickness feet	Depth feet
Limestone, high magnesian	680	0–680
Shale	85	680–765
Sandstone, St. Peter	65	765–830
Limestone, high magnesian, with streaks of shale	320	830–1150
Sandstone, Jordan	70	1150–1220
Sandstone, mixed with shale	25	1220–1245
Shale, penetrated	36½	1245–1281½

The following analyses also were furnished by Mr. Maytham for the company.

Devonian and Silurian limestone, between 0 and 680 feet

	0-400 ft. per cent	400-500 ft. per cent	500-600 ft. per cent	600-680 ft. per cent
Silica	14.80	16.48	4.28	6.12
Alumina and iron oxide	4.00	4.48	2.32	2.68
Lime (CaO)	27.14	32.92	40.92	48.12
Magnesia (MgO)	17.06	11.75	11.90	3.80
Loss	37.00	34.37	40.58	39.28

	Maquoketa shale, between 680 and 765 feet per cent	St. Peter sandstone, 765 to 830 feet per cent	Prairie du Chien beds, between 830 and 1150 feet per cent	Jordan sandstone, 1150 to 1220 feet per cent	St. Lawrence beds, 1245 to 1281½ feet per cent
Silica	48.00	96.56	32.30	97.52	21.26
Alumina and iron oxide	29.60	0.88	4.88	1.20	6.51 2.05
Lime	1.80	1.72	19.72	0.80	21.56
Magnesia	trace	trace	13.60	trace	14.47
Loss	10.54	0.40	29.50	0.48	32.62

WELL OF LEHIGH PORTLAD CEMENT CO., MASON CITY

Thorpe Brothers began this well November 14, 1923, and finished it February 13, 1924. It is 1260 feet deep and its diameters are 20 inches to 251 feet, 15 inches to 755½ feet, and 12 inches to bottom. It is cased with 20 inch pipe to 14 feet, 10 inches, and 12 inch pipe to 154 feet, 7 inches. The test produced 875 gallons per minute. The static head of water is 30 feet below curb.

Log of well for Lehigh Portland Cement Co. of Mason City

	Thickness feet	Depth feet
Soil and broken rock	10	10
White limestone	10	20
White limestone	10	30
Dolomite limestone	300	330
Argillaceous limestone	30	360
Dolomite limestone	70	430
Argillaceous limestone	20	450
Dolomite limestone	70	520
Magnesian limestone—light	30	550
Limestone—light	30	580
Limestone—gray	10	590
Limestone	30	620
Limestone—light gray	30	650
Blue shale, soft, some lime	20	670
Blue shale, soft	50	720
Blue shale and white sand	10	730
White sand with some blue shale	20	750
White and brown sands	10	760
White sand	30	790
White sand with some brown sand and gray shale	10	800

Dolomite limestone with some gray shale	10	810
Dolomite limestone	20	830
Dolomite limestone and some white sand	60	890
Limestone and white sand	20	910
Dolomite limestone, light color	10	920
Dolomite limestone, dark gray	10	930
White sand	10	940
Dolomite limestone, gray	20	960
Dolomite limestone, light gray	50	1010
Dolomite limestone, light	70	1080
Dolomite limestone, light with some sand	10	1090
Dolomite limestone, light gray	10	1100
Dolomite limestone, gray	10	1110
White sand, coarse	40	1150
White sand, coarse and fine	20	1170
Dolomite limestone, gray with some blue shale	10	1180
Dolomite limestone, gray	60	1240
Dark gray limestone	20	1260

MAYNARD, FAYETTE COUNTY

(Altitude 1099 feet)

The town of Maynard formerly drew its public supply from a well 702 feet deep. The diameter is reported at 10 inches and the yield at 32,000 g.p.d., while the town consumption amounted to but 8,000 g.p.d. at maximum. This well has now been abandoned, and a shallow well, dug to the depth of eight feet and thence drilled to a total depth of 70 feet, has been substituted. The water stands so that a suction pump with a pumping capacity of 60,000 g.p.d. can be used.

MONONA, CLAYTON COUNTY

(Altitude 1216 feet)

WELL OF INTERSTATE POWER COMPANY

This well was drilled in 1922 by the F. M. Gray, Jr., Company. The depth is 814 feet and the diameters are from 12 to 8 inches.

*Record of Strata**

	Depth in Feet
Drift, no samples	0–46
Galena (269 feet thick):	
Dolomite, buff and blue	46–95
Dolomite, mottled gray and blue	95–105
Dolomite, gray	105–190
Dolomite, gray; chert, white	190–240
Dolomite, gray	240–255
Dolomite, gray and blue; chert, white	255–275
Dolomite, gray	275–285
Dolomite, coarse-grained, mottled gray and blue	285–295
Dolomite, gray; chert, white	295–315

* By F. T. Thwaites, geologist, Madison, Wisconsin.

Decorah (50 feet thick):	
Limestone, blue	315–335
Limestone, mottled blue and gray	335–355
Shale, blue, very calcareous	355–365
Platteville and Glenwood (40 feet thick):	
Limestone, light bluish gray	365–385
Dolomite, gray	385–395
Dolomite, gray; floating sand grains; shale greenish blue	395–405
Saint Peter (55 feet thick):	
Sandstone, medium to fine, coarser below	405–455
Sandstone, fine to coarse, gray, calcareous; shale, green	455–460
Shakopee (85 feet thick):	
Dolomite, light gray	460–545
New Richmond (6 feet thick):	
Sandstone, medium, light gray	545–551
Oneota (194 feet thick):	
Dolomite, gray, slightly sandy	551–565
Dolomite, gray	565–595
Dolomite, bluish and yellowish gray, creviced	595–600
Dolomite, gray	600–620
Dolomite, gray; chert, white	620–650
Dolomite, light gray	650–670
Dolomite, light gray; chert, white	670–680
Dolomite, light gray	680–725
Sandstone, fine, hard, calcareous, light gray	725–740
Dolomite, sandy, gray, specks of green shale	740–745
Madison (20 feet thick):	
Sandstone, coarse to fine, gray, calcareous; shale, green	745–765
Jordan (40 feet thick):	
Sandstone, fine to medium, white, calcareous	765–805
Saint Lawrence (penetrated 9 feet):	
Sandstone, exceedingly fine, light gray, very calcareous	805–814

MORNING SUN, LOUISA COUNTY

(Altitude 741 feet, C., R. I. & P. Ry.)

In 1928 a well 1205 feet deep was drilled at Morning Sun for city supply. No information is obtainable from the town officials, and possibly nothing is known locally as to this important property. The drillers, the McCarthy Well Company of Saint Paul and Minneapolis, have kindly supplied the data given below.

The diameters are from 10 to 8 inches. The static level is about 122 feet from the surface of the ground. At the test of the well 130 gallons per minute were pumped for 10 hours, with a drop pipe of 195 feet, without drawing air. The chief supply comes from the Saint Peter sandstone, which was encountered at 1141 feet.

Driller's log

	Thickness in feet
Pleistocene and Recent (64 feet thick; top 745 feet above sea level):	
"Black dirt"	0–4
"Yellow clay"	4–64
Kinderhook, upper beds (101 feet thick; top 681 feet above sea level):	
"Limerock and shale"	64–99

"Sandrock"	99–102
"Limerock"	102–165
Kinderhook shale (283 feet thick; top 580 feet above sea level):	
"Shale, cavy"	165–448
Devonian, Silurian and Maquoketa (340 feet thick; top 297 feet above sea level):	
"Rock"	448–458
"Rock and shale, cavy"	458–788
Galena and Platteville (304 feet thick; top 33 feet below sea level):	
"Rock"	788–1048
"Sandrock"	1048–1051
"Shale"	1051–1054
"Rock"	1054–1092
Glenwood formation (49 feet thick; top 347 feet below sea level):	
"Sandrock (St. Peter)"	1092–1117
"Shale"	1117–1141
Saint Peter sandstone (36 feet thick; top 396 feet below sea level):	
"Sandrock (St. Peter)"	1141–1177
Prairie du Chien, Shakopee (penetrated 28 feet; top 432 feet below sea level):	
"Limerock"	1177–1190
"Shale"	1190–1205

Notes.—Although Morning Sun is well within the boundary of the outcrops of the Osage group of the Mississippian, it seems probable that at the depth of the bed rock only the limestones, shales and sandstones of the upper beds of the underlying Kinderhook would be encountered. The heavy Kinderhook shale is well delimited, but the Maquoketa shale is vaguely indicated as a part, whose thickness is unstated, of the 330 feet described as "Rock and Shale, cavy" extending from 458 to 728 feet.

The sandstone assigned to the Saint Peter is overlain as usual by a shale, the Glenwood. In its outcrops in northeastern Iowa and in many deep well sections of the state the Glenwood beds include sandy layers resembling in color and shape of grain the underlying Saint Peter sandstone. Here the sandstone of the Glenwood is exceptionally thick.

*Mineral Content of City Well, Morning Sun**

	P.P.M.
Bicarbonate	370.9
Chloride	24.
Sulphate	77.9
Silica	6.0
$Fe_2O_3+Al_2O_3$	9.6
Calcium	63.7
Magnesium	23.7
Na + K as Na	61.4
Total solids	451.6

* Analysis by Harry F. Lewis, Chemical Laboratory, Cornell College, Mount Vernon, 1927.

MOUNT PLEASANT

(*Altitude 725 feet*)

WELL OF THE MOUNT PLEASANT ELECTRIC LIGHT AND WATERWORKS

A well was drilled for this company in 1915 by J. D. Shaw of Davenport. The depth is 1820 feet, the diameters from 12 to 8 inches. The main water bed is the Jordan sandstone at 1715 feet. Water was also found at 198, 1103, 1340, 1560, and 1668 feet.

The static level is 74 feet below the surface, or 659 feet above sea level, with a draw down of 25 feet under pumping. The varying static levels as the drilling was in progress are shown in the following table:

Depth in feet	Static Level in feet	Depth in feet	Static Level in feet
590	100	1293	122
770	105	1592	110
930	110	1690	100
1081	110	1738	98
1125	110	1779	80
1280	96	1820	87
			After casing 74

Thus the Cambrian waters are under higher head than are the Ordovician waters, while their normal static level may be lowered by leakages through uncased higher pervious beds.

This well is cased with wrought iron drive pipe as follows: 12 inch from curb 68 feet to first limestone; 10 inch from curb to 500 feet; 8 inch 67 feet long joined above with lead packer and below with reducing nipple to 1113 feet of 6 inch, packed at bottom with wall packer. The cost of the well was $10,000.

Chemical analysis of water by Dearborn Chemical Co., Chicago

	Grains per gallon
Silica	.595
Oxides of iron and aluminum	.153
Calcium carbonate	5.480
Calcium sulphate	13.880
Magnesium carbonate	8.600
Sodium and potassium sulphates	32.299
Sodium and potassium chlorides	8.500
Loss	.339
Total	69.846
Total incrusting solids	28.708
Total nonincrusting solids	41.138

Record of strata, well of Mount Pleasant Electric Light and Waterworks

	Depth in Feet
Pleistocene and Recent (68 feet thick; top 719 feet above sea level):	
No samples	0–68
Mississippian, undifferentiated (166 feet thick; top 651 feet above sea level);	
Limestone, blue-gray, argillaceous, soft, earthy, effervescence rather slow in cold dilute HCl; some buff limestone	68–80
Limestone, light gray, soft, crystalline-earthy, in flaky chips; some drab shale	80–130
Chert, white; some white limestone	165
Limestone, blue-gray, effervescence rapid; chert, blue	198
Limestone, white, crystalline-granular, rapid reaction	210
Limestone, yellow-gray and drab, response rapid; 2 samples	220, 231
Kinderhook (Devonian shale at base?) (368 feet thick; top 485 feet above sea level):	
Shale, blue, hard, calcareous, siliceous (microscopic angular grains), in chips	234
Shale, blue, in concreted masses	241
Sandstone, buff, calciferous, microscopic angular grains	260
Shale, blue, plastic; some white chert at 286	286, 317
Shale, drab, plastic	329
Shale, blue, plastic	351
Shale, blue, some brown	370
Shale, blue, plastic	387
Shale, brown, inflammable	398
Shale, blue, drab at 484; 8 samples	424–561
Devonian (138 feet thick, top 117 feet above sea level):	
Limestone, light yellow and gray, rapid effervescence, in sand	602, 622, 660
Shale, yellowish, calcareous, in concreted mass	689
Shale, whitish, calcareous, in concreted mass	729
Silurian (68 feet thick, top 21 feet below sea level):	
Limestone, light brown, response rapid; some gypsum	740
Limestone, gray, response rather slow; gypsum in white grains	770
Limestone, yellow-gray, response slow; gypsum in white chips and concreted masses; drab shale	790
Shale, gray, calcareous, in concreted masses; much gypsum	803
Maquoketa (37 feet thick; top 89 feet below sea level):	
Shale, blue, plastic	808
Dolomite, buff, in chips; shale; fine quartz sand in well-rounded grains	830
Galena, Platteville, Glenwood (305 feet thick; top 126 feet below sea level):	
Dolomite, buff and gray, below 882 feet in sand and powder, cherty at 965 and 983; 11 samples	845–1032
Shale, brown, highly inflammable; some dolomite and limestone	1061
Dolomite, light buff and gray, in sand and powder	1081
Dolomite, buff, in sand; some brown shale from above	1099
Dolomite, light yellow-gray, in chips; a fragment of brown crystalline quartz	1103
Sandstone, white, fine, grains rounded and frosted; some dolomite, yellow-gray, in chips	1112–1122
Shale, blue green, hard, noncalcareous	1131
Saint Peter sandstone (38 feet thick; top 431 feet below sea level):	
Sandstone, white, Saint Peter facies; larger grains up to 1.2 mm.	1150
Sandstone, white	1165
Prairie du Chien (527 feet thick; top 469 feet below sea level):	
Dolomite, light gray in chips; cuttings chiefly quartz sand	1188
Dolomite, buff and gray	1210, 1230
Dolomite, gray; some quartz sand	1246–1253
Dolomite as above	1280–1293
Dolomite, gray; a little quartz sand; 3 samples	1300–1328
Dolomite, yellow-gray, chert at 1340; 4 samples	1340–1382

Dolomite, gray; much chert	1425
Dolomite, gray; some quartz sand	1439
Dolomite, gray, cherty, much fine quartz sand	1458
Dolomite, gray, much fine quartz sand, but no imbedded grains	1475
Dolomite, gray, highly arenaceous, grains fine, rounded, secondary enlargements	1495
Dolomite, light buff, cherty	1500, 1505
Dolomite, whitish, some chert	1524
Dolomite, gray	1542
Dolomite, gray; some chert	1567
Chert, in large chips	1592
Dolomite, gray; much chert	1622
Dolomite, light gray, a little chert	1642
Dolomite, blue-gray, crystalline, pure except for slight residue of microscopic siliceous particles	1664
Chert, white and yellow-gray; some gray dolomite	1666–1668
Dolomite, gray and buff, rusted; some chert	1670
Dolomite, light gray, arenaceous, in sand	1690
Dolomite, gray and light brown; some chert	1703, 1706
Jordan sandstone (100 feet thick; top 996 feet below sea level):	
Sandstone, light cream colored in mass, fine, grains rounded, some dolomitic cement, some chert matrix	1715–1719
Sandstone, whitish, dolomitic cement, fine	1738
Sandstone, gray, some stained brown, fine-grained, secondary enlargements, dolomitic cement, in chips; 2 samples	1741,1758
Dolomite, yellow-gray, arenaceous, in chips showing imbedded grains; 2 samples	1762,1770
Sandstone, whitish, fine, in sand and powder, grains rounded, largest reaching 0.7 mm. diameter, dolomitic cement	1804
Sandstone, whitish, dolomitic, secondary enlargements, in chips	1796
Saint Lawrence, Trempealeau dolomite (top 1096 feet below sea level):	
Dolomite, gray and yellow-gray, in fine chips	1815

Notes.—The beds superjacent to the Maquoketa carry much gypsum, as in other deep well sections at Mount Pleasant, and are therefore assigned to the Silurian (Salina group). The dolomites of the Niagaran outcrops are not in evidence.

The Maquoketa shales, while clearly defined, have thinned much from their normal thickness in east-central Iowa. If any sandstone is connected with the formation, as appears to be the case at New London, it escaped notice and record while the well was being drilled, although some quartz sand grains appear in a sample at its base (830 feet). The Galena-Platteville is wholly dolomitic.

The relations of the Saint Peter sandstone and the Glenwood shale are peculiarly intimate, and it is to be remembered that in its outcrops the latter formation is sometimes sandy. According to a drawing of the well supplied by the Company, a sandstone extends from 1103 to 1115 feet, and is underlain by a shale 18 feet thick referable to the Glenwood. Below this lies the

Saint Peter sandstone, or the main body of the Saint Peter sandstone, 40 feet thick. The sample cuttings described above confirm this record as to the sequence of the strata, although differing somewhat from it as to dimensions.

The strata of the Prairie du Chien are typical both in their complete dolomitization and in the presence of chert and quartz sand at various levels. The New Richmond sandstone is not in evidence. Water was found at two horizons.

The main aquifer is stated to be the Jordan sandstones. This formation, while 100 feet thick, is by no means a clean pervious sandstone throughout, but has, on the whole, a large dolomitic content.

WELL OF MOUNT PLEASANT STATE HOSPITAL FOR THE INSANE, 1915

A well 1945 feet in depth was put down for this institution in 1915 by J. D. Shaw, of Davenport. The diameters are from 8 to 6 inches. The main supply was found at 1900 feet, and no records are extant of other water beds. The static level was 52 feet from the surface on completion of the well, with a pumping capacity of 80 g.p.m. The static level now stands at 110 feet, with a draw down to 150 feet. Under compressed air, the jet placed at 340 feet, the well delivers 200 g.p.m.

NAHANT, SCOTT COUNTY

(Altitude 563 feet)

WELL OF THE CHICAGO, MILWAUKEE, ST. PAUL AND PACIFIC RAILROAD AT THE NAHANT SHOPS NEAR DAVENPORT

This well, drilled by C. W. Varner, of Dubuque, is 1030 feet deep and was completed in 1928. The diameters are 20 inches for 115 feet in which are placed 30 feet of 20 inch casing and 115 feet of 15 inch casing; 15 inches to 306 feet, lined with 306 feet of 12 inch casing; 12 inches to 600 feet and 10 inches to the bottom, both uncased.

Static water stands at ground level, with a draw down to 70 feet when pumped at 225 g.p.m.

Driller's Log

	Depth in feet	Elevation above sea level, feet
Sand and gravel	0–18	563
Boulders and blue shale	18–26	
Shale and limestone	26–115	
Limestone	115–165	
Shale and limestone	165–300	
Limestone	300–420	
Shale (Maquoketa)	420–560	143
Limestone (Galena-Platteville)	560–905	3
Shale (Glenwood)	905–920	342
Sandstone (Saint Peter)	920–1030	357

*Chemical analysis**

	Grains per Gallon
Oxides	0.47
Calcium carbonate	7.50
Calcium sulphate	2.89
Magnesium carbonate	6.05
Alkali sulphate	14.95
Alkali chloride	30.20
Total	62.06

This analysis was received too late for consideration under the subject of the saltness of the wells of the Davenport field. The content of sodium chloride (alkaline chloride), 30.20 grains per gallon, is but little in excess of that of similar wells analyzed before 1900, such as the Witt's Bottling Works well, sodium chloride content 26.17 g.p.g. and the Crystal Ice and Cold Storage Company well, sodium chloride content 26.26 g.p.g.[57a] It can hardly be said, therefore, that the Nahant well offers proof of any considerable recent rise of the deep saline waters underlying this area.

NEVADA

In 1916 a city well was completed by the J. P. Miller Artesian Well Company of Chicago. The depth reached was 2792 feet. The diameters of the well are from 16 to 6 inches. The well is cased to 1780 feet.

The principal supply is said to have been struck at 2792 feet, while other water beds were found from 1800 feet downward.

The static level is 163 feet below the surface of the ground, while under continuous pumping at capacity of 180 gallons per minute there is a draw down to 212 feet below the curb.

* By Chemist of Chicago, Milwaukee, St. Paul and Pacific R. R. Co., January, 1929.

57a Norton, W. H.; Artesian Wells of Iowa: Iowa Geol. Survey, vol. VI, pp. 274-275.

*Mineral Content of City Well of 1916, Nevada**

	P.P.M.
Bicarbonate	317.2
Chloride	35.
Sulphate	417.2
Silica	7.2
$Fe_2O_3 + Al_2O_3$	7.6
Calcium	114.7
Magnesium	48.8
Na + K as Na	108.9
Total solids	898.0

*Record of strata, Nevada city well, 1916**

	DEPTH IN FEET
"Glacial drift" (60 feet thick; top 1005 feet above sea level)	0–60
"Coal Measures" (198 feet thick; top 945 feet above sea level)	60–258
Mississippian (332 feet thick; top 747 feet above sea level):	
"Limestone"	258–260
"Brown sandy shale"	260–277
"Limestone, white; 3 samples"	277–310
Shale, drab, calcareous; limestone, buff and gray, considerable quartz sand in irregular grains, and chalcedonic silica	305–310
Shale, lighter drab, calcareous	310–320
Limestone, gray-buff, fine-grained, earthy, rather slow effervescence in cold dilute HCl	320
"Shale, gray, calcareous"	330
"Shale, as above, with the addition of some light blue shale"	340
Shale, drab; limestone, gray-buff; white chert; flakes of chalcedonic silica	350
Limestone, gray, soft, fine crystalline-granular and earthy, rather rapid effervescence; vein quartz and crystals	350–360
Limestone, brown, reaction rather rapid, a little white chert, and chalcedonic silica intercrystallized with calcite	370
Limestone, light gray, soft, earthy, rather slow effervescence	390
Chert, light blue-gray and drab, large flakes; gray limestone in smaller chips; chalcedonic silica; quartz crystals; 4 samples	400–430
Chert, as above; buff limestone, minutely arenaceous	440
Limestone, yellow and buff, reaction rapid, crystalline and some oölitic; 4 samples	450–480
Limestone, dark drab, and gray-buff, rapid effervescence	490
Limestone, dark gray-buff, and light yellow-gray, in flakes, reaction rapid	500, 520
Limestone, gray-buff; rather slow effervescence; a little white chert	530
Limestone, gray-buff, rather slow effervescence	540
Limestone, brown, fine-grained, reaction rapid; blue chert	550
Limestone, brown, reaction rather slow; blue chert	560
Limestone, dark brownish gray and buff, reaction rather slow; white chert	570, 580
Shale, blue-gray, reddish brown, purple, calcareous	590
Shale, green and blue-gray, calcareous; 4 samples	600–630
"Limestone, gray, contains rounded quartz grains"	640
"Shale, light blue, noncalcareous"	650, 660
Devonian and Silurian (680 feet thick; top 335 feet above sea level):	
Limestone, light gray, calcilutite, in flaky chips	670

* Analysis by Harry F. Lewis, Chemical Laboratory, Cornell College, Mount Vernon, 1927.

* Apparently no samples of cuttings were saved below 1917 feet. The set examined by the writer is somewhat incomplete, and it is therefore supplemented by determinations made in the geological laboratory of the State College of Agriculture and Mechanic Arts when the well was drilled, and by the driller's log.

Limestone, blue and light yellow-gray and whitish, fine-grained, compact, reaction rapid, some blue shale at 680, fossiliferous at 780; 6 samples	680–730
Limestone, brown, fine crystalline-granular, and light yellow-gray	740
"Limestone, white and brown, pyritiferous"	740–780
Shale, blue, plastic, calcareous	780
Shale, gray, with some impure gray and buff limestone of rather slow effervescence	790
Shale, blue, as at 780	800
Limestone, blue-gray, reaction rapid, limestone, buff, rather slow effervescence	810
Dolomite, brown, crystalline	820
Limestone, whitish and light gray, rapid reaction; 3 samples	830–850
Limestone, brown, reaction rather slow; limestone, gray, rapid reaction; in sand	860
Limestone, light blue-gray, calcilutite, rapid effervescence	870, 880
Shale, light blue-gray, highly calcareous	890
Limestone, gray-buff, crystalline-granular, reaction rapid, some rather slow	900, 910
"Limestone, dolomitic, brownish white"	920, 930
Dolomite, gray-buff, very fine crystalline-granular; 4 samples	940–970
Dolomite, light yellow-gray and buff, crystalline-granular; some limestone, reaction rapid; 3 samples	980–1000
"Dolomite, brown; contains some light blue noncalcareous shale"	1010
Dolomite, brown and buff, crystalline-granular; 4 samples	1020–1050
Gypsum, white, in hard concreted masses, with some dolomite; 3 samples; at 1080 rusted and pyritiferous	1060–1080
Dolomite, buff; limestone, buff; a little gypsum	1090
Dolomite, buff-gray, fine-grained, compact, a little gypsum at 1120; 3 samples	1100–1120
"Limestone, white, argillaceous"	1130
Limestone, light buff-gray, calcilutite, rapid effervescence	1140, 1150
Limestone, brown and light gray, rather slow effervescence	1160, 1170
Shale, light blue-gray, calcareous	1180
Dolomite, buff, argillaceous; 3 samples	1190–1210
Dolomite, buff and gray; shale, drab, fissile	1220
Limestone, buff, reaction rather slow; much blue-gray and white chert	1230
Chert, blue-gray and white, some translucent, limestone, light gray, reaction rather slow; 3 samples	1240, 1260
"Dolomite, white, highly siliceous, very hard to dissolve in HCl; 6 samples"	1270–1320
Dolomite, whitish; some white chert	1320
"Dolomite, brownish white"	1330
Dolomite, light yellow-gray; a little chert	1340
Maquoketa shale (50 feet thick; top 345 feet below sea level):	
Shale, blue, calcareous, in moulded masses, including some chips of white chert	1350
Shale, blue, calcareous; some purplish drab, fissile, somewhat calcareous	1360
Shale, drab and purplish drab	1370
Shale, light blue-green, calcareous	1380, 1390
Galena to Platteville inclusive (480 feet thick; top 395 feet below sea level):	
Dolomite, brown, cherty	1400, 1410
Dolomite, gray, cherty, in fine crystalline meal	1420
Dolomite, gray, much chert of the same color in chips of same size	1430
"Dolomite, brownish white"	1440–1490
Dolomite, gray, much chert of same color	1500
"Dolomite, white"	1510–1530
Dolomite, yellow-gray, in fine crystalline sand	1540
"Dolomite, white"	1550–1570
Dolomite, yellow-gray, in fine crystalline sand, cherty at 1600 and 1620; 3 samples	1580–1620
Limestone, whitish, argillaceous, in friable masses; rather slow reaction	1630

Dolomite, light buff, in crystalline sand	1650
"Limestone, brownish white"	1660–1720
Dolomite, light buff-gray	1720
"Limestone, brownish white; 2 samples"	1720–1830
"Limestone, brown"	1830
"Dolomite, white, contains particles of blue noncalcareous shale (Glenwood shale)"	1840–1860
"Limestone, white"	1870
Saint Peter sandstone (47 feet thick; top 875 feet below sea level):	
"Sandstone, white, water-worn; and blue shale"; 2 samples	1880–1917

Driller's Log

	Depth in Feet
Soil and yellow clay	0–30
Gravel and boulders	30–33
Sand and yellow clay	33–60
Black and gray shale	60–75
Red marl	75–93
Brown shale	93–100
Dark brown shale	100–150
Black shale	150–200
Gray slate	200–202
Black shale	202–248
Gray soft slate	248–258
Lime	258–260
Brown sandy shale	260–277
Got solid lime at	277
Gray and brown lime	277–305
Brown shale	305–310
Gray shale	310–320
Shale	320–345
Lime	345–355
Shale	355–365
Broken lime	365–430
Brown lime	430–470
Gray and blue lime	470–570
Red and brown shale, looks like iron bog	570–580
Shale, blue, looks whitish when drilled up	580–667
Lime	667–668
Shale	668–672
White lime	672–760
Shale	760–775
Lime	775–780
Shale	780–810
Lime	810–811
Shale	811–820
Lime, very good	820–1140
Very dark brown hard lime	1140–1260
Quartz lime (1260)	1260–1325
Brown lime	1325–1345
Green shale	1345–1406-5
Brown hard limestone	1406-5–1513
White hard lime	1513–1690
Brown yellow lime	1690–1800
Had 2 feet soft drilling after 1800 and green shale	1800–1840
Hole caves badly	1844
Hard lime	1844–1870
Lime	1870–1884
Sand, hard	1884–1917
Lime	1917–2080
Sand	2080–2090
Lime	2090–2120
Sand and sandy lime	2120–2198
White sand	2198–2235
Lime	2235–2407
Sand	2407–2432
Sandy lime	2432–2650
Shale, marl and lime, streaked; water stands at 145 feet from the surface	2650–2720
Green sand and lime	2720–2750
Lime and sand rock	2750–2792

CITY WELL OF 1928

This well, drilled by Thorpe Bros. Well Co. of Des Moines, is 2791 feet deep with diameters from 16 to 6 inches. The main supply was found from 2723 to 2791 feet, in or just below the Franconia beds of the Saint Lawrence formation. Other water beds reported are: 1890 to 1925 feet (Saint Peter sandstone), 2190 to 2215 feet (New Richmond sandstone), and 2240 to 2250 feet (Oneota dolomite). Tests, however, of these beds "did not show much water". The final tests showed a pumping capacity of 250 g.p.m. The static level is 165 feet below the surface or within 2 feet of that of the well of 1916. The static level as the well was drilled is stated to have been about the same as at the completion. The draw down is to 241 feet below the surface of the ground. The temperature of the water is 67°. Its effect on boilers is bad. The cost of the well was $29,000.

The casing of the well is as follows: 303 feet of 16 inch, 533 feet of 12 inch, 622 feet of 10 inch, 519 feet of 8 inch, and 885 feet of 6 inch.

*Mineral Analysis of Nevada well of 1928**

Constituent	Parts per million	Grains per U. S. Gallon
Sodium and potassium	103.2	5.99
Calcium	139.5	8.10
Magnesium	59.97	3.50
Iron and alumina	4.34	0.25
Sulphate	554.3	32.2
Nitrate	none	none
Chloride	30.0	1.74
Bicarbonate	327.0	18.98
Normal carbonate or hydroxide	none	none
Silica	22.2	1.29
Total mineral residue	1217.	70.5
Fixed mineral residue	1011.	58.6
Organic and volatile residue	206.	11.9
Total hardness (soap method)	380.	22.1

An analysis made in August, 1928, by the International Filter Co. of Chicago gives the following hypothetical combinations:

	Parts per million		Parts per million
Calcium carbonate	273.	Suspended matter	20.
Calcium sulphate	88.	Sodium sulphate	482.
Magnesium sulphate	195.	Sodium chloride	63.
Iron oxide (unfiltered sample)	4.3	Free carbon dioxide	6.0
Silica	13.		

Record of strata, Nevada Well, 1928

	Depth in Feet
Pleistocene and Recent (68 feet thick; top 1005 feet above sea level):	
Till, brown-buff, sandy, calcareous, in lumps	10
Till, buff, calcareous	20
Till, or clay, light drab, feebly calcareous; some coarse sand; in moulded masses	30
Till, bright yellow, sandy, calcareous	35, 40
Till, yellow, pebbly, calcareous	57
Sand and gravel, pebbles up to 2½ cm.	65
Till, greenish drab, calcareous, sandy	68

*By M. K. Tenny, Des Moines, August, 1928.

Pennsylvanian (203 feet thick; top 937 feet above sea level):	
Shale, red, yellow and whitish, unctuous, noncalcareous	77
Shale, pink, some blue	88
Shale, drab and black	95
Shale, blackish, some pebbles from the drift; coal	105
Shale, light blue-gray, very finely arenaceous	115
Shale, pink and gray; 3 samples	127–150
Shale, black	162
Shale, gray	170
Shale, dark drab	185
Shale, gray and blackish	205
Shale, drab	220
Shale, black	230, 240
Shale, very light gray, finely arenaceous	258
Shale, drab; sandstone, gray, calcareous, fine irregular grains	262
Shale, gray and blackish	268
Mississippian (390 feet thick; top 725 feet above sea level):	
Limestone, yellow-gray, fine-grained, rather rapid effervescence in cold dilute HCl; in large chips concreted in shale	280
Limestone, drab in mass, yellow-gray, crystalline-earthy, rapid and moderately rapid effervescence, slightly arenaceous with fine irregular grains of clear quartz	300, 310
Shale, light gray	320
Shale, drab, and limestone	350
Chert and chalcedonic silica in chips; some quartz sand; a little buff and drab limestone; concreted with gray shale	360
Shale, drab, a little white chert; drab argillaceous limestone	370
Shale, gray; milky quartz; gray soft limestone of rapid effervescence; colorless quartz	380
Limestone, light gray and drab, rather slow effervescence; milky quartz; shale, gray, in hard concreting masses	390
Limestone, gray; some milky quartz	390–400
Chert, light blue-gray and white in large chips; milky quartz; some gray limestone of rather slow effervescence	410–430
Limestone, buff, rapid effervescence; some white chert; chip of aggregate of calcite, pyrite, chalcedony and clear quartz	440
Limestone, yellow and buff, rapid effervescence, crystalline-granular, in sand	450–470
Limestone, light brown and gray, some mottled, rapid effervescence; in large flakes	480, 490
Limestone, gray, yellow-gray and brown, rapid effervescence	500-520
Limestone, drab, fine crystalline, moderately rapid effervescence; in large flakes	530
Limestone, brown, moderately slow to rapid effervescence; much blue-gray, gray and white chert; 4 samples	540–570
Kinderhook shale:	
Shale, brown, some light blue, arenaceous	580
Shale, greenish and light blue-gray, calcareous	600, 610
Limestone, gray, cherty, pyritic, slow effervescence	630
Shale, light blue-gray, calcareous; 3 samples	640–660
Devonian (330 feet thick; top 335 feet above sea level):	
Limestone, gray, fine-grained, earthy, rather rapid effervescence; in large flakes	670
Limestone, light yellow-gray and gray, calcilutite and fine-grained, rapid effervescence; 5 samples	680–720
Limestone, very light gray, fossiliferous, soft, earthy-fine-crystalline; gray limestone harder, compact, of very fine grain; all of rapid effervescence	740, 750
Limestone, as above, in sand; much blue-gray calcareous shale in chips and a little dark gray argillaceous and microscopically quartzose limestone	760
Limestone, drab, fine-crystalline, rather slow effervescence; some shale	770

Shale, blue-gray; limestone of same color, crystalline-granular, rather rapid effervescence	780
Shale, light blue, calcareous; in hard moulded masses	800, 810
Limestone, whitish and light gray, rapid effervescence, earthy; 4 samples	830–860
Limestone, or dolomite, dark gray, slow effervescence, fine-crystalline	870
No samples	880, 890
Limestone, light gray, rapid effervescence	900
Dolomite, buff and gray, crystalline-granular	910–920
Dolomite, buff and yellow-gray; some drab limestone	930
Dolomite, buff, hard, crystalline-granular	940
Limestone, magnesian, or dolomite, gray-buff, rather slow effervescence, fine-grained	950, 960
Limestone, buff, gray-buff and brown, some macrocrystalline, rather slow effervescence, with calcite	970, 980
Limestone, light yellow-gray, some rapid, some slow effervescence; in sand	990
Limestone, gray and light yellow-gray, rather rapid effervescence	1000
Silurian (340 feet thick; top 5 feet above sea level):	
Dolomite, brown, some gray, a little gypsum in small white chips	1010
Dolomite, buff, brown and gray, a little gray shale	1020
Dolomite as above, a little gypsum in white chips	1030
Dolomite, brown and buff, fine crystalline-granular; flakes of yellow-gray limestone	1040
Dolomite, gray; drab laminated shale, considerable gypsum in chips	1050
Gypsum, in large gray chips; hard greenish drab shale, laminated, non-calcareous in large chips; brown dolomite in sand	1060
Dolomite, gray, fine-grained, rather slow effervescence, a little gypsum	1070
Gypsum, gray, in hard concreted mass with some dolomite	1080
Dolomite, buff and gray, fine-grained, much gypsum in chips and concreted masses	1090, 1100
Dolomite, gray and buff, hard; an occasional flake of dolomite with selenite	1110, 1120
Dolomite, buff; some white argillaceous masses with a little chert	1130
Limestone, light buff-gray, rapid effervescence; some buff dolomite; considerable light blue shale	1140
Dolomite, buff-gray; some limestone	1150
Dolomite, brown, rather slow effervescence, cherty at 1160; 3 samples	1160–1180
Dolomite, buff and yellow-gray, argillaceous; 3 samples	1190–1210
Chert, white, blue and yellowish, some translucent, but polarizing as flint; some gray limestone or dolomite of rather slow effervescence; 10 samples	1220–1310
Dolomite, light yellow-gray, a little white chert	1320
Dolomite, blue-gray	1330
Ordovician:	
Maquoketa shale (80 feet thick; top 335 feet feet below sea level)—	
Shale, light blue-gray and red, calcareous, in concreted masses	1340
Shale, blue and greenish gray, drab at 1390, with chips of chert probably from above; 6 samples	1350–1400
Galena-Platteville (440 feet thick; top 415 feet below sea level)—	
Dolomite, buff and brown in mass, in fine crystalline sand, cherty, much gray and buff chert at 1460; 5 samples	1420–1480
Shale, drab; much dolomite in fine crystalline sand	1490
Dolomite, drab, highly argillaceous, in chips; much drab flint and shale	1500
Dolomite, buff-gray, in crystalline sand and chips, argillaceous; much flint of same color, and some milky quartz	1510
Dolomite, drab in mass, argillaceous; much flint of same color	1520
Shale, drab; considerable light gray limestone of rapid effervescence and white chert	1530
Dolomite, gray, yellow-gray and buff, in crystalline sand; 11 samples	1540–1640

Limestone, buff-gray and light gray, rapid effervescence; some dolomite; cinders; 3 samples ... 1650–1670
Limestone, gray, fine-crystalline, soft, in large chips ... 1680, 1690
Dolomite, gray and light brown, in sand, cherty except at 1700; 4 samples ... 1700–1730
Limestone, gray and yellow-gray in mass, rapid effervescence, some large thin flakes; some dolomite and chert ... 1740, 1750
Limestone, light gray, whitish, gray and buff, earthy, rapid effervescence; fossiliferous and with a little shale at 1830; 8 samples ... 1760–1830
Limestone, gray in mass, some brown inflammable shale in large flakes ... 1840
Limestone, gray, fossiliferous ... 1845
No samples ... 1845–1860

Glenwood shale (20 feet thick)—
Shale, dark green, in small flakes; much limestone, light gray, soft, earthy; pyrite ... 1860
Shale, as above, feebly calcareous, in large flakes; limestone as above ... 1860–1870
Shale and limestone as above ... 1870–1878
Shale, dark slaty green, hard, in parts with conchoidal fracture, noncalcareous ... 1878–1880

Saint Peter sandstone (40 feet thick; top 875 feet below sea level)—
Sandstone, gray in mass, grains medium, well rounded, frosted, of clear colorless quartz; much green shale in large flakes ... 1880–1890
Sandstone as above, grains up to .7 mm. in diameter; much shale in small flakes ... 1890–1895
Sandstone, white, as above; considerable shale; sandstone finer at 1913; 4 samples ... 1895–1920

Prairie du Chien—
Shakopee dolomite (190 feet thick; top 915 feet below sea level)—
No samples ... 1920–1950
Dolomite, brown; much white chert; a little quartz sand ... 1950
Dolomite, gray, some quartz sand ... 1960, 1970
Dolomite, buff, white siliceous oölite in fine spherical grains 1980
Chert, white; dolomite, brown-gray ... 1990
Dolomite, light buff and light gray; cherty at 2000 and 2020; a little quartz sand; 4 samples ... 2000–2030
Dolomite, buff and gray; considerable quartz sand; imbedded grains in dolomite chips; secondary enlargements; some chert and pyrite; 6 samples ... 2040–2090
Dolomite, brown-gray, highly arenaceous; imbedded grains; an occasional quartz crystal ... 2100
Dolomite, light buff, oölitic; highly arenaceous ... 2110

New Richmond beds (100 feet thick; top 1105 feet below sea level)—
Sandstone, white, grains well rounded, frosted, secondary enlargements, grains up to 1 mm. in diameter; some buff dolomite ... 2120–2130
Dolomite, yellow-gray; a large chip pyritic and with sandstone laminae ... 2140
Dolomite, yellow-gray; some quartz sand ... 2150
Dolomite, gray, arenaceous with imbedded grains; sandstone fine, in chips and sand, secondary enlargements ... 2160
Dolomite, very light gray; sandstone with dolomitic cement and secondary enlargements ... 2170
Sandstone, white, rusted yellow, fine, larger grains well rounded, frosted; secondary enlargements; a little dolomite ... 2180, 2190
Sandstone, white, larger grains 1.2 mm. in diameter, well rounded, frosted; some chips of fine sandstone with dolomitic cement ... 2200, 2210

Oneota dolomite (160 feet thick; top 1205 feet below sea level)—
Dolomite, gray and buff, vesicular and macrocrystalline at 2240, embedded grains of quartz sand at 2250; cherty at 2300; more or less quartz sand in all samples; 15 samples 2220–2370
No samples 2380, 2390

Cambrian:
Jordan sandstone (30 feet thick; top 1385 feet below sea level)—
Sandstone, light yellow-gray in mass, fine, well rounded grains; some dolomite in chips showing imbedded grains 2400, 2410
Sandstone, yellow, clean, larger grains 1 mm. diameter 2420

Saint Lawrence—
Trempealeau dolomite (200 feet thick; top 1415 feet below sea level)—
Dolomite, gray, a little quartz sand 2430
Dolomite, light yellow-gray, in finest crystalline sand or in chips; 3 samples 2440–2460
Sandstone, blue-gray in mass, grains minute or microscopic, pyritic, dolomitic; in chips and powder slightly concreted 2470
Dolomite, blue-gray, minutely arenaceous, pyritiferous; argillaceous at 2510; 4 samples 2480–2510
Dolomite, gray, brown and buff; 3 samples 2520–2540
Dolomite, gray, minutely arenaceous, pyritic, in chips and concreting powder 2550
Dolomite, dark gray, in chips 2560
Dolomite, gray, pyritic and minutely arenaceous at 2580; 6 samples 2570–2620

Franconia beds (165 feet penetrated, top 1615 feet below sea level)—
Shale, light gray, in friable moulded masses; dolomite, glauconitic, minutely arenaceous 2630
Shale, drab, unctuous, in hard concreted masses inclosing small chips of highly quartzose dolomite 2640
Sandstone, gray, grains minute, highly glauconitic, dolomitic 2650
Sandstone, gray, grains minute, some fine and rounded, pyritic, glauconitic, dolomitic; splintery flakes of dark drab laminated shale slightly dolomitic; 3 samples 2660–2680
Shale, dark drab, finely laminated; a little limestone, very light gray, mottled dark gray and buff, rapid effervescence, soft, earthy, in thin flakes, minutely quartzose, glauconitic; some sandstone at 2710, grains minute, calcareous, rapid effervescence, glauconitic; 3 samples 2690–2710
Sandstone, fine and of microscopic grains, glauconitic, dolomitic; shale, dark drab, in large flakes 2720
Shale, strong green, highly glauconitic and arenaceous; or sandstone, argillaceous; in concreted friable masses; shale, dark drab, fissile, in flakes 2730
Sandstone, gray in mass, in detached grains, highly diverse in size from minute quartzose particles to fine, some grains well rounded, a few secondary enlargements of clear colorless quartz, highly glauconitic; 3 samples 2735–2745
Sandstone, green and gray, grains as above, highly glauconitic; argillaceous, powder; much drab shale in thin flakes 2750, 2760
Sandstone, gray, grains as above, glauconitic; splinters of drab shale 2765, 2770
Sandstone, clean except for a little drab shale, very fine, not well rounded except some of larger grains, an occasional grain of feldspar and ferromagnesian mineral 2775, 2780
Sandstone, buff, coarser, a few grains reaching 1 mm. diameter; much green shale in friable masses, highly arenaceous and glauconitic; much drab shale 2785
Sandstone, buff, gray and green, in small chips, hard, minute, some grains fine and rounded, highly glauconitic, nondolomitic; much drab shale in large thin flakes, cuttings mostly shale 2790

Notes.—In the Nevada section no attempt has been made to discriminate the different formations of the Mississippian above the Kinderhook shale. To this formation is assigned the shale from 570 to 680 feet (driller's log of well of 1916), which clearly is the same as the shale in the Marshalltown well at corresponding depth.

No definite line can be drawn between the Devonian and Silurian, since the lower beds of the Devonian are, in places, as at Cedar Rapids, dolomitized. At Ames Beyer assigned to the Devonian a thickness of 310 feet. A like thickness at Nevada will carry the Devonian near to the gypsum-bearing beds at 1010 feet (well of 1928), which credibly may be taken as Silurian of the Salina group. The heavy chert bed near the base is worthy of note, since chert characterizes the basal beds of the Niagaran.

The shale from 1340 to 1420 may be assigned to the Maquoketa with confidence, and perhaps the shales and argillaceous dolomite from 1490 to 1540, together with the 70 feet of overlying cherty dolomite, should go to the same formation. Gray cherts are characteristic of this horizon.

In the cuttings of the well of 1916 a sample labelled 1620-1650 is of sandstone of St. Peter facies, with shale of Glenwood facies and some dolomite. This was omitted from the record of strata as evidently an error in labelling. The samples of the well of 1928 show no sandstone of the kind above the Saint Peter at 1880 feet.

The persistent brown inflammable shale at 1840 feet signalizes the near approach of the Glenwood shale and the Saint Peter sandstone.

The Glenwood shale is not well made out in the cuttings of 1916, but is clearly shown in those of the well of 1928. Here it is 20 feet thick, and unless the limestone in the upper cuttings is foreign, includes considerable limestone, showing a gradation into the overlying Platteville.

The Saint Peter sandstone occurs considerably below the depth at which it might be expected with a fairly uniform descent from the east and some share in the Ames Anticline of Beyer. The gradient from Cedar Rapids, where the Saint Peter is abnormally thin, to Belle Plaine is five feet to the mile. From Belle Plaine to Nevada the gradient is somewhat steeper, 6.5 feet to the mile.

But in the eight miles from Nevada west to Ames the Saint Peter rises 455 feet in the Ames anticline and but 30 feet of this can be laid to the greater thickness of the formation at Ames. This pronounced upfold is thus narrower on the eastern limb than might have been expected and the position of the Saint Peter is correspondingly deeper at Nevada. A rather narrow downfold at Nevada may accompany the Ames upfold. Thus the writer's forecast of the normal depth to the Saint Peter at Nevada, as about 1600 feet, based on a uniform dip from the east, was about 280 feet astray.[58] The three members of the Prairie du Chien are well demarked—the Shakopee dolomite, oölitic at two levels, the sandstone and sandy dolomites of the New Richmond, and the Oneota dolomite.

The Jordan is but 30 feet thick and in part carries a dolomitic matrix which seriously interferes with its capacity as an aquifer.

The Trempealeau dolomites of the Saint Lawrence include characteristic sandy layers of minute angular grains of clear quartz, and at 2630 feet pass into the Franconia beds, characterized by shales, minutely arenaceous dolomites, and sandstones of microscopic grain, all of which may be glauconitic. In certain beds the glauconite is so abundant as to constitute a veritable "greensand".

No coarse, clean sandstone of Dresbach facies was encountered. Apparently at the bottom of the well the drill was still in the Franconia. It is possible, however, that the sandstone at 2765 feet is the westward extension of the Dresbach and that the footing of the well is in the Eau Claire beds.

The following table shows the comparative thickness in feet of the formations below the Saint Peter in the deep wells of this area.

	Nevada	Grinnell	Ames	Boone	Des Moines
Prairie du Chien	450	449	610	-----	393
Jordan	30	60	105	-----	147
Trempealeau	200	110	10+	-----	-----
Total of above	680	619	725+	525	540
Franconia	165+	140+		421?	435?
Dresbach				54?	
Eau Claire				14+?	

58 Underground Waters of Iowa, Iowa Geol. Survey, vol. XXI, p. 912.

Driller's log of Nevada Well, 1928

	Depth in Feet		Depth in Feet
Soil	0–5	Brown lime	1500–1550
Yellow clay and sand	5–23	Hard white lime	1550–1620
Blue clay	23–35	Brown lime	1620–1630
Yellow clay, sandy	35–186	Hard brown lime	1630–1715
Dark yellow clay	186–195	White lime	1715–1765
Sand and gravel	195–203	Brown lime	1765–1827
Light blue shale	203–213	Shale, blue	1827–1828
Red shale	213–223	Brown lime	1828–1845
Shale mixed	223–251	Green shale	1845–1849
Red shale	251–264	Brown lime	1849–1878
Light shale	264–274	Green shale	1878–1890
Dark colored shale	274–288	St. Peter sand	1890–1925
Slate colored shale	288–331	Gray lime	1925–1932
Dark colored shale	331–375	Case with 8 in. casing 532-4	1932–2451
Lime rock broken with streaks of shale	375–448	Gray lime	1932–1940
Solid white lime	448–485	Gray lime, hard	1940–1980
Broken lime and shale	485–701	White lime	1980–1992
Shale, blue	701–744	White lime, hard	1992–2030
Lime rock	744–766	Brown lime	2030–2103
Shale	766–781	White sandy lime, dolomitic	2103–2190
Lime rock	781–864	New Richmond sand	2190–2215
Shale	864–866	Lime, dark, hard	2215–2240
Lime, white	866–911	Lime, some water, no cuttings	2240–2250
Shale, light	911–933	Brown lime, hard	2250–2280
Lime rock, white	933–1132	White lime	2280–2340
Brown lime	1132–1205	Brown lime	2340–2404
Lime, brown, hard	1205–1254	Sand	2404–2425
Lime, white	1254–1268	Brown lime	2425–2580
Brown lime	1268–1315	Gray lime	2580–2654
Gray lime	1315–1350	Green shale	2654–2660
Lime broken with shale, sandy	1350–1420	Lime, broken, streaks of shale	2660–2723
White lime	1420–1500	Sand, green color	2723–2785
		Lime	2785–2791

NEW ALBIN, ALLAMAKEE COUNTY

(Altitude 651 feet)

Eight artesian wells in the village of New Albin are listed in the Report on the Underground Water Resources of Iowa, 1912, and since that time several others have been drilled. As for the most part no pains have been taken to prevent waste, the supply is now overdrawn and the static level has sunk from 682 feet to 659 feet above sea level.

In 1925 a deep well was completed for public supply by the Howard R. Green Company of Cedar Rapids, with J. W. Welsh of La Crescent, Minnesota, as driller. The depth is 585 feet, the diameters are 10 and 8 inches. During the drilling water stood between 25 and 30 feet below the surface until at a depth of 365 feet, in the sandstones of the Mount Simon formation, it overflowed. The head is four feet above the surface and the pumping capacity is more than 150 gallons per minute. In a 30 hours pumping test with this discharge the water level in the casing was lowered one foot. Wrought iron 10 inch casing is inserted to the depth of 148 feet. The cost of the well was $924. The discharge is kept under strict control without surface waste.

Record of strata in New Albin City well no. 1

	Depth in Feet
Pleistocene and Recent:	
Cambrian:	
Eau Claire—	
Sandstone, light green-gray, argillaceous, calcareous, grains mostly microscopic, with some coarser rounded grains	165
Sandstone, buff, very fine, grains imperfectly rounded	185
Sandstone, green-gray, glauconitic, argillaceous, grains minute, noncalcareous	220
Shale, red, highly arenaceous, quartz grains coarse and fine, in tough concreted masses	270
Shale, gray, calcareous, highly arenaceous, grains coarse and fine; in friable concreted masses	302
Sandstone, light green-gray, coarse and fine, larger grains rounded, argillaceous	325
Mount Simon:	
Sandstone, white, clean, rounded grains up to 1 mm. and 1.5 mm. diameter; 2 samples	365, 463
Sandstone, light yellow-gray, grains rounded, coarse and fine, at 515 feet many about 2 mm. diameter and some more than 3 mm.; 3 samples, 467½, 515 and	530
Sandstone, red, coarse and fine grains of clear quartz with much red argillaceous material, noncalcareous	575
Sandstone, light pink in mass, mixture of grains of clear quartz and minute chips of red sandstone	585

Notes.—At New Albin the summit of the Jordan sandstone has been placed by Calvin [59] at 966 feet above sea level. The 476 feet which intervene between this datum and the first argillaceous sandstone in the above section seems a fairly ample measure to include the Jordan, the Saint Lawrence and the Dresbach, whose combined thickness at Lansing, McGregor and Dubuque is about 500 feet. It is therefore assumed that the Dresbach sandstone has been cut out by the ancient channel of the Mississippi, and that the first clayey sandstone struck belongs to the Eau Claire.

From New Albin to McGregor the summit of the Jordan outcrops falls 292 feet, and the summit of the Eau Claire in deep well sections falls at least 288 feet from New Albin to Prairie du Chien. Thus with some thickening of the Eau Claire beds, it is easily possible that the red argillaceous sandstone struck at 575

59 Calvin, Iowa Geol. Survey, vol. IV, p. 55.

feet at New Albin (80 feet above sea level) may be the same as a red sandstone 45 feet thick which was struck at 272 feet below sea level at Prairie du Chien.[60]

Both the character of the material and the probable nearness of the Algonkian or Archean floor—crystalline rock was struck at 108 feet below sea level at Lansing—suggest that the red sandstone at the bottom of the New Albin well may also be the equivalent of the Red Clastic beds of Minnesota. The Mount Simon, however, also includes in Wisconsin pink and reddish beds.

NEW LONDON, HENRY COUNTY

(Altitude 765 feet)

In 1916 a deep well was completed for the town of New London by William Jennings of Burlington. The depth is 1485 feet and the diameters are from six to four inches. The principal supply was found at 1450 feet in the Prairie du Chien dolomites. No other water beds are reported. The static level is 140 feet below the surface. With the pumping cylinder at 250 feet the pumping capacity is now 40 g.p.m., a decrease of but 10 g.p.m. since the well was completed. The water is reported too hard for boiler use. Maximum consumption is stated to be 60,000 gallons per day.

Record of strata of well of town of New London, 1916

	Depth in Feet
No samples, or record	0–273
Mississippian:	
Limestone, buff and light yellow, rapid effervescence in cold dilute HCl, in fine sand; quartz sand in ill-rounded grains; white chalcedonic silica	273–286
Sandstone, light blue-gray, calciferous, argillaceous, grains microscopic, angular; in rusted chips	285–295
Limestone, brown and dark gray, rather slow effervescence; some whitish, soft, rapid; white chert and chalcedonic silica	294–302
Sandstone, as at 285; some chert and chalcedonic silica; 2 samples	302–320
Kinderhook (and Devonian shale at base ?) (287 feet thick; top 448 feet above sea level):	
Shale, blue, calcareous	320–460
Shale, brown, inflammable	460–470
Shale, blue, calcareous	470–607
Devonian (153 feet thick; top 161 feet above sea level):	
Limestone, light blue-gray, highly argillaceous, rapid effervescence; some shale, chert and pyrite; 2 samples	607–632
Limestone, yellow-gray and buff, effervescence rapid; shale and white chert	632–646
Limestone, blue-gray, earthy, fossiliferous, soft, some large chips	646–651
Limestone, yellow-gray, effervescence rapid, in fine chips	651–663

60 Geol. of Wisconsin, vol. IV, p. 61.

Limestone, brown, effervescence rapid, earthy, in chips	663–667
Limestone, blue-gray, effervescence rapid; pyrite and a little chert	667–670
Limestone, blue-gray, argillaceous, fossiliferous	670–673
Limestone, dark gray, earthy, in large flakes, rapid effervescence	673–685
Limestone, blue-gray, rapid effervescence; in fine chips	685–695
Limestone, yellow-gray, earthy, rapid effervescence, fossiliferous, in flaky chips; 4 samples	695–720
Limestone, yellow-gray, compact, effervescence rapid, fossiliferous, in fine chips	720–730
Limestone, whitish, rapid effervescence, in flaky chips	732–740
Limestone, blue-gray and yellow, compact, effervescence rather slow; chocolate brown limestone, effervescence rapid, inflammable; whitish limestone, rapid effervescence	740–744
Limestone, yellow-gray, effervescence rapid, in sand; 2 samples	744–760
Silurian (58 feet thick; top 8 feet above sea level):	
Limestone, brown and buff, effervescence rapid, in sand; gypsum in white soft masses and chips; 3 samples	760–796
Limestone, brown, effervescence rapid, some slow; white chips of crystalline quartz, nongranular, a few cleavages noted (altered from anhydrite?)	796–806
Limestone, blue-gray, effervescence rapid; some quartz; shale in powder	806–818
Ordovician:	
Maquoketa shale (42 feet thick; top 50 feet below sea level)—	
Shale, blue, plastic, calcareous	818–830
Shale, blue; limestone, blue, argillaceous; limestone, light gray	830–837
Sandstone, light gray, fine ill-rounded grains, in flaky chips	837–843
Limestone, blue-gray, highly arenaceous, or sandstone, calciferous, grains as above	843–850
Sandstone, gray, calciferous, larger grains well rounded, up to 0.6 mm. diameter, in chips and sand	850–852
Galena, Platteville, Glenwood (282 feet thick; top 84 feet below sea level)—	
No sample	852–860
Dolomite, blue-gray and light buff, cryptocrystalline, in sand	860–870
Dolomite, buff and light yellow-gray, in fine crystalline sand and flour; some powder of limestone with rather rapid effervescence from 1065 to 1082; 24 samples	870–1100
Dolomite, brown and buff, in fine chips	1100–1105
Dolomite, buff, in fine sand; shale brown, inflammable; brown and gray chert	1105–1113
Limestone, light buff, in fine sand, effervescence rather rapid; 2 samples	1113–1134
Saint Peter sandstone ? (top 366 feet below sea level)—	
Sandstone, white, grains well rounded, some secondary enlargements, larger grains 0.5 mm. in diameter	1134–1170
Shale, green, unctuous, noncalcareous, pyritiferous	1170–1180
No samples	1180–1340
Prairie du Chien:	
Dolomite, gray, in sand; much quartz sand in sample and a little chert	1340–1345
Chert, white; dolomite, light yellow-gray	1345–1360
Dolomite, gray, in sand; much fine quartz sand	1360–1385
Dolomite, light yellow-gray; chert	1385
Dolomite, light buff, oölitic; quartz sand	1390
Dolomite, light yellow-gray; chert	1400
Dolomite, light buff	1418
Dolomite, gray, with minute cavities as from removal of oölitic grains; chert, oölitic	1440
Dolomite, gray, cherty at 1460 and 1482; 4 samples	1450–1482
Sandstone, clean, white, grains well rounded and frosted, many larger grains of 1 mm. diameter, some secondary enlargements	1485

Notes.—The thin bed of sandstone or calciferous limestone at the base of the Maquoketa may be compared with the layer of sandstone in the well of the Electric Company, Mount Pleasant (page 265) at about the same horizon, and represented only by well rounded sand grains in a single sample. Sand grains are also found in one of the samples representing the Maquoketa from Hospital well no. 3 at Mount Pleasant.

It is quite possible that the sandstone at 1134 feet and the shale at 1170 feet may be the Glenwood, and that the Saint Peter lies within the reach unrepresented by samples from 1180 to 1340. The sandstone encountered at the base of the well, 1485 feet, might easily be referred to the Jordan, but this would assign a considerable less thickness to the Prairie du Chien than it carries at Mount Pleasant, where it reaches 527 feet.

*Mineral Content of City Well, New London**

	P.P.M.
Bicarbonate	261.1
Chloride	149.
Sulphate	491.8
Silica	6.6
$Fe_2O_3+Al_2O_3$	17.0
Calcium	86.5
Magnesium	35.4
Na + K as Na	272.2
Total solids	1189.0

NORTH ENGLISH, IOWA COUNTY

(*Altitude 784 feet*)

A deep well was completed in 1921 for this city by Thorpe Brothers' Well Company of Des Moines. The depth is 1678 feet and the diameters are from 13 to 6 inches. The chief supply was found at 1678 feet, and another water bed at 1300 feet. The water rises within 70 feet of the surface. With the pumping cylinder at 220 feet the capacity of the well is 100 gallons per minute and continuous pumping has no effect on the height of the water.

* Analysis by Dr. Harry F. Lewis, Chemical Laboratory, Cornell College, Mount Vernon, 1927.

*Chemical Analysis of Water**

	Parts per million
Silica, SiO_2	3.00
Iron, Fe	2.38
Aluminum, Al	2.12
Calcium, Ca	269.20
Magnesium, Mg	107.80
Sodium, Na	33.90
Potassium, K	28.00
CO_3 radicle	102.70
SO_4 radicle	1462.60
NO_3 radicle	.035
Chlorine, Cl	63.90
Barium, Ba	3.44
Total solids	2079.075

Before the well was drilled this office was consulted by the city officials and the advice was given to exhaust the possibilities of the drift and country rock above the Kinderhook shale before going deeper. It was stated that the Maquoketa shale would probably be found to lie from 800 to perhaps 950 feet from the surface and the Saint Peter at about 1300 feet, while lower water beds to 1900 or 1950 feet would give a larger supply. But as no log can be obtained of the well it is impossible to say how accurate these forecasts were. The water bed at 1300 feet may be the Saint Peter, which was predicted at this depth.

OAKDALE, JOHNSON COUNTY

(Altitude 805 feet)

The well drilled for the State Sanatorium at Oakdale in 1919 by the Thorpe Bros. Well Company of Des Moines has a depth of 1137 feet and diameters from 12 to 6 inches. The principal supply was struck at 1097 feet at the bottom of the Saint Peter sandstone. A small vein was found at 750 feet at the summit of the Galena dolomite. The static level is 127 feet below the curb and is lowered "greatly" by continued pumping. An air compressor is used. At the test it lifted 50 gallons per minute at the start and after five hours 40 gallons to the end of 24 hours. The temperature is reported as about 67° Fahr. The water is hard and needs softening for boilers. The well is cased with 12 inch casing to 154 feet and with 6 inch casing from the top to 785 feet.

* By Dr. Nicholas Knight, Chemical laboratory of Cornell College.

Record of strata, State Sanatorium well, 1919

	Depth in Feet
Pleistocene and Recent (165 feet thick; top 805 feet above sea level):	
Till, yellow, predominantly clayey, sandy, calcareous, some pebbles	85, 95
Till, drab	105, 125
Clay, yellow-drab, fine-grained, plastic, calcareous, practically free from grit; 3 samples	135–155
Sand, grains varicolored, coarse and fine, irregular; some limestone, light gray, rapid effervescence in cold dilute HCl, in sand	165
Devonian:	
Limestone, blue-gray, soft, earthy, rapid effervescence, encrinital, fragments of shells of ribbed brachiopods, in flaky chips	175
Limestone, blue-gray, response rapid, earthy, of almost lithographic fineness, conchoidal fracture, fossiliferous	185
Limestone, whitish gray, argillaceous, in meal and powder, rapid response, some residue of fine quartz sand and cryptocrystalline silica; 3 samples	195–215
Limestone, in fine sand and powder, light yellow-gray, some mottled blue, response rapid, pyritiferous, a little quartz sand in drillings	225
Limestone, light yellow-gray, fragments of fine ribbed brachiopods, earthy, rapid response	235
Limestone, light brown, calcilutite, conchoidal fracture, some gray flint; some minutely fragmental limestone with small mass of whitish crystalline quartz; fossil of young *Atrypa* in gray limestone, and some blue-gray soft earthy limestone (from above ?)	245
Limestone, yellow-gray, fine-grained, rapid response	255
Limestone, light yellow-gray, argillaceous, in powder and sand, at first rapid response, then slow; some blue-gray, some buff, moderately slow response	265
Limestone, blue-gray, and buff, argillaceous, moderately slow response; light yellow, rapid response	275
Limestone as above, some chips of limestone with thin laminæ of dark brown shale, resembling certain layers of the Otis limestone at the Cedar Rapids quarries	285, 295
Dolomite, or magnesian limestone, light yellow-gray, finely crystalline, in sand and flour, response slow; 3 samples	305–325
Shale, blue, calcareous, in concreted masses and powder	335
Dolomite, light yellow-gray, some blue-gray; in sand with much blue argillaceous powder	345
Dolomite, or magnesian limestone, gray, moderately slow response, with blue argillaceous powder	355
No samples	355–650
Devonian and Niagaran (see record of well no. 2):	
"Shale, green"	355–395
Niagaran:	
"Lime"	395–570
Ordovician:	
Maquoketa (145 feet thick; top 235 feet above sea level)—	
"Shale, light blue"	570–600
Dolomite, or magnesian limestone, dark blue-gray, crystalline-granular, soft, labelled "washed from blue shale"	650
Galena-Platteville—	
Dolomite, buff, in fine sparkling sand; no quartz, "About 10 feet of sand at 750 feet, water raised to 180 feet of top"	750
Dolomite, brown, in sand and chips, rather slow, some cryptocrystalline silica, and a very little quartz sand	760
Dolomite, gray, soft, earthy, argillaceous, fine crystalline-granular, in chips, sample washed	780
Limestone, light yellow-gray, rapid effervescence; with some darker, rather slow	820
Limestone, gray, soft, earthy, effervescence rapid; limestone, light	

brown, response rather slow; some chips show both colors, effervescing rapidly on one side and rather slowly on the other	834, 842, 850
Dolomite, or magnesian limestone, light brown, compact, crystalline, response rather slow; limestone, light gray, response rapid, in larger chips; 4 samples	858–886
Magnesian limestone, response moderately rapid, light brown, with considerable chert; limestone, whitish, rapid response	896
Limestone, light gray to buff, earthy, response rapid, cherty at 925, 910, 954, 947, 989; large flakes of drab shale at 944 and 964; 7 samples	910–989
Shale, brown, inflammable; limestone, gray, rapid response	994
Limestone, gray, response rapid, in flakes; flakes of green shale	1010, 1020
Limestone, blue-gray, soft, earthy, fossiliferous	1030
Glenwood—	
Shale, drab, inflammable; some light gray limestone	1040
Shale, green, plastic, calcareous	1048
Limestone, blue-gray, rapid response, some flakes of shale	1050
Saint Peter (51 feet thick; top 254 feet below sea level)—	
Sandstone, gray in mass, of clean quartz grains rounded and frosted, up to 1 mm. diameter; some shale	1059
Sandstone, white, fine; 4 samples	1070–1100
Prairie du Chien—	
Shakopee (penetrated 27 feet; top 305 feet below sea level)—	
Dolomite, gray; quartz sand; 3 samples, bottom of well 1137	1110–1130

Driller's Log

	Depth in Feet		Depth in Feet
Glacial drift	0–118	Shale, light blue	570–600
Sandstone	118–132	Limestone	600–695
Broken shale and lime	132–152	Shale	695–715
Shale and limestone	152–162	Lime	715–1047
Limestone	162–348	St. Peter sandstone	1047–1097
Green shale	348–395	Lime to bottom	1097–1137
Lime	395–570		

WELL OF THE STATE SANATORIUM, OAKDALE, 1928

This well was drilled 16 feet from the well of 1919 and the curbs are at practically the same elevation, 805 feet above sea level. The depth is 1754 feet and 10 inches. The diameters are from 15 to 10 inches. The main supply was found in and below the Jordan sandstone (driller's log). No report of water from higher horizons has been made. Under a sixty hour test the well maintained a discharge of 370 g.p.m. The static level is 117 feet (688 feet above sea level), with a draw down to 126 feet. The well is cased with 164 feet of 20 inch pipe to 164 feet, 350 feet of 16 inch pipe from the surface into the Niagaran limestone, 223 feet of 12 inch pipe from 325 feet to 548 feet and 591 feet of 10 inch pipe from 548 feet to 1140 feet, footing in the Shakopee; thus cutting out all water above that formation.

The static level, 688 feet, of Jordan water may be compared with that of the Saint Peter water in 1919 in the well of Oakdale sunk that year, which then stood at 678 feet. It may also be compared with the original head of the lower water beds at Cedar Rapids, which in 1888 stood at 761 feet above sea level, and with static level of the West Liberty wells, which in 1888 was 705 feet above sea level, from the Jordan water beds, and the head three years later of the well at Wilton, 684 feet, from the Saint Peter.

The Oakdale well was drilled by Thorpe Bros. Well Co. of Des Moines.

*Chemical analysis of water of Oakdale Sanatorium well, 1928**

	Parts per million	Grains per gallon
Sodium	155.4	
Magnesium	49.0	
Calcium	113.8	
Iron	0.1	
Ammonia	0.2	
Carbonate (CO_3)	0.0	
Bicarbonate (HCO_3)	266.0	
Sulphate (SO_4)	498.0	
Chlorine (Cl)	42.0	
Nitrate (NO_3)	0.1	
Silica (SiO_2)	14.9	
Hypothetical Combinations		
Sodium nitrate	0.138	0.008
Sodium chloride	69.287	4.05
Sodium sulphate	395.523	23.13
Ammonium sulphate	0.732	0.04
Magnesium sulphate	242.591	14.18
Calcium sulphate	51.667	3.02
Calcium bicarbonate	246.195	14.39
Ferrous bicarbonate	0.031	0.002
Silica	14.9	.87
Total	1021.164	59.69

Record of strata, State Sanatorium well, 1928

	Depth in Feet
Pleistocene and Recent (164 feet thick; top 805 feet above sea level):	
Sample no. 1 yellow till	
Sample no. 2 blue till	
Sample no. 3 sand, fine, dark gray, mostly of clear quartz, but many of dark minerals, a few greenish and pink, and of limestone, grains irregular	
Sample no. 4 sand, coarse, and gravel up to 1 cm. diameter, blackish diorite, etc., common.	
Devonian, Cedar Valley (84 feet thick; top 641 feet above sea level):	
Limestone, yellow-gray, fossiliferous, encrinital, earthy, rapid effervescence in cold dilute hydrochoric acid, in large flaky chips, same as sample no. 5	164–175

* Done under supervision of Prof. Jack J. Hinman, Laboratories of State Board of Health, Iowa City.

Limestone, blue-gray, speckled dark, fossiliferous, encrinital, effervescence rapid; nodule of blue chert with white rim, large chips	181
Limestone, gray and brown, in small chips, limestone gray with dark crusts, fossiliferous, encrinital, rapid reaction in large chips	181–190
Shale, blue-gray, calcareous, response rapid, laminated, pyritic, in large flakes	190–200
No sample, "light blue shale" of log	200–210
Limestone, light gray, some speckled, fossiliferous, crushes to powder similar to cuttings at 215 feet in well of '19	210–220
Limestone, buff-gray, crystalline-earthy, rapid reaction, speckled in sand, some chips fossiliferous	220–230
Limestone, gray, earthy, rapid effervescence, soft, sample taken at 240 feet	230–240
Limestone, buff-gray, earthy, argillaceous, effervescence rapid, speckled, highly fossiliferous	242–244
Devonian, Wapsipinicon (100 feet thick; top 557 feet above sea level):	
Limestone, dark gray, crystalline-earthy, texture of Upper Davenport beds, rapid response, fossiliferous, some chips a fine coquina	248–260
Limestone, light yellow-gray, calcilutite, conchoidal fracture, rapid reaction; some dark gray, macrocrystalline-earthy, and fine crystalline mottled, pyritic; 2 samples	260–275
Limestone, magnesian, or dolomite, dark gray, fine crystalline, in clean small chips; limestone, fine crystalline-earthy, light gray, rather rapid effervescence	275–285
Limestone, magnesian, or dolomite, light cream yellow, fine crystalline-granular, in minute chips with highly argillaceous powder of same, effervescence at first rapid, then slow. "White mud" of log	285–290
Limestone, light cream-yellow, very fine grain, disintegrating under weak acid under rather slow effervescence into large whitish argillaceous residue; some of same color,rapid reaction	290–298
Shale, light blue-gray, plastic, in concreted masses, with a little argillaceous limestone; gray limestone rapid in reaction	300–305
Limestone, light gray, moderately slow, response markedly less slow than LeClaire, in small chips; limestone, light yellow-gray of rapid response; limestone, larger chips, blue-gray, mottled, crystalline, rapid reaction	305–308
Limestone, magnesian, or dolomite, dark gray, reaction less slow than LeClaire, fine crystalline, some saccharoidal, moderately large argillaceous residue slightly quartzose	308–315
Limestone, magnesian, or dolomite, blue-gray, moderately slow effervescence, some rapid; some yellowish flint	315–325
Dolomite, gray, cryptocrystalline, nonargillaceous, effervescence slow as LeClaire, very slight quartzose residue	325–328
Shale, light greenish gray, in friable masses, calcareous, somewhat arenaceous with fine grains of clear quartz, many of which are well rounded; (cuttings from below show a light green-gray unctuous noncalcareous shale, arenaceous, apparently caved from this horizon); white chert pyritic; much gray dolomite	330–348
Silurian:	
Niagaran (162 feet thick; top 457 feet above sea level)—	
Dolomite, light gray. and blue-gray; 4 samples	348–380
Dolomite, drab, highly argillaceous	380–390
Dolomite, light yellow-gray	385–398
Shale, whitish, calcareous, microscopically quartzose	398–404
Dolomite, light yellow-gray	404–415
Dolomite, whitish, much powder	415–425
Dolomite, light blue-gray in mass; 7 samples	425–500
No cuttings	500–510
Ordovician:	
Maquoketa (190 feet thick; top 295 feet above sea level)—	
Shale, light blue-gray, plastic; 2 samples	510–545

Dolomite, crystalline, dark blue-gray; 2 samples	546–570
Shale, light blue-gray	570–575
Dolomite, drab	575–585
Dolomite, blue-gray, earthy, cherty, argillaceous; 3 samples	585–615
Dolomite, buff-gray, earthy, in flaky chips	615–620
No sample, ''sandy gray shale'' of log	620–628
Shale, light blue-gray, not arenaceous, but microscopic grains of cryptocrystalline quartz in residue	628–638
Dolomite, gray, earthy	638–645
No sample, ''dark shale'' of log	645–652
Shale, light blue-gray; 2 samples	652–668
Shale, drab	680–700
Galena-Platteville (350 feet thick; top 105 feet above sea level)—	
Dolomite, buff, hard, crystalline; 2 samples	700–725
Dolomite, as above, with rare flakes, slightly inflammable	725–730
No samples, ''hard lime'' of log	730–740
Shale, light blue-gray, calcareous, plastic	740–755
Dolomite, light buff, rough, vesicular, in rather large chips, clean; 3 samples	755–775
Limestone, light yellow-gray and buff, crystalline-earthy, in flakes and powder, rapid effervescence; 5 samples	775–835
Dolomite, gray-buff, crystalline, in small chips	835–870
Limestone, light yellow-gray, reaction moderately rapid; very light gray, rapid; a little buff dolomite	870–890
Limestone, light yellow-gray, rapid effervescence	890–902
Limestone, light buff-gray, rapid response	902–908
No samples, as below, according to log	908–918
Limestone, buff-gray, response moderately rapid and rapid, no quartz sand	918–930
Limestone, magnesian, or dolomite, with nonmagnesian limestones, in sand, cherty at 940–950; 4 samples	930–970
Limestone, whitish, soft, rapid effervescence	970–980
Limestone, light yellow gray, rapid response, in sand and powder; 4 samples	980–1020
Limestone, brownish, reaction rapid, inflammable, some chips highly inflammable	1020–1038
Shale, green-gray, calcareous	1038–1040
Limestone, very light yellow-gray, much powder	1040–1050
Glenwood (20 feet thick; top 245 feet below sea level)—	
Shale, green, calcareous, pyritic	1050–1058
Limestone, light gray and mottled darker, rapid effervescence	1058–1060
Shale, green, plastic; some chocolate brown, inflammable	1060–1070
Saint Peter (32 feet thick; top 265 feet below sea level)—	
Sandstone, rusted buff, Saint Peter facies, larger grains about 1 mm. diameter; some flakes of hard green noncalcareous shale (from above?) no flint or chert	1070–1080
Sandstone, light yellow in mass, finer than above, individual grains mostly clear uncolored quartz	1080–1100
Sandstone, white, medium to fine	1100–1102
Prairie du Chien (428 feet thick; top 297 feet below sea level)—	
Shakopee dolomite (168 feet thick)—	
Dolomite, gray, yellow-gray and whitish, cherty 1140-1180, and at 1260; 19 samples	1102–1270
New Richmond sandstone (20 feet thick)—	
Sandstone, light gray, fine to medium, larger well rounded, secondary enlargements common, highly dolomitic, in chips and detached grains	1270–1280
Sandstone, well rounded grains of clear quartz; dolomite, light yellow-gray, in chips, no imbedded grains noted	1280–1290
Oneota dolomite (240 feet thick)—	
Dolomite, light yellow-gray, some quartz sand in cuttings; 2 samples	1290–1310

Dolomite, whitish, a little quartz sand in detached grains; 2 samples 1310–1330
Dolomite, very light gray; 2 samples 1330–1350
Dolomite, light gray and yellow-gray, cherty at 1350, 1380, 1410, 1430-1450, highly cherty at 1390, 1450-1470; 15 samples 1350–1510
Dolomite, purplish, large chips show cavities lined with pearl spar and pyrite, vesicular; imbedded chert 1510–1520
Dolomite, light buff; white chert, some with imbedded grains of quartz sand, some highly pyritic; fine to medium, well rounded grains of quartz sand 1520–1530

Cambrian:

Jordan (30 feet thick; top 715 feet below sea level)—

Sandstone, yellow-gray in mass, fine, many secondary enlargements, dolomitic cement and dolomite with imbedded grains; some white chert 1530–1540
Sandstone, white, grains up to 0.7 mm. diameter, larger grains well rounded; secondary enlargements 1540–1550
Sandstone, white, well rounded, frosted grains up to 1 mm.; some fine pink sandstone with dolomitic matrix in chips 1550–1560

Saint Lawrence—

Trempealeau dolomite of the Saint Lawrence (187 feet thick; top 755 feet below sea level)—

Dolomite, light yellowish and light gray, highly arenaceous with fine fairly well rounded grains of quartz sand, in chips showing imbedded grains closely spaced; some pyritic; 13 samples 1560–1690
Dolomite, gray, slight microscopic residue quartzose and argillaceous; 4 samples 1690–1730
Dolomite, very light gray, residue argillaceous and of minute grains of clear quartz 1730–1747

Franconia beds of the Saint Lawrence (penetrated 8 feet; top 942 feet below sea level)—

Dolomite, pink; large argillaceous residue, with minute quartz grains 1747–1752
"Shale, red" 1752–1755

Notes.—The logs of the two Sanatorium deep wells are not in agreement as to the depth to rock. In that of the well of 1919, 14 feet of "sandstone" rests on "broken shale and lime" at 132 feet. In that of the well of 1928 42 feet of "quicksand" rests on "lime" at 164 feet. Such rapid changes in level in the preglacial rock surface are not unknown in this area, but in this case the log of well 1919 seems to be in error, as it is not supported by the cuttings, which from 135 to 155 feet are of yellowish sedimentary clay, entirely free of limestone and palpable grit. The log also gives "sandstone" from 118 to 132 feet, while cuttings from 125 feet are glacial till.

The log of well 1928 agrees here with the cuttings of well 1919, if we interpret the "blue mud" from 60 to 122 feet as blue till. The cuttings of the last well show a succession downward of yellow till, blue till, and sand, fine and coarse, but the depth of these cuttings is not given. The first recorded depth is that of limestone at 164 feet and with this the log specifically agrees, and this is therefore taken as the thickness of the Pleistocene at Oakdale.

The clay of the cuttings of the well of 1919 from 135 to 155 feet is not represented in the well of 1928 in either cuttings or log.

In interpreting the Devonian portion of this geological section, it will be remembered that in outcrops in Johnson and neighboring counties to the north and east the Cedar Valley limestones rest on an assemblage of beds, the Wapsipinicon, which where fully developed consists of the following members:[61]

5 Upper Davenport limestone
4 Lower Davenport limestone
3 Kenwood, or Independence, shales
2 Otis limestone
1 Bertram beds

Number 1, found only in eastern Linn county, and the lower part of no. 2 are dolomitized. Number 2 and no. 4 are lithologically characterized by beds of calcilutite of lithographic fineness, while no. 2 embraces also a wide variety of other types of limestone. Number 2 is in places fossiliferous and no. 5 is universally highly fossiliferous. No fossils are to be expected in nos. 1 and 4. Number 3 is unfossiliferous, except in two or three outcrops of uncertain stratigraphic relations.

As the Wapsipinicon, we may assume, was laid on a subsiding erosion surface, we may expect to find the full succession of its beds only on the lower levels of that surface. The dolomitization of the strata also may be variable in vertical extent. In the cuttings of deep wells a difficulty is encountered in distinguishing the dolomitized beds of the Wapsipinicon from the Silurian dolomites which they overlie.

Interpreting the cuttings of the two Sanatorium wells at Oakdale and that of the University well at Iowa City in accordance with the sequence of Devonian strata in the nearby outcrops, we assign to the Cedar Valley limestone the beds above 235 feet in the Oakdale well of 1919, above 248 feet in the Oakdale well of 1928 and above 65 feet in the University well.

At this point a thin bed of highly fossiliferous limestone, with

61 Norton, Wapsipinicon Breccias of Iowa: Iowa Geol. Survey, vol. XXVII, pp. 370-433.

the facies of the Upper Davenport limestone in the Oakdale well of 1928, overlies in all three wells a bed of yellowish calcilutite of conchoidal fracture. The fossiliferous bed can not be lower than the Upper Davenport, while the calcilutite can not be higher than the Lower Davenport, and to these formations they are referred with some confidence. The underlying Kenwood is represented pretty clearly by first a light yellowish argillaceous limestone or calcareous shale, powdered by the drill, at 265 feet in the Oakdale well of 1919, at 285 feet in the Oakdale well of 1928, and at 110 feet in the well of the University. In one respect these cuttings differ from the typical Kenwood shale; they are dolomitized, as shown by a slow effervescence in cold dilute HCl, after a first rapid effervescence due to intermingling with the cuttings of powdered limestone from above. In their magnesian content these light yellowish argillaceous beds are like the lower dolomitized beds of the Otis.

In each of the three wells these argillaceous beds, crushing to powder under the drill, are underlain by beds represented by chip cuttings of argillaceous limestones, mostly magnesian or dolomitic. Some of these are peculiar in texture and as at 285 and 295 feet in Oakdale well of 1919, can be exactly matched at outcrops of the Otis, as at Cedar Rapids. In the University well, also, chips from 120 to 130 feet might have been taken from outcrops of the Otis in Cedar county.

These limestones rest in all the three well sections on green shale (Oakdale 1919, at 335 feet; Oakdale 1928, at 330 feet; University, at 201 feet).

The concreted masses of the shale are calcareous, but bits of green shale found in cuttings a few feet below apparently caved from this bed, are unctuous and noncalcareous. The shale also is sparingly arenaceous with fine rounded grains of clear quartz. It rests on the Niagaran dolomite.

Several placings of this shale are possible. With the shales above it and included argillaceous limestones it may be referred to the chief shale horizon of the Wapsipinicon, the Kenwood. Moreover, in places the Kenwood is finely arenaceous, like this shale, and with rounded grains.

Again, recalling the fact that the Otis develops in some of its outcrops shaly partings, it is possible that here it has developed a bed of shale of considerable thickness. And since the stratigraphic place of the fossiliferous Independence shale is uncertain, its outcrops without discernible floor or cover in the midst of deformed Devonian strata permitting the theory of upthrust from below, or that of valley fill, the shale in question may be regarded as a possible Independence shale from below the horizon of the Otis. However, no basal shales occur where the Wapsipinicon is most fully developed, and the Siluro-Devonian contacts in Iowa show Otis limestones or dolomites in contact with the Niagaran.

It may also be suggested that the shale in question is a cavern fill in the Niagaran, such as are found at a number of points over the outcrop both of the Hopkinton and Gower limestones of that terrane. In favor of this reference is the three foot layer of dolomite, indistinguishable from the LeClaire phase of the Gower, which overlies the shale in the Oakdale well of 1928. The clays of cavern fills in the Niagaran are commonly whitish, and while quartzose, the quartz, at least in clay pockets at Mount Vernon and at Clinton, is in highly irregular particles and in a deposit near Miles according to Galpin,[62] in quartz fragments and crystals. Moreover, the occurrence of the shale both at Iowa City and at Oakdale makes in favor of a somewhat widespread deposit and against a local cavern fill. The heavy cover of Devonian limestones does not favor a Niagaran pocket fill in post-Devonian time, but does not preclude a fill before or at the beginning here of Devonian sedimentation.

On the whole, the writer is rather inclined to draw the Kenwood, or Independence, shale to include all the shales with the interbedded limestones, from 285 feet in the last Oakdale well down to the Niagaran limestone at 348 feet, and to assume that here the Otis limestones were not laid.

In the section at the Oakdale well of 1928 the thickness assigned to the Niagaran, 162 feet, shows a notable thinning to the south from Cedar Rapids, where it is about twice as thick. The Niagaran continues to thin farther southward, as at Washington it measures but 29 feet.

62 Galpin, S. L., Refractory Shales of Iowa: Iowa Geol. Survey, vol. XXXI, pp. 59-61.

The Maquoketa continues here in full force from its outcrops and well sections to the north and east. It includes considerable impure drab and blue-gray earthy dolomite, chiefly in a median body about 50 feet thick. It is probable that these washed samples of dolomitic chips represent considerable interbedded shale.

The light blue plastic shale at 740 feet has quite the facies of the Maquoketa. It is included here with the Galena, since the 35 feet of dolomite which overlies it is typically Galena, and at Iowa City the shale at this level has thinned to but 5 feet according to the driller's log.

The Galena-Platteville ranges as usual from a rough vesicular dolomite to light gray earthy limestones. Near the base occurs a bed of brownish inflammable *limestone,* taking the place of the brown bituminous shale characteristic of this horizon. In the cuttings of the Glenwood green shale are also found flakes of brown inflammable shale which may come from the upper horizon, although not found in the bailing taken to represent it.

The Saint Peter presents no abnormal lithologic feature. Rather strangely the elevation of the top differs by about 20 feet in the two Oakdale wells. If the shale of the University well struck at 156 feet below sea level is the Glenwood, the Saint Peter probably lies about 100 feet higher at Iowa City than at Oakdale, and we have another illustration of the wide margin of error to be reckoned with in forecasting for any locality the depth to this rather irregular formation.* Yet the tops of the formations above the Glenwood shale are about on the level at the two stations, as might be expected from their strike. The top of the Saint Peter is abnormally high compared with Cedar Rapids and West Liberty.

	Oakdale 1928 well	Iowa City	Cedar Rapids Y.M.C.A.
	Elevation in feet above sea level		
Top of Niagaran	457	467	638
Top of Maquoketa	295	312	289
Top of Galena-Platteville	105	119	13
Top of Glenwood	–245	–156(?)	......
Top of St. Peter	–265		–292

In the Prairie du Chien the New Richmond horizon is well

* A note from the drillers stating that the drill "started to penetrate sandstone at 840 feet" confirms the inference as to the Glenwood shale.

marked. The Jordan sandstone is perhaps more closely defined by the log than by the sample cuttings.

The Trempealeau dolomite is in great force and may be compared with the sub-Jordan dolomites 230 feet thick in the Grinnell section, 110 feet of which is assigned to the Trempealeau, while the remainder is placed with the Franconia because of the presence of glauconite.

Driller's log, State Sanatorium, Oakdale, 1928

	Depth in Feet
Surface soil and clay	0–60
Mud, blue	60–122
Quicksand	122–136
Quicksand	136–164
Lime	164–178
Blue shale	178–181
Lime, white	181–190
Broken lime	190–197
Light blue shale, caves	197–200
Light lime	200–219
Shale	219–222
Broken lime	222–242
Shale, caves	242–248
Gray lime	248–285
White mud	285–290
Broken lime	290–298
Light shale	298–305
Limerock	305–308
Flinty sandstone	308–330
Green mud	330–348
Sandy lime	348–358
Limerock	358–360
Broken lime	360–375
Sandy lime	375–385
White mud	385–389
Hard lime	389–398
White slate	398–404
Lime	404–415
Hard lime	416–425
White muddy shale	425–430
Lime	430–475
Hard lime	475–485
Lime	485–500
Hard lime	500–510
Shale	510–545
Lime	545–550
Sandy shale	550–570
Blue mud	570–575
Lime	575–585
White shale	585–600
Sandy shale	600–608
Lime	608–615
Shaly lime	615–620
Sandy gray shale	620–638
Lime	638–645
Dark shale	645–670
Hard lime	670–675
Dark shale	675–705
Hard lime	705–740
Dark shale	740–755
Gray lime	755–815
White lime	815–820
Flinty lime	820–835
Hard brown lime	835–870
Gray lime	870–890
Hard gray lime	890–902
Hard brown lime	902–908
Very hard gray sandy lime	908–930
Lime rock	930–950
Lime rock, very hard	950–970
Lime rock	970–980
Lime rock, hard	980–1000
Shale and rock	1000–1010
Shale	1010–1020
Lime rock	1020–1030
Shale and rock	1030–1040
Lime rock	1040–1050
Shale	1050–1058
Lime rock	1058–1060
Brown shale	1060–1070
Saint Peter sandstone	1070–1102
Blue lime	1102–1112
Blue lime, very hard	1113–1117
Gray lime, very hard	1117–1128
Gray lime, not so hard	1128–1140
Gray lime, hard	1140–1150
Hard sandy lime	1150–1180
Gray lime	1180–1200
Gray lime, very hard	1200–1250
Gray sandy lime	1250–1275
Gray lime	1275–1300
Gray sandy lime	1300–1340
Gray lime, not so hard	1340–1360
Sandy lime	1360–1375
Hard gray lime	1375–1400
Hard brown lime	1400–1430
Gray lime, very hard	1430–1460
Gray sandy lime, hard	1460–1475
Gray sandy lime, very hard	1475–1512
Broken lime	1512–1534
Sandstone (some water), Jordan	1534–1550

Limestone	1550–1555
Broken limestone, cavy (some water)	1555–1565
Sandy limestone	1565–1580
Sandy limestone, very hard	1580–1670
Sandstone (some water)	1670–1680
Lime and sandrock, very hard	1680–1700
Lime, with crevices, very hard (some water)	1700–1747
Pink limestone	1747–1752
Red shale	1752–1754 10 in.

Mineral Content of Sanatorium well, Oakdale, 1928*

	P.P.M.
Bicarbonate	312.3
Chloride	26.
Sulphate	258.8
Silica	15.8
$Fe_2O_3+Al_2O_3$	6.8
Calcium	97.5
Magnesium	39.1
Na + K as Na	72.8
Total solids	672.9

OAKLAND, POTTAWATTAMIE COUNTY

(Altitude 1102 feet)

The city well, drilled by the Thorpe Brothers Well Company of Des Moines, is 1936 feet in depth and its diameters are from 16 to 7 inches. The well is cased with 16 inch pipe to 65 feet, 12 inch to 460 feet, 10 inch to 960 feet, 8 inch to 1090 feet, 7 inch to 1608, and 5 inch to the bottom.

No water except seep was found until the depth of 1840 feet was reached where for 30 feet cuttings were washed away. Water was found in this bed of creviced dolomite from 1840 to 1925 feet. The static level is 92 feet from the surface and at the final test pumping at the rate of 150 gallons per minute produced a draw down of 66 feet with the cylinder at 230 feet. The cost of the well was $16,875.

Driller's log and Record of strata

	Depth in Feet
Pleistocene and Recent (62 feet thick; top 1102 feet above sea level):	
"Sandy clay"	0–10
"Sand"	10–35
"Sandy clay"	35–62
Pennsylvanian:	
Missouri series (393 feet thick)—	
"Lime rock and shale"	62–455
Des Moines series (635 feet thick)—	
"Shale with streaks of sandstone"	445–1090
Mississippian and other formations (top 12 feet above sea level):	

* Analysis by Dr. Harry F. Lewis, Chemical Laboratory, Cornell College, Mount Vernon, 1927.

"Limestone"	1090–1486
Limestone, light yellow-gray and light blue-gray, rapid effervescence in cold dilute HCl; flakes and poorly rounded grains of limpid quartz; whitish cryptocrystalline silica; cuttings in sand and powder	1130
Limestone, gray, rapid effervescence	1140
Limestone, gray, fine grained, rapid effervescence, buff, moderately rapid; a little blue shale in minute chips, siliceous with irregular grains and minute particles of clear quartz and cryptocrystalline silica	1150
Limestone, blue-gray, effervescence moderately rapid; white, crystalline, rapid reaction, fine-grained; a little shale	1160
Shale, greenish, calcareous; limestone, effervescence rapid, blue-gray; chalcedony and clear quartz; a little brown shale	1170
Limestone as above; silica as above; a little shale	1180
Limestone, blue and brownish gray, effervescence moderately rapid, argillaceous; dark flint, chalcedony; 3 samples	1190–1210
Limestone, light brown, hard, siliceous, response slow; some rapid; silica as above	1220
Limestone, as above; some green shale; pyrite	1230
Shale, greenish, calcareous, in chips	1240
Limestone, light gray, response rapid; shale in minute chips; whitish silica; pyrite	1250
Limestone, gray, rapid reaction; white silica; black fissile shale at 1260 and 1280; 3 samples	1260–1280
Shale, drab; white chalcedonic silica; limestone, gray	1290
Shale, dark drab, fissile	1300
Shale, as above; limestone	1310
Limestone, response rapid; chert; chalcedonic silica; shale; pyrite	1320
Shale, blue	1330
Limestone, buff, in sand; chips of shale	1340
Shale and limestone, light buff, in fine sand; limpid quartz and cryptocrystalline silica	1350, 1360
Shale, blue, in powder; some limestone and cryptocrystalline silica; 3 samples	1370–1400
Limestone, buff, moderately rapid reaction; much cryptocrystalline silica in minute flakes and crystalline quartz in microscopic particles	1410
Sandstone, fine, grains imperfectly rounded	1420
Shale, blue, in chips	1430
Limestone, effervescence rapid, buff; cryptocrystalline silica and quartz	1440–1450
Limestone, light yellow-gray, rapid response; a little silica as above	1460
Shale, blue, in fine sand	1463–1467
Limestone, light buff, effervescence rapid; sandstone; some shale	1470
Limestone, light buff, slow effervescence	1480
Driller's log; "shale (Kinderhook?)"	1486–1583
Limestone, light buff, some slow, some rapid reaction; chalcedony and quartz sand; shale in powder and chips	1500
Shale, light blue, calcareous; 2d sample at	1500
Shale, blue, calcareous; 4 samples	1510–1540
Limestone, light yellow-gray, effervescence rapid; some chips of shale	1550
Limestone, as above; shale, blue, some bright green	1560
Limestone, as above, in flaky chips, earthy	1570
Limestone, as above, in small chips	1580
Limestone, gray, some whitish, rapid effervescence	1590, 1600
Dolomite, light blue-gray, crystalline	1610
Limestone, light buff and whitish, effervescence rapid, called "hard" by driller	1620
Limestone, buff, in fine sand, some rapid effervescence, some darker and rather slow, considerable residue of quartzose microscopic particles and some grains of limpid quartz; blue shale, pyrite	1630
Limestone, gray, reaction moderately rapid, "hard"	1640
Limestone, blue-gray, moderately slow reaction, argillaceous	1650

Limestone and shale, limestone brown, moderately slow reaction	1660
Shale and limestone, blue-gray, reaction slow; at 1680 also white and gray cryptocrystalline silica and microscopic quartz particles	1670, 1680
Dolomite, light blue and gray, cuttings in fine sand and flour, much chalcedonic silica and some fine quartz sand; 3 samples	1690–1710
Shale, blue-gray, with dolomite and silica as above	1720
Silica, white, chalcedonic; whitish limestone of rapid effervescence; fine quartz sand; all in powder and sand	1730
Shale, light blue-gray, siliceous as above, calcareous	1740
Dolomite, in powder and fine meal; shale, light blue-gray, in powder, quartzose	1750
Dolomite, gray, in fine crystalline sand; cuttings blue-gray in mass from argillaceous powder	1760
Dolomite, buff and gray, in fine crystalline sand; 6 samples	1770–1820
Dolomite, light yellow-gray; some flakes of blackish fossiliferous shale, inflammable, similar in appearance to that at 1280	1830, 1840
No samples, ''drillings washed away''	1840–1870
Dolomite, subcrystalline, light yellowish and light brownish gray, in chips; some shale as above	1870
Dolomite, and some magnesian limestone of rather slow effervescence; light yellow-gray; considerable calcite	1927
Dolomite, light buff, in clean fine meal	1932

Notes.—The floor of the Coal Measures, placed by the above interpretation of the driller's log at 12 feet above sea level, is in accord with the elevation of this floor at points north, east and south where it has been reached. About 25 miles to the west in the Council Bluffs-Omaha area the altitude at the floor as defined by the summit of heavy limestones referred to the Mississippian stands 550 feet above sea level, indicating a rather sharp upwarp toward the west, if not faulting.

The Oakland well reaches a depth of 730 feet below sea level. No evidence of the Saint Peter sandstone or of its superincumbent shales is found in the cuttings and the sandstone probably lies 200 or 300 feet below the bottom of the well. The dolomites in which the well foots may be referred to the Galena with some probability.

OELWEIN

(*Altitude 1042 feet*)

WELL OF CHICAGO GREAT WESTERN RAILWAY COMPANY

This well, completed in July, 1919, was drilled by F. M. Gray, Jr., of Milwaukee. The depth is 1382 feet; the diameters are 12 inches to 397 feet, 9 inches to 950 feet, and 7 inches to bottom.

Water was found in the Saint Peter sandstone to the amount of 40 gallons per minute. The final tests, however, showed a capacity of at least 250 gallons per minute.

During the drilling of the well the static level remained stationary at about 18 feet below the surface, a fact which led to the opinion that little water had been found. A month afterwards the water had sunk to about 100 feet from the surface and when after various delays the pumping test was made in October the head was found at 200 feet below the surface.

Record of strata of well of Chicago Great Western Railroad Company

	DEPTH IN FEET
Pleistocene and Recent (57 feet thick; top 1036 feet above sea level):	
Sand and gravel, yellow	0–57
Silurian:	
Niagaran limestone (108 feet thick, top 979 feet above sea level)—	
Dolomite, light buff, in fine sand and chips; 12 samples	57–130
Limestone, magnesian, or dolomite, light gray, crystalline, moderately slow effervescence in cold dilute HCl	130–145
Dolomite, buff and gray, cherty	145–165
Ordovician:	
Maquoketa shale (215 feet thick; top 871 feet above sea level)—	
Shale, blue, plastic, sample taken at 290	165–325
Limestone, gray, moderately rapid effervescence, fine-grained	325–365
Shale, blue-gray, in concreted masses	365–380
Galena and Platteville limestones (405 feet thick; top 656 feet above sea level)—	
Limestone, buff and light gray, fine-grained, moderate effervescence; and gray, rapid effervescence, in chips an dsand	380–510
Shale, light brownish gray, in concreted masses	437–439
Limestone, light gray, in powder, argillaceous, rapid effervescence	510–720
Shale, green, hard, fissile	702–703
Limestone, light gray, rapid effervescence	720–785
Saint Peter sandstone (75 feet thick; top 251 feet above sea level)—	
Sandstone, white, rounded grains; 2 samples	785–860
Prairie du Chien (380 feet thick, top 176 feet above sea level)—	
Dolomite, gray, cherty	860–881
Shale, green-gray	881–887
Dolomite, in fine crystalline sand, much quartz sand in cuttings and some shale	887–950
Dolomite, white and gray, sparse imbedded grains of quartz, some plastic blue shale	955
Dolomite, light buff	980
Shale, blue-gray, iu concreted masses with some quartzose marl	995–1002
Shale, blue-gray, in concreted masses	1002–1025
Sandstone, fine, rounded grains of clear quartz, dolomite and shale in cuttings (New Richmond ?)	1025–1037
Dolomite, gray, cherty	1037–1105
Dolomite, with much shale	1105–1145
Dolomite, gray, cherty	1145–1195
Dolomite, gray and white; 2 samples	1195–1240
Cambrian:	
Jordan sandstone (77 feet thick; top 204 feet below sea level)—	
Sandstone, fine-grained, with considerable dolomite in cuttings	1240–1265
Sandstone, in fine rounded grains	1265–1295
Sandstone, as above, with calcareo-argillaceous powder	1295–1317
Saint Lawrence (Trempealeau dolomite) (top 281 feet below sea level)—	
Dolomite, in fine crystalline sand with some argillaceous residue	1317

CITY WELL, OELWEIN

This well was drilled by the Bert Sharff Drilling Co. of Oelwein in 1924. The depth is 1316 feet and the diameters are from 12 to 8 inches. The only water found, so far as reported, was at 140 feet in the Niagaran limestone. Both the Saint Peter and the Jordan sandstones are stated to be hard and dry. The static level stands at 30 feet. Tests showed a capacity of only 90 gallons per minute and the well was never put into operation. Twelve inch casing was inserted to a depth of 37 feet and 248 feet of 8⅝ inch pipe were inserted from 152 to 400 feet to case out the Maquoketa shale. The cost of the well is stated to have been $10,000.

Since this well hole is entirely useless in its present condition it would seem quite worth while to experiment with a charge or charges of dynamite to see if deep lying water channels can not be opened up. In the well of the Chicago Great Western Railroad just described the deeper waters at first failed to find access to the tube and the water held the static level of the Drift and Niagaran waters. At last the deeper channels opened up without artificial aid and the static level fell accordingly, but in the severer case of the city well an operation is indicated.

Driller's log of City well, Oelwein (from blue print)

	Depth in Feet
Clay	0–38
Lime (Niagaran)	38–165
Shale (Maquoketa)	165–352
Limestone (Maquoketa)	352–373
Shale, blue (Maquoketa)	373–390
Limestone (Galena-Platteville)	390–435
Shale, brown (Galena-Platteville)	435–443
Limestone (Galena-Platteville)	443–739
Shale (Glenwood)	739–745
Sandstone (Saint Peter) hard and dry	745–795
Limestone (Shakopee)	795–864
Sandstone (New Richmond)	864–875
Limestone, very hard (Oneota)	875–1179
Shale, green	1179–1185
Sandstone, hard and dry (Jordan)	1185–1290
Limestone (Trempealeau)	1290–1316

OGDEN, BOONE COUNTY

(Altitude 1097 feet)

CITY WELL NO. 2

In 1929 a second well, 2852 feet deep, was completed for the city of Ogden by the Thorpe Brothers Well Company of Des Moines. The principal supply was found near the bottom, in the

Dresbach sandstone. Only small amounts were found above this stratum and these were cased out. The pumping capacity on completion was tested to 150 g.p.m., with a draw down from the static level of 163 feet below the surface to 297 feet. The well is cased with 16 inch casing to 403 feet, 12 inch to 670 feet, 10 inch to 1313 feet, 8 inch to 1851 feet, 6 inch to 2680 feet and 4½ inch to the bottom.

Record of strata

	Depth in Feet
Pleistocene and Recent (140 feet thick; top 1094 feet above sea level):	
Till, yellow, calcareous, clayey, in hard masses inclosing sand and pebbles of drift	10, 20
Till, gray, as above; 3 samples	30–50
Gravel, with some clay	50–60
Till, yellow, calcareous, with pebbles and sand; 2 samples	60–80
Till, gray, many pebbles	80–90
Till, yellow and orange, highly sandy and pebbly, feebly calcarous; 2 samples	90–110
Till, yellow, highly sandy and pebbly	110–120
Till yellow, clayey, calcareous	120–130
Till, drab, clayey, calcareous	130–140
Pennsylvanian:	
Des Moines (230 feet thick; top 954 feet above sea level)—	
Shale, drab, noncalcareous; 2 samples	140–160
No samples	160–180
Shale, gray and drab, blackish at 200, 220, 240, 250 and 270 feet; 17 samples	180–350
Conglomerate, largest pebbles 15 to 20 mm. diameter, a few rolled pebbles of yellow-gray and red granites and feldspathic rocks, greenstones, quartz, chert or chalcedonic silica, blue-white, with irregular surfaces, some limestones; with sand and powder of shale; 2 samples	350–370
Mississippian (260 feet thick; top 724 feet above sea level):	
Chert, blue-gray and white; some coarse sand	370–380
Chert as above; with much drab shale	380–390
Limestone, gray, rapid effervescence in cold dilute HCl, some soft, macrocrystalline, fossiliferous; some chert, some arkosic grains from above	390–400
Limestone, gray and drab, rapid effervescence, fine crystalline-granular; 10 samples	400–500
Limestone, brownish, tinge of drab, fine crystalline-granular, moderately rapid effervescence; 2 samples	500–520
Limestone, gray, oölitic, moderately rapid effervescence; 3 samples	520–550
Shale (Kinderhook), light blue-gray, calcareous; 6 samples	550–610
Limestone, drab and gray, rapid effervescence	610–620
Shale, light blue-gray, some large chips show lamination	620–630
Devonian (350 feet thick; top 464 feet above sea level):	
Limestone, cream-colored, laminated, in flaky chips, earthy, rapid effervescence	630–640
Limestone, cream and yellow-gray, rapid effervescence, fine-grained; 3 samples	640–670
Limestone, light gray, calcilutite, conchoidal fracture, rapid effervescence, laminated at 700; 4 samples	670–710
Limestone, light yellow gray, fine crystalline-granular, laminated, rapid effervescence; 2 samples	710–730
Limestone, light yellow-gray calcilutite, and blue-gray, crystalline-earthy, rapid effervescence, with powder of drab shale	730–740

Limestone, light yellow-gray, fine crystalline-granular, laminated, rapid effervescence	740–750
Shale, gray with greenish tinge, in tough concreted masses with chips of drab, fine-grained, hard limestone	750–760
Limestone, drab, fine crystalline-granular, hard, slow effervescence, residue highly argillaceous, quartzose with microscopic grains, sparsely arenaceous with minute ill rounded grains of clear quartz; 3 samples	760–790
Dolomite, gray, macrocrystalline and crystalline-granular, rough surfaced chips; 5 samples	790–840
Dolomite, brown-gray, fine-grained, compact; 5 samples	840–890
Dolomite, light buff, disintegrating under acid into fine crystalline sand	890–900
Limestone, light yellow-gray and buff, laminated, rapid effervescence (some slow); 4 samples	900–950
Limestone, buff and light gray mottled brown, rapid effervescence	950–960
Limestone, buff and light gray, slow and rapid effervescence	970–980
Silurian (280 feet thick; top 114 feet above sea level):	
Dolomite, buff and brown, fine crystalline-granular	980–990
Dolomite as above; white grains of gypsum	990–1000
Dolomite as at 980, some limestone of rapid effervescence; 4 samples	1000–1040
Dolomite, blue-gray, some chips of gypseous dolomite, gypsum in white masses; 2 samples	1040–1060
Dolomite, gray, buff and brownish; chips of gypsum, anhydrite and gypseous dolomite; 7 samples	1060-1130
Clay, white, in powder and soft grains; dolomite, light gray and buff, in sand; gypsum considerable at 1130, in small amount at 1150; 3 samples	1130–1160
Dolomite, gray and buff, at 1190 light yellow-gray, soft and earthy; 10 samples	1160–1260
Ordovician:	
Maquoketa (40 feet thick; top 166 feet below sea level)—	
Shale, light greenish gray, some reddish brown, calcareous, unctuous, in hard lumps	1260–1270
Shale, ocher-yellow, calcareous	1270–1280
Shale, as at 1260	1280–1290
Shale, ocher-yellow and terra cotta red, calcareous	1290–1300
Galena-Platteville (484 feet thick; top 206 feet below sea level)—	
Chert, light gray and whitish, a very little dolomite and fine quartz sand in ill rounded grains; 7 samples	1300–1370
Dolomite, gray and buff, cherty; 2 samples	1370–1390
Dolomite, gray	1390–1400
Chert and gray dolomite; 2 samples	1400–1420
Shale, gray, in hard masses, calcareous, not quartzose	1420–1430
Dolomite, light gray and light yellow-gray; gray shale at 1430; 4 samples	1430–1470
Dolomite, light gray; gray chert; 9 samples	1470–1560
Dolomite, light gray and buff, brown-gray at 1660; 14 samples	1560–1690
Dolomite, light yellow-gray, with much gray and blue-gray shale, slightly arenaceous, grains fine and rounded; 4 samples	1690–1730
Limestone, earthy, light yellow-gray, rapid effervescence; 2 samples	1730–1750
Shale, medium dark green, in hard masses concreting chips of limestone as above	1750-1760
Limestone, light yellow-gray and buff, in flaky chips, rapid effervescence; shale from above in dark green noncalcareous splintery flakes; 2 samples	1760–1784
Glenwood shale (6 feet thick; top 690 feet below sea level)—	
Shale, dark green, hard, in noncalcareous chips and concreted masses	1784–1790
Saint Peter sandstone (38 feet thick; top 696 feet below sea level)—	
Sandstone, white, grains rounded and frosted; 4 samples	1790–1828

Prairie du Chien (352 feet thick; top 738 feet below sea level)—
- Dolomite, light gray, crystalline; much hard green shale from above in large flakes; quartz sand 1828–1840
- Sandstone, fine; some dolomite 1840–1850
- Dolomite, white, highly arenaceous, imbedded grains; 2 samples 1850–1870
- Dolomite, light yellow-gray and gray, arenaceous, imbedded grains; 5 samples 1870–1920
- Dolomite, very light gray; shale in concreting powder; quartz sand with secondary enlargements; splintery shale 1920–1930
- Sandstone, white, larger grains about 0.8 mm. in diameter, secondary enlargements; some dolomite; 4 samples 1930–1970
- Dolomite, light buff and gray, cherty at 2010, 2030, arenaceous in places, as 2070, 2080, 2150; much hard shale at 2120; 21 samples 1970–2180

Cambrian:

Jordan sandstone (30 feet thick; top 1086 feet below sea level)—
- Sandstone, white, grains well rounded and frosted, larger grains a little over 0.8 mm. diameter; 2 samples 2180–2200
- Sandstone, as above, finer 2200–2210

Saint Lawrence, Trempealeau beds (100 feet thick; top 1116 feet below sea level)—
- Dolomite, gray, arenaceous at 2240 and 2300, argillaceous at 2260 and 2280; 10 samples 2210–2310

Saint Lawrence, Franconia beds (410 feet thick; top 1216 feet below sea level)—
- Sandstone, light greenish gray in mass, glauconitic, dolomitic, argillaceous, grains minute, some medium, coarser at 2340, with chips of dolomite at 2350; 10 samples 2310–2410
- Sandstone, green-gray, glauconitic, argillaceous, dolomitic, grains minute 2410–2420
- Shale, blue-gray, in concreted masses, glauconitic, dolomitic, minutely arenaceous; flakes of hard drab shale; 2 samples 2430–2450
- Shale, dark olive-green and drab, in flakes 2450–2460
- Sandstone, gray in mass, in detached grains, some 1 mm. in diameter, well rounded, mostly in fine and minute grains, dolomite in chips, blue-gray, glauconitic, highly arenaceous in minute grains 2460–2470
- Dolomite, buff-gray in mass, minutely and finely arenaceous; much quartz sand in detached grains 2470–2480
- Dolomite, gray in mass, in fine sand with much quartz sand in grains from minute to medium 2490–2500
- Shale, blue-green, hard, finely laminated, "paper shale" 2500–2510
- Shale, blue-green, in moulded masses inclosing chips of same 2510–2520
- Shale, reddish and blue-gray, finely laminated, noninflammable; 2 samples 2520–2540
- Shale, red and green 2540–2550
- Shale, blue-gray and olive-green, in thin splintery flakes; some sandstone, dolomitic and glauconitic of minute grains; 5 samples 2550–2600

(This record is completed in the appendix.)

Notes.—The gray, drab and blackish shales underlying the drift are typical of the Des Moines, but the conglomerate or gravel which underlies them is exceptional. It may be compared with the Pennsylvanian sandstone and conglomerate found in troughs eroded in the Mississippian and earlier formations of eastern Iowa, and with the much thicker arkosic sandstones and conglomerate in which the drill stopped at Manson 1200 feet below the surface. The lack of rounding of the pebbles is not inconsistent with the theory of their origin as a land deposit. The presence of some of the pebbles is probably to be accounted for by cave. But it is highly improbable that all or even a large part are due to an extensive downfall from the gravels of the drift, the only other possible source, so accurately timed as to occur at the precise time when the drill had just passed through the shales of the Des Moines. The cherts with irregular surfaces are clearly Mississippian and probably are residual material. Those of the lower of the two samples, however, may belong to rock in place which the drill was entering.

The Mississippian may consist wholly of the Kinderhook limestones and shales, although the upper cherts suggest the Montrose beds. Cherty beds, however, occur in the Kinderhook of this area. The oölitic limestone at 520 feet is characteristic. The shale 80 feet thick at 550 feet is assigned to the Kinderhook shale. At Boone this shale extended from 590 to 630 feet.

The limestones placed with the Devonian permit only the most general reference at best and the lower limit is uncertain.

The gypseous dolomites pretty clearly belong to the Salina group of the Silurian, while the shale beneath them is readily assigned to the Maquoketa, although the ocher-yellow and terra cotta red of the basal layers are quite exceptional. But 25 feet of buff shale is reported by Beyer at this horizon in the deep wells at Boone.

The Galena-Platteville is present in great force, and is dolomitic throughout, except for 50 feet of limestone of "Trenton" facies and shale at base. The heavy beds of chert at top are worthy of note and perhaps should go to the Maquoketa.

The Glenwood shale is given a thickness of but six feet. An entirely similar shale in a thin bed along with limestone occurs about 30 feet higher up and in these transitional strata might possibly be placed with the shale beneath.

Both the Saint Peter and the Jordan sandstones are thin. The Prairie du Chien is divided, as is common, by the sandy beds of the New Richmond, 1930 to 1970 feet.

The Trempealeau and the Franconia beds of the Saint Lawrence are sharply delimited, the latter showing its usual glauconitic, dolomitic and argillaceous sandstones of minute grains and its hard splintery shales.

ORANGE CITY

(Altitude 1471 feet)

CITY DEEP WELL NO. 2

Previous to 1921 the public supply of Orange City had been drawn from a drilled well 215 feet deep, two shallow wells, and a deep well sunk in 1911 to a depth of 562 feet. As these sources became inadequate and unsatisfactory a well 825 feet deep was drilled in 1921 by the Thorpe Brothers Well Company of Des Moines to tap the deeper water beds of the area. On completion the pumping capacity was found to be 110 gallons per minute with the cylinder set 280 feet below the surface. The static level, 200 feet below the curb, is not drawn down by continuous pumping.

The sandstone in which the well ends was considered water bearing as the cuttings were largely washed away. The work was stopped here because of extensive caving of the overlying shales. The diameter had already been reduced to 5 inches and to go on would require pulling 80 feet of casing and reaming. The water is very hard and unsatisfactory for boilers.

Record of strata

	DEPTH IN FEET
Pleistocene and Recent (160 feet thick; top 1412 feet above sea level):	
Till, yellow, clayey, with pebbles	10, 20
Clay, dark buff, plastic, gritty	30
Gravel, with some clay	40
Till, bright yellow, with pebbles	50
Till, darker yellow, with pebbles	60
Sand, yellow, coarse	80, 90
Clay, blackish, fine-grained, in hard concreted masses, gritty with coarse sand consisting largely of chert and limestone	100
Till, brown, pebbly	110
Sand, yellow, rather fine	120
Till, dark buff, clayey, with pebbles	130
Clay, buff, sandy	140
Sand and fine gravel	150
Cretaceous:	
Colorado (330 feet thick; top 1252 feet above sea level)—	
Sandstone, gray, grains ranging widely in size, poorly rounded, mostly of quartz	160
Shale, brownish gray, calcareous, fine-grained, polishing under the finger nail, with sand and pebbles, chiefly of limestone, some of diorite	170
Shale, blue-gray, fine-grained, plastic, calcareous, somewhat gritty with fine sand mostly of quartz	180

Sandstone, as at 160 feet, but coarser, some grains of limestone, some of ferro-magnesian minerals, mostly of clear quartz; some pink and yellow	190, 200
Marl, light yellow-gray, rapid effervescence in cold dilute HCl, in powder concreted to friable masses, clayey, minutely arenaceous	210
Sandstone, very fine, of minute particles of quartz, mostly clear, some red and pink, some ferro-magnesian minerals, calcareous, argillaceous	220
Shale, gray, unctuous, calcareous, somewhat gritty, in hard concreted masses	230
Sandstone, as at 220 but more argillaceous	240
Shale, as at 170	250
Shale, yellow-gray, gritty, somewhat calcareous	260
Shale, as at 170; 3 samples	270–290
Shale, blue-gray, unctuous; 5 samples	300–340
Sandstone, gray, fine, grains imperfectly rounded; 3 samples	350–370
Limestone, rapid effervescence, in chips; shale, hard, calcareous, siliceous	380
Shale, highly pyritiferous and siliceous, in blue-gray powder and small chips	390
Shale, blackish and dark gray, unctuous; 5 samples	400–440
Shale, light gray, soft; dark gray, hard; in small chips, calcareous, siliceous; quartz sand	450
Shale, dark gray, highly siliceous with particles of impure cryptocrystalline silica and some grains of clear quartz	460
Shale, gray, hard, slightly calcareous, siliceous as above	470
Shale, blue-gray, pyritiferous, siliceous as above	480
Dakota (top 920 feet above sea level)—	
Sandstone, gray and yellow-gray, fine and coarser, of clean quartz, grains imperfectly rounded, many larger grains angular and subangular; some coaly shale in cuttings at 570; 20 samples	490–685
(Fragments brought up from 635 to 637 are (1) of limestone, gray-buff, earthy, argillaceous, with black specks, highly siliceous with minute particles of crystalline quartz, and (2) of shale, hard, dark buff, calcareous, with much crystalline quartz in minute imbedded particles, and (3) of sandstone, gray, calcareous, moderately fine, grains imperfectly rounded, mostly of uncolored quartz, some pinkish.	
Fragments from 670 to 672 are (1) a rounded concretionary mass of pyrite; (2) shale, blackish, coaly, burns white, but noninflammable; (3) shale, whitish, consisting largely of particles of cryptocrystalline silica, laminated, speckled with microscopic black grains)	
Shale, greenish yellow, unctuous, noncalcareous	685, 696
(Of the fragment from 692-696 one-half is of whitish limestone of rapid effervescence, crystalline, vesicular, with greenish clay in vesicles, residue argillaceous and with small grains of crystalline quartz)	
Sandstone, gray in mass, and light buff, of grains of clear quartz, widely differing in size, imperfectly rounded; at 750 some grains with bright red and orange stain as if from imbedment in red clay; 7 samples	696–750
Glenwood shale (?) (55 feet thick)—	
Shale, dark red, plastic, in hard concreted mass, highly calcareous, residue of fine quartz sand with rounded grains	745-753
Shale, gray, fine-grained, calcareous, minutely arenaceous, samples in thin mud; 6 samples	753–790
Saint Peter (?) (penetrated 23 feet; top 610 feet above sea level)—	
Sandstone, color in mass gray, moderately fine, but some irregular grains up to 2 mm. in diameter; grains of clear uncolored quartz excepting a few surficially stained pink or yellow.	

Many grains well rounded and frosted, but not so uniformly as the grains of the Saint Peter of eastern sections; some chips of hard dark shale. Sandstone soft, 20 feet drilled in ten hours	802–825

CITY WELL NO. 1

The facts as to this well seem important enough to place on record although it is not now in use. It was completed in 1911 by G. J. Savidge of Sioux City. The depth is 652 feet; diameters are from 8 to 6 inches. Water was found from 410 to 564 feet and also at 300 feet. The capacity of the well was 20 gallons per minute, with the cylinder set at 320 feet. The static level was 225 feet below the surface of the ground.

The following log is made out from a diagram of the well:

Driller's Log

	Depth in Feet
No record	0–300
Rock	300–331
Blue clay	
Sandstone, not much water	412–442
Clay	442–512
Sandstone, white, soft, water	512–562

*Mineral Content of City Well No. 2, Orange City**

	P.P.M.
Bicarbonate	351.4
Chloride	29.
Sulphate	829.0
Silica	10.2
$Fe_2O_3+Al_2O_3$	39.8
Calcium	276.5
Magnesium	97.8
Na + K as Na	153.0
Total solids	1610.0

OTTUMWA

(*Altitude 645 feet*)

WELL NO. 5, JOHN MORRELL AND COMPANY

In 1928 the fifth deep well of this packing company was completed by S. B. Geiger and Co. of Chicago. The depth is 2002 feet and the diameters are from 20 to 10 inches. The principal supply was found at 1803 feet, the horizon of the Jordan sandstone. Water was found also at 150 feet in brown sand of the Mississippian, at 1115 feet in "sand" supposed to be the Galena dolomite, and at 1680 feet in creviced dolomite of the Oneota.

After the drill reached 150 feet the static head never fell below the surface of the ground and on completion it stood at 28 feet above the surface, giving a natural discharge of 1,850 g.p.m. With a surface pump the capacity is 3,000 g.p.m.

* Analysis by Dr. Harry F. Lewis, Chemical Laboratory, Cornell College, Mount Vernon, 1927.

From the top to 218 feet is set an 18 inch pipe and a 12 inch pipe extends from 266 to 706 feet, casing out the Kinderhook shale and some of the overlying strata.

Mineral analysis

Constituent	Grains per U. S. gallon	Constituent	Grains per U. S. gallon
Silica	0.28	Soluble incrusting solids	6.53
Iron and alumina oxides	0.04	Insoluble incrusting solids	15.02
Calcium carbonate	13.10		
Magnesium carbonate	1.60	Total incrusting solids	21.55
Magnesium sulphate	6.53	Hardness	20.50
Sodium sulphate	34.40	Alkalinity	15.00
Sodium chloride	12.10		
Organic and volatile matter	1.27		
Total solids	69.32		

Driller's log of Well no. 5, John Morrell Co., Ottumwa, with assignment to formations

	Depth in Feet
Pleistocene and Recent (20 feet thick, top 643 feet above sea level):	
Clay and quicksand	0–20
Mississippian, undifferentiated (535 feet thick; top 623 feet above sea level):	
Lime shell	20–25
Shale and lime shells	25–90
Sandy shale	90–105
Shale	105–142
Brown sand, water flow	142–150
Lime	150–165
Shale	165–213
Lime	213–280
Shale, cavy about 300 feet	280–315
Lime	315–320
Lime and shale	320–335
Lime	335–555
Kinderhook shale (140 feet thick; top 88 feet above sea level)—	
Shale	555–622
Broken lime	622–667
Shale	667–695
Devonian, and Silurian (?) (75 feet thick; top 52 feet below sea level):	
Lime	695–720
Lime and shale	720–725
Lime	725–770
Ordovician:	
Maquoketa shale (55 feet thick; top 127 feet below sea level)—	
Shale	770–825
Galena-Platteville (417 feet thick; top 182 feet below sea level)—	
Lime	825–835
Shale	835–845
Sandy lime	845–855
Shale	855–870
Lime	870–875
Shale	875–900
Lime	900–955
Sand	955–970
Hard lime	970–993
Blue shale	993–997
Hard creviced lime	997–1010

Lime	1010–1090
Sandy lime	1090–1115
Sand	1115–1120
Sandy lime	1120–1180
Sand	1180–1200
Blue shale	1200–1205
Soft sand	1205–1242
Glenwood shale (10 feet thick; top 599 feet below sea level)—	
Shale	1242–1252
Saint Peter sandstone (43 feet thick; top 609 feet below sea level)—	
White sand	1252–1295
Prairie du Chien—	
Shakopee (185 feet thick; top 652 feet below sea level)—	
Lime	1295–1325
Sandy lime	1325–1480
New Richmond (55 feet thick; top 837 feet below sea level)—	
Sand	1480–1535
Oneota (247 feet thick; top 892 feet below sea level)—	
Sandy lime	1535–1635
Lime	1635–1645
Sandy lime	1645–1655
Sand	1655–1665
Lime	1665–1680
Creviced lime	1680–1730
Sand	1730–1740
Lime	1740–1782
Cambrian:	
Jordan (100 feet thick; top 1139 feet below sea level)—	
Sandy lime	1782–1795
Sandy lime	1795–1803
Big flow	1803–1805
Lime	1805–1845
Sandy lime	1845–1872
Soft sand	1872–1882
Saint Lawrence—	
Trempealeau dolomite of the Saint Lawrence (penetrated 177 feet; top 1239 feet below sea level)—	
Lime	1882–1930
Lime	1930–1982
Sandy	1982–1992
Lime	1992–2002

Notes.—The geologic section at Ottumwa is based on five well logs, none of which is confirmed by any cuttings. There is much diversity among these logs, especially above the horizon of the Saint Peter, so that any interpretation is both difficult and uncertain. The first heavy shale, assigned to the Kinderhook, is reported in the Morrell well no. 5 at 88 feet above sea level and 140 feet thick; in well no. 1, at 123 feet above sea level and 185 feet thick; in well no. 2 at 37 feet above sea level and 102 feet thick. In the well of the Artesian Well Co. the first heavy shale is said to have been found at 219 feet above sea level and to be 160 feet thick.*

* Norton, W. H., Iowa Geol. Survey, vol. XXI, pp. 735-738.

The Maquoketa shale is not represented in the logs of the Artesian Well Co. and of Morrell well no. 1. In the log of the Morrell well no. 4 it appears as heavy shale extending from 137 to 307 feet below sea level, thus including strata assigned to the Galena in the log of well no. 5. The interpretation of well no. 5 is conservative as to the lower limits of the Maquoketa, which perhaps in fact includes some of the upper shaly beds placed with the Galena.

The same conservatism in interpretation limits the Saint Peter to the "white sand" at 609 feet below sea level which is overlain with a shale taken to be the Glenwood. In this and other logs we may discriminate between "white sand" and "sand", "sand rock", "sandy lime", or "limestone mixed with sand". As the latter terms are applied in the Ottumwa logs to beds high up in the Galena as well as to beds near its base they probably are used to designate the crystalline sand to which the Galena dolomite often crushes. This use by drillers is well known, as in the log of the well of the Electro-Metals Co. of Keokuk. On the other hand, if the term "sand" in the above log is consistently interpreted as sandstone, the Glenwood formation becomes of interesting and extraordinary complexity, with a thickness of 397 feet.

The Prairie du Chien is normal, but the horizon of the Jordan sandstone does not show any clear sandstone of considerable thickness, and the assignment is here quite uncertain. The heavy "lime" beginning at 1882 feet is probably the top of the Trempealeau. Well no. 4 of the Morrell Co. extends 203 feet below the footing of well no. 5, but it can not be told from the log whether or not the Eau Claire was reached. At these levels sandstones of microscopic grain cutting into chips are apt to be termed "lime".

OXFORD, JOHNSON COUNTY

(Altitude 736 feet)

In July, 1925, a well 586 feet deep was completed for the town of Oxford (Johnson county) by Chas. D. Nolan of Cedar Rapids. Ten inch casing extends to 156 feet and 8 inch casing "for 145 feet", the remainder of the well being uncased. A flow testing 3 gallons per minute was found at 305 feet in "sand rock". The main flow comes from 450 to 586 feet, probably in Niagaran limestone. The head is 62 feet below the curb and with the cylinder at 125 feet the pumping capacity is 75 gallons per minute. The cost of the well was $3300.

Driller's Log

	Depth in Feet		Depth in Feet
Blue clay and sand	0–156	Rock	290–586
Lime, soapstone and shale	156–290	Shale	586

The driller reports also a second city well drilled at the same time as well no. 1 and 12 feet distant, apparently of the same dimensions, but not so strong a flow.

PLEASANTVILLE, MARION COUNTY

(*Altitude 926 feet*)

A well 1826 feet in depth was drilled in 1920 for the town of Pleasantville by the Thorpe Brothers Well Company of Des Moines.

The well is cased with 10 inch pipe to 135 feet. Eight inch casing reaches from the top to 348 feet, 6 inch casing from 340 to 1460 feet and 4 inch from 1400 feet to the bottom. The casing was perforated from the bottom up for 120 feet, and above the perforations were set two disc and two compression packers, sealing all lines completely from the surface to 1706 feet, and permitting only the water below the latter depth to enter the well.

Water was encountered at 328 feet at the top of the Mississippian with a flow of about 23 gallons per minute and of poor quality. Another water bed was found at the base of the Silurian from 1100 to 1190 feet. The chief water beds, apparently in the Saint Peter, the upper 40 feet of the Shakopee, and the lower 54 feet of the Galena-Platteville, on final test supplied 70 gallons per minute. The static level of this water is 180 feet below the curb.

Driller's log of Pleasantville City well

	Thickness in feet	Depth in feet	Elevation of top above sea level in feet*
Glacial deposits	135	0–135	926
Pennsylvanian shales	190	135–325	791
Mississippian lime	351	325–676	601
Kinderhook shale	127	676–803	250
Devonian and Silurian	387	803–1190	123
Maquoketa shale	231	1190–1421	–264
Galena and Platteville	339	1421–1760	–495
Saint Peter sandstone	26	1760–1786	–834
Sandy lime (Shakopee)	40	1786–1826	–860

* Added by W. H. Norton.

Notes.—The above log with the assignment to formations as given by experienced drillers is so reasonable that it is accepted although unconfirmed by samples of cuttings and even though it involves the assumption of either an unexpected upfold or the practical absence of dip from at least as far east as Pella. In thickness and elevation of the different formations, the Pleasantville section nearly duplicates that at Pella, and the summit of the Saint Peter is but 17 feet lower at the former than at the latter point. Normally in this distance the difference might easily amount to 150 or 200 feet. Thus the broad spacing of the contours (see map, Plate I) showing the elevation of the summit of the Saint Peter, long known to exist in southeast Iowa, is now carried considerably farther to the west. If an upfold exists in this area it probably is a continuation to the south-southeast of the Ames anticline. And if the elevation of the Saint Peter at Pleasantville is but 834 feet below sea level, there must be an unusually steep descent to the bottom of the Des Moines syncline, since at Des Moines the Saint Peter lies some 300 feet lower.

*Mineral Content of City Well, Pleasantville**

	P.P.M.
Bicarbonate	300.1
Chloride	132.
Sulfate	579.8
Silica	12.4
$Fe_2O_3+Al_2O_3$	7.4
Calcium	105.5
Magnesium	39.5
Na + K as Na	231.7
Total solids	1258.3

PRESTON, JACKSON COUNTY

(Altitude 659 feet)

The deep well of the Preston Water Company was drilled in 1922 by Thomas James of Shullsberg, Wisconsin. The depth is 989 feet and the diameters are from 10 to 5 inches. The principal supply was found from 900 to 989 feet in the Jordan sandstone. Water rises within 19 feet of the surface and the pumping capacity of the well is 75 gallons per minute with the pumping cylinder set 145 feet below the curb.

* Analysis by Dr. Harry F. Lewis, Chemical Laboratory, Cornell College, Mount Vernon, 1927.

A full set of cuttings from the well were saved, but unfortunately were soon destroyed. A blue print, however, which had been made by J. G. Thorne of Clinton, Engineer in charge, had a better fate and from it the following log is taken, with the elevations relative to sea level added:

Driller's Log

	DEPTH IN FEET	ELEVATION OF TOP
Maquoketa shale	0–120	660
Galena to Platteville, inclusive	120–470	540
Blue shale (Glenwood)	470–490	190
Saint Peter sandstone	490–530	170
Red sandstone	530–743	130
Red sandstone	743–760	
Red shale	760–763	
Red sandstone	763–803	
Clay and sand	803–813	
Red sandstone	813–887	
Clay and sand	887–895	
Hard blue clay	895–897	
White sand	897–903	–237
Jordan sandstone	903–989	–243

*Mineral Content of City Well, Preston**

	P.P.M.
Bicarbonate	370.9
Chloride	15.
Sulfate	51.6
Silica	7.6
$Fe_2O_3+Al_2O_3$	19.0
Calcium	58.9
Magnesium	17.8
Na + K as Na	20.3
Total solids	375.6

RHODES, MARSHALL COUNTY

(*Altitude 1011 feet*)

A well for the public supply of this town was drilled in 1914 by E. A. Ford of Marshalltown. The depth is 300 feet, the diameter is 8 inches. The well ends in sand 95 feet thick after passing through 205 feet of clay. It has been sufficient for the consumption of the town, which averages 5000 gallons per day.

RIPPEY, GREENE COUNTY

(*Altitude 1068 feet*)

The well of the Rippey waterworks, completed early in 1922 by Thorpe Bros. of Des Moines, is 1770 feet deep. The pumping capacity is rated at 60,000 g.p.d., five times as much as the con-

* Analysis by Dr. Harry F. Lewis, Chemical Laboratory, Cornell College, Mount Vernon, 1927.

sumption of the village. The diameters are 12 inches to 161 feet, 10 inches to 230 feet, 8 inches to 713 feet and 6 inches to the bottom. The total amount of casing is 1058 feet, placed as follows: 10 inch from top to 161 feet, 8 inches from 150 to 250 feet, 6 inch from 200 to 712 feet, and liners from 645 to 741 feet, from 1150 to 1237 feet, from 1337 to 1491 feet, and from 1640 to 1728 feet.

Record of strata

	Depth in Feet
No record	0–152
Pennsylvanian (minimum thickness, 98 feet; top (?) 912 feet above sea level):	
"Limestone"	152–153
"Black shale and slate"	153–169
"Coal"	169–171
"Slate and black shale"	171–182
"Fire clay"	182–190
"Green and blue shale"	190–227
"Hard pan"	227–230
Mississippian (385 feet thick; top 834 feet above sea level):	
"Brown limestone"	230–250
Shaly limestone	250–292
"Gray shale"	292–300
"Shaly limestone"	300–390
"Hard blue limestone"	390–405
"Marl"	405–430
Limestone, drab, rapid effervescence in cold dilute HCl; much chert, drab and white	422
Chert, gray and white; chips of vein quartz; some pyrite	442
Limestone, dark gray, fine crystalline and crystalline-earthy, rapid effervescence; in flaky chips; 2 samples	465, 476
Limestone, dark gray, saccharoidal, vesicular, rapid effervescence; some gray chert; 3 samples	487–496
Limestone, dark blue-gray, fine-saccharoidal, vesicular, considerable chert at 510, 514, 519; effervescence rapid; 4 samples	505–519
Chert, light blue-gray; some limestone as above	522
Limestone, drab, fine crystalline-granular, argillaceous, rapid effervescence; much blue-gray chert; 3 samples	527–537
Limestone, buff, subcrystalline, rapid effervescence	545, 550
Limestone, buff, pyritiferous, effervescence rapid; much clear quartz in minute irregular grains	556
No samples "limestone"	556–570
"Shale"	570–615
Devonian (155 feet thick; top 419 feet above sea level):	
Shale, dark green and drab, hard, in flakes; limestone, gray, effervescence rapid; limestone, buff, effervescence slow; quartz in small chips; chert; red sandstone in friable chips of poorly rounded grains and minute angular particles of clear quartz	715
Limestone, light gray and whitish, effervescence rapid, in sand; a little fissile light blue-gray shale in flakes, calcareous	750, 760
Silurian (350 feet thick; top 264 feet above sea level):	
Dolomite, light gray, in fine crystalline sand	770, 780
Dolomite, yellow and blue-gray, subcrystalline; limestone, lighter colored, rapid effervescence	790, 800
Dolomite, dark buff, subcrystalline; light gray shale	810
Dolomite, light yellow and blue-gray, subcrystalline, rather slow and slow effervescence; 8 samples	820–890
Dolomite, brownish mottled, a little white gypsum	900

Dolomite, buff and brown, in sand, also in chips at 910; 4 samples	910–940
Dolomite, blue gray	960, 970
Dolomite, light buff, subcrystalline	980, 990
Gypsum, white, in hard concreted masses; somewhat calcareous	1000
Limestone, buff and gray, moderately rapid effervescence; 3 samples	1010–1030
Limestone, brown, or dolomite, rather slow effervescence	1040
Limestone, buff, effervescence rather slow; limestone, buff, rather rapid effervescence	1060
Gypsum, gray, in hard concreted masses; some brownish limestone	1070
Limestone, light buff, moderately rapid effervescence, very fine-grained, in flakes; a little gypsum in white grains	1080
Dolomite, gray, effervescence rather slow; much gypsum in concreted masses and in detached grains and small chips; 3 samples	1090–1110
Dolomite, light yellow-gray, much white chert	1120
Ordovician:	
Maquoketa (150 feet thick; top 66 feet below sea level)—	
Limestone, blue-gray, highly siliceous; shale	1130
Limestone, as above; chert, blue-gray	1140
Shale, blue-gray, calcareous, plastic	1168, 1224
Limestone and chert as at 1140; 3 samples	1230–1250
(Sandstone, very fine, light gray in mass; hard dark green fissile shale; general facies of St. Peter, probably misplaced	1260)
Galena-Platteville:	
Chert, white; a little gray dolomite, no quartz sand or green shale	1280
Dolomite, light buff; in fine sand	1300
Chert, light drab; dolomite	1310
Dolomite, buff and gray, much white chert	1330, 1340
Dolomite, buff, in sand; gypsum in grains	1350, 1360
Shale, light blue-gray, calcareous, in moulded masses	1362–1368
Dolomite, buff, in sand, rather slow effervescence	1370
Gypsum, in concreted gray masses with some dolomite	1380
Dolomite, buff, effervescence rather slow, disintegrating under weak acid into microscopic crystalline particles	1390
Limestone, dark blue-gray, rapid effervescence	1400
Dolomite, gray and buff, cherty at 1430, 1440, 1460, 1470, 1550, 1570, 1580, 1600; 22 samples	1410–1660
Limestone, gray, in flakes and sand, rapid effervescence, earthy	1670, 1680
Glenwood (30 feet thick; top 626 feet below sea level):	
Shale, dark blue-green, fissile, with rusty specks from oxidation of pyrite, slightly calcareous; much gray and brown limestone in sand, effervescence rapid; 3 samples	1690–1710
Saint Peter (48 feet thick; top 656 feet below sea level):	
Sandstone, fine rounded grains, much shale as above	1720
Sandstone, as above, clean, larger grains up to 0.7 mm. in diameter	1734
Sandstone as above, finer	1745
Sandstone as above, larger grains 1 mm. diameter; considerable green shale	1750
Sandstone as above; 2 samples	1755, 1765
Prairie du Chien—	
Shakopee (entered, top 704 feet below sea level):	
Gray dolomite in fine sand and much quartz sand as above	1768

Driller's Log

	Depth in Feet
Given in *Record of strata*	0–430
Hard blue limestone	430–440
Limestone	440–570
Shale	570–615
Limestone	615–1168
Sandy shale	1168–1224
Limestone	1224–1362
Shale	1362–1387
Limestone	1387–1685
Shale	1685–1688
Limestone	1688–1723
St. Peter sandstone	1723–1766
Hard limestone	1766–1770

*Mineral Content of City Well, Rippey**

	P.P.M.
Bicarbonate	317.2
Chloride	110.
Sulfate	729.0
Silica	3.8
Calcium	153.4
Magnesium	71.0
Na + K as Na	214.9
Total solids	1462.7

RIVERSIDE, WASHINGTON COUNTY

(*Altitude 631 feet*)

This well has a depth of 565 feet and its diameters are from 10 to 6 inches. It is cased within 320 feet of the bottom. When tested it pumped about 40 gallons per minute.

*Record of strata**

	Depth in Feet
Pleistocene:	
Clay and black dirt	0–24
Sand, very fine, gray, clean; "quicksand" of driller	24–30
Sand, fine, gray, with small admixture of clay; "blue clay" of driller	30–80
Clay, yellowish, very smooth and sticky; "clay" of driller	80–110
Sand, gray, fine, some small masses of blue clay, a little lime present shown by effervescence with acid; "sand" of driller	110–235
Mississippian:	
Kinderhook:	
Clay, light blue, very fine and smooth, no grit; "soapstone" of driller	235–410
Devonian and Silurian:	
Limestone, in small chips, mixed with sand, clean clear quartz and other materials. Sand in excess in sample; "rock" of driller	410–455
Limestone in fine sand, with quartz sand in about equal proportions, or perhaps an excess of limestone; "rock" of driller	455–500
Limestone, in very fine sand and mingled with fine quartz grains; "rock" of driller	500–565

SEYMOUR, WAYNE COUNTY

(*Altitude 1066 feet*)

The following log of a diamond drill prospect hole put down for oil at Seymour in 1926 is furnished by the drillers, the Sullivan Machinery Company of Chicago. The assignment to formations is by the writer.

	Depth in feet and inches
Pleistocene and Recent (152 feet thick; top 1066 feet above sea level):	
Soil	0 – 2
Yellow clay	2 – 15
Blue clay	15 – 18

* Analysis by Harry F. Lewis, Chemical Laboratory, Cornell College, 1927.

* By Dr. James H. Lees, Asst. State Geologist.

Fine sand	18 – 20
Hard pan (glacial till?)	20 – 45
Fine sand	45 – 49
Hard pan (glacial till?)	49 – 59
Gravel	59 – 63
Hard pan (glacial till?)	63 –132
Pennsylvanian (490 feet, 10 inches thick, top 934 feet above sea level):	
Gray shale	132 –139- 6
Shaly limestone	139- 6–147
Gray sticky shale	147 –150
Red and gray shale	150 –154- 6
Gray sandy shale	154- 6–172
Shaly limestone	172 –174
Blue sticky shale	174 –187
Gray shale	187 –190- 6
Dark shale	190- 6–191- 4
Coal	191- 4–192- 9
Bone	192- 9–192-10
Coal	192-10–193-10
Fire clay	193-10–195- 4
Shaly limestone	195- 4–201- 6
Gray shale	201- 6–218
Dark shale	218 –222
Soft sticky shale	222 –228
Shaly limestone	228 –229
Sticky shale	229 –240
Dark shale	240 –243
Gray sticky shale	243 –244
Sticky shale	244 –259
Sandstone	259 –300
Shale	300 –301
Sticky shale	301 –314- 7
Coal	314- 7–315
Dark shale	315 –316
Fire clay	316 –318- 2
Shaly limestone	318- 2–319- 4
Sticky shale	319- 4–324- 4
Conglomerate	324- 4–325- 7
Sticky shale	325- 7–328
Black shale	328 –338
Blue shale	338 –346- 2
Coal	346- 2–346- 8
Lime shale with pebbles	346- 8–355
Shaly limestone	355 –360- 8
Sticky shale	360- 8–361-11
Coal	361-11–362- 5
Dark shale	362- 5–362-10
Sticky shale	362-10–371- 8
Shaly limestone	371- 8–373
Sticky shale	373 –381
Sticky shale, lime bands	381 –387
Sticky shale	387 –396
Dark shale	396 –396- 3
Coal	396- 3–396- 4
Dark shale	396- 4–398- 6
Shaly limestone	398- 6–402-10
Limestone	402-10–407-10
Sticky shale	407-10–412
Sticky shale, gray	412 –423
Sandy shale	423 –425- 6
Dark shale	425- 6–437- 4
Bony coal	437- 4–437- 8

Sandy shale	437- 8–438
Sticky shale	438 –447
Shaly limestone	447 –452
Sticky shale	452 –459-10
Black shale	459-10–463-11
Sandy shale	463-11–481
Sandstone, shale streaks	481 –486- 6
Sandstone and coal, mixed	486- 6–487-10
Sandstone	487-10–496- 2
Coal	496- 2–496- 8
Fire clay	496- 8–499- 4
Dark shale	499- 4–509- 4
Bony coal	509- 4–511- 9
Shaly sandstone	511- 9–517
Dark sticky shale	517 –535- 9
Coal	535- 9–536
Soft sticky shale	536 –538- 5
Coal	538- 5–539- 2
Sandstone	539- 2–540
Limestone	540 –544- 5
Shaly limestone	544- 5–548- 9
Bony coal	548- 9–549- 4
Dark shale	549- 4–551- 1
Bony coal	551- 1–551- 9
Sticky shale	551- 9–560- 4
Limestone	560- 4–563- 1
Dark shale	563- 1–568
Sandy shale	568 –590
Sandstone	590 –614- 7
Dark shale	614- 7–617-11
Sticky shale	617-11–621- 3
Sandstone	621- 3–622-10
Mississippian (penetrated, 377 feet, 2 inches; top 443 feet above sea level):	
Hard limestone	622-10–624
Shaly limestone	624 –633
Sandstone	633 –643
Limestone	643 –644
Sandstone and lime mixed	644 –680
Limestone	680 –694
Lime shale	694 –728- 3
Limestone	728- 3–730- 9
Lime shale	730- 9–732- 5
Hard limestone	732- 5–736
Broken limestone	736 –746
Soft shale	746 –747
Limestone	747 –748- 4
Shale	748- 4–749- 9
Limestone	749- 9–750- 6
Shale	750- 6–751- 4
Limestone	751- 4–754- 8
Hard limestone	754- 8–774- 2
White quartz	774- 2–774- 6
Lime shale	774- 6–775- 2
White quartz	775- 2–775- 5
Lime shale	775- 5–779-11
White quartz	779-11–780- 6
Lime shale	780- 6–780- 9
White quartz	780- 9–781- 1
Lime shale	781- 1–782- 8
Hard limestone	782- 8–783- 8
Lime shale	783- 8–784- 4

Hard limestone	784- 4–785- 6
Lime shale	785- 6–786- 6
Lime and white quartz	786- 6–788- 4
Lime shale mixed	788- 4–789- 9
Hard limestone	789- 9–807
Hard chert	807 –808
Chert	808 –809- 3
Hard limestone	809- 3–832
Hard broken limestone	832 –847
Chert	847 –847- 4
Hard broken limestone	847- 4–957
Hard limestone	957 –974
Hard broken limestone	974 –991
Limestone	991 –1000

Arrangements had been made with the local promoters to save sample drillings. A few were sent to the Survey office for determination while the work was progressing and these are described below by Dr. Lees. After drilling stopped, however, it was impossible to learn anything about samples or to secure any.

	Depth of sample feet
Sandstone, grains fine, clear, fairly well rounded. A few fragments of gray and black noncalcareous shale. A few specks of pyrite	647
Sandstone, similar to above	656
Limestone, dark gray, very finely granular. A few clear quartz grains	671
Limestone, similar to above but with more quartz, some in fine embedded grains	681
Limestone, dark gray, finely granular; and shale, gray. Some limestone chips are only very slightly respondent to acid	690
Shale, dark gray to black, fine texture, noncalcareous; sandstone with dolomitic cement, sand grains fine, clear, also some sandstone chips are dark gray or brown	694
Sandstone and shale mixed. Sandstone is broken up more than in preceding sample, grains are clear but much dark material, perhaps from shale, imparts a dark color to the sample	699

SHELLSBURG, BENTON COUNTY

(Altitude 776 feet)

WELL NO. 1, IOWA CANNING COMPANY

This well, 1160 feet in depth, was drilled by C. D. Nolan of Cedar Rapids. Footing in the Shakopee dolomite, its capacity is from 70 to 80 g.p.m. The static level is 30 feet below the surface, or 30 feet above that of well no. 2, footing in the Jordan. Account must here be taken of the fact that in well no. 1 the upper waters were not effectively cased out.

With the air pipe at 248 feet, the draw-down was estimated as to 110 feet below the surface of the ground. The water is charged with sulphuretted hydrogen gas and is somewhat laxative.

No log or samples of cuttings are available from this well. It is stated that the Saint Peter was reached at 1012 feet and that a "sand" was found at 865 feet. In well number 2, however, the drill at this depth was working in clean nonmagnesian limestones of the Galena-Platteville.

As the supply was insufficient and the well could not be deepened, since a string of drilling tools, fishing tools and a whipstock had been left in it, a second well became necessary.

WELL NO. 2, IOWA CANNING COMPANY

This well, 1519 feet deep, was completed in 1928 by C. W. Varner of Dubuque. The diameters are 10 inches to 1055 feet and 8 inches to the bottom. The principal supply was found in the Jordan sandstone, from 1474 to 1519 feet. Water was found also from 997 to 1028 feet in the Saint Peter sandstone, and from 1195 to 1218 feet in the New Richmond sandstone.

The static level is 50 feet below the surface, 751 feet above sea level. Until the Jordan sandstone was reached the head seems to have been about 90 feet below curb. With the foot piece of the air lift at 320 feet the draw down is estimated at 71 feet. The cost of the well was $7500.

Record of strata, well no. 2, Iowa Canning Co., Shellsburg

	Depth in Feet
Pleistocene and Recent (50 feet thick; top 801 feet above sea level):	
No samples	0–50
Devonian, Wapsipinicon (140 feet thick; top 751 feet above sea level):	
Limestone, buff and light yellow-gray, calcilutite; light buff, crystalline-earthy; blue-gray, earthy, finely laminated, argillaceous, pyritic; all of rapid effervescence in cold dilute HCl; blue-gray powder of shale	50
Limestone, buff, rapid effervescence, some earthy, in small chips; large chips of shale as below	60
Shale, light green and blue-gray, hard, highly calcareous, rapid effervescence, in large chips and concreting powder; limestone, brown-gray, rapid effervescence	60–70
Limestone, yellow-gray, gray and dark gray mottled, crystalline, rapid effervescence; pyrite; gray chert; light brownish unctuous shale; concreting powder of blue-gray shale; cinders	70–80
No sample	80–90
Limestone, buff gray, somewhat mottled, fine crystalline-earthy, rapid effervescence, clean large flakes; calcite; cinders	90–100
Limestone, gray, rapid effervescence; shale, blue-gray and yellow-gray	100–110
Limestone, magnesian, or dolomitic, yellow-gray, rather slow effervescence, crystalline, porous, disintegrating under weak acid into crystalline sand	120–130
Limestone, cream color, soft, fine, earthy	150

Limestone, buff and light gray, rapid effervescence, in fine sand; shale, light bluish, in fine chips; quartz sand, fine to 1.3 mm. diameter, grains mostly ill-rounded, some well rounded, a few secondary enlargements, some small chips of sandstone, fine, secondary enlargements, calcareous, rapid effervescence; pyrite; shale	150–160
Limestone, light cream yellow, calcilutite and very fine-grained, earthy, rapid effervescence	170
Limestone, light buff-gray, fine crystalline-granular and earthy, rapid effervescence; some chips of blue-gray shale	180
Silurian (260 feet thick; top 611 feet above sea level):	
Dolomite, buff-gray, vesicular, casts of fossils, cavities lined with drusy spar, facies of Niagaran dolomite	190
Dolomite, buff-gray and light gray, rather slow effervescence; some large chips of fine-grained limestone, rather rapid effervescence; blue and white chert	200, 210
Chert, white, gray and drab; dolomite, very light gray; one chip of calcite and chert; some milky quartz	220, 230
Chert, white; a little dolomite, light yellow-gray; 4 samples	240–280
Chert, white and blue-gray, some pyrite; considerable quartz sand, rounded grains up to about 1 mm. diameter; a little calcite	290
Chert, etc., as above; considerable light gray dolomite	300
Chert, etc., as above; very little dolomite	310
Chert, etc., as above; considerable very light gray dolomite; large chips of blue-gray and drab shale, noncalcareous, arenaceous with quartz sand of rounded grains up to 1 mm. diameter and cherty	320
Dolomite, very light gray, some pink; chert; quartz sand; pyrite; much chert at 340	330, 340
Dolomite, gray; large irregular fragment of dolomitic sandstone of minute angular grains, pyritic at 360	350, 360
Dolomite, blue-gray and yellow-gray; large irregular fragment of blue-gray sandstone, minute angular and fine rounded grains, calcareous, highly argillaceous, pyritic	370
Dolomite, gray, light gray and drab; some white chert in small chips; a little quartz sand; 4 samples	380–410
Sandstone, blue-gray, grains minute, some fine rounded, argillaceous, speckled with minute pyrite crystals, calcareous, with rapid effervescence; sandstone chips show included pyritic chert; white and gray chips of chert	420, 430
Sandstone, as above except noncalcareous; dolomite, gray, crystalline, with minutely arenaceous and pyritic residue; much shale in concreting powder	440
Ordovician:	
Maquoketa shale (170 feet thick; top 351 feet above sea level)—	
Shale, light blue-gray, in hard masses, inclosing chips of sandstone as at 440 feet and white chert	450
Shale, light blue-gray, and blue and green-gray, and drab, plastic; inclosing chips of white chert and dolomite at 480 and 490; 5 samples	460–500
Shale, light gray and gray, hard, siliceous, in chips of slow effervescence, and concreting powder; cherty at 550; 8 samples	510–580
Shale, light blue-gray, calcareous, in moulded masses	590
Shale, gray, in moulded masses and chips	600
Shale, blue-gray, plastic; olive-drab chips, dolomitic	610
Galena-Platteville (367 feet thick; top 181 feet above sea level)—	
Dolomite, brown, in clean sand	620
Limestone, magnesian, or dolomite, drab and buff-gray, rather slow effervescence in chips	630, 640
Limestone, drab and brown-gray, argillaceous, rapid effervescence	650
Shale, gray, in moulded masses, inclosing chips of brown-gray, highly argillaceous limestone	660
Shale, light blue-gray, in moulded masses	670
Limestone, brown, rather rapid effervescence, in sand	680

Limestone, gray and light gray, earthy, rapid effervescence, in large flakes	690
Limestone, light gray to buff, rapid effervescence, facies of non-dolomitized Galena-Platteville; 21 samples	700–900
Limestone, blue-gray in mass, rapid effervescence	920
Limestone, yellow-gray	920
Shale, green-gray, plastic, inclosing chips of limestone	925–930
Limestone, blue-gray in mass, rapid effervescence; 4 samples	940–970
Limestone, light brown-gray, rapid effervescence	980
Glenwood shale—	
Shale, buff and drab, plastic	987–990
Saint Peter sandstone (33 feet thick; top 194 feet below sea level)—	
Sandstone, white, grains well rounded, frosted, larger grains about 1 mm. diameter; 4 samples	995–1028
Prairie du Chien (423 feet thick)—	
Shakopee dolomite (160 feet thick; top 239 feet below sea level)—	
Dolomite, light yellow-gray; much quartz sand	1040
Dolomite as above	1045–1050
Dolomite, light gray, arenaceous, with fine to medium well rounded grains, in chips concreted with blue-gray powder of shale	1060
Dolomite, light gray, arenaceous with imbedded grains	1070
Dolomite, gray	1080
Dolomite, with quartz sand in cuttings and showing numerous imbedded grains; occasional secondary enlargements; 11 samples	1090–1190
New Richmond sandstone (40 feet thick; top 399 feet below sea level)—	
Sandstone, fine, dolomitic cement, some chips of dolomite; water, static level rose	1200
Sandstone, fine, clean quartz, grains not well rounded	1210
Sandstone as above, a little dolomite	1220
Sandstone, coarser; dolomite, pyrite	1230
Oneota dolomite (223 feet thick; top 439 feet below sea level)—	
Dolomite, gray of various tints and shades, in places arenaceous with imbedded grains; 19 samples	1240–1400
No samples, cuttings washed away	1405, 1420
Sandstone; some dolomite	1430
Dolomite; some quartz sand	1440
Dolomite, arenaceous, imbedded grains	1450
Cambrian:	
Jordan sandstone (56 feet thick; top 662 feet below sea level)—	
Sandstone, grains rounded, dolomitic cement	1463
Sandstone, white, in sand and chips, grains well rounded and frosted, larger grains slightly over 1 mm. diameter, chips of finer grains, dolomitic cement	1470
Sandstone, white, finer than above, cuttings largely in chips	1480
Sandstone, white, in detached grains, larger grains from 1 to 1.3 mm. diameter	1485
Sandstone, as at 1470	1490, 1500
Saint Lawrence dolomite (?) (entered at 718 feet below sea level)—	
Dolomite, light yellow-gray in chips; quartz sand in cuttings	1519

Notes.—The Devonian cuttings do not include any of a highly fossiliferous limestone, such as the *Spirifer pennatus* beds outcropping at Vinton, or the Cedar Valley limestones cut by the drills at Oakdale and Iowa City. It is somewhat probable that the calcilutite at 50 feet is from the Lower Davenport horizon of the Wapsipinicon and the shales and limestones beneath will then fall in with the Kenwood and in part the Otis beds. Probably the strata of the Wapsipinicon are here more or less brecciated and intermingled as at Cedar Rapids and at the Aungst and neighboring quarries north of Vinton. The limestones at 120 to 150 feet strongly resemble the basal beds of these quarries, which are referred to the lower beds of the Otis limestone,[63] the equivalent of the Coggon limestone of the Linn county report.[64]

The transition from these limestones to the typical Niagaran dolomite at 190 feet is abrupt. Compared with the Vinton section as shown by the cuttings of the city wells[65] the top of the Niagaran dolomite appears distinctly higher (54 feet) at Shellsburg than at Vinton. But the fewness of the samples taken at Vinton leaves little ground for this conclusion. One sample is supposed to represent 82 feet above the Niagaran dolomite. This sample, composed of chert, quartz sand, pyrite and nonmagnesian limestone, may be compared with the Shellsburg sample at 150 feet.

The Silurian is noteworthy for the heavy beds of chert and cherty dolomite, struck at 220 feet and more than 100 feet thick, and also for the sandstone thirty feet thick at its base. Although the Hopkinton stage of the Niagaran in its outcrops is widely characterized by chert and cherty bands, especially near its base, as at Lyons, no such heavy deposits of chert are known as these at Shellsburg. To be sure the cuttings have been washed, so that chert, commonly in large chips, is more prominent in samples than dolomite and shale crushed by the drill to sand and powder and more easily washed away. But it is believed that this fact does not account for the great excess of chert in a number of the samples, since in others much of the softer constituents of the rock has been left.

The basal sandstone is exceptional in this area and may be compared with the Colmar sandstone which overlies the Maquoketa in the Colmar oil field of Illinois.

The top of the Maquoketa at Shellsburg is placed 114 feet

63 Norton, W. H., Wapsipinicon Breccias of Iowa: Iowa Geol. Survey, vol. XXVII, p. 415.

64 Norton, W. H., Geology of Linn Co., Iowa Geol. Survey, vol. IV, p. 138 seq.

65 Norton, W. H., Thickness of the Paleozoic Strata of Northeastern Iowa: Iowa Geol. Survey, vol. III, pp. 192-194.

lower than at Vinton. This suggests an error in one or the other, or both, of the sections, especially as the upper 194 feet of the Maquoketa at Vinton is determined by only two samples. These samples, however, are expressly stated to represent the entire 194 feet, and in the matter of shale are less likely of error than in the case of limestone. It is hardly possible to consider as Maquoketa the lower beds referred to the Niagaran at Shellsburg, the dolomite from 330 to 410 feet and the sandstone from 420 to 450. The cherts at 220 feet are quite too high to be considered Middle Maquoketa, which in Fayette and Clayton counties is highly cherty and is overlain by about 125 feet of plastic shale.[66]

The more satisfactory explanation of the difference in level of the top of the Maquoketa at the two nearby points is the unconformity between the Niagaran and Maquoketa already known to exist. Indeed the difference in level in this case is about the same as one noted in outcrops in Jackson county by Savage.[67] At Cedar Rapids the top of the Maquoketa is but 35 feet higher than at Shellsburg.

The thickness assigned to the Galena-Platteville-Glenwood at Shellsburg—366 feet—may be compared with that at Vinton, 401 feet, at Cedar Rapids, 305 feet, and at Oakdale 370 feet.

The only typical dolomite of the Galena beds is found in a thin stratum at top. The shales at 660 and 670 have the aspect of the Maquoketa. The limestones they overlie are entirely like the nondolomitized beds of the formation in outcrops and many deep-well sections.

The Glenwood is exceptionally thin, even for a formation whose thickness in its outcrops does not exceed a few feet. The typical green color is absent, perhaps due to oxidation by reason of the thinness of the bed.

The Shakopee, as in some of its outcrops, is distinctly arenaceous. The New Richmond is well defined and water bearing. The Jordan sandstone is easily recognized and is the chief aquifer of the well, although it contains some beds pretty well sealed with dolomitic cement and some fine-grained sandstone whose transmission capacity must be small.

While the dolomite in which the well foots may be an inter-

66 Savage, T. E., Iowa Geol. Survey, vol. XVI, p. 598.
67 Ibid, p. 607.

calated bed of the Jordan, it is more probably the top of the Trempealeau of the Saint Lawrence formation.

SIBLEY

(Altitude 1516 feet, C., St. P., M. & O. Ry.)

CITY DEEP WELLS

The water supply of Sibley is from a shallow well ten feet in diameter and 30 feet deep yielding 82,000 g.p.d., and two deep wells of later installation. Deep well no. 1 was drilled in 1908 by G. J. Savidge of Wayne, Nebraska. The depth is 314 feet, the diameter 10 inches and the well is finished with a Cook strainer. Water stands 112 feet from the surface. On completion the pumping capacity was 125 g.p.m.; in 1914 it was 50 g.p.m.

Deep well no. 2 was drilled in 1914 by E. E. Morrison, of Sibley. The depth is 325 feet, the diameter is 8 inches and the pumping capacity on completion was 35 g.p.m. The static level is the same as in well no. 1.

Log of Sibley deep well no. 1

	Depth in Feet
Gravel and clay	0 – 40
Blue clay and boulders	40 –298½
Gravel, a little water	298½–300
Blue clay, gravel and limestone	300 –304
Gravel, sand and water	304 –310
Blue clay, sand and gravel footing on blue clay	310 –314

Log of Sibley deep well no. 2

Black dirt, stones, sand and water	0 – 14
Blue clay, dark becoming lighter, containing boulders	14 –148
Sand, coarse, furnishes water 20 g.p.m., head 19 feet below curb	148 –148½
Blue clay, light, containing fine sand and some boulders, very hard at bottom	148½–306
Sand, fine	306 –307½
Bluish gray clay	307½–325

The blue clay in which these wells foot may be referred with some probability to the Cretaceous. The general character of the heavy drift of the region is shown by the logs, and its local diversity also.

SIGOURNEY

(Altitude 752 feet, C. R. I. & P. Ry., 785 feet C., M., St. P. & P. R. R.)

In 1882 the town of Sigourney had drilled a well 1888 feet deep and extending 458 feet below the base of the Saint Peter sandstone. On account of the quality of the water this well was never used and until 1923 the city depended on a shallow well supply.

Notwithstanding this unfortunate experience the city again, in 1923, had drilled a well for public supply. The depth, 1978 feet, penetrates a water bed not reached by the earlier well. The well is also completely cased to a depth of 1445 feet, presumably excluding all objectionable waters above that level. The main supply was obtained at 1928 feet and the Saint Peter sandstone at 1373 feet, as in the earlier well, was found to be a water bed. The static level is 83 feet below the curb. Under air the delivery of the well is 500 gallons per minute with a draw down of 14 feet.

As the well was being drilled the static level at 655 feet (Devonian) was 40 feet from the top; at 1525 feet (Prairie du Chien), 105 feet from the top; and on completion the static level was found to have risen to 83 feet below the curb. Three casing pipes extend from the surface, a 15½ inch pipe to 102 feet, a 10 inch pipe to 655 feet and a 8¼ inch pipe to 1445 feet.

The driller was Charles P. Brant of Indianapolis, Indiana, and the cost of the well was $18,000.

*Mineral Content of City Well, No. 2, Sigourney**

	P.P.M.
Bicarbonate	312.3
Chloride	93.
Sulfate	857.6
Silica	23.4
$Fe_2O_3+Al_2O_3$	9.4
Calcium	164.9
Magnesium	70.5
Na + K as Na	241.9
Total solids	1616.7

SIOUX CITY

(*Altitude 1103 feet*)

WELL OF THE MIDLAND PACKING COMPANY (NOW SWIFT AND COMPANY)

A well 615 feet deep was drilled in 1920 by the F. M. Gray, Jr., Company of Milwaukee.

* Analysis by Dr. Harry F. Lewis, Chemical Laboratory, Cornell College, Mount Vernon, 1927.

Record of strata

	Depth in Feet
No record	0–260
Cretaceous (?) Pennsylvanian (?) (70 feet thick; top 865 feet above sea level):	
Shale, white, kaolinic, noncalcareous, with minute angular particles of quartz and some irregular larger grains	260–265
Shale, red, calcareous, residue of quartz sand as above, color turns to yellow on boiling in HCl	270–280
Shale, whitish, noncalcareous	280–290
Shale, red and white	290–300
Shale, whitish, fine angular grains of quartz; 3 samples	300–330
Mississippian, and Galena-Platteville (260 feet thick; top 795 feet above sea level):	
Sandstone, gray in mass, fine grains of clear quartz, imperfectly rounded, in sand; chips of fine light brownish gray sandstone, hard, grains as remainder of sample; 2 samples	330–350
Sandstone, white, as above	350–360
Chert, white, brown cryptocrystalline silica with minute imbedded angular grains of crystalline quartz	360–370
Dolomite, hard, dark gray, crystalline (effervescence in cold dilute HCl less slow than LeClaire dolomite); limestone, lighter gray, rapid effervescence; limestone, soft, whitish, rapid reaction	370–380
Limestone, blue-gray, rapid reaction; limestone, light yellow-gray, earthy, rapid reaction	380–390
Limestone, as above, much quartz sand and shale as in samples below 360; chemical analysis on basis of silica free rock shows 72 per cent $CaCO_3$ and 11.9 per cent of $MgCO_3$	390–400
Limestone, as above	400–410
Limestone, light yellow-gray, soft, granular, moderately rapid effervescence; most of sample consists of chips of dark ochreous cherty calcareous rock, dark red argillaceous sandstone, hard light green shale, whitish shale, greenish yellow sandstone, calciferous and argillaceous, probably from above	410–420
Limestone, light blue-gray, 61.5 per cent $CaCO_3$, 12.7 $MgCO_3$, on basis of silica-free rock	420–430
Limestone, gray, moderately slow effervescence	430–440
Dolomite, dark blue-gray and blue-gray, crystalline, cuttings heavily rusted and stained ochre yellow, all in small chips; some rounded fragments of a white sandstone with red flecks, fine, argillaceous; and blue and pink shale taken to be from above; 4 samples	440–480
Dolomite, gray and light gray, compact, in small chips, effervescence moderately slow; 5 samples	480–530
Dolomite, grayish buff, crystalline granular, in sharp sand; 2 samples	530–550
Dolomite, drab and grayish buff, compact; 4 samples, that at 570-580 shows 55.24 per cent $CaCO_3$ and 40.10 per cent $MgCO_3$ on basis of silica-free rock	550–590
Ordovician:	
Saint Peter sandstone (penetrated 25 feet; top 535 feet above sea level)—	
Sandstone, white, fine grains rounded and frosted; some light green shale; some chips of greenish argillaceous, pyritiferous sandstone of calcareous cement; 2 samples	590–615

Notes.—At Sioux City and vicinity the Niobrara and the Benton of the Colorado group of the Cretaceous lie entirely above water level of Missouri river and its tributaries. At Prospect Hill within the limits of the city 42 feet of the Dakota formation is exposed, while at Sargent's Bluff, seven miles south, about 100 feet are shown of the same beds, the lower 43 feet being shale.[68] Hence the upper 260 feet of the above well section can not be correlated with any of the local outcrops.

If this gap can be filled from the section of the waterworks well we may suppose that here also are some fifty feet of Pleistocene and Recent sands and gravels overlying about 210 feet of shales and sandstones probably belonging to the Dakota.

The assignment of the shales 170 feet thick which begin at 260 feet (111 feet below extreme low water in Missouri river) and whose base is 795 feet above sea level is uncertain. They may be compared with the shales beneath the drift at Holstein, 170 feet thick, base 867 feet above sea level, and with the shales with some interbedded sandstones at Cherokee, 270 feet thick, whose base is 903 feet above sea level.

In the log of the waterworks well the place of these shales is held by 31 feet of pyrite and lignite and underlying sandstone[69] which may acceptably be placed with the Dakota. Whether the shales of the Midland Company well are an uneroded remnant of the Pennsylvanian or a local change of the Cretaceous from sandstone to shale is unresolved.

The sandstone underlying these shales is pretty surely Paleozoic, but it is uncertain whether it should be ranked with the Mississippian or the Pennsylvanian. It can hardly be a westward extension of the Saint Peter, for its grains are ill-rounded, and the limestone series beneath it is not wholly dolomitic as is the Prairie du Chien, on which the Saint Peter sandstone rests.

The limestones and dolomites between the shales from 260 to 330 feet and the Saint Peter are referred to the Mississippian and the Galena-Platteville, more on the probability that the intervening formations are here wanting than for any lithologic reasons. Probably all the limestones belong to the Mississippian, and much of the dolomites to the Galena-Platteville.

The sandstone at 590 feet carries all the grain marks of the Saint Peter, and the underlying strata, as shown in the Magee well at Sioux City,[70] confirm this reference. It may be noted that

68 Bain, H. F., Geology of Woodbury Co.: Iowa Geol. Survey, vol. V, pp. 260, 263.
69 Underground Water Resources of Iowa, Iowa Geol. Survey, vol. XXI, p. 1096.
70 Op. Cit., pp. 1097-98.

from Sioux City to Holstein the Saint Peter dips east at the rate of about 11 feet to the mile, and to Cherokee to the northeast, more in the line of the strike of the strata, the dip is about 4½ feet to the mile.

The section may be continued by the Magee well. Beneath the Saint Peter cherty dolomites of the Prairie du Chien extend at least as deep as 345 feet above sea level. And at least as high as 285 feet above sea level begin the beds of the Saint Lawrence dolomites and shales. These become glauconitic at 125 feet above sea level, marking the horizon of the Franconia beds, and are still glauconitic at 35 feet below that datum. The red clastics of the Cambrian were reached according to the log at 125 feet below sea level and samples of the cuttings show that ten feet farther down decayed friable schists of the pre-Cambrian were encountered. Oddly enough this igneous rock was called the Saint Peter sandstone in the driller's log.

This pre-Cambrian floor of schist or granite dips east to Holstein at the rate of 9⅓ feet per mile. And the formations from this floor to the top of the Saint Peter aggregate 590 feet at Holstein and 670 feet at Sioux City.

WELLS OF CHICAGO, MILWAUKEE AND ST. PAUL RAILWAY AT ROUNDHOUSE

In 1917 three wells about 297 feet deep were drilled at the roundhouse of the Chicago, Milwaukee and St. Paul Railway at Sioux City. Each has a drop pipe of 9 inches to the bottom. The chief supply was found at 240 feet and the flow increased from that depth to the bottom. Water rose within 8 feet of the surface. In 1926 the head is reported at 20 feet, but as pumping is going on most of the time at one or more of the wells, this hardly represents the true static level.

On completion the pumping capacity of the wells was found to be 318 gallons per minute, with the pumping cylinder at 60 feet. Under continuous pumping for 30 hours at 233 gallons per minute there was a draw down of 10 feet. The present capacity is 244 gallons per minute. Repairs made in 1924 by repacking and cleaning out resulted in an increased yield.

The wells are cased to 102 feet with 16 inch casing, and with 145 feet of 12 inch casing overlapping 7 feet.

Driller's Log

	Depth in Feet
Clay, sand and shale, dry	0–95
Shale and sand, dry	95–240
Sand rock, water bearing	240–280
Shale	280–297

Chemical analysis

	In grains per U. S. gallon
Calcium carbonate, $CaCO_3$	11.9
Magnesium carbonate, $MgCO_3$	5.6
Calcium sulphate, $CaSO_4$	2.8
Alkali sulphate	3.8
Alkali chloride	0.8

WELL NO. 16 OF THE CITY WATERWORKS

This well was drilled in 1919 by G. J. Savidge of Sioux City. The depth is 338 feet, the diameters are 20, 16 and 10 inches. The principal supply was found from 190 to 297 feet with another water bed from 309 to 332 feet. The static level is about 32 feet below the surface. The pumping capacity of the well on test was 1400 g.p.m. The well is cased with 181 feet 9 inches of 20 inch pipe, 110 feet 9 inches of 16 inch pipe and 60 feet of 10 inch pipe, 14 feet being used in telescoping.

Log of city well no. 16

	Depth in Feet		Depth in Feet
Clay	0–40	Dakota sandstone	190–297
Sand and gravel	40–70	Clay	297–309
Blue clay	70–80	Dakota sandstone	309–332
Sand and coarse gravel	80–190	White clay	332–338

Since 1919 two additional wells have been drilled for the city waterworks, one of 26 inches diameter and 342 feet depth and one of 20 inches diameter and 323 feet depth. Well no. 17, at West 7th and Sioux streets, 323 feet deep, yields three million gallons daily.

Log of city well no. 17

	Depth in Feet		Depth in Feet
Clay	0–40	Hard clay	274–276
Yellow sand and gravel	40–142	Sandstone	276–289
Blue clay	142–145	White clay	289–291
Blue gravel	145–152	Sandstone mixed with small streaks of white clay	291–323
Sandstone	152–274		

SOLON, JOHNSON COUNTY

(Altitude 789 feet)

In 1926 a well was drilled for city supply by Chas. D. Nolan of Cedar Rapids. Before drilling began arrangements were made for a complete set of samples of the cuttings, a matter of special interest because the drill would penetrate the entire Wapsipinicon section. It is understood that the well stopped short of the Maquoketa shale, but nothing can be learned even of its depth and capacity.

STUART, GUTHRIE COUNTY

(Altitude 1205 feet)

The deep well completed in 1916 for the city of Stuart by the Thorpe Bros. Well Company of Des Moines has the distinction of being the deepest well in Iowa, with its depth of 3021 feet. Water was found at 240 feet in glacial sands, and at 550 feet in the Coal Measures, but in inconsiderable amounts. The Saint Peter yielded little water and a test made when the drill had reached its base gave but 8 gallons a minute with a 550 foot pipe.

The chief water beds were found between 2736 and 2800 feet, where the cuttings were washed away by the flow. The head of the Saint Peter water had been 325 below the curb. From 2736 to 2830 feet it stood at 345 feet, rising slightly at the last named depth. No further fluctuations in the static level were observed and there is no evidence that any additional water beds were struck. The final test when the well had reached its present depth, lasting eighty hours with 397 feet of pipe, of which 52 feet were submerged, failed to bring the draw down below the bottom of the pipe and for the last twenty-four hours averaged 212 gallons per minute.

The diameters of the well are indicated by the casings:

12 inch	0–305	8 inch	690–1285
10 inch	260–785	6 inch	1185–1938

Chemical analyses

	Parts per million deep well*	Old city well 90 feet deep†
Silica (SiO_2)	11.8	.....
Iron and alumina	2.8	.....
Calcium	107.1	90.

*Chemical laboratory, Iowa State College of Agriculture.
†Hendrixson, Iowa Geol. Survey, vol. XXI, p. 190.

Magnesium	65.9	27.
Sodium	343.4	32
Potassium	-------	2
Carbonate radicle (CO_3)	107.4	
Bicarbonate radicle (HCO_3)	-------	408.
Sulfate radicle (SO_4)	826.0	18.
Chlorine radicle (Cl)	257.6	2.
Dissolved solids, by evaporation	1785.0	390.

The cost of the well is reported at about $19,000, and of the pumping machinery at about $3,000.

Record of Strata and Driller's Log

	Depth in Feet
Pleistocene and Recent (251 feet thick; top 1205 feet above sea level):	
"Soil and yellow clay"	0–40
"Sand, fine, mixed with clay"	40–41
"Clay, blue, with many boulders"	41–82
"Sand, medium fine, 10 to 15 gallons of water per minute"	82–86
"Clay, yellow"	86–116
"Hardpan, yellow, cemented"	116–119
"Clay, blue, numerous small pebbles"	119–141
"Sea mud, very fine, drab, no pebbles"	141–196
"Clay, blue, no pebbles"	196–211
"Sea mud, as at 141, some sand mixed"	211–225
"Sand, fine, grading into above"	225–241
"Sand, coarse, 15 to 20 gals. per minute"	241–251
Pennsylvanian (564 feet thick; top 954 feet above sea level):	
"Clay shale, blue"	251–264
"Limestone, blue"	264–271
"Slate, with hard sulphur bands"	271–287
"Boulder formation, very hard"	287–289
"Slate, with limestone bands"	289–321
"Limestone, hard, blue"	321–328
"Slate, hard, black"	328–330
"Boulder formation"	330–331
"Slate, black, very soft"	331–332
"Boulder formation, hard"	332–333
"Slate, hard, black"	333–339
"Coal"	339–341
"Fire clay"	341–342
"Limestone, blue"	342–345
"Slate, blue"	345–353
"Rock, blue"	353–355
"Shale, red"	355–360
"Limestone, blue"	360–368
"Shale, blue"	368–371
"Boulder formation"	371–375
"Shale, blue, with hard bands"	375–401
"Limestone, blue"	401–404
"Slate, blue"	404–410
"Flint rock"	410–411
"Shale, red and blue, hard bands"	411–424
"Limestone, blue, hard"	424–430
"Shale, blue"	430–441
"Shale, red"	441–453
"Hard gray rock"	453–455
"Slate, blue"	455–477
"Blue boulder"	477–481

"Shale, red"	481–487
"Flint band"	487–489
"Shale, gray, sulphur band"	489–505
"Limestone, gray"	505–513
"Shale, gray"	513–533
"Slate, black, mixed with lime rock"	533–541
"Shales with limestones, shales soft and caving"	541–765
"Shale, light colored, calcareous"	765–815
Mississippian (405 feet thick; top 390 feet above sea level):	
"Chert and shale"	815–980
"Limestone, brown"	980–1022
"Limestone, gray, effervescence rapid"	1022–1083
"Bands of chert mixed with lime, hard to drill"	1083–1106
"Limestone, brown"	1106–1126
"Lime and chert, mixed gray, bands hard, then soft"	1126–1177
"Shale (Kinderhook) greenish, with hard bands of lime"	1177–1218
Sample of cuttings; shale, blue-gray, calcareous, in plastic concreted masses, with some grains of limestone of rapid effervescence in cold dilute HCl at	1185, 1195, 1203, 1213
Devonian (155 feet thick; top 15 feet below sea level):	
Limestone, yellow-gray, soft, rapid effervescence, in sand	1220, 1227, 1234, 1241
Limestone, yellow-gray, some bluish and argillaceous, in sand	1248
Limestone, light yellow-gray, rapid effervescence, in sand	1255
Limestone, light yellow-gray, in flour and powder, argillaceous, rapid effervescence	1262
Limestone, light yellow-gray, in sand, rapid effervescence	1269
Limestone, gray and yellowish, light and darker, rapid effervescence, in sand	1277, 1284, 1291
Limestone, in fine, light gray argillaceous sand and powder	1298
Limestone, brown, dense, hard, rapid effervescence, in sand	1305, 1312
Limestone, light brown and light yellow-gray, rapid effervescence, in sand	1319, 1326, 1333, 1340, 1347, 1354
Limestone, light buff, with considerable argillaceous powder	1361
Limestone, light buff, some greenish, with considerable argillaceous powder, rapid effervescence	1368
Silurian (490 feet thick; top 170 feet below sea level):	
Shale, calcareous, gray, in argillo-calcareous powder, a little gypsum	1375
Limestone, light gray, rapid effervescence	1382
Shale, light blue-gray, with some light gray limestone	1389
Shale, whitish, with more limestone than above, rapid and moderately rapid effervescence; a little gypsum	1396
Limestone, light bluish gray, rapid effervescence, in sand, some gypsum	1403, 1410, 1417, 1424, 1431, 1438
Limestone, whitish, crystalline, some light buff, in sand, some gypsum, moderately rapid effervescence	1445, 1452, 1459
Limestone, light buff and gray, rather slow effervescence, some white and rapid, in fine sand, some gypsum	1466
Limestone, light gray, in sand, some moderately rapid effervescence, some rather slow, some lighter colored, rapid; gypsum in white grains and some chips show gypsum and calcite intercrystallized	1474, 1481, 1488, 1496
Limestone, gray, rapid and moderately rapid effervescence, some gypsum	1502, 1509
Limestone, as above, with much highly argillaceous concreted powder	1516
Limestone, buff, argillaceous	1523
Limestone, brownish gray and light yellow, crystalline, rather rapid effervescence, some whitish and rapid, some white chert, some gypsum	1530
Limestone, light gray, rapid effervescence, in coarse sand	1537, 1544, 1551
Limestone as above, heavily rusted, with steel chips of slush bucket	1559, 1567
Shale, deeply rusted, calcareous	1573
Limestone, rusted, rapid effervescence	1579

Limestone, rusted, slow effervescence, in fine meal	1585
Limestone, rusted, slow effervescence, in small chips	1591
Limestone, rusted, effervescence rapid, in meal, some gypsum	1595
Dolomite, light buff, in sand, ''hard to drill'', some gypsum in rounded grains, with much argillaceous powder	1601, 1609
Dolomite, brown, in chips, some small chips of coal	1615
Dolomite, light buff, in meal and argillaceous powder	1622, 1628
Dolomite, and gypsum, dolomite light buff in sand; gypsum in angular sand	1634, 1640
Shale, grayish brown, calcareous, in concreted powder, with gypsum	1647, 1654
Dolomite, brown, in fine meal, with much gypsum in angular sand	1661, 1668
Dolomite, buff, in fine sand with some gypsum	1675, 1682
Dolomite, buff, with considerable gypsum	1689
Shale, gray, plastic, calcareous	1696
Dolomite, or magnesian limestone, light yellow, argillaceous, with considerable gypsum, in fine meal and concreted powder; 5 samples	1703–1731
Dolomite, buff, in sand, considerable gypsum	1738, 1745
Dolomite, light yellow, in fine crystalline sand, considerable gypsum	1752
Dolomite, as above; chips of blue-gray dense limestone of rather slow effervescence, and a little soft green shale; some gypsum	1759
Limestone and shale, limestone light gray, soft, rapid effervescence, argillaceous; shale, blue, in thin flakes	1766
Limestone, as above, some blue shale, some grains of quartz sand	1773
Limestone, yellow-gray, rapid effervescence, in sand, with much flour of crystalline dolomite and whitish calcareo-argillaceous flour; some quartz sand	1780–1787
Dolomite or magnesian limestone, yellow, rather slow effervescence, in sand and concreted powder	1794
Dolomite, light buff, argillaceous, and arenaceous with rounded grains of clear quartz	1801
Dolomite, light yellow-gray, in fine meal	1808
Dolomite, or magnesian limestone, rather slow effervescence, considerable siliceous residue	1816
Limestone, gray, in small chips, some of rapid effervescence, some moderately slow, argillaceous and cherty residue	1825
Limestone, dark brownish, effervescence moderately rapid, and gray, effervescence slow, in finer grains; poorly rounded quartz sand; flakes of brown chert; 4 samples	1833–1857
Ordovician:	
Maquoketa shale (119 feet thick, top 660 feet below sea level)—	
Shale, red, highly arenaceous, with fine well-rounded grains of clear quartz and some flakes of pinkish cryptocrystalline silica, 2 feet thick according to log	1865
Shale, in light gray powder, highly calcareous, sandy and cherty residue	1873, 1880
Dolomite, gray, in easily friable concreted masses	1888, 1896
Shale, gray, calcareous; cryptocrystalline silica in minute flakes; some fine white dolomitic meal; a little selenite; 5 samples	1904–1936
Shale, blue-gray; much light gray dolomitic sand; crystals of selenite	1944
Shale, blue-gray, in small chips, siliceous, calcareous	1952
Dolomite, highly argillaceous, in gray powder; cryptocrystalline silica in minute blue-gray chips with imbedded grains of clear quartz, crystals of selenite numerous after digestion in acid; 3 samples	1960–1976
Galena to Glenwood formation inclusive (392 feet thick; top 779 feet below sea level):	
Limestone, gray, rather rapid effervescence, in chips with flour of siliceous dolomite as above and a little selenite	1984
Dolomite, buff, light yellow and light gray, in fine meal, at 2137 with large residue of cryptocrystalline silica and fine rounded grains of quartz, at 2220 cherty; 27 samples	1992–2220

Shale, gray, highly calcareous, siliceous with minute grains of quartz and flakes of cryptocrystalline silica, in concreted powder	2230
Dolomite, light yellow, in fine meal	2240
Shale, in light brown concreted powder, calcareous	2250
Shale, gray, highly calcareous	2260
Dolomite, light yellow, in fine meal, with some grains of limestone of rapid effervescence; 3 samples	2265–2281
Limestone, light gray, rapid, in small chips	2291
Shale, dark green, in small flakes, and quartz sand of rounded grains of St. Peter facies, much limestone of rapid effervescence; some pyrite	2296–2301
Limestone, light gray, rapid effervescence, in small chips	2306
Limestone, gray, in small chips, some rapid effervescence, some slow; much fine quartz sand of well-rounded grains and some green shale	2311
Shale, hard, dark green, with some fine quartz sand and limestone of rapid effervescence	2316
Shale, hard, green, in moulded masses, including laminated chips	2321
Shale, light gray, highly calcareous, in concreted powder	2326
Sandstone and shale, sand in rounded grains, fine; shale hard, green, pyritiferous; some fine flour of limestone of rapid effervescence	2334
Limestone, in fine flour, slow effervescence, some grains of limestone of rapid effervescence; some fine rounded grains of quartz	2340
Shale, blue-green, hard, plastic, in concreted masses including laminated chips	2341–2344
Limestone, as at 2340	2348
Limestone, light gray to buff, rapid effervescence, in coarse sand	2356
Shale, gray, highly calcareous, in concreted powder	2360
Sandstone, buff in mass, coloring due to iron oxide in cuttings, grains fine, rounded, considerable dolomite in fine sand	2368
Shale, light blue-gray, highly arenaceous with fine rounded grains of quartz, calcareous	2372
Saint Peter sandstone (38 feet thick; top 1171 feet below sea level)—	
Sandstone, in clear white sand, grains well rounded and frosted, larger grains up to 0.5 mm. in diameter ("top of St. Peter")	2376
Sandstone, as above with considerable argillaceous powder	2382
Sandstone, as above, nearly clean	2388
Dolomite, in buff concreted powder	2394
Sandstone, as at 2376	2400
Sandstone, light yellowish from oxidation of cuttings, facies of St. Peter, larger grains up to 0.33 mm. in diameter	2406
Sandstone, light yellow-gray, in minute grains of clear quartz	2410
Prairie du Chien (286 feet thick; top 1209 feet below sea level)—	
Shakopee dolomite—	
Marl, light gray, argillaceous, minutely arenaceous, somewhat dolomitic	2414
Sandstone, rounded grains, some double-ended crystals; dolomite sand; and some white oölitic chert	2422
"Base of sandstone"	2425
Shale, light brown, calcareous, in concreted powder	2426
Dolomite, light buff, in fine meal	2438
Dolomite, as above, highly siliceous with minute angular particles of quartz and cryptocrystalline silica	2450
Dolomite, light buff, highly arenaceous with imbedded grains	2462
Dolomite, buff and light yellow, in fine meal; 6 samples	2470–2512
New Richmond sandstone—	
Sandstone, light cream color, fine rounded grains, some with secondary enlargements, dolomitic	2528
Sandstone, as above, coarser, some sand of dolomite with im-	

bedded grains of quartz	2536, 2552
Oneota dolomite—	
Shale, in yellow concreted powder, dolomitic, siliceous with fine grains and flakes of crystalline quartz	2560
Dolomite, in fine buff meal, arenaceous, some chips with imbedded grains of quartz sand	2568
Dolomite, in buff meal, highly siliceous with flakes of cryptocrystalline and crystalline quartz	2576
Dolomite, buff, arenaceous with fine rounded grains of quartz sand	2588
Dolomite, light cream color, in flour; 3 samples	2604–2636
Dolomite, buff, residue of cryptocrystalline silica and some crystalline grains and hexagonal pointed crystals	2644
Shale, dark buff, calcareous, siliceous	2648
Sandstone, buff, fine rounded grains, some with secondary enlargements, some dolomite	2656
Shale, in yellow concreted powder, calcareous, siliceous	2664, 2668
Dolomite, light cream color, in flour, fine, siliceous, residue including hexagonal quartz crystals	2672
Marl, in concreted light buff powder, calcareous, argillaceous, siliceous	2680
Dolomite, light yellow, in flour, with fine siliceous and argillaceous residue	2692
Cambrian:	
Jordan sandstone (100 (?) feet thick; top 1495 feet below sea level)—	
Sandstone, dolomitic, or dolomite, arenaceous, in fine meal and powder, much quartz in minute angular particles and fine rounded grains; 3 samples	2700–2728
Sandstone, fine, rounded grains, stained red, probably from iron in cuttings	2736
"Cuttings washed away"	2736–2800
Saint Lawrence formation (top 1595 (?) feet below sea level)—	
Trempealeau beds (120 (?) feet thick)—	
Dolomite, light buff, residue of fine particles of quartz; 8 samples	2800–2860
Dolomite, as above, with little glauconite	2888, 2900
Franconia beds (penetrated 101 feet; top 1715 feet below sea level)—	
Sandstone, of minute angular particles of crystalline quartz, cement calcareous, of rather rapid effervescence; 5 samples	2920–2960
Limestone, light, rapid effervescence, in fine sand	2972
Sandstone, as at 2920; 4 samples	2980–3021

Notes.—Limestone outcrops of the country rock near Stuart have been correlated with beds deep in the strata of the Des Moines series.[71] As no samples of the cuttings were taken until a depth of 1185 feet the base of the Coal Measures is somewhat uncertain. The cherty shales at 815 feet (390 feet above sea level) seem to correspond to the cherty shales at Des Moines at 374 feet above sea level and may be taken as the summit of the Mississippian; while the shales from 1177 to 1220 feet seem to mark its base.

71 Tilton, J. L., The strata near Stuart, Iowa, Bull. Geol. Soc. America, vol. 33, p. 153, 1922. Also Iowa Geol. Survey, vol. XXIX, pp. 242, 280, 307-312.

As at Des Moines and several other stations the gypsum-bearing limestones (beginning at 170 feet below sea level) are assumed to be Silurian.

The shales from 1865 to 1984 feet occupy the place of the Maquoketa. The thin band of red arenaceous shale at their summit is unusual.

The shales above the Saint Peter, the Glenwood, are present in force, and, as at some of their outcrops in northeastern Iowa and in some well sections, show their affinity with the Saint Peter by their arenaceous layers.

The horizon of the Saint Peter is well marked, and as forecast in the report of 1912 (Plate I) is but slightly lower, some 57 feet, than at Des Moines.

The dolomites, marls and oölitic chert beginning at 2414 are clearly Shakopee, while the sandstone at 2528 feet may represent the New Richmond.

The summit of the Cambrian is probably marked by the dolomitic sandstone at 2700 feet, which perhaps is the far westward extension of the Jordan sandstone. The Saint Lawrence begins then with the Trempealeau dolomite, at 2800 feet or at some point between 2736 and 2800 feet, the cuttings here having been washed away, and the glauconite in the dolomite at 2900 feet may mark the beginning of the Franconia beds. It is noteworthy that the sandstones from 2920 to 3021 feet are free of glauconite, in this differing from the sandstones of the same horizon at Des Moines and from the Franconia beds in the deep wells of eastern Iowa.

The base of the Franconia is usually defined by the clean, saccharoidal sandstones of the Dresbach, but no such sandstones were reached either at Stuart or in the Greenwood Park well at Des Moines, which was sunk 313 feet farther below sea level. Obviously the Stuart well would have gained nothing by going deeper.

The temperature of the water as it is pumped from the well is 63° Fahr. This is forced by air pressure into a reservoir holding 160,000 gallons, and then pumped into a tower the capacity of which is 80,000 gallons. Water from the tower is mixed with exhaust steam in the heater, and the heated mixture is pumped into the boiler. From the analysis of this mixture the composition of the compound is determined that must be added to water pumped into the boiler. The cost of the well was as follows:

Cost of well, including drilling and casing, completed in the summer of 1917	$17,000
Cost of pumping outfit, including air compressor, drum and pipe	2,500
Cost of reinforced concrete reservoir, 36 feet diameter, 16 feet under ground, 4 feet above ground, capacity 160,000 gallons	3,800
Water tower, capacity 80,000 gallons	4,500
	$27,800

Analyses of water from Stuart well, by the Dearborn Chemical Company, Chicago, November 26, 1917

	Raw Water, Grains per Gallon	Water Pumped into Boiler, Grains per Gallon
Silica	.250	.140
Oxides of Iron and Aluminum	.090	.163
Carbonate of Lime	Trace	Trace
Suphate of Lime	23.901	21.714
Carbonate of Magnesia	12.953	6.985
Sulphate of Magnesia	Trace	3.904
Sulphates of Sodium and Potassium	59.009	34.029
Chlorides of Sodium and Potassium	18.020	14.790
Loss, etc.	.124	.269
Total soluble mineral solids	114.347	81.994
Organic matter	Trace	Trace
Suspended matter	.350	1.402
Total soluble incrusting solids, grains per gallon	37.194	29.002
Total soluble non-incrusting solids, grains per gallon	77.153	52.992
Total mineral matter, grains per gallon of 231 cubic inches	114.35	81.994
Pounds soluble incrusting solids per 1,000 U. S. gallons	5.31	4.17
Pounds soluble non-incrusting solids per 1,000 U. S. gallons	11.02	.757

TRACY, MARION COUNTY

(Altitude 715 feet)

In 1925 the Chicago, Burlington and Quincy Railroad Company put down a well at Tracy for locomotive supply. The well is 150 feet deep and its original diameters were 12 inches to 125 feet and 6 inches to bottom. When a depth of 125 feet was reached a four hour pumping test raising 70 g.p.m. failed to lower the water level, which was 81 feet above the bottom. At this stage only 20 feet of twelve inch casing had been inserted. However, the water was too hard and was cased off with six inch casing extending the full depth of the well. After the well was completed the six inch hole was filled with concrete, the six inch casing was all withdrawn and the twelve inch casing was driven to 66 feet. Water then stood 39.5 feet below curb. A test gave 71 g.p.m. for five hours and lowered the water level only eight inches. In 1927 the well was reamed with a twelve inch bit into the concrete filling.

Driller's Log

	Depth Below Grade, Feet
Clay	0–24
Shale, black	24–66
Shale, hard, gray	66–92
Limestone. Reamings are: finely sandy, gray, sparkling facets; fine-grained, gray, black, some concretionary, some lithographic, some with patches of calcite; flint, white and gray; pyrite; sandstone, fine, gray, black films	92–108
Rock, hard, white, with soft streaks	108–116
Limestone, white	116–123
Limestone, soft	123–125
Limestone, hard, creviced. Reamings show chert or flint, dark gray, very fine-grained, some response to acid	125–130
Sandstone, hard	130–138
Sandstone, soft, white	138–139
Sandstone, hard	139–150

URBANA, BENTON COUNTY

(Altitude 901 feet)

The public supply of this town is a well 1154 feet deep, its diameters ranging from 8 to 6 inches. The chief water bed, found at the bottom, is probably the Saint Peter sandstone as the well is deep enough to reach that formation. The static level is 125 feet below the surface and with the cylinder hung at 300 feet the pumping capacity is 35 g.p.m., ample to a maximum consumption of 10,000 g.p.d.

*Mineral Content of City Well, Urbana**

	P.P.M.
Bicarbonate	314.7
Chloride	6.
Sulphate	30.2
Silica	9.2
$Fe_2O_3+Al_2O_3$	5.4
Calcium	119.5
Magnesium	40.7
Na + K as Na	26.6
Total solids	394.9

* Analysis by Dr. Harry F. Lewis, Chemical Laboratory, Cornell College, Mount Vernon, 1927.

VAN BUREN COUNTY

Log of well drilled on farm of A. Nixon, 5½ miles southeast of Stockport. S. Shearard, of Colchester, Illinois, driller.

	Depth in Feet
Surface formation	0–40
Limestone	40–85
Slate (muddy); streak of coal, streak of shale, a little shale oil	85–110
Lime	110–270
Slate	270–272
Limestone	272–320
Slate and shale	320–380
Lime, shelly	380–385
Blue shale	385–430
Brown shale	430–470
Light blue shale	470–635
Salt water sand	635–642

The heavy shale from 320 to 470 feet may be referred to the Kinderhook, and possibly its basal portions to the Devonian. The color and place of the "light blue shale" (470-635) suggests argillaceous limestones of the Devonian, while the "salt water sand" recalls the gypseous beds of the Silurian at Mount Pleasant at this horizon, on account of the frequent association of gypsum and salt.

VAN HORNE, BENTON COUNTY

(Altitude 946 feet)

WELL OF CHICAGO, MILWAUKEE AND SAINT PAUL RAILWAY

After consultation with this office, the Van Horne deep well was drilled in 1915-16 for engine supply. The depth is 2340 feet; the diameters are 16 to 6 inches; the contractor, S. B. Geiger of Chicago. When the well had reached its present depth, advice was sought as to continuing the work. It was pointed out in reply that the drill hole was already one of the deepest in Iowa, measured in the distance below the Saint Peter sandstone. The drill had pierced strata as deep as or deeper stratigraphically than the 3000 foot wells of Boone and Des Moines. The main water beds had been passed through and the Algonkian floor was probably near. There was no probability that more water would be found, and if found it probably would be highly mineralized. In accordance with this advice the drilling was stopped.

The forecast which had been made of the formations through which the drill would pass was proved to have a sufficient degree of accuracy. The Saint Peter sandstone, the driller's first objective, predicted at 1290 feet, was found at 1270 feet, and the Jordan sandstone within a narrower margin.

The poor quality of the Ordovician and Cambrian waters was unexpected. The nearest deep wells to the east, at Vinton and Cedar Rapids, yield good water at these horizons. Van Horne is situated well to the east of the Mississippian zone of outcrop, and even if the Silurian should be found to carry gypsum, as at Marshalltown, deleterious upper waters could be cased out. But although special efforts were made to effectively case out upper flow, the deep artesian waters were found highly mineralized. The well was therefore abandoned. It has since been leased to the town and the public supply is drawn from it.

It will be noted in table that two water beds supply distinctly better waters than the others: the Galena limestone (906-960 feet) and the Prairie du Chien (1540 feet). The Galena water is free from both calcium and magnesium sulphates and carries little more than one-half the total solids of the rest. The discharge was tested at various depths with the estimated results given in the following table.*

SUITABILITY FOR BOILER USE	DEPTH IN FEET	DISCHARGE IN GALLONS PER HOUR	HEAD BELOW SURFACE IN FEET	GEOLOGICAL FORMATION OF WATER BED
	290	600	150	Devonian
	480	600	140	Devonian (?)
	510	......	110	Devonian (?)
	Water cased out to 485 feet			
	620	1000	135	Silurian
	Water cased out to 820 feet			
	920	500	200	Galena
Suitable	950	3000	200	Galena
Unsuitable	1000	....	160	Platteville
Unsuitable	1225	....	160	Platteville
	1300	12000	200	Saint Peter
Unfit	1400	....	200	Shakopee
	Water cased out to 1450 feet			
Poor	1485	1200	160	New Richmond
Poor	1710	....	160	Jordan
Poor	1885	4500†	160	Jordan

It will be noted that the supply from the Galena dolomite and Saint Peter sandstone as tested at 1300 feet, with all water cased

* As reported by officials in charge.

† With pump cylinder 250 feet below surface.

out to 820 feet, reached the ample figure of 200 gallons per minute. With water cased out to 1450 feet, the supply from the New Richmond, Oneota and Jordan combined reached only 75 gallons per minute.

Chemical Analyses of Water of Van Horne deep well, in grains per U. S. gallon

Probable Combination	Depth in feet							
	300-415	485-675	906-960	1000	1400	1540	1770	1855
Calcium carbonate			4.93			1.33		
Calcium sulphate	25.63	14.44	......	19.16	27.34	20.08	28.37	26.07
Magnesium carbonate	15.28	16.12	7.44	11.15	15.28	12.89	13.05	12.38
Magnesium sulphate	6.14	17.27	......	6.58	4.90	......	5.88	6.28
Oxides	0.41							
Incrusting solids	47.46	47.83	12.37	36.89	47.52	34.30	47.30	44.73
Alkali carbonate			3.10					
Alkali sulphate	33.49	32.82	26.80	34.26	35.11	22.22	35.03	35.02
Alkali chloride	1.55	8.46	3.41	2.34	1.46	1.36	1.17	1.46
Non-incrusting solids	35.04	41.28	33.31	36.60	36.57	23.58	36.20	36.48
Total solids	82.50	89.11	45.68	73.49	84.09	57.88	83.50	81.21

Description of Strata and Driller's Log

	Depth in Feet
Pleistocene and Recent (254 feet thick; top 943 feet above sea level):	
''Surface to rock''	254
Devonian (231 (?) feet thick; top 689 feet above sea level):	
Limestone, light yellow and brownish gray, some minutely mottled with dark brown grains, rapid effervescence in cold dilute HCl, in flaky chips; ''lime rock''	254–418
Shale, clayey, light blue-gray, some drab, brittle, nonlaminated; ''lime-rock and mud caves''	418–485
Unknown, no samples; ''lime rock''	485–520
Silurian (195 (?) feet thick; top 423 (?) feet above sea level):	
Limestone, yellow, blue-gray and buff, compact, fine-grained, some minutely pyritiferous, rapid effervescence, in small chips; with much flint, white and drab, no quartz sand; ''sandy lime''	520–560
Dolomite, light yellow-gray, cherty; ''lime rock''	560–710
Ordovician:	
Maquoketa shales (193 feet thick; top 233 feet above sea level)—	
Shale, blue-gray, somewhat calcareous; ''blue shale, caves''	710–785
Shale, light blue-gray, some dark olive green, some blackish; ''shale and streaks of lime, 785-960 feet.''	785–903
Galena and Platteville limestone (362 feet thick; top 40 feet above sea level)—	
Dolomite, dark brown, some saccharoidal, with greenish shale in water worn lumps	903–960
Limestone, light yellow, Platteville facies, rapid reaction	960–1175
Limestone, light brownish, compact, rapid reaction, in sand; ''lime and thin streaks of shale''	1175–1198
Shale, blue-green, in concreted masses, with some sand of limestone, pyritiferous; ''blue shale''	1198–1205
Limestone, yellow-gray, earthy, in flakes, rapid reaction	1205–1258
Shale, blue-green, as at 1198; ''caves a little''	1258–1265

Saint Peter sandstone (40 feet thick; top 322 feet below sea level)—	
Sandstone, light yellow in mass, moderately fine of grain, grains well rounded, and ground	1265–1305
Prairie du Chien (435 feet thick; top 362 feet below sea level)—	
Shakopee dolomite (180 feet thick)—	
"Shale, caves a little"; no samples	1305–1311
Dolomite, yellow-gray, in fine sand, with some chert, grains of quartz sand, and rounded lumps of green shale; "lime"	1311–1430
Dolomite, as above, with more quartz sand; "sandy lime"	1430–1450
Dolomite, buff, with white oölitic chert, and some quartz sand; "sandy lime"	1450–1485
New Richmond sandstone (50 feet thick)—	
Sandstone, calciferous, with considerable calcareous powder, some white chert; "sand"	1485–1535
Oneota dolomite (205 feet thick)—	
Dolomite, arenaceous, buff, in fine sand, grains of quartz imperfectly rounded; "sandy lime"	1535–1545
Dolomite, whitish, in fine sand; "lime"; 2 samples	1545–1740
Cambrian:	
Jordan sandstone (190 feet thick; top 797 feet below sea level)—	
Sandstone, light buff in mass, fine grains, imperfectly rounded; "sand"	1740–1754
"Sandy lime"; no sample	1754–1775
Sandstone, light yellow, fine grained; "sand"	1775–1847
Sandstone, calciferous, fine-grained, larger grains well rounded, much fine angular quartzose material, cement dolomitic; "lime" and "sandy lime"; 2 samples	1847–1930
Saint Lawrence (Trempeauleau dolomite) (120 feet thick; top 987 feet below sea level)—	
Dolomite, gray, crystalline	1930–1950
"Lime"; no samples	1950–2050
Saint Lawrence (Franconia shales) (290 feet thick; top 1107 feet below sea level)—	
Shale, blue gray, clayey	2050–2145
Shale, bright green, glauconitic	2145–2183
Sandstone, rusted, rather fine of grain, grains moderately well rounded	2183–2194
Marl, light chocolate brown, clayey, with much fine angular quartzose matter, somewhat calcareous, in powder	2194–2220
Marl, darker brown than above, with much fine quartz sand and finest angular quartzose matter, in powder	2220–2250
Shale, and sandstone, shale dark brown and green, noncalcareous, in chips; sandstone, brownish, fine-grained, hard, glauconitic, and white, calciferous, glauconitic; to bottom of well	2250–2340

Notes.—The samples of the cuttings of the Van Horne well are too few for accurate determination of the strata. Thus but two samples of limestone represent the 195 feet assigned to the Silurian. The upper of these samples, 520-560 feet, lithologically is much more like the Devonian, and the presence of flint may be expected from the lower Devonian strata as well as from the Niagaran. But to assign this body of limestone to the Devonian would reduce the thickness of the Silurian to 150 feet, while at Cedar Rapids, Vinton and Belle Plaine the dolomites clearly referable to the Silurian exceed twice that measure. Probably this sample, if correctly labelled, was taken at or near 520 feet and the change to the Silurian dolomites escaped the driller's notice. To accord with the Cedar Rapids-Belle Plaine section the summit of the Silurian should be placed even above the "lime rock" from 485 to 520 feet, of which no samples were taken.

While the driller's log records "shale with streaks of lime" from 785 to 960 feet, the sample representing the run from 903 to 950 feet is of dolomite. The blue print showing the progress of the well records this run as "brown siliceous dolomite".

The gradient of the summit of the Saint Peter sandstone from Van Horne to Cedar Rapids is little more than one foot to the mile. To the southwest the gradient to Belle Plaine is about 11 feet to the mile.

WACONIA, LINN COUNTY

At this station on the Cedar Rapids and Iowa City Interurban Railway about 4 miles southeast of Cedar Rapids a well was sunk for the Waconia Sorghum Mills Company in 1926 by Chas. D. Nolan of Cedar Rapids.

The well is 384 feet deep and 12 inches in diameter. A fair flow was found at 70 feet. The limestones yielded water all the way to the bottom, with the best flow at 300 feet. Water stands 15 feet below the curb and with the pumping cylinder 60 feet below the curb the capacity is 375 gallons per minute. The well exhausts on pumping 400 gallons per minute. The well is cased to 64 feet and cost $2304.

Record of strata

Pleistocene:	
Sand, orange	5-35
Wapsipinicon and Niagaran (?):	
Dolomite, light buff, fine grained, compact	80-95
No samples	95-220
Niagaran:	
Dolomite, light blue and yellow-gray, cherty at 365; 7 samples	220-370

WALNUT, POTTAWATTAMIE COUNTY

(Altitude 1295 feet)

A well 2510 feet in depth was completed for the town of Walnut in 1919 by the J. P. Miller Artesian Well company of Chicago. The well is cased throughout, the lowest casing, 5 inch, being perforated. The diameters are shown by these casings:

	Feet	Inches
12 inch pipe	302	
10 inch pipe	938	3
8 inch pipe	159	
6 inch pipe	641	3
5 inch pipe	489	6

Water was found at about 300 feet, as reported by the city officials, probably in or just below the "fine sand" (Pleistocene?) of the driller's log occurring from 280 to 290 feet. According to the driller's report water stood at 265 feet below the curb in the "sandy lime" from 1804 to 2050 feet and at 255 feet in the "lime, shale and rock, caving from above" from 2050 to 2137 feet. Here the well pumped on test 125 gallons per minute through an eight inch pipe, but when pumped faster than at the above rate showed a draw down below the cylinder at 335 feet.

The sandstone from 2475 to 2510 was the chief water bed and it is the driller's opinion that water also came in crevices in the limestone below 2400 feet. On completion, the static level was 265 feet below the curb, and with the pumping cylinder set at 335 feet the well delivered through an 8 inch pipe 175 gallons per minute.

At present under air the well delivers without draw down 400 gallons per minute. The water is liked by the consumers and although it scales badly in boilers has no medicinal or injurious physiological effects. The cost is reported at $15,003.

Log of City well, Walnut

	Depth in Feet
Drift and shale	0–280
Fine sand	280–290
Limestone, rotton	290–305
Shale	305–315
Red caving material	315–325
Shale	325–440
Lime	440–452
Yellow and blue shale	452–780
Streaks lime and shale	780–830
Coal	830–836
Soapstone	836–848
Shale and broken lime	848–1035
Mostly lime	1035–1100
Shale	1100–1110
Shale, caving badly	1110–1130
Shale and lime	1130–1150
Lime mixture	1150–1205
Shale	1205–1250
Broken lime and shale	1250–1550
White limestone, first good rock	1550–1666
Hard lime	1666–1800
Streak light green shale	1800–1804
Sandy lime	1804–2050
Lime, shale and rock caving from above	2050–2137
Sandy lime	2137–2185
Shale and lime	2185–2200
White lime	2200–2250
Sandy lime	2250–2300
Light brown sandy lime	2300–2390
Shale, like slate	2390–2400
Lime, some crevices	2400–2475
Soft water-bearing sand; finished in lime	2475–2510

Notes.—In the above section the base of the Coal Measure shales is certainly as deep as 848 feet, and more probably lies at 1035 feet (158 feet above sea level), 290 feet lower than at Audubon, 23 miles northeast, and 142 feet higher than at Oakland, 14 miles southwest. At both Walnut and Oakland the floor of the Coal Measures is considerably lower than had been estimated on the basis of a uniform gradient toward the Council Bluffs-Omaha area.[72]

The depth of the well at Walnut, 1217 feet below sea level, is more than sufficient to reach the Saint Peter sandstone, according to any accepted estimates. At Audubon the top of the Saint Peter is at 745 feet below sea level, and according to the probable spacing of the Saint Peter contours the Saint Peter should be struck at Walnut between 800 and 900 feet below sea level (2093 and 2193 feet from the surface). In the driller's log the "lime, shale and rock caving from above, 2050-2137 feet" may possibly designate the horizon of the Glenwood shale, which usually caves. If this is the case, and the Saint Peter is absent the "sandy lime" describes the Prairie du Chien, whose arenaceous dolomites are commonly thus referred to in logs.

If the summit of the Saint Peter dips to the southwest from Audubon at the same rate as the Coal Measures floor, it would be expected at Walnut at about 1035 feet below sea level, 2328 feet from the surface.

A letter from Mr. C. P. Miller, of the experienced firm of contractors, tends to support the theory that the Saint Peter is here absent, and hence to refer the stratum in which the well foots to the Jordan or some other Cambrian sandstone. "Concerning the Saint Peter sandstone formation, we are under the impression that we never found this stratum, unless it was the short streak of sand we encountered between 2475 and the completion of the well at 2510 feet. However, the writer was on the job at the time and I would not definitely say it was the Saint Peter sand from the fact that it had a different color and a mixture that differed entirely from what we encountered in the eastern part of the state."

72 Underground Water Resources of Iowa: Iowa Geol. Survey, vol. XXI, fig. 7, p. 1100.

*Mineral Content of City Well, Walnut**

	P.P.M.
Bicarbonate	209.8
Chloride	207.
Sulfate	577.2
Silica	114.
$Fe_2O_3+Al_2O_3$	1.2
Calcium	152.2
Magnesium	68.1
Na + K as Na	211.4
Total solids	1336.0

WASHINGTON

WELL NO. 4 OF THE MUNICIPAL WATER AND LIGHT PLANT

This well was drilled in 1924 by the F. M. Gray, Jr., Company of Milwaukee. The depth is 1817 feet, and the diameters are 15½ inches to 256 feet, 12 inches to 620 feet, 10 inches to 1510 feet, and 8 inches to the bottom. The well is cased to 1510 feet.

Water Beds

Formation	Head in feet below curb	Depth in feet
Glacial sands		70
Glacial sands		105–120
Glacial sands		230–235
Saint Peter sandstone	130	1200
Oneota dolomite	230	1500
Oneota dolomite	180	1520
Trempealeau dolomite	180	1785
Trempealeau dolomite		1817

The final and present head is reported at 120 feet below the curb, but the log does not make it clear that this was the head of the lower Trempealeau waters at 1817 feet. The well pumps 550 gallons per minute (draw down, 61 feet), pumping cylinder at 150 feet.

*Record of Strata**

Drift (255 feet thick):	
White and blue clay (no samples), till	0–70
Gravel, fine, buff	70–75
Clay, blue, till (no samples)	75–105
Sand and fine gravel, gray	105–120
Clay, blue, calcareous, till	120–235
Sand and fine gravel, gray	235–255
Mississippian (180 feet thick):	
Shale, white (no samples)	255–360
Shale, brown (no samples)	360-385

* Analysis by Dr. Harry F. Lewis, Chemical Laboratory, Cornell College, Mount Vernon, 1927.

* By F. T. Thwaites, Wisconsin State Geological Survey.

Shale, blue (no samples)	385–435
Devonian (99 feet thick):	
Limestone, brown (no samples)	435–475
Limestone, gray (no samples)	475–527
Limestone, brown (no samples)	527–534
Silurian:	
Niagaran (31 feet thick):	
Dolomite, gray	534–565
Ordovician:	
Richmond (Maquoketa) (200 feet thick):	
Shale, blue and greenish gray, calcareous	565–605
Shale, brown (no sample)	605–620
Shale, blue, calcareous	620–700
Shale, brown, sandy (no samples)	700–735
Shale, blue, calcareous	735–765
Galena-Black River (Galena-Platteville) (343 feet thick):	
Dolomite, gray	765–795
Limestone, light and dark gray, layers of oil shale toward base	795–1050
Lime, dark gray and brown	1050–1080
Sandstone, coarse to fine, light gray, calcareous; much dark gray shale	1080–1108
Saint Peter (102 feet thick):	
Sandstone, white, medium to fine, calcareous toward base; with red shale seams	1108–1208
Shale, red and green	1208–1210
Prairie du Chien—	
Shakopee (148 feet thick):	
Dolomite, gray, much sand; some green shale, and white chert	1210–1250
Dolomite, gray, little sand	1250–1353
New Richmond (27 feet thick):	
Sandstone, white, medium	1353–1365
Dolomite, pink	1365–1375
Sandstone, white, medium; pebbles of chert	1375–1380
Oncota (205 feet thick):	
Dolomite, gray	1380–1410
Dolomite, gray, much white chert, part oölitic	1410–1585
Cambrian:	
Jordan (75 feet thick):	
Sandstone, light gray, medium, calcareous	1585–1660
Saint Lawrence—	
Trempealeau (penetrated 157 feet):	
Sandstone, fine, light gray, calcareous; with streaks of gray dolomite	1660–1705
Sandstone, like above; with abundant beds of gray dolomite	1705–1735
Dolomite, light gray; some sands	1735–1785
Dolomite, light pink; little fine sand	1785–1817

Driller's log

	Depth in Feet
Soil, black, soft	0–3
Shale, yellow, hard	3–15
Gravel, yellow, soft	15–70
Sand and gravel, soft	70–75
Shale, dark, soft	75–105
Quicksand, gray, soft	105–120
Slate, dark, hard	120–135
Slate, dark	135–230
Sand, light, hard at top, soft at bottom	230–235
Slate, dark, soft	235–245
Slate, white, cavy; hard, top; soft, bottom	245–365
Slate, brown, hard	365–430
Lime, brown, hard	430–450
Lime, light, hard	450–540
Lime, brown, hard	540–565
Slate, blue, cavy, soft	565–600
Slate, brown, soft	600–615
Slate, light, soft	615–725
Slate, dark, soft	725–780
Lime, dark, hard	780–795

Lime, light, hard	795–945	Sand, lime, light, soft	1425–1460
Lime, gray, hard	945–1025	Lime, light, hard	1460–1515
Lime, brown, hard	1025–1050	Sand, light, hard	1515–1530
Lime, gray, hard	1050–1080	Lime, gray, hard	1530–1585
Slate, blue, soft	1080–1100	Sand, white, soft	1585–1605
St. Peter sand, white, hard and soft	1100–1195	Sand, white, hard	1605–1655
Slate, blue, soft	1195–1205	Lime, brown, hard	1655–1665
Lime, red, hard	1205–1210	Lime, white, hard	1665–1685
Lime, gray, hard	1210–1355	Sand, white, hard	1685–1725
Lime, red, hard	1355–1365	Lime, gray, hard	1725–1745
Lime, gray, hard	1365–1425	Lime, brown, hard	1745–1785
		Lime, pink, hard	1785–1817

Notes.—In comparing the above section of well 4 with the sections of the earlier wells[73] their substantial agreement will be noted, and as well their mutual supplement as either the earlier or the later sections have the fuller data.

In Calvin's section of one of the earliest of the Washington wells, samples attest a calciferous sandstone at the horizon of the Hoing sandstone of the Silurian, above the Maquoketa shales. Norton's section of well no. 3 gives here a siliceous dolomite with calciferous sandstone. In Thwaite's section of well no. 4 no sandy beds occur at this horizon, and it is perhaps more probable that the Hoing sands were not struck by the drill in this well—for the sands are spotty and lenticular—than that the samples fail to completely represent the rock.

The Maquoketa in well no. 3 is represented by samples extending from 563 to 620 feet, and the first sample of the Galena dolomite occurs at 710 giving a thickness to the shales of 147 feet. Calvin's data, however, led him to place the summit of the Maquoketa at 632 feet and its base at 793 feet—giving a thickness of 161 feet. In well no. 4 the top is placed at 565 and the base at 765 feet giving the formation a thickness of 200 feet. These differences seem due to difference in the interpretation of transitional beds as well as to difference in the data at hand.

In well no. 4 the Saint Peter is overlain by a "blue shale" according to the log—"sandstone, much dark gray shale", of the record. Calvin also found here an "arenaceous shale", and Norton records "shale, hard, green, fissile; and sandstone." While placed with the Galena-Platteville in the sections, the affinities of this shale, the Glenwood, are with the Saint Peter.

73 Underground Water Resources of Iowa, Iowa Geol. Survey, vol. XXI, pp. 743-46.

The "sandstone with streaks of dolomite" from 1660 to 1705 and the 30 feet of underlying "sandstone with abundant beds of dolomite" in the section of well no. 4, classified as Trempealeau, were placed with the Jordan sandstone in the section of well no. 3.

WATERLOO

(Altitude 849 feet, I. C. R. R.)

CITY WELL NO. 4

The fourth well of the city of Waterloo was completed in 1914 by the J. P. Miller Artesian Well Company of Chicago. The depth is 1378 feet and the diameters are from 16 to 9 inches. The principal supply was struck at about 850 feet (St. Peter sandstone). Other water beds were found at 800 and from 1200 to 1350 feet.

On completion of the well the water flowed over the top. In 1927 the head had fallen to 34 feet below the surface. The pumping capacity with the cylinder set at 128 feet continues to be 750 gallons per minute, and under capacity pumping in all wells the static head is lowered 62 feet. The cost of this well was $8,365. The following log is reported by the superintendent of waterworks:

	Depth in Feet
Loam, clay, sand and gravel	0–20
Cedar Valley limestone	20–100
Wapsipinicon limestone	100–150
Shale	150–200
Niagaran dolomite	200–300
Maquoketa shale	300–575
Galena limestone	575–850
Platteville shale and limestone	850–900
Saint Peter sandstone	900–950
Shakopee dolomite	950–1100
New Richmond sandstone	1100–1150
Oneota dolomite	1150–1275
Jordan sandstone	1275–1375
St. Lawrence sandstone	1375–1378

CITY WELL NO. 5, WATERLOO

This well was completed in 1922 by the F. M. Gray, Jr., Company of Milwaukee. The depth is 1409 feet and the diameters are from 20 to 10 inches. The well is cased to 876 feet. The Saint Peter is the chief water bed. In well no. 1 the main flow was found in the Jordan or the Trempealeau. The static level is

50 feet below curb with a draw down of 100 feet when pumping up to capacity of 1350 gallons per minute. The pumping cylinder is set at 156 feet.

*Record of strata**

	DEPTH IN FEET
Devonian (165 feet thick);	
Limestone, light brown	0–10
Limestone, gray, mottled brown at top	10–40
Limestone, gray, sandy, cherty	40–55
Limestone, gray	55–90
Limestone, gray, sandy, cherty	90–110
Limestone, gray and blue, brecciated	110–125
Limestone, light brownish gray	125–135
Limestone, bluish gray, sandy	135, 165
Silurian:	
Niagaran (75 feet thick):	
Dolomite, mottled blue and light gray; no samples from 195-210	165–240
Ordovician:	
Cincinnati (Maquoketa) (230 feet thick):	
Shale, blue, calcareous	240–295
Shale, no sample	295–310
Shale, blue, calcareous	310–425
Dolomite, dark gray, shaly	425–445
No sample	445–455
Dolomite, dark gray, shaly	455–470
Galena—Platteville (371 feet thick):	
Limestone, gray (Galena ?)	470–485
No samples, limestone	485–698
Limestone, gray	698–745
Shale, bluish gray, calcareous (Decorah)	745–760
Limestone, light bluish gray	760–775
Shale, blue, calcareous	775–780
Limestone, bluish gray (Platteville)	780–785
Limestone, light gray	785–835
No sample	835–841
Saint Peter (38 feet thick):	
Sandstone, medium gray, calcareous	841–879
Lower Magnesian (Prairie du Chien) (365 feet thick):	
Dolomite, gray and blue; pyrite and sand	879–895
Sandstone, fine, gray, calcareous	895–910
Dolomite, gray, sandy	910–955
Dolomite, light pink, sandy	955–985
Dolomite, gray	985–1000
Dolomite, gray, sandy	1000–1030
Dolomite, light pink, sandy	1030–1045
No sample	1045–1050
Sandstone, fine, white, calcareous	1050–1060
Dolomite, gray, very sandy	1060–1135
Dolomite, dark gray, cherty, sandy	1135–1150
Dolomite, light pink, cherty, sandy	1150–1165
Dolomite, gray, cherty, sandy	1165–1255
Cambrian:	
Jordan (145 feet thick):	
Sandstone, fine, gray, calcareous, part breaks in chips	1255–1300
No sample	1300–1315

* by Prof. F. T. Thwaites, University of Wisconsin.

Sandstone, medium to fine, white, calcareous, no sample from 1330 to 1345	1315–1380
Sandstone, very coarse to very fine, gray, calcareous	1380–1390
Sandstone, fine, gray, calcareous	1390–1400
Saint Lawrence (Trempealeau) (9 feet penetrated):	
Sandstone, very fine, gray, exceedingly calcareous	1400–1409

*Chemical analysis of sample of water from the Waterloo City wells**

	Parts per million
Calcium oxide (CaO)	72.0
Magnesium oxide (MgO)	19.5
Chlorine (Cl)	10.6
Sulphur trioxide (SO_3)	19.0
Carbon dioxide (CO_2), free	13.2
Carbon dioxide (CO_2), bound	59.9
Iron and alumina (Fe_2O_3 and Al_2O_3)	.7
Silica (SiO_2)	8.9

	Probable combination in grains per U. S. gallon
Calcium carbonate ($CaCO_3$)	4.16
Calcium sulphate ($CaSO_4$)	1.89
Calcium chloride ($CaCl_2$)	1.25
Magnesium carbonate ($MgCO_3$)	2.38
Carbon dioxide, free	.77
Iron and alumina	.04
Silica	.52
Incrusting solids	11.05

CITY WELL OF 1928

The sixth deep well of the city of Waterloo was completed in June, 1928, by the Thorpe Bros. Well Co. of Des Moines. The depth is 1407½ feet, about the same as that of the other wells. The diameters are from 16 to 12 inches. The elevation of the curb is 876 feet above sea level. The static level is within 40 feet of the surface. The well has not yet been fully tested. This well is located in the same alignment on the flood plain of Cedar river as are the other city wells and about three-quarters of a mile northwest of well no. 5.

With the cylinder placed at 156 feet the yield is approximately 1,000,000 gallons per day, but it is expected to lower the cylinder to 188 feet. The cost of the well was $20,400, and of the pumping machinery $3500. The geologic section of well no. 1[73a] will give the formations penetrated by well no. 6 with sufficient accuracy.

* American Water Softener Co., Philadelphia, 1919.

73a Norton, W. H., Underground Water Resources of Iowa: Iowa Geol. Survey, vol. XXI, pp. 310-311.

	Thickness	Depth in feet
Pleistocene and Recent	30	0–30
Devonian:		
No samples	70	30–100
Wapsipinicon limestone	58	100–158
Silurian:		
Niagaran limestone	107	158–265
Ordovician:		
Maquoketa shale	215	265–480
Galena-Platteville limestone	335	480–815
Saint Peter sandstone	47	815–862
Prairie du Chien stage—		
Shakopee dolomite	168	862–1030
New Richmond sandstone	30	1030–1060
Oneota dolomite	145	1060–1205
Cambrian:		
Jordan sandstone	48	1205–1253
Saint Lawrence, Trempealeau dolomite	120	1253–1373

WAUKON

(Altitude 1216 feet)

CITY WELL NO. 3

In 1913 it was found necessary to obtain a larger water supply for the city of Waukon on account of increase in consumption due in part to the installation of a sewer system. Neither of the two deep wells of the city, both 577 feet deep, had shown signs of failure, but well no. 1 on account of defective casing which allowed leakage into the well, had largely fallen in disuse, while the drill hole was so crooked that repairs would probably be expensive.

On consultation with this office as to the depth to which a new well should be drilled, the city officials were advised that the well if necessary should be sunk through the Dresbach sandstone, and a well 1450 feet deep probably would tap the water beds of the Cambrian which yield the supply at Lansing and McGregor.

In 1914 a third well was drilled by W. H. Gray and Brother of Chicago to the depth of 910 feet, where work was stopped on account of tools lodging at the bottom of the drill hole. The diameter was 16 inches to 510 feet, where it was reduced to 12½ inches. The static level is 308 feet below the surface—971 feet above sea level. Three tests were made of the capacity of the well. In the first, a so-called "drinking test", 200 gallons per minute were discharged for thirty minutes into the well from a hose connected with a fire hydrant. The water level during this time rose 14 feet and ceased to rise any higher. This was taken to indicate that 200 gallons per minute could be pumped continuously with a draw-down of only 14 feet. A pumping test was also made with the working barrel set 112 feet below the surface of the water. A discharge of 265 gallons per minute was maintained for three hours with a draw-down of 17 feet during the first 12 minutes of the test, the water level remaining constant during the remainder of the time. Another pumping test was made while the pumps of the old well were in operation. The discharge from the new well was 350 gallons per minute for one hour and ten minutes, while the pumps of the two old wells each lifted 60 gallons per minute. The draw down of the new well was 26 feet, and was all effected in the first ten minutes. In the first pumping test the pump speed was 26 strokes per minute; in the second, 34.

Record of strata

	Depth in Feet
Pleistocene and Recent (20 feet thick; top 1279 feet above sea level):	
Loess, yellow, calcareous	10
Clay, buff, friable, calcareous, an occasional quartz pebble	18
Ordovician:	
Galena limestone to Glenwood shale inclusive (175 feet thick; top 1259 feet above sea level)—	
Limestone, yellow, (in large chips, at 20 feet), rapid effervescence in cold dilute HCl; 3 samples	20–35
Limestone, blue-gray, crystalline-earthy, rapid reaction	40
Limestone, blue-gray and yellow, argillaceous, residue minutely quartzose	45, 50
Limestone, light yellow-gray, in flaky chips	55
Limestone, blue-gray, crystalline-earthy, some whitish	60
Limestone, gray, in chips; with bluish calcareo-argillaceous powder	65
Limestone, light buff and yellow, crystalline-earthy, fossiliferous at 110, reaction rapid; 8 samples	70–110
Limestone, blue, mottled, highly argillaceous; green calcareous shale intercrystallized with limestone; in chips, with much bluish argillo-calcareous powder; residue siliceous with crystalline and cryptocrystalline quartz; pyritiferous	115
Limestone, blue and green-gray, fossiliferous, earthy; in large chips and powder as above	120, 127
Limestone as above, highly argillaceous; 3 samples	132, 140
Shale, green, fissile, with a little limestone as above, fossiliferous	145, 150
Shale, and limestone, as above; unfossiliferous	155
Limestone, gray, fossiliferous, crystalline-earthy, in flakes	157
Limestone, yellow gray, highly argillaceous; at 185 speckled and fossiliferous; 6 samples	160–185
Shale, green, plastic (Glenwood shale)	190
Saint Peter sandstone (65 feet thick; top 1084 feet above sea level)—	
Sandstone, moderately fine (fine at 250 feet), light gray in mass or buff from rusted grains, grains of clear quartz well rounded; 11 samples	195–255

Prairie du Chien (290 feet thick; top 1019 feet above sea level)—	
Dolomite, blue-gray (buff at 260, 270); 7 samples	260–295
Dolomite, gray, crystalline, porous; 3 samples	300–310
Sandstone and dolomite, sand grains moderately fine, well rounded	315
Dolomite, yellow-gray, in chips, with much quartz sand	320
Dolomite, gray, arenaceous	325
Dolomite, blue-gray	327
Dolomite, arenaceous and minutely quartzose, in yellow powder and small chips; much quartz sand	330, 340
Sandstone, buff, moderately fine	350
Dolomite, blue-gray, in chips	360
Shale, light yellow, calcareous, plastic	365
Dolomite, blue-gray, cherty at 410, 420; 14 samples	370–510
Dolomite, highly arenaceous, gray	520
Dolomite, gray	525, 530
Dolomite, buff, arenaceous	540
Cambrian:	
Jordan sandstone (120 feet thick; top 729 feet above sea level)—	
Sandstone, buff in mass, fine grains moderately well rounded; 4 samples	550–580
Sandstone, white, grains well rounded and up to 1 mm. in diameter (at 620 up to 1.5 mm. in diameter)	590, 620
Sandstone, buff, fine	640
Sandstone, buff, grains up to 1 mm. in diameter, with chips of buff, fine-grained calciferous sandstone	660
Saint Lawrence, Trempealeau beds (90 feet thick; top 609 feet above sea level)—	
Marl, blue, cuttings in sand and powder, chiefly of microscopic angular quartzose particles, argillaceous, calcareous	670
Dolomite, blue-gray, highly siliceous as above, in small chips	680–690
Sandstone, blue-gray, hard, of fine grains and quartzose particles, calciferous (coarser with rounded grains at 720); 3 samples	700–720
Dolomite, blue, highly siliceous with quartzose particles and fine grains, in chips; 3 samples	730–750
Saint Lawrence, Franconia beds (penetrated 150 feet, top 519 feet above sea level)—	
Sandstone, in powder and some chips, of very fine grains and microscopic particles, glauconitic	760
Shale, green, in powder, highly siliceous with fine grains and quartzose particles, glauconitic, slightly calcareous; 3 samples	770–790
No samples; "green clayey shale" of driller's log	800–870
Sandstone, light gray, fine rounded grains, some dolomite and shale	880
Sandstone, as above, color of cuttings greenish; dolomite and shale in powder; numerous black opaque nonmagnetic grains	890
Sandstone as at 880	900
Sandstone, light yellow, fine grains of clear quartz, well rounded	910

Driller's log

	Depth in Feet
Surface clay	0–20
Limestone, grayish	20–115
Shale	115–155
Limestone	155–185
Shale	185–190
Saint Peter sandstone	190–260
Limestone, brownish	260–315
Sand	315–320
Limestone	320–335
Sandstone, hard, changing from white to brown	335–350
Limestone, hard, blue, many crevices	350–450
Limestone, whitish	450–520

Jordan sandstone	520–665
(Sand caved at 585 feet, cased off with 59 feet of 10 inch pipe. Bottom of pipe seated in hard sandstone at 600 feet. Hard sand 5 feet thick, then 60 feet of softer water-bearing sandstone. At 575 feet water level dropped from 120 feet to 300 feet from the surface.)	
Limestone, bluish	665–685
Limestone, grayish	685–745
Limestone, blue	745–760
Shale, green, clayey	760–880
Sandstone, white, very hard	880
(Work stopped at 910 feet, with 67 feet of tools stuck.)	

Notes.—It will be seen from the above record of strata that the entire 175 feet of the Galena-Platteville beds of this well section completely escaped dolomitization. No limestone cuttings contain enough magnesium carbonate to retard brisk effervescence in cold dilute HCl. The shales and highly argillaceous limestones from 115 to 157 feet probably represent the Decorah shale, and the underlying limestone is the Platteville. The Glenwood shale is here only five feet thick.

The Prairie du Chien is not clearly tripartite here, although the arenaceous beds from 300 to 360 feet may be taken in whole or part to represent the New Richmond sandstone.

The Trempealeau beds—the "dolomite" of the "Saint Lawrence dolomite and shale"—correspond lithologically with the outcrops of the formation to the east in the Mississippi bluffs, but are less dolomitic than in many well sections to the west and south.

The Franconia beds are marked by their usual glauconitic and argillaceous content, and by the ambiguous strata which often leave the observer in doubt as to whether they should be called shale or sandstone or even dolomite.

The sandstone at 880-900 feet is probably transitional to the Dresbach sandstone, as the dolomite and shale of the cuttings may possibly be from higher levels. The clean sandstone at 910 in which the drill stopped may easily be the uppermost of the Dresbach beds. Certainly the Dresbach was to be expected a few feet deeper at the most. Truly it would have been highly unfortunate that the drilling was compelled to stop so near or even at the top of a generous water sand, were it not for the fact that the supply already obtained was later found by tests to be ample for the needs of the city.

WEBSTER CITY

(Altitude 1050 feet, I. C. R. R.)

In the Report of the Iowa Geological Survey for 1912 mention is made of the city supply then drawn from 13 drift wells, and of a well sunk by the Gas Company to a depth of 1250 feet. The water of this deep well was found so highly corrosive that it was never used except for a public watering trough. Lest the failure to obtain good water at this depth might discourage further efforts, the following forecast was made by Norton.[74]

"Had the drilling been continued 150 feet deeper, the Saint Peter sandstone probably would have been struck, and 400 to 600 feet deeper the creviced limestones and sandstones which yield the chief supply for the Iowa wells would have been tapped. A well about 1850 feet deep could have given a largely increased yield of much better water, the sulphate content being greatly lessened."

As the supply from the wells in drift had become inadequate a deep well was contracted for with Thorpe Brothers of Des Moines, who completed the well Jan. 1, 1925. Saint Peter sandstone was reached at the depth of 1420 feet (depth predicted 1400 feet) and an abundant supply was found in the underlying formations well within the recommended depth of 1850 feet.

The depth of the well is 1805 feet; diameters, 16 inches to 560 feet, 12 inches to 1420 feet, 8 inches to bottom of the well. The casing of heavy wrought iron was set and packed so as to exclude upper waters, which might be expected to be heavily mineralized: 16 inches, 105 feet to rock; 12 inches to 560 feet with 25 feet of concrete filling between the 12 inch and 16 inch casings, 10 inches to 1420 feet, 8 inches from 1400 to 1520 feet, the remainder of the boring uncased.

Small flows at 600 and 1100 feet were cased out. The Saint Peter sandstone is reported as dry. The supply was obtained from the New Richmond sandstone and the Oneota dolomite, the main flow being struck in the former at 1620 feet.

The well had flowed until the depth of 1620 feet was reached when the water fell to the present static level of six or seven feet below the curb. The pumping capacity is rated at 2,500,000 gal-

74 Underground Water Resources of Iowa, Iowa Geol. Survey, vol. XXI, Des Moines, 1912, pp. 844-45.

lons a day, and under protracted capacity pumping the head is drawn to, but not below, 32 feet below the curb.

The water from these deep horizons is of the sodic-magnesic sulphated class as is seen from the following:

Analysis of water, by Graver Corporation

	GRAINS PER U. S. GALLON
Calcium carbonate	17.60
Calcium sulphate	4.08
Magnesium sulphate	18.10
Sodium sulphate	16.90
Sodium chloride	4.21
Silica	0.44
Iron and aluminum oxide	0.15
Suspended matter	0.78
Incrusting and corrosive solids	41.15
Nonincrusting solids	21.11
Total solids	62.26
Hardness	35.68
Alkalinity	17.60

Special acknowledgements are due the City Manager, Mr. G. J. Long, who secured and supplied the above information and also furnished to the Survey a very complete set of samples of the cuttings.

Record of strata in City well (1925) of Webster City

Recent and Pleistocene (103 feet thick; top 1030 feet above sea level):	
"Earth and clay"	
"Gravel"	
"Clay"	
Mississippian, Kinderhook stage (467 feet thick; top 927 feet above sea level):	
"Rock"	103–120
Limestone, whitish and light yellow-gray, soft, earthy, with calcite crystals, rapid effervescence, in large flakes, some samples in smaller chips. At 150 feet cherty and with some imperfectly rounded quartz sand. At 200 feet with some reddish chalcedony; 12 samples	120–230
Limestone, dark brown, argillaceous, crystalline, rapid response; and some white cherty limestone	240
Limestone, greenish gray, minutely crystalline-earthy, argillaceous, effervescence moderately rapid, in flaky chips with much argillo-calcareous powder; 4 samples	240–280
Chert, blue and white, with argillaceous limestone as above	290
Limestone, as at 240-280; 5 samples	300–340
Shale, light greenish grey, plastic, in concreted masses; 2 samples	350, 360
Limestone, dark blue-gray, fine crystalline-granular, vesicular, some mottled with flint, moderately slow effervescence, in chips	370
Limestone, light yellow-gray, in sand, rapid effervescence, and light blue-gray, in chips, less rapid	380
Limestone, whitish, crystalline, effervescence rapid, with some flakes of light blue-gray shale	390
Shale, light green-gray, in concreted masses	400

Limestone, whitish, and light yellow-gray, crystalline, reaction rapid	410
Shale, greenish; with white limestone, rapid effervescence	420
Limestone, blue and yellow-gray, a calcilutite, rapid effervescence, in small flaky chips, with some white, macrocrystalline; 2 samples	430, 440
Limestone, blue-gray, some white, some yellow gray calcilutite, some mottled, in small chips, rapid effervescence	450
Limestone, blue-gray and brown, some mottled, effervescence moderately rapid, fine crystalline-granular	460
Limestone, light gray-buff, fine crystalline-granular, reaction moderately slow, with a little green fissile shale; 2 samples	470–480
Limestone as above, and shale, blue-gray, calcareous; some dark drab limestone, highly argillaceous, soft, with minute nonsiliceous balls resembling oölite	490
Limestone, drab, compact, reaction moderately slow, residue argillaceous and with much microscopic crystalline and cryptocrystalline quartz; some shale; 2 samples	500, 510
Limestone and considerable shale; limestone in fine sand, light gray, response rapid; and dark gray and light yellow, rather slow response	520
Shale, gray, calcareous, in chips, some drab, with minute calcareous balls as at 490	530
Limestone, gray, moderately slow response, hard, compact, fine-grained; some shale	540
Limestone, blue-gray, soft, fine crystalline-granular, argillaceous	550
Limestone, iron gray, fine crystalline-granular, slow response; some microscopic quartzose residue	560
Limestone, blue-gray, soft, argillaceous	570
Devonian (100 feet thick; top 450 feet above sea level):	
Dolomite, light yellow-gray, fine-granular; and shale, blue, calcareous, in chips; 2 samples	580, 590
Dolomite, yellow-gray, fine granular-crystalline, in clean chips	600
Dolomite, light buff, in fine crystalline sand, with some irregularly rounded grains of quartz	610
Dolomite, brownish buff, in fine crystalline sand	620
Limestone, blue-gray, hard, fine-grained, argillaceous; with some chips of shale of same color	630
Limestone, dark gray, in flaky chips, some porous	640, 650
Shale, some brown, inflammable, some lighter color, giving empyreumatic odor when heated	660
Limestone, blue-gray, argillaceous, response moderately rapid; and brown crystalline dolomite; also light blue shale	670
Silurian (290 feet thick; top 250 feet above sea level):	
Limestone, light brown, crystalline-granular, porous, with white calcite; some drab and argillaceous, both moderately slow in reacting to acid, in flaky chips	680
Limestone, brown, as above	690, 700
Limestone, light blue-gray, argillaceous, rapid reaction	710
Limestone, light gray, soft, response rapid, with a little white gypsum in rounded chips	720
Dolomite, brown, in flaky chips	730
Dolomite, light yellow-gray, crystalline-granular, with some gypsum	740
Limestone, blue-gray, moderately slow reaction; shale, and some gypsum	750
Limestone, brown, crystalline, reaction moderately slow; with hard blue calcareous shale in chips, and some gypsum in rounded grains	760
Shale, blue	770
Limestone, dark drab, reaction rapid, fossiliferous, in flakes	780
Limestone, drab, earthy, argillaceous, reaction slow, a little gypsum	790
Limestone, dark drab, reaction rapid, in flaky chips, some gypsum in rounded grains	800
Limestone, drab, moderately slow response, some gypsum	810
Limestone, drab, response rapid, some gypsum	820

Gypsum, white, with some limestone	830
Limestone, brown and blue-gray, moderately slow reaction; with gypsum; 4 samples	840–870
Gypsum, with light blue limestone of rapid effervescence	880
Gypsum, in hard white concreted masses, slightly calcareous	890
Limestone, brownish, in small chips and flakes, rapid effervescence	900
Limestone, brownish, in small chips, moderately slow effervescence	910, 920
Limestone, gray, rapid effervescence	930
Limestone, light gray, rapid response, fossiliferous, with fragments of brachiopods, shell material preserved	940, 950
Limestone, light brownish gray, rapid response	960
Ordovician:	
Maquoketa shale (70 feet thick; top 60 feet above sea level)—	
Shale, blue and drab, calcareous; 6 samples	970–1020
Limestone, gray, highly argillaceous, moderately rapid effervescence	1030
Galena and Platteville formations (380 feet thick; top 10 feet below sea level)—	
Limestone, gray, rapid effervescence	1040
Limestone, light gray, argillaceous, with a little olive green shale with bituminous odor when heated	1050
Limestone, gray, crystalline, rapid effervescence	1060, 1070
Dolomite, light gray, in fine crystalline meal	1080
Dolomite, gray and buff, in crystalline meal, with much gray and blue gray flint; 6 samples	1090–1140
Dolomite, as above, with limestone, gray, in flaky chips	1150
Limestone, gray, earthy, rapid reaction, in flaky chips, with some dolomitic meal	1160
Limestone, light yellow-gray and blue-gray, earthy, reaction rapid, in flaky chips; crystalline-granular and moderately rapid response at 1240, with flint at 1250 and 1270-1290	1170–1360
Shale, light blue-gray and dark green, with some limestone meal, pyritiferous	1370
Limestone, dark drab, in meal, reaction rapid; with shale	1380
Shale, bright green, fissile; 3 samples	1390–1410
Saint Peter sandstone (50 feet thick; top 390 feet below sea level)—	
Sandstone, fine, light yellow-gray in mass, grains of pure quartz, well rounded, some rusted	1420
Sandstone, as above, white, coarser, a little hard bright green shale from above; 4 samples	1430–1460
Prairie du Chien—	
Shakopee dolomite (120 feet thick; top 440 feet below sea level)—	
Dolomite, gray, light drab and light buff, in chips, in places with imbedded grains of quartz; quartz sand and green shale in drillings; 6 samples	1470–1520
Dolomite, as above, in flour, with much fine sand in drillings; 6 samples	1530–1580
New Richmond sandstone (80 feet thick; top 560 feet below sea level)—	
Sandstone, in minute, irregular grains, with considerable dolomite	1590
Sandstone, light gray, fine, grains rounded, with some dolomite with imbedded grains of quartz sand	1600, 1610
Sandstone, gray, fine, grains moderately rounded, some dolomite	1620
Sandstone, yellow-gray, dolomitic (or dolomite, arenaceous), grains moderately well rounded, much cryptocrystalline silica at 1640; 3 samples	1630–1650
Sandstone, fine, drillings much rusted, moderately well rounded grains	1660
Oneota dolomite (135 feet thick to bottom of well; top 640 feet below sea level)—	

Dolomite, light buff or gray, in fine sand, with a few irregular grains of quartz sand, large residue of cryptocrystalline silica in fine sand at 1670; 11 samples	1670–1770
Dolomite, reported at bottom of well, no samples	1780–1805

Notes.—No attempt is made to subdivide the Kinderhook, although the upper whitish limestones probably represent the Alden beds. The shale struck at 350 feet might plausibly be taken as the Sheffield, but on the whole considering the sections of other deep wells of the territory it has seemed best to draw the base of the Kinderhook as low as the bottom of the argillaceous limestones at 570 feet. The Devonian is presumed to be thin, as it is found to be over its area of outcrop to the east, and is assigned but 100 feet. Both its summit and base are arbitrarily drawn, the latter to include an inflammable shale, since such thin shales occur in the Otis and Independence of the Devonian outcrops. A similar shale occurs at Fort Dodge 97 feet lower than at Webster City, denoting a dip, if the two shales are of the same horizon, of some five feet to the mile. The summit of the Saint Peter sandstone, however, lies at about the same level at both localities.

Beneath the bituminous shale just mentioned occur magnesian limestones containing gypsum. As at Marshalltown, Des Moines, Grinnell, Pella and Mount Pleasant, the presence of gypsum in limestones lying between the Kinderhook and the Maquoketa is taken to mark the Silurian horizon, but more probably the Salina, than the Niagaran of the Iowa outcrops.

The Maquoketa shale and the Saint Peter sandstone are here reliable markers and determine clearly the Galena-Platteville limestones and basal shales.

All the strata below the Saint Peter are assigned to the Prairie du Chien, with its three component formations, the Shakopee dolomite, the New Richmond sandstone and the Oneota dolomite. This assignment agrees with that of the deeper Fort Dodge section, where the corresponding dolomites are found to be underlain by a sandstone best referred to the Jordan. If the water-bearing sandstones below 1590 feet represent the Jordan, the Prairie du Chien is here abnormally thin, as compared, for example, with the section of the deep well at Ames.

WEBSTER COUNTY

WELL OF J. C. RITCHIE, SW. 1/4 SEC. 23, HARDIN TP.*

The altitude of the well curb is about 1125 feet above sea level. The depth of the well is 552 feet. Water was found from 330 to 375 feet and at 527 feet. The water heads 150 feet below the curb.

Record of strata of Ritchie well

	Depth in Feet
Clay, yellowish, calcareous; limestone pebbles; glacial till; 3 samples	20–40
Clay, gray, limestone pebbles; glacial till	50, 60
Clay, dark gray and buff, pebbly, many limestones, calcareous	70, 80
Clay, mostly yellowish, pebbly, calcareous	90
Sand, very fine, yellow	100
Clay, gray, blue-gray and dark gray, pebbly, calcareous; 16 samples	110–260
Clay, some dark gray, some yellowish, some pebbles; dark fragments calcareous; yellowish parts noncalcareous and probably a shale. The pebbles seem to be in the darker portion and the lighter parts are somewhat laminated	270
Gravel and sand, rather rusty yellow, very little limestone	280
Sand, yellow like preceding, finer	290
Clay, dark gray, with some fragments of lighter gray, noncalcareous; few small dark pebbles	300, 310
Clay as above, rather abundant quartz and dark pebbles	320
Clay, light blue-gray, some dark pebbles and some of white chert, no response to acid	330
Sand, dark gray, in angular chips and rounded grains; white chert	340, 350
Clay, dark gray, slight response to acid, some dark pebbles; some sand from 340, 350	360
Limestone, light gray, in small chips and powder, brisk effervescence; 4 samples	370–400
Limestone, medium dark gray, fine grains and larger chips, chips show subcrystalline structure; some chips of limy shale, dark gray	410
Limestone, as above; 4 samples	420–450
Limestone as above, some chips of very dark gray, noncalcareous shale	460
Shale, blue-gray, fine textured and soapy	470, 480
Limestone, in rather fine powder, rather dark gray; as with all limestones above brisk effervescence; chips of noncalcareous shale	490
Shale, dark gray, with some fragments of lighter gray color; fine shiny specks probably quartz scattered through the shale	500
Limestone, gray, in small chips, and fine powder, brisk effervescence; 5 samples	510–552

WESLEY, KOSSUTH COUNTY

(Altitude 1252 feet)

CITY WELL NO. 1

This well, drilled in 1921 by Jas. Lee of Algona, is 1100 feet in depth, and its diameters are 8 and 5 3/10 inches. Some water was found at 275 feet and the main supply was reached at 1030 feet, 227 feet above sea level, a depth at which the Saint Peter

* By Dr. Jas. H. Lees, Assistant State Geologist.

sandstone should be encountered. The static level is 215 feet below the surface. With the cylinder set at 250 feet the pump delivers 35 g.p.m., an amount sufficient for the town of 440 inhabitants with a consumption of 7,000 to 10,000 g.p.d. There is no draw down under pumping. The casing is 8 inch to 215 feet, 5⅝ inches from the top to 1007 feet, and at bottom 40 feet of 5 3/16 inch casing with 14 feet of overlap.

The quality of the water is described as very hard with much iron and pronounced rusting. This is borne out by a sanitary water analysis of February, 1927, which finds the sample of very red iron color, very decided turbidity, and with a heavy iron flocculent sediment. The cost of the well was $8,000.

*Mineral Content of City Well, Wesley**

	P.P.M.
Bicarbonate	495.3
Chloride	7.
Sulfate	77.0
Silica	10.4
$Fe_2O_3+Al_2O_3$	7.6
Calcium	65.4
Magnesium	27.6
Na + K as Na	74.2
Total solids	516.8

WINFIELD, HENRY COUNTY

(*Altitude 704 feet*)

The city well of Winfield was completed in 1921 by the McCarthy Well Company of Saint Paul. The depth reached was 1268 feet. The work was accomplished "in 63 days, excluding Sundays and one day on account of a break of machinery, making an average of 20 feet a day." Casing was put down to rock and through the heavy Kinderhook and Maquoketa shales.

The pumping test of 24 hours showed a capacity of 150 gallons per minute with a draw down of 84 feet. The static level is 73 feet below the surface. The chief water bed was the Shakopee dolomite from 1180 to 1268 feet.

Record of strata and driller's log

	Thickness in feet
Pleistocene and Recent (80 feet thick; top 698 feet above sea level):	
"Clay"	3–80

* Analysis by Dr. Harry F. Lewis, Chemical Laboratory, Cornell College, Mount Vernon, 1927.

Mississippian (110 feet thick; top 618 feet above sea level):
"Limerock, hard, many seams or layers" 80–190
Kinderhook shale (320 feet thick, top 508 feet above sea level)—
Shale, plastic, blue 190–510
Devonian and Silurian (108 feet thick; top 198 feet above sea level):
Limestone, magnesian, or dolomite, as tested by slow response to cold dilute HCl, drab; some lighter colored limestone of brisk effervescence 510–618
Ordovician:
Maquoketa shale (210 feet thick; top 80 feet above sea level):
Shale, light blue, plastic, "in streaks of color running from green to brown" 618–808
Shale, brown, hard, in chips, feebly inflammable, slightly calcareous 808–818
Shale, brownish drab, plastic 818–828
Galena to Glenwood inclusive (315 feet thick; top 130 feet below sea level)—
Limestone, blue, earthy, rapid effervescence, in flaky chips 828–1114
"Sandrock, white, very hard and fine-grained" (no sample, Glenwood beds) 1114–1128
Shale, green and drab, hard (Glenwood) 1128–1143
Saint Peter sandstone (37 feet thick; top 445 feet below sea level)—
Sandstone, white, fine, well rounded and frosted grains 1143–1180
Prairie du Chien:
Shakopee dolomite (penetrated 88 feet; top 482 feet below sea level)—
Dolomite, dark gray; white chert; drab shale 1180–1268

*Mineral Content of City Well, Winfield**

	P.P.M.
Bicarbonate	280.6
Chloride	80.
Sulfate	434.6
Silica	13.8
$Fe_2O_3+Al_2O_3$	3.2
Calcium	201.6
Magnesium	36.1
Na + K as Na	152.1
Total solids	1061.7

WOODWARD, DALLAS COUNTY

(*Altitude 1060 feet*)

In 1916 a deep well was drilled by Chas. Nolan of Cedar Rapids for the State Hospital and Colony for Epileptics near Woodward. The well is located in the Ne. ¼, sec. 31, Cass Tp., Boone county, at an elevation of about 1060 feet. The depth of the well is 1800 feet and the diameters are from 12 to 6 inches. The static level is 110 feet below the surface of the ground. The pumping capacity on completion was found to be 220 g.p.m.

The quality of the water, however, was unsatisfactory and in 1922 the well was abandoned in favor of a supply drawn from Des Moines river. The following log is from a blue print by H.

* Analysis by Dr. Harry F. Lewis, Chemical Laboratory, Cornell College, Mount Vernon, 1927.

F. Liebbe, State Architect. The assignment to formations is by the writer:

Log of well at Epileptic Colony

	Depth in Feet
Pleistocene (145 feet thick; top 1060 feet above sea level):	
Clay, yellow, soft, sticky	0–27
Sand, very fine, some water	27–46
Clay, yellowish gray, containing wood	46–51
Clay, light blue	51–69
Clay, grayish yellow, containing sand and gravel	69–110
Clay, deep brown	110–140
Sand, quartz, fine uniform grains	140–145
Pennsylvanian (380 feet thick; top 915 feet above sea level):	
Rock, hard, blue	145–150
Shale, blue, hard, brittle	150–210
Slate, sandy; some coal	210–230
Shale, light blue	230–305
Shale, bituminous, mixed with ash-colored fine clay, coal and iron	305–375
Shale, black and sandy	375–410
Shale, gray and blue	410–445
Flint rock, streaked with shale	445–452
Shale, gray, blue	452–485
Shale, sandy	485–493
Lime rock, hard, brown	493–495
Sand rock, white, testing 35 g.p.m.	495–525
Mississippian (315 feet thick; top 535 feet above sea level):	
Shale, blue	525–528
Sandstone, white	528–534
Shale, blue, sandy	534–560
Limestone, gray	560–720
Limestone, white, brittle	720–790
Shale, light blue, fine texture (Kinderhook)	790–840
Devonian and Silurian (505 feet thick; top 220 feet above sea level):	
Limestone, blue	840–865
Limestone, gray, hard	865–970
Shale, brown, hard, cavy	970–983
Limestone, sandy; some water	983–995
Limestone, soft, light color	995–1040
Shale, yellow	1040–1045
Limestone; some quartz	1045–1110
Shale	1110–1113
Limestone, gray, hard	1113–1240
"St. Peter sandstone"	1240–1285
Shale, bluish	1285–1290
Limestone, hard, brown	1290–1345
Ordovician (penetrated 455 feet):	
Maquoketa shale and Galena-Platteville limestone (378 feet thick; top 285 feet below sea level)—	
Shale	1345–1350
Limestone, blue; granite streaks (blue chert?)	1350–1410
Limestone, light color	1410–1475
Shale, light blue	1475–1530
Lime, brown, hard, fine-grained	1530–1650
Sandstone, white, round shape	1650–1655
Limestone, brown, very hard	1655–1723
Glenwood shale (2 feet thick; top 663 feet below sea level)—	
Shale, green	1723–1725
Saint Peter sandstone (penetrated 75 feet; top 665 feet below sea level)—	
"Jordan sandstone"	1725–1800

WORTHINGTON, MINNESOTA

A test well at Worthington, Minnesota, was drilled in 1928 and is here placed on record because, situated but eight miles north of the Iowa state line, it gives, no doubt, authentic information as to conditions of water supply in northern Osceola county. The country rock in both the southwestern corner of the county and in the northeastern corner is the Sioux quartzite.[75] The elevation is about 1575 feet above sea level.

Driller's log, A. Engerbretsen

	Depth in Feet
Mixture of blue and yellow clay	0 –125
Yellowish gray sand, water to within 50 feet of top	125 –167½
Gray sand, quite coarse, water sand	167½–172
Yellow and gray sand	172 –295
Gray sand	295 –300
Yellow and gray clay	300 –354
Gray sand	354 –387
Yellow and gray clay	387 –395
Gray sand	395 –398
Yellow and gray clay	398 –440
Hard sand rock	440 –470
Hard rock	470 –478
Soft rock and sand, mixed with yellowish clay	478 –508
Hard rock, but not so hard as the stratum between 470 and 478	508 –513

Driller's log, continued, C. W. Varner, Dubuque

Sand rock	513 –535
Clay or hard pan, caving	535 –553
Sand rock, caving at 583	553 –601
Hard sandstone	601 –604
Fissure of one foot	604 –605
Softer sandstone	605 –610
Hard sand	610 –612
Softer sand	612 –617
Hard sand	617 –630
Clay, caved in presumably from about 550 feet	630 –641
Hard sand rock	650 –705
?	705 –750

Record of strata, Worthington test well, 1928

The following determinations were made of samples preserved by Mr. Varner. No cuttings had been kept previously to his taking over the work.

	Depth in Feet
Sandstone, gray in mass, speckled grains irregular, mostly of colorless quartz, up to 2 mm. in diameter, secondary enlargements, sparkling, some greenish yellow grains, some black, some of pink quartz; a little gray shale; 2 samples	510–520

75 O. E. Meinzer, Underground Waters of Southern Minnesota, p. 288.

Sandstone, gray, speckled, coarser than above, grains up to 2 mm. diameter, mostly clear, colorless quartz, some yellow, red, rose red and greenish; greenish yellow grains showing cross-hatching and high polarization colors; blackish grains (streak brown) yellowish by transmitted light, isotropic; grains mostly broken, a few well rounded	520–525
Sandstone as above, finer	530–535
Shale, light drab, noncalcareous, micaceous (white mica), microscopically quartzose	535–553
Sandstone, light gray, and light yellow-gray, fine, form of grains and mineral constituents as at 520, also micaceous (white mica), and biotite mica at 590, pink grains rather common at 615; 11 samples	553–620
Sandstone, yellow-gray, fine, cuttings mostly in angular fine fragments, some rounded grains, secondary enlargements, a little feldspar, black grains rare, vari-colored quartz rare, micaceous; 6 samples	615–645
Sandstone, coarse to fine, grains up to 2 mm. and 3 mm., much fine quartzose material, grains largely of colorless quartz, a few pinkish, many whitish, in part of feldspar, irregular, broken, secondary enlargements, some rounded, not frosted; 3 samples	645–660
Sandstone, gray, very fine, micaceous, grains irregular	660–665
Sandstone, light yellow, slight pink tinge from grains of this color, micaceous, almost wholly of quartz; ball of pyrite, size and form of grains as at 645	665–670
Sandstone, light yellow, medium to fine, micaceous, some pink grains, irregular, broken	670–675
Sandstone, fine to medium, light gray, as above	675–680
Sandstone, light gray, slight pinkish cast, fine to medium as above; 2 samples	680–690
Sandstone, yellow-gray, fine to coarse, some greenish, pink and yellow grains	690–695
Sandstone, light pinkish, terra cotta colors, argillaceous, in friable masses, a few yellow, pink and bright red grains	700–705
Crystalline rock, minerals: quartz, orthoclase, plagioclase, biotite, other ferro-magnesian mineral, masses of kaolinitic material from rock decay; 8 samples	705–750

Notes.—Water, it is said, was found at 125 feet in considerable amount, and continued to come in to a depth of about 300 feet. A larger supply was struck at 400 feet, rising to nearer the surface. This vein is probably the "gray sand" of the log at 395-398 feet. Below 400 feet it is not known that any water was found.

This section is noteworthy because it gives here the elevation of the Paleozoic floor of the crystalline rocks of the Archean, about 870 feet above sea level, and because two bodies of rock which might have been expected—the Sioux quartzite and the Red Clastics of the Cambrian—are entirely absent. Yet the Sioux quartzite occurs both to the north and to the west of Worthington within the county limits; and in a number of deep well sections in Minnesota and Iowa the sandstones and shales of the Red Clastics overlie the crystalline Archean rocks. Nor is there a trace of the glauconitic sandstones and "marls" of the Cambrian.

Probably drift deposits extend to at least 172 feet. And to the Cretaceous may safely be referred the 268 feet of "yellow and gray sand", "gray sand", and "yellow and gray clay" of the log.

The upper gray and speckled sandstone of the cuttings is said to have begun at 465 feet. The variety of minerals present, the lack of assortment and the irregular form of the grains indicate a near shore of crystalline rocks, but of course do not record any particular geologic period of time. The lower sands, separated from the upper sands by 18 feet of drab shale at 535 feet, in large part finer, and more predominantly of colorless quartz, though also poorly rounded of grain, record a more distant source of supply, with a longer period of effacement of the weaker minerals by wave work. Yet the two sandstones are on the whole much alike in mineral composition and shape of grains.

It is not determined whether these sands are Cretaceous or Cambrian.

Although these sands of the cuttings below 510 feet at Worthington seem to have been found dry, it does not follow as a sure conclusion that they would be found everywhere dry across the Iowa line. They do not encourage drilling, but they do not forbid it. Their texture, caving at one horizon, suggests that in places they may perhaps be water-bearing.

QUITMAN, MISSOURI

(Altitude 906 feet)

Mr. Gerald Bednar, President of Iowa's First Oil Development Company, which drilled the oil prospect south of Clarinda, has furnished a log of a prospect which was drilled near Quitman, Nodaway county, Missouri, by G. H. Rose and Son of Maryville, Missouri. This well is in the hills one mile south and two miles east of town, in the southeast corner of SE. ¼ NE. ¼ Sec. 15, T. 64, R. 37, at an elevation of 953 feet above sea level, and was completed June 6, 1927. It is about 40 miles south of the Clarinda boring and nine miles south of Maryville.

Driller's log of prospect in Cardin Lease, Quitman, Nodaway County, Missouri, well no. 2

	Depth in Feet
Soil	0–10
Yellow clay	10–25
Gravel (water)	25–35
Blue shale	35–45
Lime	45–48
Light shale	48–52
Lime	52–53
Light shale	53–55
Lime	55–60
Light shale	60–62
White lime	62–74
Light shale	74–82
Lime	82–89
Shale	89–90
Lime	90–105
Shale, dark	105–108
Lime	108–112
Shale, dark	112–114
Lime	114–116
Shale, dark	116–126
Lime	126–128
Shale, light	128–129
Lime	129–132
Shale, light	132–177
Lime	177–190
Shale, dark	190–193
Lime	193–198
Shale, light	198–210
Lime	210–214
Lime, broken	214–217
Lime	217–230
Shale, dark	230–233
Lime	233–248
Shale, dark	248–260
Shale, light	260–273
Red bed	273–285
Shale, light	285–424
Lime	424–429
Shale, broken	429–443
Lime	443–447
Shale, light	447–452
Lime	452–457
Shale, light	457–461
Lime	461–467
Shale, dark	467–475
Lime	475–485
Shale, light, sandy	485–487
Lime, hard	487–488
Shale, light	488–500
Lime	500–515
Shale, light	515–518
Lime	518–522
Shale, light	522–524
Lime	524–526
Shale, sandy	526–530
Lime	530–535
Shale, dark	535–555
Shale and broken sandstone	555–560
Lime	560–570
Shale, dark	570–575
Shale, brown	575–585
Lime, brown	585–588
Red bed	588–593
Shale, sandy	593–600
Lime	600–604
Shale, dark	604–606
Lime, hard	606–632
Shale, dark	632–635
Lime	635–642
Shale, sandy	642–644
Lime	644–668
Shale, black	668–676
Lime, very hard	676–696
Shale, black	696–700
Lime	700–702
Shale, dark	702–707
Lime	707–718
Shale, dark, broken	718–720
Lime	720–732
Shale, broken	732–737
Lime	737–739
Shale, broken	739–746
Lime	746–748
Shale, dark	748–752
Lime	752–757
Shale, blue	757–762
Lime	762–770
Shale, blue	770–777
Lime	777–779
Shale, blue	779–784
Red bed	784–788
Shale, light	788–803
Lime	803–808
Shale, dark	808–837
Lime	837–844
Shale, light	844–848
Shale, dark	848–860
Lime	860–862
Shale	862–865
Lime	865–870
Shale, dark	870–873
Lime	873–876
Shale, dark	876–882
Lime	882–885
Shale, dark	885–889
Lime	889–897
Shale	897–902
Lime	902–903
Shale, black	903–904
Lime	904–905
Shale, dark	905–910
Lime, gray	910–914
Shale, light	914–918
Lime, gray	918–922
Shale, dark	922–929
Shale, green	929–954

Shale, dark	954–1016
Lime	1016–1020
Shale, black	1020–1028
Lime, hard	1028–1030
Shale, black	1030–1037
Shale, blue, sandy	1037–1044
Lime	1044–1045
Shale, dark	1045–1047
Lime	1047–1048
Shale, dark	1048–1066
Lime	1066–1070
Shale, dark	1070–1080
Lime	1080–1082
Shale, dark to black	1082–1104
Lime	1104–1105
Shale, dark	1105–1116
Lime	1116–1118
Shale, dark	1118–1125
Shale, yellow	1125–1132
Shale, dark	1132–1151
Lime	1151–1153
Shale, dark	1153–1160
Shale, sandy	1160–1165
Shale, dark	1165–1172
Lime	1172–1173
Shale	1173–1176
Lime	1176–1178
Shale, dark	1178–1195
Shale, light, sandy	1195–1211
Lime, gray	1211–1213
Shale, light, sandy	1213–1218
Shale, dark	1218–1300
Sand, water (oil showing)	1300–1305
Shale, dark	1305–1308
Lime	1308–1311
Shale, black	1311–1313
Shale	1313–1314
Lime	1314–1316
Shale, black	1316–1332
Water sand (oil showing)	1332–1337
Shale, light	1337–1357
Shale, dark	1357–1367
Shale, black	1367–1370
Shale, dark	1370–1387
Shale, black	1387–1390
Shale	1390–1391
Shale	1391–1395
Lime and particles of iron	1395–1400
Shale, black	1400–1404
Shale	1404–1410

Deep Wells Abandoned Since 1912 (Compiled in 1925)

Location	Depth in feet	Year completed	Remarks
Amana			
Woolen mill well	1640	1883	Heads now 2 feet above curb, discharge 100 g.p.m.
Belle Plaine			
City well	1503	1907	Soon after completion superseded by artesians 200 feet deep. Supply now from shallow wells in gravel on Salt creek
Burlington			
Iowa Soap Co.	509	1904	Cost of chemical treatment as much as that of city water
Sanitary Milk Co.	487	1905	Plant moved to other location
Cedar Rapids			
City wells nos. 2 and 3	1450	1888	Cost of pumping, due to lowered static level
Y. M. C. A. well	....		Building now used for other purposes
Centerville			
City well no. 2	1540	1895	Replaced by impounding reservoir. Quality of well water poor
City well no. 3	2054	1904	Replaced by impounding reservoir. Quality of well water poor
Cherokee			
State Hospital for the Insane	1070	1902	Replaced by 4 wells 200 feet deep
Clinton			
C. & N. W. Ry. Shops	1159	1896	Supply now pumped from Mississippi River
C. & N. W. Ry. Shops	?	1900	
Clinton Paper Co.	1076	1883	Property sold
Excelsior Laundry Co.	737	1910	Plant moved. Present head + 16 feet. Increased flow when City well no. 6 was drilled
Council Bluffs			
Hurd Creamery Co. (Bloomer Ice Co.)	1280	1906	Cessation of flow and cost of pumping
State School for Deaf, well no. 1	1012	1885	
State School for Deaf, well no. 2	1080	1889	Rusting of casing and fill
Dubuque			
City well, 6th Ave.	1927	1900	
Consumers' Steam Heating Co.	802	1884	
Cushing factory	965	1888	
Schmidt Brewery	886	1891	
Linwood cemetery well no. 1	1765	?	City water found cheaper than cost of pumping
Linwood cemetery well no. 2	1954	1891	City water found cheaper than cost of pumping
Steam Heating Co.	802	1884	
Dunlap			
City well	1500	?	Superseded by four 5 inch sand points

Deep Wells Abandoned Since 1912 (Continued)

Fort Madison			
Atlee Lumber Co.	720	?	
Hinde and Dauch Paper Co., no. 1	689	1888	Replaced by 5 wells from 130 to 145 feet deep
no. 2	689	1903	
Jefferson			
City well	2026	1886	
Keokuk			
Hubinger Tile and Brick Co.	800	?	Plant abandoned
Hubinger house wells	2000-2230	?	Property sold, lakes fed by wells drained, and houses built on site
Keokuk Pickle Co.	710	1892	Company out of business
Rand Park	1800	?	
Mallard			
City well	1050	1903	Fill with sand
Mason City			
City wells nos. 1, 2, 4, 5	651-616	1892	Supply now drawn from 4 wells 1200 feet deep
Onawa			
City well	863	1905	Infection
Ottumwa			
Y. M. C. A.	800	?	
Waterloo			
City well no. 1	1373	1905	Adequate supply from later wells, soil infected
Waukon			
City well no. 1	577	1896	Supply from wells nos. 2 and 3

Deep Wells of Diminished yield, reported in 1925

	Depth	Date of Completion	Date of first notice of diminution	Head above or below curb: Original	Head above or below curb: Present (1925)	Yield: Original	Yield: Present (1925)	
	FEET	YEAR	YEAR	FEET	FEET	GALS. PER MINUTE	GALS. PER MINUTE	ALLEGED CAUSE, REPAIRS
Burlington								
Ice Company	852	1911		+51		500	75	Rusted casing
Murray Iron Works	831	1903		+92	=	300	50	Repacked, recased
Bettendorf								
Water works well no. 1	1650				—3	1000	600	
Bloomfield								
City well	1817	1900		—130	—172	300	300	No repairs
Cedar Rapids								
City well no. 1	1450	1894		+28	—18	250		
Clinton								
Corn Syrup Refining Co.	1226	1908			—14	400	275	No repairs
Curtis Bros. & Co.	1150	1911			—7		150	No repairs, draw down of 14 feet when pumping at capacity
Gas and Electric Co.	1605	1911		+2	—14	500	250	No repairs
Davenport								
Independent Produce Co. (Malting Co.)	1285	{1896 1904	1917					Interference from other wells
French & Hecht (Metal Wheel Co.)	1539	1909	1919-25	+21	=	200	65	Recased and repacked in 1921
Independent Baking Co.	900		1920		+2		17	No repairs
Kohr's Packing Co. (Tri-City)	1100	1893	1922	+46	—35	250	300	No repairs
Nichols Steel & Wire Co. (Corn Products Co.)	[1500 2007	1876 1892		[+58 +81	[+10 =			No repairs
Schmidt Bldg.	1200	1892	1922	+30	—30	45	40	Recased and cleaned in 1924
Witts' Bottling Works	780	1891	1899	+82	—6	300	20	Cleaned and repacked in 1905; loss sudden in 1899

	Depth	Date of Completion	Date of first notice of diminution	Head above or below curb		Yield		
				Original	Present (1925)	Original	Present (1925)	
	FEET	YEAR	YEAR	FEET	FEET	GALS. PER MINUTE	GALS. PER MINUTE	ALLEGED CAUSE, REPAIRS
Dubuque								
Bank & Insurance Bldg.	1380	1900	1920	+10		125		Repaired in 1925, effect, 35 per cent increase in flow
Jas. Beach & Sons	965	1897		+34	=			Recased in 1908 and 1912
Elkader								
City wells 1 and 2	180	1896	1913	+20		500	145	Dynamited, cleaned, recased, repacked
Fort Madison								
Santa Fe Ry. Shops	700	1906	1922	+69	=	300		Filling with sediment
Hampton								
City well no. 1	1709	1900	1923	—50	—123		366	Filling, rusting of casing, no repairs
Homestead								
City well	1895		1914	—90	—155			No repairs
Keokuk								
Y. M. C. A. well	769	1902	1921	+50	+20	350		Cleaned in 1919
Ottumwa								
John Morrell Co. Well no. 1	1110	1888	1895				100	Rebored in 1892
John Morrell Co. Well no. 2	1554	1892	1895				50	No repairs
John Morrell Co. Well no. 3	1702	1897	1902				450	No repairs
John Morrell Co. Well no. 4	2205	1904					1000	
Rockwell City								
City well no. 1	1475		1920	—115	—160			No repairs
Sabula								
City well	973	1895		+74	+27	720		Repacked and recased in 1913 without effect
West Liberty								
City well	1768	1888		+9	—23	120	250	No repairs
Condensed Milk Co. (Bought by City)	1721	1904				300	325	Recased and cleaned in 1923

WELL WATER RECESSIONS IN IOWA[1]

JAMES H. LEES

Well waters of Iowa may be grouped into two classes, so far as their origin is concerned. These are waters derived from the glacial drift, with its interbedded sands and gravels, and those obtained from the underlying bed rock. The great body of the glacial drift consists of more or less pebbly compact clay which absorbs water rather slowly, hold but little and yields it grudgingly. Associated with the mass of this clay, or till, however, are bodies of sand and gravel, some of them more or less lenticular and of limited size, some of them with more uniform dimensions and of very considerable extent, either as widely distributed layers or as long narrow accumulations filling channels in glacial drift or in rock. Such bodies make excellent reservoirs and yield their stores of water readily enough, except in cases where the sand is very fine. Another type of material which is associated with the glacial till, although it is of eolian rather than strictly glacial origin, is the loess—a very fine-textured clay or silt, typically without sand or pebbles, although these are found locally, especially near the base of the loess deposit. Despite its fine grain and texture the loess is very porous and transmits water quite freely, hence it, and especially its sandy base, forms an aquifer of some importance.

FIVE DRIFT SHEETS

Five glacial drift sheets have been recognized in Iowa. The oldest of these, the Nebraskan, covered the entire state and apparently it still constitutes the major fraction of the glacial deposits of western Iowa at least. A basal sand seems to be widely present and supplies a number of wells which penetrate the overlying beds. A second drift sheet, the Kansan, covered all of

1 Reprinted by permission and with additions from the Journal of the American Water Works Association, Vol. 18, No. 3, September, 1927. Presented before the Chicago Convention, June 9, 1927.

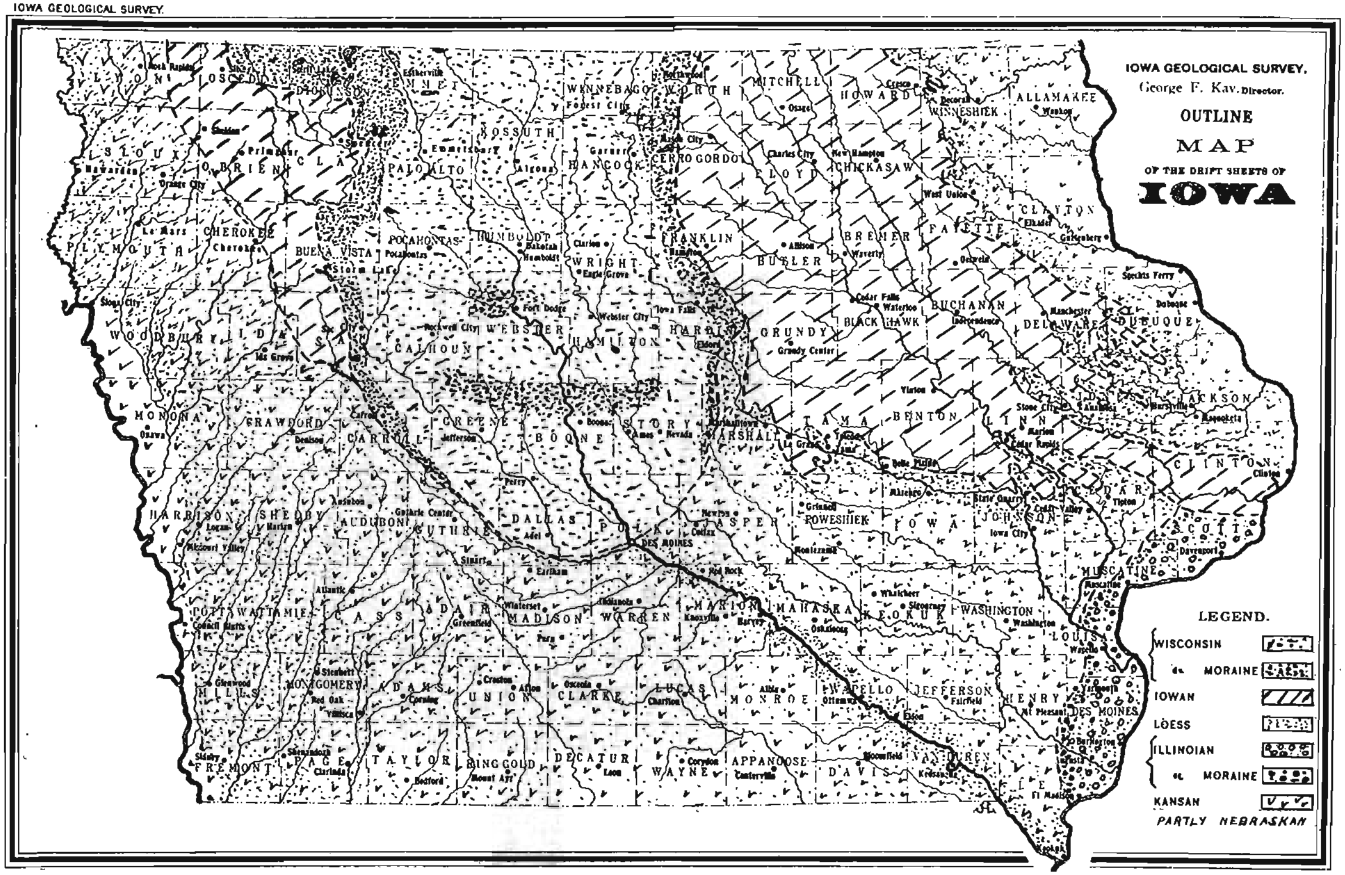

Fig. 1.—Glacial drift sheets of Iowa.

Iowa except the northeast corner and forms the surface drift of southern and northwestern Iowa. It is separated from the Nebraskan by a generally distributed gumbotil, a dark gray, very fine-textured gumbo clay which is residual from chemical weathering of the underlying till and which forms a floor for the basal sands which are related to the Kansan drift. A narrow strip of southeastern Iowa between Davenport and Fort Madison is covered by Illinoian drift, which resembles the older drifts in general character, in the presence of embedded and basal sands and in being overlain by gumbotil. Most of the northeast quarter of the state is covered by Iowan drift, which is notable for its exceptional thinness and for the great deposits of loess which mark its boundaries and spread in an ever-thinning blanket over the older drifts. Loess of approximately the same age is piled up also in thicknesses of thirty to a hundred feet or more along the bluffs of the two bordering rivers of the state and in lesser quantities along the Des Moines and over the intervening territory. In north-central Iowa, however, the Des Moines valley loess is mantled by the Wisconsin drift, the youngest of the glacial deposits of the state. Within recent years the Iowa Geological Survey has determined the presence in northwestern Iowa of a strip of Iowan drift west of the margin of the Wisconsin lobe. This is shown on the map, figure 1.

TOPOGRAPHY OF DRIFT AREAS

The topography of the northeast corner of Iowa, the only part of the state uninvaded by glaciers later than the Nebraskan, is exceedingly rugged, the drift is almost entirely eroded away and the only unindurated materials are alluvium and coarser filling in the valleys and residuum from rock wastage and loess on the uplands. The valley filling furnishes an abundant and permanent supply of water to wells sunk therein, but the upland covering is thin and over much of the area is well drained so that comparatively few wells find sufficient water in it, but are compelled to enter the underlying rocks. The thickness of the Kansan and Nebraskan drifts of southern Iowa is much greater than that of the northeast corner and reaches a maximum of 500 feet or more in some of the western counties. The topographic features are markedly erosional, although some upland tabular divides still indicate the level character of the original drift plain. Near the "breaks" water is likely to be found only at considerable depths and this is true of some parts of the uplands, as where no gravel beds have been penetrated and hence wells must be sunk through the entire thickness of the drift to search for the sand bed at its base. The deep, wide valleys of this province supply many town and farm wells although even here some failures are to be noted and recourse must be had to ponded surface supplies. The characters of the Illinoian drift plain are similar to those of the province just described except that here are three drifts with their contained gravels and sands from which water may be drawn.

The loess overlying the three older drifts in southern and northwestern Iowa has always been utilized as a source of water for shallow wells, which generally have been sunk to the basal sand layer. In some parts of western Iowa a good many wells are supplied from a layer of gravel which lies immediately under the loess, but which seems to be residual from the wastage of the drift rather than depositional, as a part of the loess. The Iowan drift plain of northeast Iowa has typically a rather gently rolling surface, which, where the drift is thin, permits of fairly free natural drainage of the ground water. Where the thickness of the drift is greater, ranging up to 200 to 300 feet, the water content is much larger. The topography of the Wisconsin drift sheet is very immature so that except near the few larger streams the glacial materials are water-logged and the head of water is high, permitting the use of many shallow wells.

INTERMEDIATE WATER SUPPLIES

It is impossible of course to distinguish sharply between the waters of the glacial drift and those of the country rock, as there is naturally a continuous interchange, especially where the rock under the drift is limestone or sandstone. Not only are these rocks sufficiently porous to permit absorption of the overlying water, but wherever the solid strata are overlain by broken or residual materials these latter hold a supply of water and in many cases serve as a valuable aquifer. Where the country rock

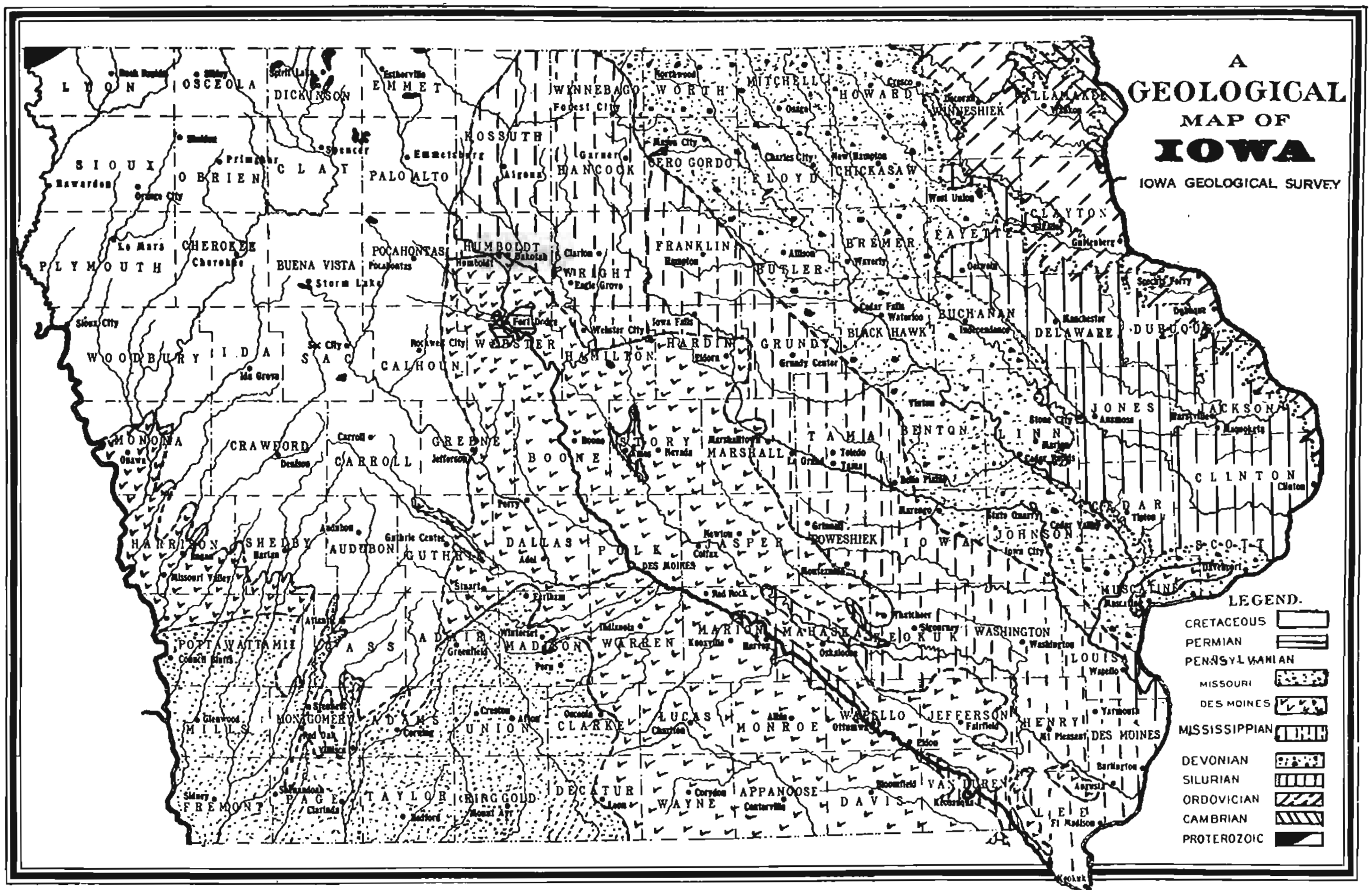

Fig. 2.—Geological map of Iowa

is shale, however, it acts as a confining rather than a contributing agent.

DISTRIBUTION OF STRATIFED ROCKS

The stratified rocks come up to the glacial beds in a series of broad irregular belts with a general northwest-southeast trend, as is shown on the geological map, figure 2. The series includes sandstones, shales, limestones and intergradations of these three types. There are no eruptive rocks to break the sedimentary succession and very little faulting and comparatively little warp-

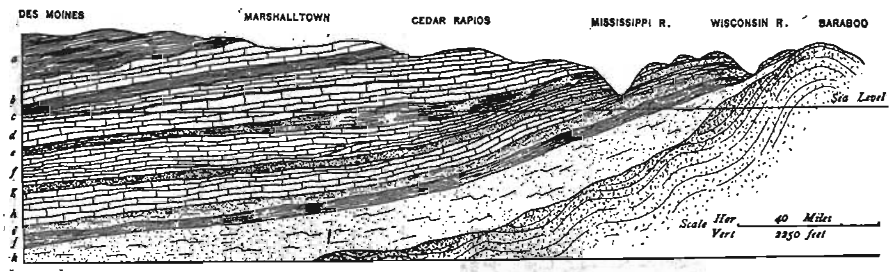

Fig. 3.—Geological section from Baraboo, Wisconsin, to Des Moines, Iowa, showing the general stratigraphy of the region. The drift is not shown. The chief aquifers are the Saint Peter, the Jordan and the Dresbach sandstones. The line of juncture of the Cambrian sandstones and the underlying Huronian is hypothetical. *a* Des Moines; *b* Mississippian; *c* Devonian; *d* Niagaran; *e* Maquoketa; *f* Galena-Platteville; *g* Saint Peter; *h* Prairie du Chien; *i* Jordan sandstone; *j* Saint Lawrence; *k* Dresbach and underlying Cambrian. By W. H. Norton.

ing have occurred to rupture or deform the beds. In age the strata range from Upper Cambrian to Upper Cretaceous, with the older rocks exposed in the northeastern part of the state and the younger ones to the west, southwest and south. From their outcrops the strata have a general dip toward the southwest of about ten feet per mile, hence the older beds lie within reach of the drill over most of the state, exception being made of the northwest corner, where some of them are absent, and of the southwest, where search for them is hardly practicable. Exception should be made also of the disposition of the Upper Cretaceous beds in western Iowa, which instead of being arranged conformably with the older strata of that region lie upon the upturned eroded edges of these older beds. The entire series of sedimentary rocks rests on a substructure of quartzite known in Iowa as the Sioux quartzite, which is practically impervious to water and hence marks the lowest limit of efforts to obtain supplies in wells. Its surface forms a great trough which rises above the

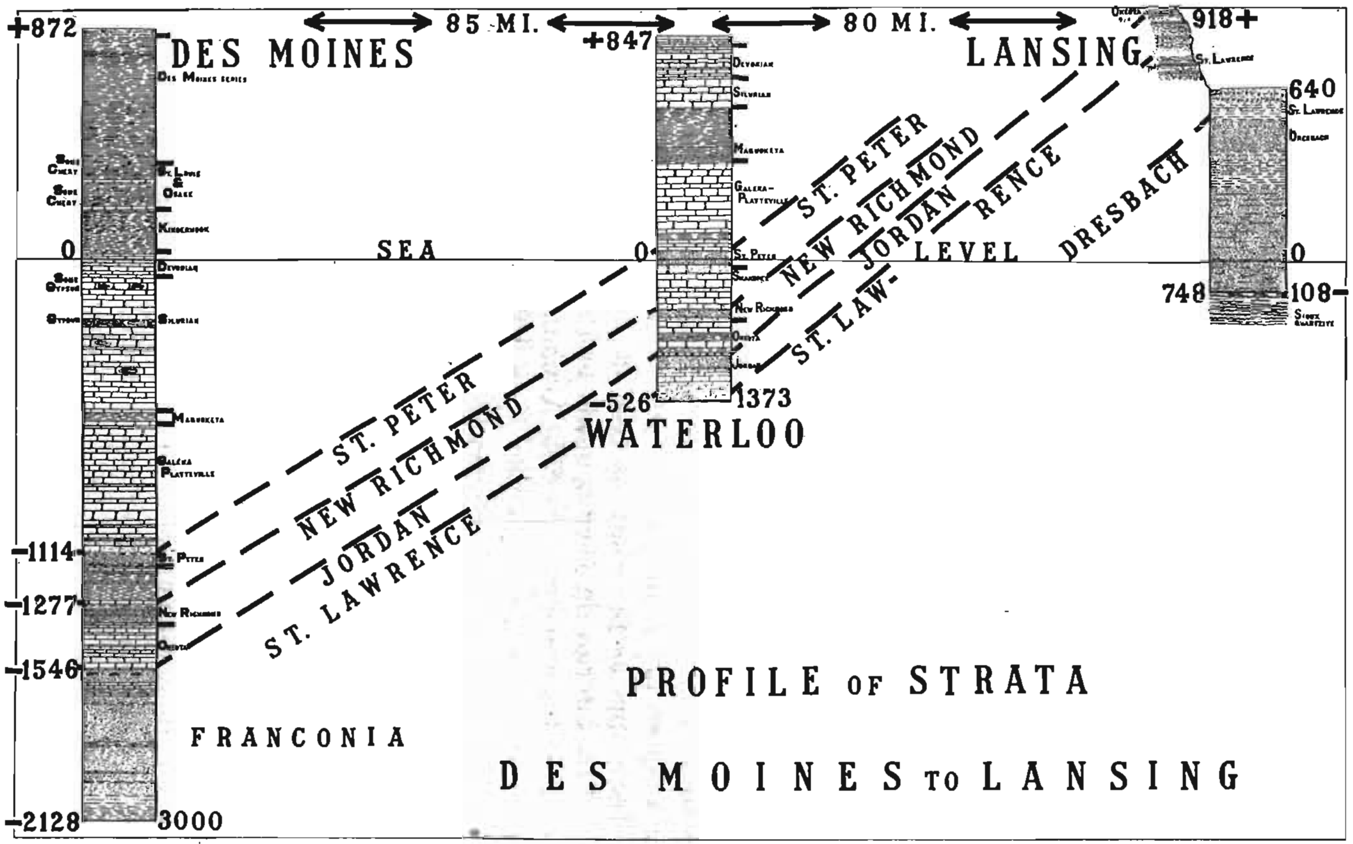

Fig. 4.—Profile showing dip of water-bearing beds from Lansing to Des Moines.

newer strata in the northwest township of the state, is 1600 feet deep or more in the north-central counties and is 750 feet below the Mississippi in the northeast corner of Iowa. Wells in central Iowa do not reach it at 3000 feet.

WATER BEARING BEDS

The limestones, of course, are water-bearing and yield generously when a crevice or a channel is reached by the drill, but the most reliable aquifers are the great sandstones, including the Jordan, Dresbach and Mount Simon sandstones of the Cambrian and the New Richmond and St. Peter of the Ordovician. These beds have a large area of outcrop in the adjoining parts of Iowa, Wisconsin, and Minnesota, they also have a very wide distribution under the younger rocks beyond the area of their outcrop and their physical characters are such as to enable them to carry enormous volumes of water under considerable head and under conditions of exceptional purity. These characteristics give the sandstones such high favor that over probably three-fourths of the state they are sought as the ultimate desiderata where deep-lying supplies are required. Flowing wells are obtained along the Mississippi as far south as Keokuk, but under the higher lands of the interior the head is insufficient in most cases to bring the water to the well curb. At New Albin in the northeast corner of the state the Jordan sandstone rises 966 feet above sea level while at Des Moines it is 1546 feet below sea level and at Stuart, the farthest southwest at which it has been reached, its surface is 1495 feet below sea level. The distance from the Jordan to the New Richmond is about 175 feet while the St. Peter lies about 150 feet above the New Richmond. The Dresbach and underlying sandstones are at least 500 or 600 feet thick. The Jordan averages about 100 feet, the New Richmond 50 and the St. Peter nearly 100 feet in thickness, thus assuring an abundant water-containing volume.

The foregoing summary may serve to give a generalized impression of the ground water situation in Iowa and furnish the background for a study of the depletion of ground water resources. That there has been such a depletion since settlement began is a matter beyond question—the difficulty lies in determining the causes and the amount, as well as the remedy.

McGEE'S STUDY OF WELLS

An investigation into the relations of wells and subsoil water was made in 1910 by W J McGee, a native of Iowa, who at that time was in charge of Soil Water Investigations for the U. S. Bureau of Soils. This investigation covered all of the United States, but only Iowa will be considered here.[2] Illinois, Indiana and Iowa were classed as having the most dependable records.

The 99 counties of Iowa were represented by 517 reporters, who sent information about 1527 wells, the highest number reported from any state except Missouri, which had the same number. Besides information about the locations and ownership of the wells the reporters were asked for data as to the character of wells, dates of making, and original and present depths of water in the wells. McGee divided the wells upon which reports were made into shallow or dug and deeper or drilled wells, excluding flowing wells and those of great depth. The summarized data for the two classes of wells were tabulated and arranged as in table 1.

Ground water levels.—A number of the reporters remarked that the water level had not changed much in the preceding 20 years, that is since 1890. Some observed that there had been little change in 40 or 50 years, others that some springs and wells gave better supplies than formerly. But most observers reported that the general water level had lowered so much that, whereas the settlers and early residents had obtained sufficient water from dug or bored wells 10 to 30 feet deep, now nearly all the wells within the reporters' knowledge were drilled—to depths of 60 to 100 feet, or some to 200 and 300 feet. In his own summary McGee states: "To one familiar with the state since the settlement of the eastern counties (as he was) the records and remarks jointly indicate a mean lowering of the subsoil water level during an average of 50 years that can hardly be put at less than 20 feet." However, as an average of the wells reported to him McGee estimated 12.5 feet as the lowering during the preceding

2 United States Department of Agriculture, Bureau of Soils Bulletin 92.

half century. For the typical agricultural states McGee states that "the average lowering since settlement would appear to be no less than 9 feet, i.e., from well within to about the limit of capillary reach from the surface."

Table I, McGee Classification of Wells

	SHALLOW		DEEP		AVERAGE
	NUMBER		NUMBER		
Date of making, average	768	1875	535	1895	1887
Depth of well, feet	895	36.1	632	153.0	
Original depth of water	749	15.4	506	77.8	
Present depth of water	852	11.8	551	74.4	
Rise	20	4.17	7	8.93	5.41
Fall	373	6.71	128	14.30	8.65
Depth to water table	895	24.1	607	78.7	46.1

Causes of lowering.—In discussing the causes of the lowering water table McGee dismissed a lessened rainfall as being negligible and unproved. Industrial causes such as tile and open ditch drainage, large wells, mining, etc., are of only local and rather superficial importance, as is consumption by animals and men. The greatest amount of lowering—amounting to 80 or 90 per cent—McGee assigns not so much to consumption of accumulated stocks as to the cutting off of the natural source of supply—the fact that under present conditions of cultivation storm waters do not enter the ground, but run off to the streams and so are unable to replenish the stores of ground water. The remedy, McGee points out, is to make each farm take care of all the water falling on it during the entire year by retaining this water by means of mulch or well-tilled soil or contour furrows and ridges so that it will be forced to pass into the ground.

STUDIES BY UNITED STATES AND IOWA SURVEYS

For a number of years prior to 1910 the Iowa and United States Geological Surveys had coöperated in a special study of underground water conditions in this state and in the prosecution of this study every county in the state had been visited. While the collection of statistical data on the general ground water level was not the main object much information was gathered and in many of the reports on the various counties statements are made regarding the head of water. A few citations will tell the tale of changing conditions.[3]

The pioneer wells of a flowing field in Bremer county were sunk more than 30 years before and the head of a number has diminished. The static head of some wells on the hill slopes has been so drawn down that they have ceased to flow, but the supply is still ample on the bottom lands. On the open prairie of Buchanan county some of the early settlers obtained water by wells ending in pockets or streaks of gravel in the Kansan drift. Nearly all of these wells were abandoned long ago. In Cedar county the shallow wells, which at an early date found plenty of water at the base of the loess in ashen silts and basal sands, have been generally either abandoned or sunk deeper. Many of the older wells in Iowa county were dug or bored a short distance into the drift, but at present many drilled wells range in depth from 50 to more than 300 feet, ending in sand and gravel interbedded with or immediately below the drift. At Fairfield in Jefferson county shallow wells must now be bored 10 to 15 feet deeper than formerly. Ground water beneath the level prairies of Keokuk county stands high. The basal silts and sands of the loess yield sufficient for house use. Most of the water supply of Lee county is still drawn from the drift, but an increasing number of wells in recent years have been drilled to the water beds of the country rock. The Wisconsin drift of Cerro Gordo county is so imperfectly drained that where it occurs the ground-water table is near the surface. Elsewhere the Iowan drift is too thin and too well drained to be a reliable aquifer. The sandy base of the loess of Marshall county was formerly an important aquifer but drainage and cultivation have reduced the ground-water level far below it. Wells in Adams county have been deepened to the sands at the base of the drift and the same is true of Cass county wells. In general less is said about lowered water levels in the area of the Wisconsin drift than in regions of older drift, more mature topography and better natural drainage, although even here a progressive lowering has been noted.

3 Iowa Geological Survey, vol. xxi; U. S. Geological Survey, W. S. Paper, 293.

STUDY OF DEEP WELLS

Ever since the inception of its work the Iowa Geological Survey has made the study of underground water resources and conditions a major line of effort. Some of the results of this study of drift wells have been noted. The investigation of the deeper, artesian wells drawing water from the great rock aquifers is attended with less definite and satisfactory results. One can state in many cases that the head has declined, but the reasons are more obscure and one can not always assign changing conditions to stated causes. However, the facts may be stated even though definite conclusions can not be drawn.

Some cases of lowering.—In the northeastern counties, where the Ordovician and Cambrian sandstones lie not far beneath the surface, flowing wells are common in the deeper valleys. Many of these still flow, but the head of the Lansing well has fallen 15 feet and the yield has decreased from 700 to 300 gallons a minute. Many of the wells of this region have been allowed to flow unrestrainedly for years, virtually wasting the stores upon which they were continually drawing. A similar lowering of head was noted at McGregor. Dubuque has a number of deep wells, some of which reach the Jordan, some the underlying Dresbach and some still deeper sandstones. A number of these have suffered diminished flows, from all water-bearing horizons. In some cases the loss is attributed to deterioration of casings, in others to the local effects of nearby wells and in others to general lowering of static head, due to overdraft.

The Davenport artesian field has shown from the beginning a progressive loss of pressure, lowering of static level and diminution of discharge. This has been especially notable in the case of wells drawing chiefly from the St. Peter. The head of the Jordan and lower waters remains higher than that of the St. Peter and it is evident that the latter bed is at least locally overtaxed. The head of the Witt's Bottling Works well has fallen from 81 feet above curb to 6 feet below curb and the yield from 300 to 20 gallons per minute.

Two of Cedar Rapids' city wells have been abandoned owing to the increased cost of pumping caused by the lowered static level and the well of the Burd Creamery Company at Council

Bluffs has had the same history. The head of the Bloomfield city well has dropped from 130 to 172 feet below curb, although the yield remains the same. The head of the West Liberty city well has fallen from 9 feet above curb to 23 feet below, but the yield has increased from 120 to 250 gallons per minute. There have been no repairs. The head of one deep well at Washington has dropped from 44 to 133 feet below curb while the head of another rose from 100 to 70 feet below curb. Waterloo's first deep well (1905) had a static level 20 feet above curb while the fifth one (1922) never flowed and its head has been about 50 feet below curb, or 70 feet below the head of the first well. The static level of the Sioux City wells is reported as falling at the rate of four inches yearly. From 1907 to 1921 the recession was stated to be a foot a year.

These records as well as many others at hand seem to show that a variety of causes has been effective—some of them evidently conflicting. Deterioration of casing, local clogging of the water-bearing beds, interference of nearby wells, filling of the bore hole, leakage into the surrounding strata, these are some local causes which would tend to diminish the supply and lower the head. In some cases the field is really being overtaxed, at least that portion of it near the wells. Whether the entire artesian field is being permanently overdrawn can not be told without intensive study of the relation between the supply and the demand.

RECENT INVESTIGATION OF GROUND WATER

When I was asked to prepare this paper I enlisted the coöperation of the United States Weather Bureau and the Weather and Crop Bureau of the Iowa Department of Agriculture in circularizing crop reporters and well drillers to obtain recent data on wells and ground water. Between 650 and 700 letters were sent out asking for information about the location of wells as to county, township and section; character, whether dug, bored, driven or drilled; whether in valley, hillside or upland; dates of making; depth; original and present depths to water and of water; and owners. The response to this inquiry was not very complete but some of the best and most dependable of the records submitted are tabulated below.

These records bear out the statements of the drillers to the effect that shallow wells respond quickly to seasons of drought or heavy rains but that deep wells are not so affected. Had this study been made before the rains of 1926 and 1927 undoubtedly many shallow wells would have shown a fall in water level instead of standing equal to the level of early years or rising above that level. Perhaps, also the high level maintained by shallow wells in some localities is due to especially favoring geologic or topographic conditions, as for instance broad level plains underlain by fairly impervious clay or rock, which would tend to retain the ground water. Where a lowering of water level in wells is noticed it is variously attributed to tile and ditch drainage, in so far as shallow changes are concerned, to greater demands from a vastly increased amount of stock, to local causes such as clogging of the aquifer, overdrafts on individual wells or to the exhaustion of sand or gravel beds which had supplied wells.

Table II, showing changes in wells

County	Dug (d), bored (b), driven (drv), drilled (drl)	Valley (v), hillside (h), upland (u)	Date of making	Depth, feet	Original depth to water, feet	Original depth of water, feet	Present depth to water, feet	Present depth of water, feet	Rise +, fall −, same =, feet
Buena Vista	b	u	1895	72	10	62	8	64	+2
Butler	b	u	1880	16	10	6	14	2	−4
	d	u	1898	16	10	6	14	2	−4
Carroll	drl	u		170	40		55		−15
	drl	u		130	40		50		−10
	drl	u		110	35		42		−7
Cass	d	v	1896	29	10	19	15	14	−5
	drl	u	1921	228	198	30	70	158	+128
	b	h	1923	85	30	55	30	55	=
Chickasaw	hydr		1897	63	12	51	20+	43−	−8
Clay	b	u	1897	49	30	19	15	34	+15
	b	u	1895	70	30	40	22	45	+8
Clinton	drl	u	1890	186	90	96	90	96	=
	drv	v	1914	17	15	2	15	2	=

Table II, showing changes in wells (continued)

County	Dug (d), bored (b), driven (drv), drilled (drl)	Valley (v), hillside (h), upland (u)	Date of making	Depth, feet	Original depth to water, feet	Original depth of water, feet	Present depth to water, feet	Present depth of water, feet	Rise +, fall −, same =, feet
Dallas	drl	u	1908	133	60	73	80	53	−20
Decatur	b	u	1892	46	31	15	25	21	+6
Dickinson	drl	u	1926	484	270	214	270	214	=
	drl	u	1925	127	111	16	111	16	=
	drl	h	1923	440	236	204	236	204	=
Emmet	drl	u	1922	302	144	158	144	158	=
	drl	u	1896	160	97	63	100	60	−3
Hamilton	drl	u	1923	80	80	Flow		Flow	=
Harrison			1895	20	10	10	12	8	−2
			1890	18	8	10	8	10	−2
Jasper	drl		1909	107	67	40	67	40	=
Jackson	drl	u	1895	125	90	40	90	40	=
	drl	h	1880	220	80	120	150	70	−50
Keokuk	d		1890	50	33	17	33	17	=
Kossuth	drl	u	1911	100	45	55	45	55	=
Louisa	drl		1890–1927	100	60–80	20–40	Same	Same	=
Lyon	b	v	1914	90	20	70	30	60	−10
	b	v	1920	30	10	20	10	20	=
	b	u	1924	210	54	156	30	180	+24
Mahaska	d		1853	45	29	16	29	16	=
Marshall	drl	u	1912	280	100	180	120	160	−20
	drl	u	1913	2100	300	1800	115	1985	+185
Montgomery	d	v	1894	20	10	10	16	4	−6
O'Brien	b	u	1905	20	12	8	6	14	+6
Plymouth	drl	u	1897	160	100	60	100	60	=
Pottawattamie	b	h	1923	26	20	6	20	6	=
Shelby	drl	u	1922	270	200	70	200	70	=
Sioux	drl	h	1895	140	110	30	110	30	=
	b	u	1917	34	14	20	8	26	+6
Van Buren	d	h	1860	30	15	15	15	15	=
Warren	d	u	1880	28	25	3	12	16	=13
Webster	drl	u	1906	85	26	59	26	59	=

Comments.—The following comments, gleaned from the reports of crop reporters and well drillers over the state, are, perhaps, more illuminating than the records of wells as they reveal widespread conditions and general impressions gained through years of experience.

Adair county, Orient—Water level rose during April, 1927. Will be normal soon. *Bremer,* Janesville—Water level 75 to 100 feet deep. *Buchanan,* Independence—Depth of wells previous to 25 years ago ranged from 20 to 25 feet. Wells stone walled but of no use now. Drilled wells 75 to 240 feet deep, water level constant. *Buena Vista,* Marathon—Bored wells going dry; have to drill to get water; never less than 140 feet, some as deep as 520 feet. *Butler,* Allison—Many wells drilled deeper. Springs flowing as for past 50 years. *Carroll,* Breda—Surface wells last only in low lands. *Cass,* Atlantic—Some shallow wells 25 feet deep. *Chickasaw,* Ionia—Head of some wells put down 30 years ago has lowered very materially. Shallow wells have changed most. *Clarke,* Murray—There are no springs as there used to be. *Clay,* Spencer—Shallow wells mostly dry before rainy season. Water in deep wells varied but little. *Clayton,* Farmersburg—Formerly used dug wells, up to 90 feet deep; now are drilled, 150 to 400 feet. Ravines dried out. *Clinton,* Grand Mound—Water 40 to 50 feet down. Calamus—driven wells not good in dry season. Drilled wells unvarying. *Crawford,* Denison—Water in wells fell 12 feet in 50 years. *Dallas,* Adel—Draining land causes wells to go dry if they are not over 15 to 35 feet deep. Best dug wells range from 50 to 100 feet, not affected by dry or wet weather. Waukee—Water in drilled wells lowered 20 feet in 20 years. Bored wells 38 to 50 feet deep. Water at about level of tile drains (1927); rarely gets lower than 25 feet. *Decatur*—Many ponds and springs dry and wells low previous to rains of 1926. Now up to normal. *Delaware,* Manchester—Most wells 75 to 100 feet deep, in rock, water within 50 feet of top. Some drive points 20 to 30 feet, plenty water. *Des Moines,* Danville—Haven't heard of a well going dry for 10 years. Wells nearly all bored, 25 to 75 feet deep. *Dickinson,* Milford—Rains in fall of 1926 helped shallow dug and bored wells greatly. Can't notice any change in water level of deep wells. Bored wells not satisfactory in dry years. *Grundy,* Grundy Center—Very few dug wells dependable, all wells drilled, average depth to water 125 to 150 feet. *Guthrie,* Herndon—Many shallow wells, 16 to 30 feet, but not dependable. Stock wells about 125 feet deep. *Hamilton,* Roland—Water level lowered at least 10 feet in 38 years. *Hancock,* Crystal Lake—Water level in drilled wells 150 to 200 feet down. *Harrison,* Modale—Drainage canals have lowered water level on Missouri bottoms. Missouri Valley—In 1900 water reached at 80 feet on high ground, now at 100 feet. Moorhead—Surface water gradually going deeper, dug wells going dry. *Howard,* Cresco—Wells 250 feet deep, plenty water. *Jackson,* Miles—In early day got wells in dirt. Then had to drill short way into limestone. From 1880 to 1895 nearly all wells had to be made deeper. *Jasper,* Sully—Very little change in 18 years. Seasons do not seem to affect drilled wells but dug and bored wells fluctuate very much. *Iowa,* Conroy—Wells 150 to 500 feet, deepest in limestone. *Jones,* Martelle—Wells 80 to 160 feet, average 100. Center Junction—Wells 80 to 300 feet deep. *Kossuth,* Lu Verne—Rain or drought has no affect on drilled wells. Algona—Bored wells playing out. A few springs have stopped running. Head of drilled wells has not changed. *Louisa,* Wapello—Every farm has drilled well. *Lyon,* Inwood—Deep wells not affected by drought. Tile drains not running so much as a few years previously (before fall rains of 1926). Rock Rapids—Wells all drilled, 250 to 350 feet, water not very good. Along Rock river wells 15 to 25 feet, plenty of good water. *Mahaska,* Cedar—Wells go to gravel bed 25 to 60 feet deep and do not vary. *Marshall*—Water level lowered 10 feet in 38 years. *Mills,* Henderson—Water reached on high hills at 50 feet in 1917, at 75 feet in 1926. Drilled wells up to 225 feet deep. *Monona,* Soldier—Water reached in dug wells at 70 feet. Sloan—Wells on Missouri bottoms all drive pipes, 20 to 30 feet deep. *Monroe*—Deep wells and shafts show as much water as 37 years ago. *Montgomery*—No ponds now, wells have to go deeper. Red Oak—Water reached on high ground at 60 feet in 1915; at 75 feet in 1926; on lower ground 25 to 40 feet. Wells mostly bored or drilled, a few dug. *O'Brien,* Paullina—Water plentiful at 25 to 50 feet. Sheldon—Water level raised last three months (spring, 1927). *Page,* Villisca—Water abundant in bottom lands; irregular in hills, many sand beds dry. Wells have to go deeper now. *Plymouth,* Ireton—Deep wells not affected by wet or dry seasons, surface water is opposite. *Pocahontas,* Pomeroy—House wells on hills about 20 feet to water, on low ground about five feet. *Polk,* Elkhart—no lowering of ground water level seen in 30 years. *Pottawattamie,* Oakland—Has bored 4000 wells in Pottawattamie, Cass, Shelby, Montgomery, Mills; 35 years ago water plentiful anywhere, today on side hills is a thing of the past, plenty on wide uplands, over 100 feet deep at breaks; plenty water at 250 to 350 feet on hills. As much water at 40 feet in valleys as 25 years ago, surface water at 10 feet 85 per cent gone as compared with 15 years ago. Ponds and springs decreased 50 per cent in five years. Hancock—Since Nishnabotna river was dredged water level lowered 15 or 20 feet in wells as far back as two miles from the stream. Ponds and surface moisture disappearing a little each year. Underwood—In 1895 water reached at 50 feet on high ground, now at 70 feet. *Ringgold,* Mount Ayr—Wells 7 feet on flats to 90 feet on upland. One well 40 feet deep in use 40 years, stronger than ever. Benton—Water seems to be same depth as 30 years ago. Shallow water at 10 to 50 feet, deeper vein discovered at 100 to 175 feet. *Scott,* Le Claire—Every farm has drilled well, sunk ten or more years ago, 140 to 300 feet deep, flow in rock, rises within 90 or 100 feet of surface. *Sioux*—More drilled wells made every year, get plenty water, but it is harder. In 1926, very few shallow wells held out but does not know of a drilled well that gave out. Eagle Tp.—Drilled wells 75 to 275 feet, average 175, not affected by drought. Boyden—Water level almost as high as ever has been. *Story,* Roland—Depth of pumping wells in north half is 75 to 300 feet. *Taylor,* Lenox—Water in same clay now as before—on high level land 30 to 40 feet deep, just above a hard clay. *Van Buren,* Bentonsport—Plenty of good wells and springs. Sees no difference in water level since he was a boy. *Warren,* Indianola—Surface water lowered a good deal in 25 years. Top water just above blue clay, bottom water (for bored wells) below blue clay. *Washington*—Can see no change in amount of water. *Webster,* Clare—Wells drilled, 300 to 400 feet. *Wright,* Belmond—Water has lowered 3 to 5 feet, but no drilled well properly made ever goes dry. Bored or dug wells getting very scarce. Water generally found on top of limestone. Eagle Grove—Used to get flowing wells at 50 feet, now at 125 to 150 feet. Where flows are not obtained water rises within 20 to 30 feet of surface. Dows—Still a few bored wells but mostly drilled. Some flowing wells 35 to 80 feet, get weak in dry weather. A few drilled wells over 200 feet, water generally 35 to 45 feet below curb. In last 2 or 3 years water is 5 to 8 feet lower.

It is only fair to the crop reporters and well drillers to say that their replies furnished a great deal of valuable information concerning wells and ground water conditions even though as in some cases they did not include the comparative data which were especially desired for this inquiry. Common knowledge of early water conditions in Iowa coupled with the table and comments given above will enable any one to draw conclusions as to changes in underground water supply.

USES OF RAINFALL AND GROUND WATER

If the ground water supply has been depleted, by exhaustion or by nonreplenishment, it may be worth while to consider the causes of that depletion, such as consumption by a greatly increased population, interception by an enlarged plant cover, tile and open drainage, methods of cultivation and other changes incident to present day civilization.

Consumption of water by human beings, other animals and machinery may be estimated thus:

Table III, Daily Consumption of Water

CLASS	NO. IN IOWA	EST. DAILY CONS. PER UNIT, GAL.*	EST. TOTAL DAILY CONSUMPT., GAL.
Human	2,420,000	100	242,000,000
Horses	1,164,800	10	11,640,000
Cattle	4,122,000	12	49,500,000
Hogs	8,330,000	2	16,660,000
Sheep	696,000	2	1,290,000
Poultry	28,840,000	0.5	14,420,000
		Estimated daily consumption	335,510,000

Estimated annual consumption 122,462,000,000
1,000,000 gallons equals 3.07 acre-feet (3.07 acres one foot deep)
Estimated annual consumption equals 375,960 acre-feet, or 4,511,520 acre-inches
Acres land in Iowa, 35,575,040
Depth of water consumed in Iowa (acres-inches divided by area) equals 0.13 inch

Much of the water used in human affairs goes right back to the streams. It would be difficult to measure accurately the amount used, but the Des Moines waterworks pumps about 80 gallons per capita per day and much is pumped besides for industrial purposes. There are about 1840 locomotives in Iowa and these will use about 4000 gallons per hour for at least four hours daily. There seem to be no statistics available giving the number of steam industrial plants. However, the arbitrary figure of 100 gallons per day is probably sufficiently accurate to cover the entire population. It is evident in any case, from the data given, that consumption by animals and man is practically negligible. What of the amount received and transpired by plants?

Use by plants.—Of each rainfall a small fraction (1) is intercepted by vegetation and evaporated back to the air without ever reaching the ground, a much larger fraction (2) reaches the ground and runs off to the rills and streams and ultimately back to the ocean and the remainder enters the soil. Thence a part (3) is evaporated, another part (4) is absorbed by plants and is transpired from their leaves, a third part (5) is retained in the soil and subsoil by molecular attraction as soil water and the remainder (6) sinks downward to join the ground water. It is this last part which must maintain the—more or less—steady flow of the streams, must sustain wells and other sources of human and other animal water supplies and must, in intervals

* Adapted from Howell Drillers News, vol. VII, no. 11, Nov., 1928, p. 2: How Much Water per Day? Cows giving milk will drink 20 to 30 gallons per day.

between rainy periods, furnish moisture to the soils above—wherever capillarity can bridge the gap—and so assist vegetation to endure the drought that might otherwise be fatal. Now what portion of the annual rainfall of Iowa, which averages nearly 32 inches, can be assigned to each of these divisions?

1. Raphael Zon, in his excellent memoir, Forests and Water in the Light of Scientific Investigation,[4] which is to be much quoted in the discussion that follows, cites European workers as finding that broadleaf forests intercept and return directly to the atmosphere 13 to 8.48 per cent of the precipitation (pp. 25, 26). Figures for this return in nonforested areas are not at hand, but from data on transpiration it would seem that crop and grass lands would intercept nearly as much of the rainfall as would forests.

2. "In the Mississippi basin one-quarter of the total rainfall forms the run-off."[5] "The run-off of most Iowa streams is close to one-fifth of the rainfall."[6] Of course these fractions include some water supplied from the ground water, so that the fraction contributed by surface water would be less than these figures.

3. Zon states (p. 27) that evaporation from soil in a beech forest with leaf litter is 6 per cent of the precipitation, without leaf litter 15 per cent. The evaporation from soil in an open field with some vegetation is said to be not over one-third of the precipitation. From bare soil the evaporation is about 50 per cent of the precipitation.

4. It is common knowledge that plants evaporate, or transpire, a great amount of water into the air. Zon says (p. 3): "For every pound of dry substance produced it has been found that corn evaporates 233 pounds of water and turnips 910 pounds. Under good cultivation an acre may produce about 7 tons of dry substance. If the evaporation of water be only five hundred times more than the amount of dry substance produced, then an acre will evaporate during the vegetative period about 3500 tons of water." This figure seems rather high for ordinary Iowa cultivation, but other figures given perhaps approach nearer the normal. Speaking of forests Zon gives figures for transpiration

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4 U. S. Dept. Agri., Reprint, 1927.

5 Pirsson and Schuchert, Geology, pt. I, p. 32, 2d Ed.

6 Nagler, Floyd, State University of Iowa, Personal letter.

as 567 to 1,019 pounds of water per pound of dried leaves of birch and ash, 436 to 914 pounds for beeches and maples, 253 to 692 pounds for oaks. Stating the case in another way he says: "Höhnel estimates that a fully stocked beech stand, 115 years old, consumes from 1,560 to 2,140 tons of water per acre, or 1.15 acre feet per year..............He found that elm transpired 43½ per cent of the precipitation of 1880, beech 25 per cent and birch 40 per cent" (p. 29).

Considering crop land, Doctor Bakke tells me[7] that "a growing crop of corn uses in our climate about one-third of the annual rainfall;" also that "the amount of water given off by an acre of wheat may be as much as 900 tons." This amounts to 0.662 acre-foot, an acre-foot being an acre covered a foot deep. Wheat uses a little more water than oats, as it produces more dry material.[8] "A square foot of long pasture grass gives off nearly 4 2/5 pints or as much as 106 tons of water to the acre" in 24 hours. "A square foot of turf will yield more than 1 1/5 pints of water in 24 hours," or 27.25 tons per acre.

5. The amount of water that is retained in the soil, both that which is available for plant use and that which can not be so withdrawn, depends on the soil texture and composition and so ranges within wide limits. The subject is elaborately treated by Meinzer[9] who states (p. 62) that King determined that "the water content in materials above the water table ranges from about 4 per cent of the dry weight for coarse mixed sands to 32 per cent for clays of finer texture. This range is equivalent to about 6 to 37 per cent by volume." Some of this water is so firmly held that plants and even evaporation can not remove it from the soil.

6. The ground water is the chief ultimate supply for streams and underground aquifers. At the time of settlement of this state, we are told, the water table, the upper level of ground water, was not far below the surface and could easily be reached by shallow holes. Now in most places it lies rather far below the surface and deep drilling is necessary to reach it. It must be re-

[7] A. L. Bakke, Iowa State College, Personal letters.

[8] Bakke, A. L., and Plagge, H. H., The Extent to Which Weeds Modify the Transpiration of Cereals: Res. Bull. No. 96, I. S. C., June, 1926.

[9] Meinzer, O. E., The Occurrence of Ground Water in the United States: U. S. Geol. Survey, W. S. 489.

membered, of course, that a drilled hole, on account of its small size, can not receive so much water as a larger dug hole and therefore would need to be sunk to a greater depth to obtain the same amount of water. However, the verdict seems to be fairly general that the water level has actually lowered, but, as to the reasons there is diversified opinion and rather bitter argument. The tables given seem to indicate that what lowering has occurred can not be charged to increased use by either animals or plants or to increased evaporation and so must be due to some cause or causes that prevent replenishment. These would seem to be various factors attendant on human use of the land. Such would be destruction of the prairie sod and its replacement by crops, some of which at least would consume more soil water, while furnishing the soil less protection from erosion and evaporation; clearing of forest lands, some of which have since suffered from erosion; artificial drainage and straightening of streams; and methods of cultivation which are not adapted for avoiding soil erosion or for holding the rainfall until it can sink into the ground.

Numbers 1, 2, 3 and 4 may be tabulated as follows, on the basis of figures given by the authorities already cited. Zon's figures are based on a rainfall of 31.5 inches, practically the same as Iowa's rainfall.

Table IV, Total Amount of Water Lost to Streams and Soil

CLASS	INTERCEPTED BY VEGETATION	EVAP. FROM SOIL	TRANSPIRED BY LEAVES	TOTAL LOSS	TOTAL LOSS OF ANN. RAINFALL
	Inches	*Inches*	*Inches*	*Inches*	*Per cent*
Beech forest with litter (1)	6.7	1.9	10.8	19.4	61.5
Beech forest, no litter (1)	4.7	4.7	10.8	20.2	64.1
Potato field (1)				13.5	42.9
Grain field (1)				25.3	80.3
Field crops in general (1)				19.4	61.6
Corn (2)			10.5		
Wheat (2)			8.		
Long grass (120 da.) (2)			111.6		
Turf (120 da.) (2)			28.6		
Runoff (3)				7	22

(1) From Zon, p. 30, (2) from Bakke, (3) from Nagler. See also page 400.

It seems probable that interception and evaporation from field crops and grasses and evaporation from soils on which these were growing would be in some degree comparable with those from the forests. If this is true the total loss to the land would equal these items plus transpiration plus runoff, or approximately 27 inches, leaving about five inches for soil water and ground water. Nagler says that evaporation and transpiration account for 24 inches, but this leaves practically none to stay in the ground.

Changes in transpiration.—It is an interesting speculation as to whether evaporation and transpiration have changed materially in Iowa since settlement was an established fact. According to the Iowa Census of 1865 there were 23,310 acres of orchard and 26,285 acres of planted forest. Native forest probably covered 2,400,000 acres, as the 1875 census recorded 2,321,659 acres of native timber and certainly extensive clearing had been done during the decade.[10] This gives a total tree-covered area of 2,450,000 acres. The census of 1925 gives the acreage of timber as 2,132,461 and the Iowa Weather and Crop Service estimates the acreage of orchards in 1928 as 75,000, giving a total acreage of about 2,207,500. So it seems that forest transpiration has been eliminated over 242,500 acres. Eastern and southern Iowa is said by early residents to have been covered with high lush grasses while northwestern Iowa bore shorter prairie grass. According to the figures given in table IV these grasses must have transpired enormous amounts of moisture, especially as they were active from early spring until autumn. Again, then, it would seem that transpiration from the primeval prairie would have been greater than from our present day crop and pasture lands.

The foregoing paragraphs are not intended as a complete discussion of the subject but rather are hoped to give a reasonably accurate summary of the ultimate disposition of our annual rainfall. There are many important questions asking for a solution which can come only with time and experience. For example: If the water level gets below the capillary reach of crops will

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10 For a map showing original forest area of Iowa see The Prairies, by B. Shimek, Bull. Lab. Nat. Hist. S. U. I., vol. VI, no. 1, 1911.

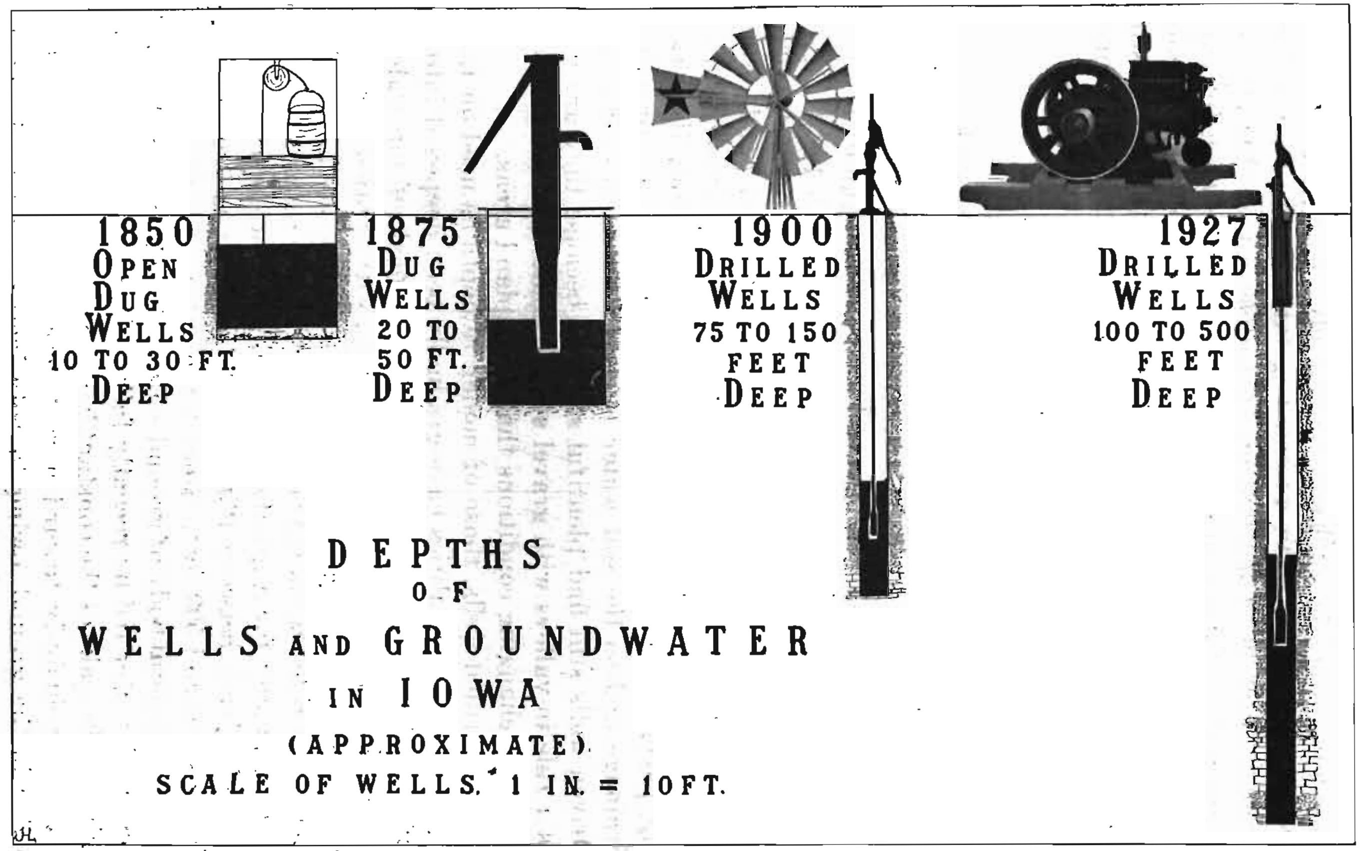

Fig. 5.—Diagram showing gradual change in character and deepening of wells in Iowa owing to improved sanitation and lowering of water table. Reduction not true to scale.

summer rainfall be sufficient indefinitely to keep up growth of crops and other shallow rooted vegetation that can not reach ground water but must depend on vadose water—the moisture in the soil and upper subsoil? Will the zone between the capillary fringe above the ground water and the overlying vadose water become dry or so nearly so that plants can get no moisture from it? In such a case how shall we get the utmost benefit from the ground water resources?

CONCLUSIONS

I believe that we are justified by the evidence at hand in drawing these conclusions: With regard to the shallow types of wells, dug or bored especially, in general these have become scarcer with the passing years because the supplies of water within their reach have gradually been depleted, partly by increased consumption by animals, by increased transpiration by cultivated crops, by open and closed drains, and partly by increased runoff of rainfall from cultivated areas. However, some parts of the state do not seem to have suffered from this lowering, perhaps because conditions are not so favorable for natural drainage and so the soil water is retained to a greater extent. Driven wells still find plentiful supplies because they are made as a rule in valleys with gravel strewn floors, which are less affected by changing conditions than are upland areas.

As to drilled wells, those of moderate depth as used on farms or smaller municipalities have gradually been deepened into the lower strata of the drift—many drillers speak of top water in yellow clay and lower water in blue clay, with another horizon in sand at the base of the drift. In parts of the state having thinner drift drilled wells now enter the stratified rocks, some for a few feet, many for a greater distance. Most wells of this class range in depth between 100 and 200 feet, although some are as deep as 400 and 500 feet. Since these wells draw their supplies from the general body of ground water rather than from the shallower soil water fed by recently fallen rains, their gradual deepening in the wake of the constant lowering of head seems to point rather conclusively toward a real lessening of the amount of water in the ground, owing to both increased demand and decreased supply. In some localities this lowering of head amounts to 20 feet or more during the present century, according to the reports of several drillers, and the total lowering from the time of settlement must be much more than this amount. However, other drillers state that they see little or no difference in ground water conditions while they have been drilling and of course those local factors which affect shallow wells would have some, though less, influence on wells of this type. Again, while shallow wells fluctuate with the seasons and respond quickly to periodic variations in rainfall, deeper wells show much less change from season to season and year to year.

Finally, as to the deep artesian wells which seek out the great aquifers of the stratified rock series, the evidence so far obtainable seems to be far from conclusive or even consistent. Some of these wells have suffered diminished yields and lowered heads, some of them headed lower from the start than did earlier wells in the same region. But some have higher heads than would be expected from the known factors and a few report higher heads or greater yields than formerly. Unfortunately for purposes of study these wells are not spaced closely enough for us to say definitely whether or not the general level or the amount of water has receded or remained the same, or, in other words, whether such changes as have occurred are due to local or to widespread causes. Of course, the deeper a well is the greater is the available radius from which it may draw its supply and the greater its chance of surviving drought or draft. Therefore, these deep wells as a class will always have a large assurance of permanence even in the face of the unfavorable factors.

Addendum—Since the above was written the writer has had access to Dr. Meinzer's Plants as Indicators of Ground Water (Water Supply Paper 577) and a mimeographed report by Mr. W. N. White on work in the Escalante Valley of Utah on the discharge method of estimating ground-water supplies. Meinzer (p. 87) cites the studies of other workers, as G.E.P. Smith (Trans. Am. Soc. Civ. Eng., vol. 78, pp. 226-230, 1915) showing that the ratio of transpiration to evaporation seems to be independent of such factors as light, temperature and humidity; also that, climatic factors being equal, transpiration depends on the ease of obtaining supplies from the ground water and the character of the vegetation. He states that alfalfa has been found to use 831 tons, or 0.637 acre foot, of water for each ton of dry plant produced. In line with data given above in table IV, Smith states that alfalfa grown in Wisconsin transpired 41 inches of water and that evaporation from the soil amounted to 10 inches additional. Transpiration and evaporation from soil in a clover field amounted to 22.3 inches during the growing season.

White's work indicated that beneath an alfalfa field the daily draw down of the water table averaged 1¼ inches and that while there was some recovery during the night it did not quite equal the diurnal loss. The daily draw down under sedges and marsh grasses reached as high as 4¼ inches. The depths of (added) water required to raise the water table one inch ranged in different soils from 0.024 to 0.09 inch. This gives an indication of the effect of rainfall on the water table.

MUNICIPAL WATER SUPPLIES OF IOWA CITIES AND TOWNS*

Town	Source	Diameter	Depth, feet	Head, feet	Supply
Ackley	3 wells	12 in.	127		Ample
		10 in.	150		Ample
		13–9 in.	263		100 g.p.m.
Adair	well	20 ft.	30		Ample in wet seasons
	12 wells	3 ft.	30–60		Used in dry weather
Adel	well	8 ft.	28		3, 3 in. strainers extend into sand (reserve)
	Raccoon R. water is filtered				
Afton	well	12 ft.	35		Ample. Low ground
Ainsworth	well	6 in.	180		Ample
Akron	2 wells	36 in.	43		Ample. Into gravel, 75 ft. apart
Albert City	well	12 in.	182	–30	Unfailing
Albia	Surface reservoir, cap. 300,000,000 gal.				Sufficient all seasons
Alden	well	8 in.	305		Overflows when not in use. Pump lowers head 25 ft. Tests 100 g.p.m. On river bank
Alexander	well	8 in.	117		Ample
Algona	3 wells	12 in.	1000		100 g.p.m.
		6 in.			100 g.p.m.
		12 in. +	1885	–100	200 g.p.m.
Allison	well	6 in.	250 +		Not affected by pumping 40 gal.p.m. 16 hr. per da. for 31 da.
Alta	2 wells	8 ft.	72		46 g.p.m.
		12–4 in.	1465	–320	100 g.p.m.
Alta Vista	well	10 in.	144		Ample and reliable
Alton	2 wells	14 ft.	34		On bank Floyd R. In dry weather pump empties wells in 2 hrs., refill in 5 hours
		10 ft.	34		
Alvord	6 wells	6 in. (1)	39		
		2 in. (5)	37		Ample

* This table was prepared from the pamphlets published by the Iowa Insurance Service Bureau, which give data regarding the water supplies and fire protection of all Iowa cities and towns. The Geological Survey is indebted to the manager of the Service Bureau, Mr. K. L. Walling, for permission to use the information in the files of the Bureau and to the engineers, Messrs. Corcoran and Stokes, for their help in bringing the data in the table down to date.

MUNICIPAL WATER SUPPLIES OF IOWA CITIES AND TOWNS (Continued)

Town	Source	Diameter	Depth, feet	Head, feet	Supply
Ames	3 wells	12 in.	105		
	1 well	16 in.	180		Ample (4th ward)
	1 well	large	100 +		large, gravel-pack
Anamosa	well	10 in.	1800		300,000 g.p.d., reliable
Anita	well	20 ft.	30		Limited. Low ground
Ankeny	well	8 in.	507		20 g.p.m. without lowering
Anthon	1 well	....	136	–19	
	1 well	10 in.	144	–30	200 g.p.m. No draw down
Alpington	well	8 in.	134	curb	Ample in all seasons
Arcadia	well	6 ft.	16		67% of normal in dry weather
Arion	well	6 in.	56		Ample in all seasons
Arlington	2 wells	6 in.	190		Ample at all times
	1 well	8–5½ in.	823		....
Armstrong	2 wells	6 in.	180		Adequate
Arnolds Park	Lake Okoboji	6 in. pipe	350 ft. long		....
Arthur	2 wells	24 ft.	20		May be pumped dry in 1 hr. 40 min. } Enough for 4 hrs. pumping
		14 ft.	18		May be pumped dry in 35 min.
Ashton	well	30 in.	68	overflows	Ample at all times
Atlantic	7 wells	12 in.	80–85		Sufficient & reliable, gravel-pack, 7th in 1928, pump 150 g.p.m. from each
Auburn	well	10 in.	180		Test 50 g.p.m. 4, 24 hr. da., not lowered Well ends in sand rock
Audubon	well	12 in.	2492	–225	Unfailing—pumped at 275 g.p.m.
Aurelia	2 wells	8 in.	210 & 216		Ample at all times
Avoca	5–3 in. sand points		27		Ample at all times. Low ground
Ayrshire	well	10–6 in.	877	–116	Tested at about 120 g.p.m. No decrease
Bagley	well	6 in.	70	–15	Ample at all times
Baldwin	well	8 in.	167		Ample. Into limestone
Bancroft	1 well	6 in.	500		Ample, diminishing
	1 well	10–8 in.	600	–16	135 g.p.m., drilled 1928

Battle Creek	12, 2 in. sand points driven into sand and gravel bed				
Baxter	well	8 in.	503		Supplies 30 g.p.m. 243 ft. in rock
Bayard	well	10–8 in.	208	–30	Ample at all times
Bedford	Reservoir, dam across 102 River, 70 ft. long, 6 ft. high.				No shortage
Belle Plaine	3 wells	8 in.	36		Yield 450 g.p.m. (No. 4 yields 250 g.p.m. not used acct. sand)
Bellevue	dug well	20 ft.	30	About river level	In bank of Miss. R.
Belmond	well	8 in.	500		Ample continuously
Bennett	2 wells	8 in.	198		Ample
		6 in.	122		Ample
Bettendorf	2 wells	10 in.	1650	flows	40 g.p.m. Cap. 720 g.p.m. with pump
		20–10 in.	2122	flows	200 g.p.m. Cap. 1,000 g.p.m. with pump
Blairstown	well	8 in.	110	–15 at rest –30 pumped	Ample. Drilled 1919
Blanchard	2 wells	8 ft.	22	8 in. sand	point 25 feet lower } supply pump 2 hrs.,
		8 ft.	22	2 in. sand	point 25 feet lower } refilling in 4 hrs.
Bloomfield	well	8 in.	1817	–160	Ample
Bode	well	6 in.	210		Ample and reliable
Bonaparte	well		shallow		Ample, fed by river
Boone	10 wells 2 large dug wells	10 in.	40	slight during high water	Ample. On island in river, level changes with river level
Boyden	well	10 ft.	20		Fed by seepage and by 12 in. tile line 200 ft. long. Limited in dry weather. Ample in wet
Brandon	well	6 in.	196		Ample
Breda	well	10 in.	350	–180	Ample, 6 in. casing
Brighton	2 wells	5 ft.	48		16,000 g.p.d., may be pumped dry in 3 hrs.; supplied by seepage
		12 in. +	1815	–90	....
Bristow	well	6 in.	170		Ample, not affected by dry weather
Britt	well	10 in.	218		Filled with gravel 40 ft. Supply not affected

MUNICIPAL WATER SUPPLIES OF IOWA CITIES AND TOWNS (Continued)

Town	Source	Diameter	Depth, feet	Head, feet	Supply
Brooklyn	4 wells	8 in.	31–39		1st well tested 30 g.p.m. for 2 mo., then 50 g.p.m for a da., supply not affected. Other wells can supply 20 g.p.m. Level lowered to –20 ft. while pumping
	2 old wells	6 in. 8 in.	580 210		Used only in emergencies
Buffalo Center	well	5 in.	198		Ample at all times
Burlington	Miss. R.				
Burt	well	8 in.	518	–24	18 hr. test did not affect flow, 95 g.p.m.
Calmar	2 deep wells			–50	75,000 & 120,000 g.p.d. each. Not affected by dry weather
Cambridge	2 wells	4 & 6 in.	70		Ample, est. 300,000 g.p.d. Drilled
Carlisle	1 well	10–8 in.	700		35 g.p.m.
Carroll	4 wells	1–8, 3–12 in.	125–140		3 wells supply demand, no seasonal decrease. 1 supplies 75 g.p.m.
Carson	32 sand points		20		In creek valley. Ample
Cascade	large dug well, walled, fed by springs				Ample
Casey	3 wells	10–20 ft.	20–35		Enough for 5 hrs. pumping during entire year
Castana	2 wells	6 in.	75		Enough for 48 hrs. pumping. Not affected by dry weather
Cedar Falls	3 wells	8 in.	125	–11	Sufficient. In limestone
Cedar Rapids	Cedar R. direct into 2 wells 2 wells	 32 ft. 10 in.	 26, on island 1515		
Center Junction	deep well				Ample
Center Point	26, 2 in. and 2, 4 in. sand points, 30 ft. long				Reliable at all times
Centerville	Storage reservoir, 417,000,000 gal.				
Central City	2 wells	6 in.	100		Ample at all seasons
Chariton	Reservoir 100 acres, 300,000,000 gal., 3 mi. E. of Bus. section				Storage ample
Charles City	3 wells				
Charlotte	well	8 in.	185		Ample, tested 24 hrs., no sign of failure. Cap. 300,000 g.p.d. Pump cap. 288,000 g.p.d.

Charter Oak	well	29 ft.	45		In sand & gravel, 300 ft. from creek. Probably no shortage
Chelsea	2,6 in. sand points 6 ft. long, 36 ft. below surface.				Ample at all seasons. Wells 100 ft. apart
Cherokee	2 wells	8 & 10 in.	210	−70 while pumping	400 g.p.m.
Chester	well	6 in.	250		Test of 2 da. (pump cap. 58,000 g.p.d.) did not lower water
Churdan	2 wells	4 & 6 in.	160		Ample
Clare	well	8 in.	100		Ample
Clarence	2 wells	6 in.	122 & 164		Ample for pumps
Clarinda	Nishnabotna R. 2, 12 in. intake pipes				
Clarion	1 well	10 in.	250	flows	1,000,000 g.p.d.
	1 well	38 in. (16 in. casing)	160		1,000–1,200 g.p.m., 40 ft. draw down, gravel-pack
Clarksville	2 wells	6 in.	70		Ample at all times
Clear Lake	Clear Lake, 1, 12 in. suction line 800 ft. into lake, 1, 8 in. line 160 ft. into lake				
Clermont	2 wells	8 in.	216, 218		Ample. In limestone
Clinton	5 wells	2 each 6, 8, 10 in.	1135–2101		Flow 2,225,000 g.p.d. Test on No. 6 under air, produced 2,340,000 g.p.d. Total capacity 5,020,000 g.p.d.
Clutier	well	4 in.	230	flows	Ample at all times
Coggan	2 wells	8 in.	298		Ample for pump
		6 in.	200		25 g.p.m.
Coin	well	6 in.	42		Ample at all times; low ground
Colfax	6, 6 in. pipes with strainers driven 32 ft. into gravel. Head 17 ft. below pumps.				No data on capacity
Collins	2 wells	6 in.	180		250,000 g.p.d. (abandoned 1928)
		10 in.	384		40 g.p.m.
Colo	well	10 in.	262		Bottom 29 ft. filled with gravel. Original head—33 ft. Tested at 70–75 g.p.m., level constant at −188

MUNICIPAL WATER SUPPLIES OF IOWA CITIES AND TOWNS (Continued)

Town	Source	Diameter	Depth, feet	Head, feet	Supply
Columbus Junction	5 pipes	6 in.	53–83	flow	Ample when not pumped. Strainers on bottom of pipes, in gravel bed on Iowa R. bottoms
Conrad	well	10–8 in.	606	–160	Ample for pumps; 40,000 g.p.d.
Coon Rapids	2 wells	6 in.	107		Ample & reliable
Corning	Reservoir, dam 500 ft. long, 30 ft. high, cap. 40,000,000 gal.				
Correctionville	well	6 ft.	30		Ample in all seasons
Corwith	well	10 in.	153	–30	Ample, not affected by dry weather. Drilled 1919
Corydon	Reservoir, earth dam 600 ft. long, cap. 85,000,000 gal.				
Council Bluffs	Intake pipes 20 and 24 in. diam. 150 ft. long into Mo. R.				Watershed 320,000 sq. mi.
Coulter	well	8 in.	257		Ample, not affected by dry weather
Crawfordsville	2 wells	8 in.	240 695		15,000 g.p.d., drilled 1921 20,000 g.p.d., drilled 1915
Cresco	2 wells 1 well	8 in. 16 + to 12½ in.	200 & 400 670	 –151	Est. at 200,000 g.p.d. 250 g.pm.
Creston	Summit Lake, artificial reservoir, 150 acres, 25 ft. deep max.				Watershed 35 sq. mi., abundant
Cumberland	2 wells	5 in. 4 in.	150 200		Ample in all seasons Ample in all seasons. Held in reserve
Cushing	10, 1½ in. sand points 25 ft. deep				Ample for the pump
Dakota City	well	6 in.	164		Ample for 70 g.p.m. pump
Danbury	2 wells	5 in. cased 4 in. sand points	50 50		....
Davenport	Miss. R. Water passed through sedimentation reservoir and pressure filters				
Davis City	well	4 in.	900		Ample in all seasons
Dayton	well	10–6 in.	470	–100	Ample, draws down 50 ft. when pumped
Decorah	well 4, 4 in. sand points into gravel bed bordering river.	20 ft.	36	......	Ample at all times; in limestone Used for emergency
Dedham	well	6 in.	40		Ample, not affected by dry weather

Deep River	well	4 in.	244		Ample for pumps at all times
Defiance	3 cased wells	8 in. with sand points 46 ft. in gravel			Cap. 110,000 g.p.d. If emptied refill rapidly
Delmar	2 wells	8 in.	220		Ample for pump at 11 g.p.m.
		13–8 in.	1592	–196	100 g.p.m.
Denison	well	14–8 in.	1810	–88	Yield 200 g.p.m. Held in reserve
	dug wells in reserve. Yield 60,000 g.p.d.				One well yields 50 g.p.m.
	well	24 in.	57		600 g.p.m.
Denver	well	6 in.	170		Ample, reliable
Des Moines	Galleries in Raccoon R. bottoms, 11,821 feet.				Yield about 20,000,000 g.p.d.
DeWitt	2 wells	8 in.	524	......	In limestone
		6 in.	274		In limestone, yields 50 g.p.m.
	well	12½–8 in.	1646	–101	225 + g.p.m.
Dexter	well	12 ft.	28		Ample to supply present pump. By seepage
Diagonal	2 wells	13 in.	44 & 47½		Ample for pump. In sand & gravel in river valley
Dike	well	6 in.	160		Unfailing
Dixon	well	6 in.	130		Good, ample for pump
Dolliver	well	6 in.	250		Ample and reliable
Donnellson	3 wells	8 in.	275		Failing, deepened for new well
		6 in.	150		Yields 35 g.p.m.
		8¼–4½	1095	–80	Yields 80 g.p.m.
Doon	well	12 ft.	30		Ample for pumps. Can be emptied in 2 hrs., in very dry weather. Fills rapidly. In gravel. Brick lined
Dow City	well	6 ft. for 20 ft., 6 in. to base	51		Ample at all times
Dows	2 wells	3 in.	85		Ample in all seasons
		10–4 in.	500		
Dubuque	5 wells	6–16 in.	- 1,300–1,500	flow	700,000 g.p.d. Increased under air lift to 6,500,000 g.p.d.
	Reservoir fed by abandoned mine workings, 400,000 g.p.d.				
Dumont	6 wells	6 in.	25	–5	Adequate
Duncombe	well	8 to 6 in.	500		Ample for pumps at all times

MUNICIPAL WATER SUPPLIES OF IOWA CITIES AND TOWNS (Continued)

Town	Source	Diameter	Depth, feet	Head, feet	Supply
Dunlap	4, 5 in. sand points driven into gravel				Ample at all times. Installed 1918 (not in use, 1928). New well at this station
	1 well	6 in.	1500		Ample (abandoned, 1928)
Durant	well	10 ft.	60		Drawn down only 7–8 ft. by 12 hrs. pumping
Dyersville	well	20 ft.	30		Concrete lined, supply ample, by infiltration. In rock
Dysart	well	10 in.	1600	–120	Unfailing, 60 g.p.m.
Eagle Grove	dug well	16 ft.	56	–16	When 2 pumps are running water drops 10 ft. further, then stands constant
	old well	25 ft.	25	–6	Failed. 14 inch pipe extends to 60 ft.
Earlham	well	6 in.	510		Ample for pump
Earling	2 wells	6 ft.	30		Limited in dry weather. West sta.
	3 wells	6 ft.	30		Limited in dry weather. East sta.
Earlville	well	8 in.	175		Ample, reliable, unaffected by drought
Early	springs				
Edgewood	wells	8 in.	128, 260		Ample, wells new
Elberon	art. well	4 in.	200	flows	30,000 g.p.d. 200,000 g.p.d could be pumped
Eldon	2 wells	25 ft.	20		Ample for pump. Old sta.
	1 well	25 ft.	23		Cap. 210,000 g.p.d. New Sta. Both Sta. on low ground across D. M. river
Eldora	3 wells	10 in.	300		Cap. 50,000 g.p.d. (10 in. well)
		6 in.	200		
		8 in.	250	–132	Ample, affected little by dry weather
Eldridge	well	10 in.	573		Ample at all times
		8 in.	300		Not used, ample, but muddy
Elgin	2 wells	6 in.	150		Ample, drilled
Elkader	1 well	15–10 in.	659	+20	190 g.p.m.
	2 wells	10 & 8 in.	185	flow	12 g.p.m. each
Elliott	15 sand points, 2, 3 in.; 1, 1¼ in.; 12, 2 in., 30 feet deep				Ample. In use 10 years
Ellsworth	well	6 in.	340		Ample at all times

Elma	well	6 in.	100		Ample
	well	10 in.	160		Ample. Emergency supply; pump will lower water only 6 in. all day
Emerson	well	10 in.	44		Ample. In gravel
Emmetsburg	well	12 ft.	25		Ample in all seasons
Epworth	well	6 in.	120		Ample for pump
Essex	2 wells	12 in.	48		
		7 in.	35		Ample for pump
Estherville	2 wells	16 ft.	32 & 38		1,000 g.p.m., not reduced by dry weather. West bank D. M. river
Everly	well	16 ft.	20		Ample at all times
Exira	2 wells	6 in.	147		Ample and reliable
		6 in.	126		
Fairbanks	well	8 in.	219		Good record. In limestone
Fairfield	2 reservoirs—Cap. 180,000,000 gal.				
Farley	well	6 in.	225		Apparently sufficient
Farmington	Reservoir, 200,000 gal. cap., water pumped from D.M. river untreated, not used for domestic purposes				
Farnhamville	driven well	....	165		Ample, reliable; in gravel
Farragut	well	10 in.	165		Ample. Gravel bed 60 ft. thick
Fayette	2 wells	8 in.	65	near curb	Ample at all times
Fenton	well	6 in.	228	–54	Ample; drilled 1910
Fonda	well	6 in.	365		Ample at all times. 3–'27, casing reported repaired
Fontanelle	well	12 ft.	40		Ample at all times
Forest City	2 wells	6 in.	127		Flows into reservoir 24 by 19 ft. 380,000 g.p.d. in all seasons
		4 in.	117		
Fort Dodge	8 drilled wells	17 to 6 in.	1436 to 215	flow	1,300,000 g.p.d. Incr. by air lift to 2,793,000 g.p.d. Near Sta.
	3 wells		7–14		Emergency only
Fort Madison	Miss. R. 3 intake pipes 12, 14, 16 in., 150-200 ft. long in river				
Fredericksburg	well	10 & 8 in.	570		Adequate and reliable
Galva	21 driven wells, each with 2 in. sand point and strainer				Cap. est. at 250,000 g.p.d.
Garner	well	8 in.	380	–16	Ample at all times

MUNICIPAL WATER SUPPLIES OF IOWA CITIES AND TOWNS (Continued)

Town	Source	Diameter	Depth, feet	Head, feet	Supply
Garwin	well	8 in.	180	flows	10 g.p.m. at all times. Est. cap. with pump 100,000 g.p.d.
George	well	16 ft.	22	-14	Ample, when pumped down to 3 ft. runs in as rapidly as pumped out
Gilbert	well	6 in.	145	-33	Ample ("in gravel overlaid with shale")
Gilman	4, 6 in. sand points 20 ft. deep				Unfailing. 2 mi. N. of town
Gilmore City	well	6 in.	120		Unfailing
Gladbrook	2 wells	8 in.	827 & 268		Ample for pumps, 125 g.p.m.
Glenwood	well	8 in.	2165		Level dropping since well was drilled
Glidden	well	10 in.	165		Ample for pump at all times
Goldfield	well	8 in.	168		200,000 g.p.d. 48 hr. test produced no shortage
Gowrie	1 well	8 to 4 in.	775	-60	Head not much reduced by pumping
	1 well	16-8 in.	1842	-81	300 g.p.m.
Graettinger	well	12 ft.	28		Ample but falls short in hot, dry weather. In gravel
Grand Junction	well	12-10 in.	320	-15	150 g.p.m. for 24 hrs., drilled 1926
	old well	10 in.	76		Ample for 24 hrs. (1920). In sand & gravel
Grand Mound	well	6 in.	90	......	Good record. In limestone
Granger	well	8 in.	106	.....	Unfailing. 200 g.p.m.
Granville	well	10 ft.	30		Somewhat reduced in dry weather
Gray	well	8 ft.	26		25,000 g.p.d. Low ground
Greene	well, 5 ft. sq. for top 20 ft., 20 ft. diam. for lower 5 ft.				Ample for pumps
Greenfield	old works,	17 ft.	41		Will supply pumps 2½ hrs. or at rate of
	2 wells	14 ft.	45		130,000 g.p.d. 10 blks S.E. bus. dist.
	new works,	18 ft.	42	-22	150,000 g.p.d. 2 mi. W. town on low
	2 wells	6 ft.	35		In reserve ground
	well	20-8 in.	2505	-505	Not finished, Dec. 31, 1928
Grimes	well	18 in.	30		Adequate, reliable
Grinnell	5 wells	10 to 16 in.	2000	-230-250	Nos. 4 & 5. Cap. 150 g.p.m. each
	1 well	16-10 in.	2500	-258	500 + g.p.m.

Griswold	2 wells	8 in.	60		Not affected by dry seasons
Grundy Center	1 well	10 in.	255	......	80 g.p.m. Tested 50 g.p.m. for 12 hrs. when drilled
	1 well	8 in.	360		65,000 g.p.d.
Guthrie Center	7 wells	6 in.	60		350 g.p.m. all seasons
Guttenberg	well	24 ft.	25		Drains in 5 hrs., fills quickly. Seepage from bluffs and river 10 ft. away
Halbur	2 wells	10 ft. 16 ft.	25 26		Ample at all seasons
Hamburg	14 sand points, 2 in. by 4 ft., 25 ft. deep, head –13 ft.				Ample
	3 springs on side of bluff, flow into basin.				Ample for pump. ¼ mi. from pumping sta.
Hampton	1 well	10 in.	1709	–153	Ample at all times, 366 g.p.m. ¾ mi. E. bus. dist. Springs furnish some.
	1 well	20–8 in.	1700	–153	1,000 g.p.m.
Harlan	22 wells	6 in.	40		Est. 900,000 g.p.d., not affected by dry weather
Harris	well	3 ft.	70		Ample at all times
Hartley	well	12 in.	1000		Ample for pump
Havelock	well	8 in.	138	–25	Unfailing. Drift to 116 ft., sand to 124. Test, 40 g.p.m. for 6 hr. 7 ft. Cook strainer
Hawarden	well	16 ft.	35	–23	Good
Hawkeye	1 well	6 in.	182	......	900 g.p.h.
	1 well	8–6 in.	835	–265	100 g.p.m. under air
Hedrick	well	6 in.	55		Ample in all seasons
Hinton	2 wells	8 in.	40		90 g.p.m.
Holstein	old well	8 in.	2,000	–300	Ample
	new well	12–6 in.	2,040	–290	200 g.p.m. Drilled 1924
Hopkinton	well	6 in.	80		Reliable. In limestone
Hospers	well	12 ft.	33		Limited
Hubbard	well	6 in.	400	–20	Ample at all times. Cased 80 ft.
Hudson	well	6 in.	212		Ample at all times
Hull	well	8 in.	1300		Constant, sufficient for pump

MUNICIPAL WATER SUPPLIES OF IOWA CITIES AND TOWNS (Continued)

Town	Source	Diameter	Depth, feet	Head, feet	Supply
Humboldt and Dakota City	springs	Old—across river from Sta. 100 g.p.m. New—½ mi. NW. bus. dist. 300 g.p.m.			
Humeston	Reservoir 2 mi. from bus. dist. Cap. 40,000,000 gal.				
Hurstville	well	6 in.	165		Ample at all times
Huxley	well	8–5 in.	892	–125	75 g.p.m. during 24 hr. test, little effect on water level
Ida Grove	old, 3 wells		shallow		Permits 5½ hrs. pumping. Good all seasons
	new, 6 wells	3 ft. cement tile lining		–16	Permits 5 hr. pumping
Independence	4 wells	10 in.	200		Est. Cap. 900–1,000 g.p.m. or 1,300,000 g.p.d. Across R. from bus. dist.
	6 wells	10 in.	50		
	1 well	12 in.	257		
Indianola	2 wells	28 ft.	43		8 hrs. pumping at 280 g.p.m.
		25–15 ft.	43		14 hrs. pumping at 280 g.p.m.
Inwood	2 wells	6 ft. sq.	96		1¾ hr. pumping, 7,000 g.p.d.
		12–10 in.	915	–275	60 g.p.m., 86,000 g.p.d. Drilled 1917
Iowa City	10 art. wells, 2,200 ft. timber galleries, 960 ft. 6 in. tile.				Ample. Wells flow 240,000 g.p.d.
Iowa Falls	4 wells	2–8 in. 1–10 in.	270	–40	10 in. well installed 1920. Water could not be lowered more than 40 ft. below curb
Ireton	well	6 in.	160		Ample at all times
Jefferson	2 wells	8 in.	2,100	......	Good record since 1912. Into sandstone
		6 in.	125		Good record since 1916. Into sand
Jessup	well	6 in.			Ample for pump
Jewell	well	6 in.	1,000	flowed till 1922	Ample for pump of 60,000 g.p.d. cap.
Kamrar	well	6 in.	287	......	Ample for pump of 40,000 g.p.d. cap.
Kanawha	2 wells	5 in.	135	–18	Ample at all times
		8 in.	165		
Kelly	well	6 in.	222	......	Drift 40, sand 10, yellow clay 60, blue clay 40, sand 72. Test 50 g.p.m. for 10 hrs. 8 ft. strainer
Kellogg	2 wells	3 in.	21	......	Ample and reliable. Low ground
Keokuk	Miss. R. Flows to settling basin, through filters to clear wells				
Keosauqua	Des Moines R. 8 in. intake pipe to settling well on bank				

Keota	old well	9 ft.	75 ft. with sand point below		50,000 g.p.d., slightly reduced in dry weather
	new well	22 in.	254		50,000 g.p.d. Slightly reduced in dry weather
Keystone	dug and drilled well 6 ft. for 62 ft., 6 in. for 66=128 ft.				Low in summer, probably discarded for new well
	new well	12 in.			
Kimballton	6 sand points	2½ & 2 in.	41	......	20,000 g.p.d., slightly affected by dry weather
Kingsley	well	12 ft.	32	......	Seepage; ½ mi. N.W. town
Kirkman	2 wells	6 ft.	52	......	Not affected by dry weather; connected at bottom by 2 three in. pipes
Kiron	well	8 ft.	22	–13	Ample, "well to rock" (must be a bowlder)
Klemme	well	8 in.	190		Ample in all seasons
Knoxville	2 wells—concrete pit 25 ft. deep; 2, 10 in. pipes with 10 in. by 10 ft. brass strainers resting on rock 37½ ft. below bottom of pit. Wells on D.M.R. bottoms 6½ mi. N. of town, ¼ mi. from R.			......	Ample
	1 well	24 in.	35	......	720 g.p.m. for 12 hr., 1,100 g.p.m. for 1 hr.
Ladora	well	8 in.	70	......	Ample
Lake City	1 well	16–4 in.	1376	......	200 g.p.m.
	1 well	....	350	......	Ample, reserve
Lake Mills	1 well	6 in.	235	......	Ample at all times, 80,000 g.p.d.
	1 well	12 in.	374	......	250,000 g.p.d.
Lake Park	Silver Lake. Pumped into settling basin				
Lake View	2 wells	40 in.	32	......	Ample
Lakota	well	6 in.	115	–15	Ample
Lamoni	Reservoir, dam 200 ft. long. Watershed 460 A.				Enough for 2 mo. dry weather
	well	16–6 in.	2200	......	100 g.p.m.
Lamont	well	8 in.	165	–8	Ample at all seasons
La Motte	well	6 in.	144		Ample, 50,000 g.p.d. In limestone
Lansing	well	6 in.	......	flows	Another well supplies drinking fountains
La Porte	well	10 in.	348	......	Ample
Latimer	well	6 in.	150	......	Ample at all seasons

MUNICIPAL WATER SUPPLIES OF IOWA CITIES AND TOWNS (Continued)

Town	Source	Diameter	Depth, feet	Head, feet	Supply
Laurens	1 well	10 in.	1200	......	Ample at all seasons
	1 well	4 in.	300	......	Reserve supply
Lawler	well	6 in.	136	......	Ample, reliable
Lawton	2 wells	4 in.	80	......	Ample at all seasons
Ledyard	well	8 in.	193	−15	Ample
Leeds, see Sioux City					
Lehigh	well	12 ft.	25	......	Ample; max. lift 15 ft. Fluctuates with river level. Near Des Moines river
Le Mars	2 new wells	25 in.	110	......	700 & 750 g.p.m., moderate lowering, lined with concrete strainer pipe
	29 driven wells	3–8 in.	45	......	800 g.p.m. ¼ mi. W. bus. district
Lenox	Reservoir, earth dam 1,000 ft. long, 30 ft. high.				Cap. 50,000,000 gal. 1 mi. N. of town
Leon	1 well	7 in.	80		100 g.p.m. for 7 hrs. or more; not affected by seasons
	1 well	8 in.	1100	−350	
Lester	well	3 ft.	32	......	Ample
Lewis	well No. 1	10 ft.	74	......	Ample at all times
	well No. 2	10 ft.	44	......	Good now, failed once, deepened
Lime Springs	well	10 in.	160	......	Ample all times
Lincoln	well	6 in.	511	−170	Good flow, drilled 1919
Linn Grove	well	10 ft.	30	......	Ample all seasons
Lisbon	Reservoir, supplied by springs, also small well, size unknown				
Little Rock	well	18 ft.	20	......	Ample all seasons, 500 ft. from Little Rock R.
Livermore	well	6 in.	145	......	Ample all seasons, not affected by dry weather
Logan	2 art. wells	6 in.	954	+80	Flows 200 g.p.m. Chief supply
		10–6 in.	840	+30	Flowed 13 g.p.m. in 1912. Would yield 20,000 g.p.d. for emergency
	1 well	9 in.	52	......	Ample all times
Lohrville	well	8 in.	180	......	Ample at all times
Lone Rock	well	8 in.	153	......	Ample. Tested 60 g.p.m. for 8 hrs.
Lone Tree	2 wells	6 in.	86	......	Reliable; in gravel, 4 in. casing

Lost Nation	well	8½ in.	120	......	Ample. 8 hr. test, no drop. 30 ft. in soil, rest in rock
Lowden	well, drilled				
Low Moor	well	6 in.	226	......	Ample in all seasons
Luther	well	18 in.	90	......	10,000 g.p.d. all seasons, wells connected
	well	5 ft.	55	......	
Luverne	well	8 in.	154	......	Ample, reliable
Lytton	drilled well	8 in.	1141	......	Supply ample for pumping capacity. In sandstone
McGregor	drilled well	8 in.	440	flows	50 g.p.m. Pumping cap. 300,000 g.p.d.
Macedonia	old well	8 ft.	29	......	70,000 g.p.d.
	new well	3, 4 in. sand pts.	25	......	Ample all seasons
Madrid	well	16 in.	134	......	Ample, reliable. Installed 1925
Malcom	2 wells	8 ft.	20	......	Pumped dry occasionally in dry weather. Not often
		12 ft.	20	......	Supply ample for pump of 90,000 g.p.d. cap.
Mallard	well	12 ft.	33	......	Level varies during year, but enough for 7 hr. pumping
Malvern	14, 1¼ in. sand points		20–27	......	Not affected by dry seasons. At cold storage plant ½ mi. from bus. dist.
	well No. 1	14 ft.	45	......	100,000 g.p.d., reduced in dry seasons
	well No. 2	16 ft.	30 }	......	Ample at all times
	well	8 in.	42 }	......	
Manchester	drilled well	10–6 in.	1870	......	300 g.p.m.
	well	5 in. drilled from base of pit 30 ft. by 20 ft. deep			Flows when deep well is not pumped. 200 g.p.m.
Manilla	well	12 in.	62	......	Ample at all times
Manly	2 wells	10 in.	300	......	Ample, reliable
Manning	9 sand pts.		38	–9	240 g.p.m. for short period. In gravel, head 5–6 ft. higher in wet weather
Manson	well	10–4 in.	1320	–60	Ample
Mapleton	6 points	....	25–32	......	Good. In gravel; equipped with strainers

MUNICIPAL WATER SUPPLIES OF IOWA CITIES AND TOWNS (Continued)

Town	Source	Diameter	Depth, feet	Head, feet	Supply
Maquoketa	well	22.5 ft.	30	......	Ample for pumps all seasons. In gravel. 600 feet 24 in. tile laid in gravel
Marathon	well	10 in.	182	–74	100 g.p.m. for 8 hrs. Last 11 ft. in sand
Marble Rock	well	6 in.	186	......	Ample all times
Marcus	well	12 in.	300	......	No shortage. In sandstone
Marengo	1 well	25 ft.	30	......	Ample. In sand (in reserve)
	2 wells	24 in.	34	–19	Ample. 500 g.p.m. Connected
Marion	Springs 1 mi. west of business district				Ample, unfailing
Marne	well	6 ft.	31	......	1 hr. pumping lowers water 9 ft. 2 hr. seepage restores level
Marquette	well	6 in.	585	+10 flows	Ample
Marshalltown	9 wells	1, 6 in. 8, 12 in.	74 to 178	–15	10,000,000 g.p.d.
	51 wells	6 in.	37–38	......	500,000 g.p.d. Reserve. In gravel. Wells 1 mi. from town
Mason City	4 wells	12–24 in.	1,200 & 1,219	–75 to 123	5,500,000 g.p.d.
Massena	well	7 ft.	36	......	Adequate
Maurice	well	12 ft.	22	......	Ample all seasons
Maxwell	well	6 in.	380	flows	70,000 g.p.d. ''Driven into gravel under soft shale''
Maynard	1 well	10 in.	700	......	Ample, reliable, 32,000 g.p.d. (abandoned in 1928)
	1 well	....	70	......	60,000 g.p.d.
Mechanicsville	well	8 in.	300	......	Adequate at all times
Mediapolis	1 well	8 in.	54	......	150 g.p.m.
	1 well	6 in.	54	......	Ample for pump of 75 g.p.m. cap.
Merrill	well	18 in.	42	......	Kelly well. In gravel. Ample
Meservey	well	6 in.	160	......	Ample, reliable
Miles	well	8 in.	50	–6	200,000 g.p.d., draws down 15 ft. when pumping; diminished in summer. In limestone
Milford	Lake Okoboji, pumped through 6 in. main 1½ mi. to town				

Minden	A, tile well	18 in.	40	–20	20,000 g.p.d. Installed 1914
	B, brick well	7 ft.	40	...	5,000 g.p.d., less in dry weather
Missouri Valley	2 wells	10 in.	77 & 85	–13	Ample. Drilled 1918
Mitchellville	River Sta. 3 wells, 6 in. pipe driven 45 ft. into gravel, strainers at ends				Ample all times. 2 mi. NE. of town
Modale	well	6 in.	90 ft.	......	12 hr. test 200 g.p.m. showed no shortage. 1,000 ft. from bus. dist.
Monona	well	6 in.	427	......	Ample, reliable
		8 in.	814	......	
Monroe	2 wells	4 in.	120	......	Good. Ample for pumps
		6 in.	180	......	
Montezuma	well	5 in.	250	......	Ample for pumps; down to rock (reserve). New well, cylinder at 220 ft.
	Springs, run into basin 9 ft. deep, 60,000 gal. cap. 2½ mi. from town				Overflow basin in wet weather
Monticello	2 wells	8 in.	275	few ft.	
		12 in.	500	below curb	Ample all times (new well drilled 1925, not placed in service). Est. yield 250–300 g.p.m.
Moorhead	shallow well	....	......	......	Ample for pump of 20,000 g.p.d.
Morning Sun	well	12–8 in.	1205	–122	130 g.p.m.
Moulton	Reservoir, dam 560 ft. long, 24 ft. high. Cap. 55,000,000 gal. 2 m. NE. town				
Mount Ayr	Reservoir, dam of earth, cap. 5,000,000 gal. ¼ mi. N. town				
Mount Pleasant	main, well	6 in. at base	1820	......	250 g.p.m.
	old, 4 wells		50, 2 have 16 ft. sand pts. in bottom of brick lined well		Supply low in dry years
Mount Vernon	2 wells	8 & 12 in.	337 & 327	......	Over 200 g.p.m., no reduction in dry weather
Moville	21, 2 in. sand points		40 ft. deep		Ample all seasons
Muscatine	13 wells	6 in.	48, with		
	1	8 in.	strainers	–2 to 15 ft.	5,500,000 g.p.d.; good quality; 2 mi. SW. bus. dist. In gravel under island
	2	10 in.			
	3	12 in.			
Nashua	well	8 in.	160	–19	Pump lowers water to –29 ft.

MUNICIPAL WATER SUPPLIES OF IOWA CITIES AND TOWNS (Continued)

Town	Source	Diameter	Depth, feet	Head, feet	Supply
Neola	sand points	1, 10 in.	48		
		2, 6 in.		......	Ample all seasons
Nevada	3 wells	16–6 in.	2792	–163	Not affected by dry seasons, 180 g.p.m.
		16–6 in.	2791	–165	250 g.p.m.
		8 in.	1000		Reserve
New Albin	well	10–8 in.	585	flows	150 g.p.m. by pumping does not lower water
Newell	2 wells	8 in.	300	......	Ample for pumps. No shortage in dry weather
New Hampton	2 wells	10 in.	235 & 262	......	Ample all times
New Hartford	well	8 in.	237	......	Ample; top 80 ft. cased, rest in rock. Installed 2–'21
New London	well	6–4 in.	1485	–140	40 g.p.m. Into sandstone. ¼ mi. E. bus. dist.
New Sharon	2 wells	8 in.	165	......	Ample. Supplied pumps for 86 hrs., no effect. Each pump cap. 33,000 g.p.d.
Newton	8 wells	12 in.	50	......	1,000,000± g.p.d. in dry weather. On Skunk bottoms 1 mi. from river, 6 mi. SW. town
	3 wells	12 in.	47	......	1,000 + g.p.m. each
New Vienna	well	4 in.	75	......	Cap. est. 15 g.p.m.
	well	6 in.	160	......	For fire. Ample for pump.
Nora Springs	old well	8 in.	280	......	In reserve, to be enlarged & deepened
	well	8 in.	385	......	Ample; pump cap. 130 g.p.m.
North English	well	13–6 in.	1678	–70	Ample, reliable, 100 g.p.m.
Northwood	well	10 in.	90	near top	Ample all times
Norway	well	12 in.	120	......	Ample all times
Oakland	well	16–7 in.	1936	–92	Ample. Test of 150 g.p.m. 36 hrs., no change; drilled 1919
Ocheyedan	old well	16 ft.	30		1000 ft. 8 in. drain tile extending from it. In reserve 7 wells 36 in. by 30 ft. deep
	new well	6 in.	233	......	50 g.p.m.
Odebolt	No. 1, 5 wells	7–18 ft.	15–28	......	100,000 g.p.d. max., 50,000 g.p.d. in dry weather
	No. 2, well	15 ft.	22	......	40,000 g.p.d. max., 20,000 g.p.d. in dry weather
	No. 3, well	20 ft.	21	......	50,000 g.p.d. max., 30,000 g.p.d. in dry weather

Oelwein	old, 3 wells	10 in.	150	overflows 60 g.p.m	225 g.p.m. into old well pit 20 ft. diam., 40 ft. deep, 5 points in base, yield 40 g.p.m.
	new well	12–8 in.	1316	-30	90 g.p.m. 1¼ mi. S. of bus. dist. Not used
	new well	18–12	122	-3½	Connected by 2½ in. siphons and cross pipes
	new well	12 in.	111	......	
Ogden	well	10–6 in.	2200	......	Ample all seasons
	well	16–4½ in.	2852	-163	150 g.p.m.
Olin	well	....	......	......	Ample
Onawa	art. well	4 in.	940	flows	72,000 g.p.d. Intermittent
	2 wells	12 in.	110 & 111	......	1,000,000 g.p.d.
Onslow	well	6 in.	237	-160	Will supply pump for 15-20 min. Refills rapidly
Orange City	well	8 in.	825	-200	Test, 110 g.p.m. 48 hrs. Ample. Drilled 4-'22
	well	8–6 in.	562	-225	20 g.p.m. Reserved
Osage	2 wells	10 in.	782 & 820	......	Ample all seasons
Osceola	Reservoir, cap. 25,000,000 gal., drainage area 280 A.				
Oskaloosa	Skunk R.				
	2 wells, 18 in. gravel-packed Kelly wells. On flat of Skunk R. 4 mi. N. town. One has separate pump				
	39, 6 in. sand points 30–40 feet deep. Cleaned and connected with one of new wells. Cap. 1,000,000 g.p.d.				
Ossian	well	6 in.	700	-435	Good. Drilled 1916; cased to 500 ft.
Oto	5, 2 in. sand points 47 ft. deep				Ample all seasons
Ottumwa	well	22 ft.	32	-24	On Turkey Is. Extends to rock
Oxford	well	20 ft.	40	......	Seepage. Will supply pump (cap. 86,000 g.p.d.) for 8 hrs. except dry weather, then only ½ hr.
	2 wells	10 in.+	586	-62	75 g.p.m. each
Oxford Junction	well	14 ft.	16	......	Ample. Into gravel
Palmer	well	4 in.	165	......	Ample
Panama	well	6, 1¼ in. sand points 42 ft. deep			Ample, on low ground
Panora	well	6 ft.	48	-24	Ample, on low ground
Parkersburg	well	6 in.	100	......	Ample all seasons
	well	12 in.	281	......	
Paton	well	6 in.	225	......	50 g.p.m. In gravel. Strainer in bottom

MUNICIPAL WATER SUPPLIES OF IOWA CITIES AND TOWNS (Continued)

Town	Source	Diameter	Depth, feet	Head, feet	Supply
Paullina	well	20 ft.	24	......	125 g.p.m., slightly less in dry seasons; ½ mi. NE. bus. dist.
Pella	900 ft. 30 in. tile 20 ft. below surface, discharge into well				Adequate exc. very dry weather. Near D. M. river 3½ mi. SW. town
	Several sandpoints ½ mi. W. station				
Perry	4 wells	10 in.	120	......	760 g.p.m. test 30 min.
Persia	well	8 in.	60	......	Ample all seasons
Peterson	well	14 in.	80	......	Ample all seasons
	well	6 in.	80	......	Ample all seasons. Reserve
Pierson	well	13 ft.	21	–10	Pump cap. 200 g.p.m. Well near creek
Pleasantville	well	10 in.+	1826	–180	70 g.p.m.
Plover	well	8 in.	43	......	Ample for pump; cap. 60,000 g.p.d.
Plymouth	well	12 in.	268 overflows when idle		Ample for pump; cap. 180,000 g.p.d.
Pocahontas	well	10 to 6 in.	1300	......	Ample all seasons
Pomeroy	well	6 in.	135	–20	Ample all seasons for pump; cap. 91,000 g.p.d.
Portsmouth	12, 1¼ in. and 2½ in. sand points, 52 ft. deep				Ample all seasons
Postville	well	10 in.	518	–275	Good. In St. Peter sandstone; drilled 1895
Prairieburg	well	8 in.	230	......	Ample all times
Prairie City	well	5 in.	430	–70	39 g.p.m. by test
Preston	new well	10–5 in.	989	–19	Ample for pump, at 75 g.p.m.
	old well	6 in.	140	......	Adequate for pump at 35 g.p.m.
Primghar	5 wells	1, 10 ft.	20	......	In gravel. ½ mi. E. town; low ground. Intermittent
		4, 3 ft.	20	......	
Protivin	well	4 in.	75	......	Ample
Quimby	well	8 in.	140	......	Ample for pumps all periods, cap. 40 g.p.m.
Radcliffe	2 wells	6 in.	135 & 95	–74½	Ample. Into rock
Readlyn	well	8 in.	108	......	Adeqnate and reliable
Redfield	old well	10 ft.	23	......	4–9 ft. water, pump can empty in 2–4 hrs. but refills rapidly
	new well	12 in.	215+		
Red Oak	S. Sta. 2 wells	18 ft.	68 & 52		Also 160 ft. tunnel 4½ x 6 ft. 500,000 g.p.d.
	E. Sta. 1 well	18 ft.	50	......	550,000 g.p.d.

Reinbeck	2 wells	8 in.	380	-75	Ample at all times
Remsen	3 wells	2, 16 ft. 1, 18 ft.	22 & 23 34	....	Ample for pumps, reduced in dry weather
Renwick	well	6 in.	150	......	Ample all times
Rhodes	well	8 in.	300	......	Ample, reliable
Riceville	well	12 in.	525	-3	Ample, all seasons
Ricketts	6, 2½ in. sand points	20 ft. deep			Not affected by dry seasons
Ringsted	2 wells	6 in. 8 in.	517 160	 -76	Ample. In gravel
Rippey	well	12-6 in.	1770	......	60,000 g.p.d.
Riverside,	1 well	10-6 in.	565	......	40 g.p.m.
Wash. County	2 wells	3 in.	116	......	Ample at all times
Riverside, Woodbury County	see Sioux City				
Rockford	well	10 in.	185	at curb	Ample at all times
Rock Rapids	2 wells	18 ft.	35 and 32.5	....	Supply near that of pump; cap. 530,000 g.p.d.
Rock Valley	well	8 ft.	29	-21	Ample exc. extreme dry weather; refills rapidly
Rockwell	2 wells	6 in.	200 & 250	......	160,000 g.p.d. In limestone and shale
Rockwell City	2 wells	10 to 6 in.	952+		120,000 g.p.d. In service 20 yrs. Deepened since 7-'22
		12 to 6 in.	1542	-165	225,000 g.p.d. In service 10 yrs.
Roland	5 wells	1, 8; 1, 3; 3, 6 in.	70	-15	Ample ordinarily, fail during canning season. Refill rapidly. Canning plant well, 8 in. 305 feet deep, in reserve
Rolfe	old well new well	8 in. 10 in.	230 634	....	40 g.p.m. 100 g.p.m. Drilled 1924
Rudd	well	8 in.	196	......	Unaffected when well is pumped all day
Ruthven	well	5 in.	167	-50	Ample, not lowered by 24 hr. pumping
Ryan	2 wells	5 in.	400	......	Ample all times
St. Ansgar	well	10 in.	230	-40	Ample for pump all times
St. Olaf	well	8 ft.	......	......	Seepage. Lined with stone
Sabula	2 wells		300 & 900	flow with	12 lb. pressure, failing

MUNICIPAL WATER SUPPLIES OF IOWA CITIES AND TOWNS (Continued)

Town	Source	Diameter	Depth, feet	Head, feet	Supply
Sac City	Springs in valley Raccoon R., 1 mi. N. city				200,000 g.p.d. flow into reservoir, cap. 100,000 g.p.d.
Salix	2 wells	6 in.	120 & 273	......	Ample, but lowered to maximum possible lift by pumping
Sanborn	well	18 ft.	62	......	Decreased till it scarcely supplies needs
Schaller	9 wells	40 in.	20	-8 to 10	Tile lined. Ample, decrease during dry weather
Schleswig	2 wells	10 & 12 ft.	25	......	Brick lined } SE. pt. town ½ mi. from
	10 wells lined with 10 in. tile, shallow				Installed in 1921 } bus. district. In reserve
	New well	24 ft.	29	......	West of town. Ample, 300 g.p.m. for 72 hrs.
Scranton	well	6 in.	212	-150	Ample for pump all times
Sergeant Bluff	well	8 in.	350	......	Ample for pump all times
Seymour	Reservoir, cap. 40,000,000 gal.				Not affected by dry weather. ¾ mi. S. bus. district. Dam 500 by 15 ft.
Sheffield	dug well	16 ft.	25	......	Limited to pump capacity. One pump has 400 g.p.m., other 250 g.p.m. cap.
Shelby	well	14 in.	60	......	Ample all seasons
	reserve well	8 in.	170	......	20,000 g.p.d.
Sheldon	10 wells	6 & 8 in.	28	......	Ample for pumps
	3 dug wells with radiating tile drains				Act as storage, 150,000 gal.
Shell Rock	well	10 in.	169	......	Ample at all times
	new well	....	......	......	100 g.p.m. pump
Shellsburg	well	12 ft.	23	......	Normally good, reduced in dry weather, sufficient for 3 hr. pumping
Shenandoah	Sta. 6 and 2	18 in.	50	......	200,000 g.p.d. each } only slightly affected by drought
	Sta. 3	12 in.	51	......	125,000 g.p.d. }
	Sta. 5—1 well	10 in.	42	......	400,000 g.p.d., new }
Sibley	2 deep wells, No. 1,	10 in.	314	-112	Ample for pumps, alternately (cap. 100,000 and 64,000 g.p.d.)
	No. 2,	8 in.	325	-112	
	1 shallow well	10 ft.	30		82,000 g.p.d.
Sidney	Springs, not affected by dry weather				200,000 g.p.d. Low ground 3 mi. E. town. Reservoir cap. 42,000 gal.

Sigourney	well	16–8 in.	1978	–83	500 g.p.m. Air lift
Sioux Center	well	6 in.	430	......	88,000 g.p.d.
Sioux City	17 wells	16–26 in.	222–415	–40	Cap. 2,250,000 to 3,000,000 g.p.d. each
Leeds	2 wells	8 in.	267	......	400,000 in 12 hrs., 1920 summer
Riverside	2 wells	12 in.	325	......	East well tested 670,000 g.p.d.
Sioux Rapids	well	10 ft.	30	......	Ample all seasons. In gravel
Slater	well	16 in. to 190, 4 in. to base	325	......	Ample all seasons
Sloan	4 sand points				Ample all seasons
Smithland	5 sand points	2 in.	52	......	Ample, reliable. One additional well in reserve
Soldier	well	6 in.	110	......	Ample, reliable
Solon	well	6 in.	145	......	Ample, decreased in dry weather
Spencer	2 wells	20 ft.	24	......	2,200,000 g.p.d.
Spillville	well	6 in.	75	......	Good, ample
Spirit Lake	5 sand points	5 in.	14	......	Ample in all seasons. Shore Spirit Lake, in gravel, 1¼ mi. N. of town
	1 well	18 ft.	19		
Springville	well	6 in.	150	flows when not pumped	Max. cap. 400,000 g.p.d. In limestone
Stacyville	well	10 in.	100	flows when not in use	Pump cap. 130,000 g.p.d.
Stanhope	2 wells	8 in.	1,200 & 1,800		Ample
Stanton	well	14 ft.	58	–35	90,000 g.p.d.
Stanwood	well	6 in.	237	......	50 g.p.m.
State Center	well	13 ft.	19½	–11 to 6	Ample, pump 220,000 g.p.d. Located ½ mi. N. town along creek
Storm Lake	Storm Lake, 12 in. intake pipe 800 ft. into lake.				Settling basin, sand filters, clear well
Story City	3 wells	8 in.	62	flow	Est. cap. 180,000 g.p.d. Reservoir, low ground
	1 well	8 in.	65	......	Pump cap. 80,000 g.p.d.
Stratford	well	8 in.	500	–119	Ample
Strawberry Point	3 wells	7 in.	165	......	Ample, reliable
Stuart	well	8 in.	3021	–345	212 g.p.m. during 24 hr. test

MUNICIPAL WATER SUPPLIES OF IOWA CITIES AND TOWNS (Continued)

Town	Source	Diameter	Depth, feet	Head, feet	Supply
Sully	well	6 in.	325	......	Pump can empty well in 3 hrs. Refills rapidly; pump cap. 23,000 g.p.d.
Sumner	well	12–6 in.	1785	–100	Pumped to capacity. Air lift, cap. 108,000 g.p.d.
Sutherland	well	8 in.	200	......	Ample for pump (cap. 120,000 g.p.d.) all seasons
Swea City	well	8 & 6 in. casing	125	......	Ample
Tabor	Reservoir, 20,000,000 gal. cap. fed by stream at rate of 3,000 g.p.h.				
Tama	well	20 in.	55	......	1,000,000 g.p.d. In gravel
Templeton	well	8 ft.	28	......	Seepage. 5 in. tile ¼ mi. long. Installed 1922. Low ground. Reserve well 8 ft. by 26 ft.
Terrill	well	8 in.	98	......	Ample all seasons. In gravel
Thompson	1 well	4 in.	200	......	Good
	1 well	8 in.	259	–70	Ample. Estimated 125 g.p.m.
Thurman	well	6 in.	94	......	Cylinder 82 ft. Tests 40 g.p.m. 10 hrs.
Tipton	old well	10 in. at top	2,750	......	150 g.p.m. } Air lift
	new well	16 in.	1,650	......	150 g.p.m. } Air lift
Toledo	old well	6 in.	425	......	Practically abandoned
	new wells (4)	6 in.	40	......	3,000,000 g.p.d. Also may get water from Indian school
Traer	well	8 in.	260	......	Ample for pump (cap. 65,000 g.p.d.)
Tripoli	well	6 in.	102	......	Ample for pump (cap. 144,000 g.p.d.)
Underwood	well	6 in.	52	......	Ample for pump (cap. 14,000 g.p.d.)
Union	4 wells	6 in.	28	near curb	Ample for pump (cap. 62,000 g.p.d.) Lowers 6 to 8 ft. by pumping
Urbana	well	8–6 in.	1154	–125	35 g.p.m.
Ute	8 strainers	2 in.	60	......	Ample all seasons
Vail	1 well	14 ft.	25	......	Can supply pump (cap. 170,000 g.p.d.) 5 hrs. Est. cap. 40,000 g.p.d.

Valley Junction	well	16 ft.	25	......	Seepage. Est. cap. 500,000 g.p.d. (in reserve)
	3 wells	16, 10 in.	37	–17	Pump can run 8–10 hrs. p.d. max. 720,000 g.p.d. New Sta. ¼ mi. SW. old Sta.
Van Horne	well	10 to 6 in.	2300	......	Ample, uniform through year; pump cap. 90 g.p.m.
Victor	well	14 ft.	30	......	Cap. 150,000 g.p.d.
Villisca	west well	10 in.	67	......	Ample
	south wells (2)	shallow		......	Ample, but condemned
Vinton	2 wells	5 in.	1,290 & 1,350	......	Adequate all times, 400 g.p.m. Air lift
Walcott	well	6 in.	140	......	Adequate, reliable; pump cap. 100 g.p.m.
Walker	well	6 in.	220	......	Ample, reliable; pump cap. 40,000 g.p.d.
Wall Lake	4 sand points	6 & 4 in.	28	......	Ample, reliable. In gravel, low ground
Walnut	well	13–5⅜ in.	2,510	–263	Ample, air lift, cap. 400 g.p.m.
Wapello	10, 3 in. sand points		26	......	Ample 400,000 g.p.d.
Washington	4 wells	15½ to 10 in.	1,217 to 1,817	–58 to 120	1,000 g.p.m.
Washta	dug well	3 ft.	27	......	Est. cap. 175,000 g.p.d. In use 10 years
Waterloo	4 wells in use 1 well in reserve	20 to 12 & 7 in.	1,365–1,409	–40 drawn to 130 or 167	Perforated at 870 ft. opp. St. Peter. Main supply from Jordan, 1200-1400 ft. Av. consump. 1922, 1,495,549 g.p.d. Max. 2,887,435 g.p.d.
Waukon	3 wells	2, 10 in.	577	......	Used 15 yrs. no diminution. In sandstone
		1, 16–10 in.	910	–308	Test 350 g.p.m. Used few hrs. daily. In sandstone. 3d well failing
Waverly	well	10–6 in.	1,720	Originally flowed 300 g.p.m.	Present cap. 700 g.p.m. Air lift raises 350 g.p.m.
Webster City	1 well	6 in.	100 }	flow	800,000 g.p.d.
	1 well	10 in.	657 }		
	1 well	16–8 in.	1,805	–6	2,500,000 g.p.d.
Wellman	7 points	3 in.	55	...... }	Ample all times. In valley. Pump cap. 250,000 g.p.d.
	1 well	20 in.	138	...... }	
Wellsburg	2 wells	10 & 6 in.	180	......	10 in. well, supply ample for pump. 6 in. new, will not supply pump full cap.

MUNICIPAL WATER SUPPLIES OF IOWA CITIES AND TOWNS (Continued)

Town	Source	Diameter	Depth, feet	Head, feet	Supply
Wesley	well	6 in.	185		Unfailing
	well	8–5.3 in.	1,100	–215	35 g.p.m.
West Bend	well	8 in.	107	......	Ample all seasons
West Branch	well	8 in.	60	......	Reduced 12% dry weather. Pump cap. 115,-000 g.p.d.
West Burlington	well	8 in.	190	......	Ample for pump (cap. 60 g.p.m.)
Westgate	well, drilled	6 in.	98	......	Ample. In limestone
West Liberty	2 wells	12 in. old	1,018	–25 drawn down to –90 at 230 g.p.m.	Not affected by dry weather. Old well 1,650 ft., filled to 1,018 in 25 years
		12 in new	1,705		
West Point	well	6 in.	186	......	24 hr. test prod. no shortage. Pump cap. 35 g.p.m.
West Side	well	15 ft.	22	......	Ample. No test. In quicksand, brick lined
West Union	4 wells	10 in.	av. 100	overflow soon after pumps stop	1,000,000 g.p.d., dry weather has little effect. When both pumps stop water falls to –10 ft.
What Cheer	Reservoir, cap. 3,000,000 gal. dam, earth, 300 ft. by 6.				Fed by small streams, drainage area 3 sq. mi.
Wheatland	2 wells	4 in.	185	......	25 g.p.m.; air lift
		8 in.	185	......	Pump. cap. 70 g.p.m.
Whittemore	2 wells	6 in.	160	......	Decreasing, filling with fine sand
		8 in.	160	......	Adequate and reliable
Williams	2 wells	6 in.	350	......	Ample all times. Pump cap. 50,000 and 90,-000 g.p.d.
Williamsburg	3 wells	6 in.	140	–90	Supply pumps at cap. (48,000 + 72,000 + 50,000 g.p.d.) Screens replaced every 2 yrs.
Wilton Junction	well	12 in.	1570	......	Ample and reliable
Winfield	2 wells	old, 6 in.	185		20,000 g.p.d.
		new, 12 in.	1,268	–73	225,000 g.p.d. at test, only slight drop in water level
Winterset	4 cased wells	8 in.	30; sand points in bottom		Ample, 40 g.p.m., not affected by dry weather. 2 mi. S. town
Winthrop	2 wells	8 in.	173	......	
		10 in.	177	......	Ample from both wells

Woodbine	3 sand points		40	......	Test 48 hr. at 200 g.p.m., supply did not decrease, no shortage
Woodward	....	....	.....	......	Supplied by State Institution, from reservoir at edge of town
Wyoming	well	6 in.	85	–30	Ample for pump (cap. 80,000 g.p.d.)
Yale	well	8 in.	92	–6	Cap. 90,000 g.p.d.
Zearing	well	8 in.	99	flows	Tested 100 g.p.m. 6 hrs. water lowered only 11 ft. Ample

Appendix

NOTE ON ELEVATIONS

The elevation above sea level of the well curbs is assumed to be that of the tracks at the railway stations as given by Gannett,[76] except where the difference between the curb and the tracks is considerable and was ascertained by leveling. The elevations of the towns, as added by Lees, are those of Lees[77] and were published too late to use in the records of strata of the wells. Thus in several cases a slight discrepancy may be noted between the elevation of a town and that of the curb of the town wells.

BAYARD, GUTHRIE COUNTY

CENTRAL OIL & GAS CO. PROSPECT, CONTINUED

Devonian and Silurian—continued:	
"Shale and limestone, about 50 per cent of each; shale blue and green." 1320 to	1449
"Shale, gray"	1463
"Limestone, gray, cuttings coarse. Small show of oil"	1477
Dolomite, light gray, in fine crystalline granules, which dissolve slowly in cold acid, briskly in hot acid; a little residue, some chert	1472–1475
"Limestone and shale, bluish green"	1490
"Cap rock, gray, very hard"	1492
Dolomite, light tan, otherwise very simlar to sample at 1472; very small residue, mostly chert	1494
"Lime, sandy (dolomite), brown to buff"	1500
"Contained oil from 1492 to 1498."	

Probably the traces of oil occurred in the lower beds of the Silurian. The suggestion has been made that the lower beds penetrated belonged to the Galena-Platteville, but no shales were penetrated which seem to correspond to the Maquoketa of the upper Ordovician. Moreover the thickness here assigned to the Devonian and Silurian—665 feet— is not enough to include the Galena-Platteville also, which should have a thickness of at least 300 to 400 feet.

CLARINDA

WILSON NO. 1 OIL PROSPECT—CONTINUED

Des Moines series (895 feet thick; top 297 feet above sea level):
Shale, very dark gray, fine textured, smooth feel, no lime; sand in fine

76 Gannett, Henry, Dictionary of Altitudes in the United States: 4th Ed.: U. S. Geol. Survey, Bull. 274, 1906.

77 Lees, James H., Altitudes in Iowa: Iowa Geol. Survey, vol. XXXII.

frosted grains of irregular sizes; some concreted fragments of whitish powder which effervesces freely in acid but leaves a large residue of very fine material, probably "gypsum" of driller. Mostly shale at 1540 and 1563-1568; mostly sand at 1540-1545 and 1568-1575; about equal, 1545-1563; some fragments of shale show small pockets of fine sand and lime. Six samples 1540–1575

Shale and limestone; dark gray, shale finely gritty, some fragments black 1575–1580

Mississippian system (penetrated 420 feet; top 598 feet below sea level):

Meramec and Osage (315 feet thick)—

Limestone, light gray, finely crystalline; some dark gray shale in small fragments; some sand like that above (Driller's log shows that limestone begins at 1610 feet) 1614

Limestone, gray, very finely crystalline, in powder to small chips, response to acid prompt and long continued, 1614-1624; in powder and fine grains, with much sand in fine rounded frosted grains, 1624-1642; somewhat coarser granular chips below 1642 feet; darker gray, some chert, not much sand, 1647-1657; 9 samples 1614–1657

Limestone, dark gray, very finely granular, some pyrite, ready response to acid; 2 samples 1657–1667

Limestone, bluish gray, in rounded chips and granules, a good deal of powder of gray shale....1667–1674

Limestone, similar to above except for absence of shale, in small angular subcrystalline fragments 1674–1680

Limestone, pepper and salt gray, in fine angular crystalline fragments, effervescence fairly rapid, fine white siliceous residue, 1680-1689; finer, rather slow reaction in acid, 1689-1697; somewhat darker gray, some clayey material, 1697-1702; prompt reaction, 1702-1712; brownish cast, 1702-1725; a large amount of white chert, 1721-1734; somewhat lighter gray and coarser, 1725-1729; some clay, less flint, 1729-1740; pepper and salt gray, clean, with much flint, sand grains and crystalline silica, 1740-1749; finer and more uniform, sample nearly all silica, 1749-1754; 16 samples 1680–1754

Limestone, similar to above, rather dark gray, with much light gray chert and some darker insoluble fragments; a little pyrite; limestone finely sugary texture; a little finer, lighter and more uniform of grain, 1765-1769, 1778-1792; larger chips of light chert, 1773-1778, 1792-1796; some chips of greenish shale, 1773-1787; chert same dark gray color as limestone, 1805-1810; nearly all chert and crystalline silica, 1810-1827; 15 samples....1754–1827

Shale and limestone, shale dark greenish, gritty, noncalcareous, in chips and powder; limestone gray, in powder and small chips, briskly effervescent; 3 samples 1827–1842

Limestone and shale, similar to above, except that limestone is predominant; chert abundant 1842–1845

Limestone, rather light gray, briskly effervescent, very finely granular, much chert, a few small chips of green shale; in fine grains, 1845-1853; somewhat more irregular sizes, pepper and salt gray with light chert and darker gray limestone, 1853-1862; finer, more uniform grains, 1862-1875; somewhat clayey, 1871-1879; chert in irregular chips, 1879-1885, 1890-1896; all fine and uniform, 1885-1890; brownish cast, much insoluble residue, partly silica, partly clay, 1896-1904; 13 samples 1845–1904

Shale, in green chips; limestone, in gray powder that effervesces rapidly; probably about equal parts 1904–1908

Limestone, light gray chips and dark gray grains and powder; shale, in green chips, subordinate in quantity 1908–1912

Limestone, light gray, in small grains, brisk effervescence, some siliceous residue; a few chips of green shale, possibly from above 1912–1916

Limestone, dark gray chips and powder, some flint; shale in gray chips and powder; 2 samples 1916–1925

Mississippian-Kinderhook (penetrated 105 feet; top 913 feet below sea level)—

Shale, light bluish gray, very fine textured, strongly calcareous; less calcareous below 1943; dark gray, 1950-1955; same as at 1925 but not so highly calcareous, 1959-1968; 10 samples 1925–1968

Shale, mostly light brick red, very fine textured, strongly calcareous; dark brick red, 1976-1979; powder of all shale samples is more calcareous than lumps; 3 samples 1968–1979

Shale, gray to blue-gray, fine textured, noncalcareous; limestone, light gray, briskly effervescent, crystalline; apparently about equal, 1979-1988; mostly shale, 1988-1996; practically all shale, light blue, calcareous, 1996-2000; 5 samples 1979–2000

Shale, blue-gray, hard, fine textured; at 2000-2004 feet chips show no reaction with dilute HCl, but when powdered they respond fairly briskly, also the powder of all samples reacts quickly; at 2004-2010 chips show no reaction, even when powdered and heated; somewhat calcareous, 2010-2016; powder strongly calcareous, 2016-2021; much crystalline, light gray limestone in chips and powder, also some blue flint, 2021-2030; 7 samples 2000–2030

Driller's log of Wilson No. 1—continued

Character	Thickness, Feet	Depth, Feet
Water sand	5	1530–1535
Lime, gypsum, sand and dark shale	30	1535–1565
Shale and pyrites	10	1565–1575
Black shale	15	1575–1590
Pyrites of iron	5	1590–1595
Dark shale	15	1595–1610
Sandy lime	64	1610–1674
Light shale	4	1674–1678
Lime	2	1678–1680
Water sand (fresh)	20	1680–1700
Brown lime flint (salt water)	32	1700–1732
Shale, sand, broken lime	1	1732–1733
Lime	2	1733–1735
Lime streaked with sandy shale	3	1735–1738
Brown lime	12	1738–1750
Lime, gray, very fine, drills like sand	40	1750–1790
Lime, coarse	11	1790–1801
Lime, hard	4	1801–1805
Lime, coarse	26	1805–1831
Hard gray shale	4	1831–1835
Lime, hard	2	1835–1837
Shale mixed with streaks of lime	8	1837–1845
Lime, fine and very hard	53	1845–1898
Brown shale	2	1898–1900
Lime, very fine	14	1900–1914
Lime, coarse	5	1914–1919
Lime, streaks of shale	2	1919–1921
Lime, hard	13	1921–1934
Shale, black, mixed with lime shells	36	1934–1970
Shale, red	1	1970–1971
Lime	2	1971–1973
Shale, a trifle more red than above	6	1973–1979
Lime, gray, hard	17	1979–1996
Shale, hard, grayish blue	4	1996–2000
Blue shale	3	2000–2003
Lime, gray, hard, very fine	18	2003–2021
Lime, blue, hard, coarse, mixed with gray and brown	9	2021–2030

1609 feet of 6⅛ inch casing set at 1610 feet.

GREENFIELD

CITY WELL NO. 1—CONTINUED

Since the account of the Greenfield well was written (pages 211 to 215) drilling has been resumed and has now reached the depth of 3280 feet (June 24, 1929). It will be noted that at 2420 feet the drill passed out of the dolomites and limestones of the Silurian in which it had been working into a reddish shale, which may be compared with the red arenaceous shale at Stuart at 1865 feet which was referred to the summit of the Maquoketa shale. The drill then entered a bed of chert, dolomite and quartz sand which continued to 2455 feet, the last of the samples described. Much trouble was encountered here from caving and two drills were lost.

When the drilling was resumed and the well was cleared out, better samples of the caving stratum were obtained which proved it a chert conglomerate.

Record of strata—Continued.

Hoing formation, Maquoketa (?)	
Conglomerate; chert, pebbles up to 2.8 cm., surfaces worn and softer than iron; shale, buff; a pebble 1.5 cm. of limestone, white, gray and greenish, inclosing bits of white flint, quartz sand and a little greenish clay. Sample said to have come probably from	2429–2475
Chert, white, some gray, some with finely pitted surfaces as from the removal of fine grains of quartz sand; crystalline quartz; limestone, whitish, rapid effervescence; much fine well rounded quartz sand; a little shale in fine chips, green, drab and bright buff. Drillers could not be sure that the drill had yet passed through the fill and had reached rock	2475–2482
As above	2482–2487
As above	2487–2492
Sandstone, gray in mass, grains well rounded and frosted, largest about 0.75 mm.; much white and gray chert; limestone, white, rapid effervescence; considerable shale as above	2492–2497
Shale, blue-green and drab, noncalcareous, in flakes; chert, sandstone and limestone as above; 2 samples	2497–2517
Sandstone, as above; some blue-green shale and whitish limestone of rapid effervescence, fossiliferous (fragments of brachiopod and crinoid stem)	2517–2518
Sandstone as above; much chert in chips; chips of green and red shale	2522–2537
Chert and siliceous dolomite, light gray, in chips, with quartz sand as above	2540–2554
Sandstone as at 2492; much light gray chert with disseminated minute pyrite crystals	2554–2560
Sandstone as above; buff in mass; some chert	2560–2570
Sandstone as above; some chert and light gray limestone, earthy, argillaceous, rather slow effervescence	2570–2575
Sandstone as above, a little limestone and chert	2575–2580
Sandstone, as above; dolomite without inclusions of quartz grains; some chert; shale, gray, in flakes and powder	2580–2615

Shale, gray, in friable masses concreting many chips of gray chert, fine quartz sand of rounded grains, and some dolomite....2615–2622
Sandstone, grains well rounded and frosted, larger, grains about 0.4 mm.; shale gray, medium dark and light, calcareous, in chips; considerable chert; some dolomite and pyrite; 2 samples....2622–2650
Sandstone, buff in mass, grains rounded, larger grains about 0.5 mm.; considerable dark gray and brownish shale in chips....2650–2660
Shale, light gray-brown, calcareous reaction with dilute HCl; considerable quartz sand as above....2660–2670

Galena-Platteville (280 feet thick; top 1300 feet below sea level)—
Dolomite, gray and light gray; 2 samples....2670–2690
Dolomite, light gray, much white chert; 3 samples....2690–2720
Chert, white, crushed to fine sand; some dolomite; 7 samples....2720–2780
Dolomite, buff, light buff and gray; considerable chert; all in sand; some spherules of pyrite....2790–2800
Dolomite, buff, in clean sparkling crystalline sand....2803–2815
Dolomite, buff, brown and gray, with some chert; 8 samples....2815–2910
Dolomite, buff, light brown, in clean crystalline sand; a very little white chert; 2 samples....2910–2930
Dolomite, blue-gray, in small chips....2930–2940
Dolomite, gray-buff; imbedded grains of fine quartz sand and some pyrite....2940–2950

Glenwood shale (33 feet thick; top 1580 feet below sea level)—
Shale, dark green, hard, in flakes, very slightly calcareous, pyrite....2950–2960
Shale, light blue-green, in flakes and concreted masses....2960–2970
Dolomite, buff, in fine sand, much dark green shale in flakes, some fine quartz sand poorly rounded, some grains seen imbedded in flakes of shale....2970–2983

Saint Peter sandstone (17 feet thick ?; top 1613 feet below sea level)—
Sandstone, white grains well rounded, frosted, larger grains 0.6 to 0.7 mm.; 2 samples....2983–3000

Prairie du Chien—
Dolomite, light buff and gray....3000–3010
Dolomite, light buff in mass, much fine rounded quartz sand, much hard dark green shale....3010–3020
Dolomite, buff, rusted, much quartz sand as above; 3 samples....3020–3050
Dolomite, gray, some very fine quartz sand....3050–3060
Dolomite, gray and white; white chert; quartz sand, some grains imbedded in dolomite....3060–3070
Dolomite, light gray and gray, some very fine quartz sand; 3 samples..3070–3100
Marl, light gray, in friable masses of cemented powder, argillaceous, calcareous, with microscopic quartzose particles....3100–3110
Dolomite, light gray and buff (rusted) in mass; very fine quartz sand, some fine rounded; 2 samples....3110–3130
Marl, light gray, as at 3100'....3130–3145
Sandstone (New Richmond), gray to reddish brown (rusted), very fine to medium, many grains not well rounded, some secondary enlargements, dolomitic, some imbedded grains, some öolite at 3160; 4 samples....3145–3185
Dolomite, gray, much quartz sand, grains fine to medium, not well rounded; 4 samples....3185–3220
Dolomite, gray, in fine meal; 4 samples....3220–3280

Notes.—Comparing the geological section at Greenfield with that disclosed by the deep well at Stuart it will be seen that the Pennsylvanian has thickened to the south-southwest and that its base has declined from 390 feet above sea level at Stuart to 40 feet above sea level at Greenfield.

The Mississippian is also somewhat thicker at Greenfield and the base of the shale referred to the Kinderhook is 395 feet lower than at Stuart.

The base of the Silurian dolomites is placed at Stuart at 660 feet below sea level, while at Greenfield it is placed at 1055 feet below sea level. This marked south-southwestern dip together with the downthrow of the Thurman-Wilson fault is taken into consideration in determining both the Galena-Platteville, the Glenwood and the Saint Peter of the Greenfield section.

The forecasts of the depth to the Saint Peter at Greenfield (page 214) were based especially on the wells at Stuart and Nebraska City. On the scale of the Stuart well, allowing 1561 feet from the top of the Mississippian to the Saint Peter, the Saint Peter would be struck at Greenfield at 2891 feet from the surface. On the scale of the Nebraska City well, allowing 1763 feet for the same distance, the Saint Peter would be encountered at 3093 feet. In fact the Saint Peter was found about half way between these estimates—at 2983 feet.

The Silurian is distinguished, as often, by its gypsum, although no marked beds of the mineral were encountered. Near the base the dolomite becomes arenaceous.

Both at Stuart and at Greenfield the beds underlying the Silurian dolomites are distinctly different from the Maquoketa shale of eastern Iowa, although the beds contain much shale. The Greenfield section in particular recalls the Hoing sandstone and still more the conglomerate found in places below the Saint Peter sandstone. The caving stratum above 2475 feet is clearly a conglomerate of chert pebbles, limestone, shale and quartz sand. The inferior beds with their mixture of these materials may be also of the same nature, but allowance must be made for caving of the upper stratum. Apparently we have here for the most part a continental formation or a basal conglomerate, later in age than Maquoketa time. The same mingling of chert, limestone and rounded quartz sand was found at this horizon at Des Moines, Centerville and Sigourney. At Des Moines, Centerville and Shellsburg, though not at Washington, the sand of this terrane is of well rounded grains, in this respect similar to the Saint Peter sand and that of the New Richmond and Jordan.

ADDENDUM TO GREENFIELD WELL, PAGE 433

The Greenfield well was successfully finished by the Layne-Bowler Chicago Co., July 6, 1929, at a depth of 3435 feet (3437 by newspaper reports). Probably it will hold for many years the record of being the deepest well in Iowa. It was begun March 31, 1927, and is reported to have cost the contractors $64,000, although the original contract price was $36,000.

Record of strata, continued from page 433

Prairie du Chien—continued—	DEPTH IN FEET
Cuttings washed away	3290–3345
Dolomite, light gray in mass, arenaceous, grains fine, mostly broken; pyritiferous; 2 samples	3345–3360
Dolomite, whitish, in fine meal; quartz in minute grains; 3 samples	3360–3390
Jordan sandstone (penetrated 45 feet, top 2020 feet below sea level)—	
Sandstone, light yellow-gray, dolomitic cement, in fine chips and detached grains, larger grains 0.5 to 0.75 mm. in diameter, imperfectly rounded; 2 samples	3390–3410
Sandstone, light buff in mass, dolomitic, "hard, wears bit fast", larger grains less than 0.5 mm. in diameter, imperfectly rounded; 2 samples	3410–3425
Dolomite, light gray, in chips, argillaceous, minute quartz particles in residue; shale hard, drab, in flakes	3425–3430
Sandstone, gray, fine, highly dolomitic, grains imperfectly rounded, "hard, wears bit fast"	3430–3435

It will be noted that the thickness assigned to the Prairie du Chien is 390 feet, a normal thickness for this formation. The sandstone at 3390 feet thus falls in with the Jordan stratigraphically, although in its fineness and poorly rounded grains it differs lithologically from the Jordan in its northeastern sections.

While the Greenfield well is 414 feet deeper than that at Stuart it reaches only 435 feet below the base of the Saint Peter sandstone, while the Stuart well reaches 607 feet below that level and penetrates the Franconia, represented by a typical sandstone of minute angular particles not found in any of the samples of the Greenfield well. Glauconitic shales, characteristic of some beds of the Franconia, were not found at either locality.

The static level had stood at 505 feet below the surface of the ground, 865 feet above sea level, before the drill struck the Saint Peter sandstone. On reaching that formation the static level fell to 592 feet from the surface, 778 feet above sea level, and so remained until the completion of the well. It will be noted that the static level of the well at Stuart stands at 860 feet above sea level, approximately the head of the upper waters at Greenfield, a fact most easily explained on the supposition that the upper waters at Stuart are not effectively cased out.

On the final test the pump discharging 60 g.p.m., with the cylinder set six feet nine inches below the water surface, "failed to lower the level sufficiently to suck air". A newspaper item reports that the city council accepted the well "providing the company installs a Sullivan air lift pump of 200 g.p.m. A 150 h.p. motor will be required to operate the pump".

A similar item reports the popular opinion as to the potability of the water: "The first water out of the well was clear as crystal. It had a slight mineral taste which was not objectionable. In fact it was better tasting water than that now being used by the city."

Chemical analyses of the water of the Greenfield well.

Analysis no. 1, by the Dearborn Chemical Co. of Chicago, depth of well 2500 feet, water believed to enter the well at 1600 feet. For the detailed analysis see page 212.

	Grains per Gallon
Total mineral solids	120.888
Organic matter	Tr.
Total incrusting solids	31.888
Total non-incrusting solids	89.000
Pounds incrusting solids per 1000 U. S. gallons	4.55
Pounds non-incrusting solids per 1000 U. S. gallons	12.71

Analysis no. 2, by Dr. J. B. Culbertson of Cornell College, Iowa. Sample received June 24, 1929. Depth of well 3280 feet, water of sample said to have been taken from level of 3160 feet. All waters above the Saint Peter sandstone cased out.

Analysis no. 3, made by Dr. J. B. Culbertson, Cornell College, Iowa. Sample received at laboratory July 3, 1929. Depth of well 3435 feet, water of sample said to have been taken from the level where the cuttings washed away, at about 3300 feet.

	Anal. no. 2		Anal. no. 3	
	P.P.M	Gr. per Gal.	P.P.M.	Gr. per Gal.
Silicon	13	0.76	12.5	0.73
Iron and aluminum oxides (mere trace of iron)	2	0.12	5	0.29
Calcium	142	8.29	144	8.41
Magnesium	69	4.03	72	4.21
Sodium	316	18.45	394	23.01
Potassium	27	1.56	28.5	1.66
Sulfate	769	44.91	774	45.20
Chloride	309	18.05	411	24.00
Bicarbonate (determined by acid titration)	206	12.04	222	12.97
Total solids	1750	108.23	1952	120.48
Temporary hardness	169	9.88	182	10.63
Permanent hardness	470	27.44	474	27.68
Total hardness	639	37.32	656	38.31

(Hardness calculated as calcium carbonate)

KEOKUK PURE ICE CO. WELL NO. 2

This well, 1799 feet deep, was drilled by C. W. Varner of Dubuque and completed in 1929. The diameters are 12 inches for 180 feet, 10 inches to 806 feet, and 8 inches to bottom. The main supply was found from 1749 to 1799 feet. A small amount, readily bailed down, came in at 632 feet. The Saint Peter sandstone was dry. On completion the natural flow measured 210 g.p.m., and with the air lift placed at 110 feet a discharge of 480 g.p.m. was obtained. The static level was 12 feet below the curb until the casing was inserted to 180 feet, the only casing in the well. From this level to 632 feet it was necessary to put in water for drilling. From 1232 to 1749 feet water stood 40 feet below the curb and could be bailed down. The static level of the main flow was not determined. The temperature is 67° Fahr.

Driller's log

Fill	0-11
Gray shale	11-16
Soft white lime	16-89
Hard lime	89-139
Shelly lime	139-149
Hard lime	149-177
Gray hard lime	177-198
Shale	198-203
Hard lime	203-213
Shale	213-226
Hard lime	226-303
Shale	303-516
Hard lime	516-673
Sandy lime	673-708
Hard brown lime	708-773
Sandy lime	773-804
Lime and brown sand	804-845
Saint Peter sandstone	845-935
Hard lime	935-981
Shale	981-983
Hard and soft lime	983-1749

Record of strata, well no. 2, Keokuk Pure Ice Co., 1929
(Elevation of curb, 580 feet above sea level)

	Depth in Feet
No samples	0-80
Mississippian (440 feet thick; top 500 feet above sea level):	
Keokuk formation, Montrose cherts (100 feet thick)—	
Limestone, gray, mottled, macrocrystalline, fossiliferous, rapid effervescence in cold dilute HCl, in flakes; chert, blue speckled darker; shale, drab, calcareous	80
Limestone, light yellow-gray, granular; chert, white and blue	90

Chert, white, intermingled with limestone, large chips	100, 110
Limestone, whitish, macrocrystalline, rapid effervescence	120
Limestone, very light yellow-gray; some chert	130
Chert, whitish, large flakes, 140, 160; in small chips, some light yellow-gray limestone, 150; 3 samples	140–160
No sample	170
Burlington and Kinderhook limestones (120 feet thick; top 400 feet above sea level)—	
Limestone, very light yellow-gray, macrocrystalline-earthy, in small chips, rapid effervescence	180
Limestone, light buff, granular, in large chips, fossiliferous, rapid effervescence	190
Shale, blue and olive-green, calcareous	200
Shale, drab, in flakes	210
Sandstone, blue, argillaceous, calcareous, grains minute, in chips; some light yellow-gray limestone	220
No sample	230
Dolomite, buff and brown, granular, in small chips; limestone, light yellow-gray, fine granular, soft, rapid effervescence; 4 samples	240–270
Limestone, brown, calcilutite, rapid effervescence, in flakes	280
Limestone, brown, soft, granular, moderately rapid effervescence	290
Kinderhook shale (220 feet thick; top 280 feet above sea level)—	
Shale, dark blue-gray, highly calcareous, in large flakes	300
Shale, in concreted masses, blue gray; 6 samples	310–360
Shale, in concreted masses, drab, olive, some blue; at 380 includes brown inflammable chips; 12 samples	370–500
No sample	510
Devonian (120 feet thick; top 60 feet above sea level):	
Limestone, dark gray in mass, some buff and gray, rapid effervescence, fossiliferous	520, 530
Limestone, medium dark slate color, fine-grained, pyritic, rapid effervescence, fossiliferous	540, 550
Limestone, dark gray, laminated, very fine-grained, rapid effervescence, in flaky chips	560, 570
Limestone, light yellow-gray and brown, rapid effervescence, in fine chips; 3 samples	580–600
Limestone, light brownish gray and brown, calcilutite, laminated, in flakes and sand; 3 samples	610–630
Ordovician:	
Galena-Platteville limestone (210 feet thick; top 60 feet below sea level)—	
Dolomite, buff, brown and yellow-gray, granular-crystalline, notably cherty at 680, at 810 sample includes dark chocolate-brown inflammable shale; 20 samples	640–840
Saint Peter sandstone (140 feet thick; top 270 feet below sea level)—	
Sandstone, white (light yellow-gray in mass), fine, grains poorly rounded, many secondary enlargements, some of largest grains reach 0.75 mm.; some light yellow-gray dolomite	850, 860
Sandstone, white or light yellow-gray in mass, fine irregular grains; 7 samples	870–930
Sandstone, yellow-gray in mass, coarser, larger grains up to 1 mm., many grains frosted and well rounded	940
Sandstone, white, fine irregular grains	950
Sandstone, white, fine, but including well rounded grains up to 1 mm. diameter; 3 samples	960–980
Prairie du Chien (760 feet thick; top 410 feet below sea level)—	
Dolomite, light buff, some dark green shale in chips (see log); considerable quartz sand in cuttings as in all to 1370	990
Dolomite, light grayish brown, in mass considerable white chert; 3 samples	1000–1020
Dolomite, yellow-gray	1030
Dolomite, gray, arenaceous, imbedded grains, some chert	1040
Sandstone, light yellow-gray in mass, fine, ill-rounded grains, many secondary enlargements; a second sample from this depth contains dolomite	1050
Dolomite, gray, cherty; 4 samples	1060–1100

Dolomite, gray and light buff-gray; 3 samples 1120–1140
No samples 1150–1200
Dolomite, grayish brown, very cherty 1210
No samples 1220–1320
Dolomite, gray and grayish brown, cherty, 1330, 1340; gray and whitish, 1350; silicious oölite, 1360; 4 samples 1330–1360
No samples 1370–1470
Dolomite, light gray, crystalline; white chert, some sporadic among dolomite crystals 1470, 1480
Dolomite, gray, brownish gray and yellow-gray, more or less cherty; 14 samples 1490–1630
Dolomite, light gray, a few grains of quartz sand in cuttings 1640
Dolomite, very light gray, arenaceous, grains fine, rounded, some with surrounding concentric rings in matrix as in oölite; cherty 1650, 1660
Sandstone, warm yellow-gray, dolomitic, larger grains of 1 mm. diameter, rounded, in chips and detached grains 1670
Dolomite, very light gray, sporadic fine grains of quartz 1690
Dolomite, yellow-gray, highly arenaceous, grains fine 1700
Dolomite, whitish, in flour 1730, 1740

Cambrian:

Jordan sandstone (?) (penetrated 49 feet; top 1170 feet below sea level)—
Sandstone, light buff, dolomitic, fine to medium; some chert 1750
Sandstone, light yellow-gray, dolomitic cement, grains rounded, some with secondary enlargements, larger grains about 0.8 mm. in diameter, in chips 1760
Sandstone, yellow-gray, dolomitic cement, grains fine, rounded 1770, 1780
Sandstone, light yellow-gray, grains minute, poorly rounded 1790

Notes.—The samples of the cuttings of this well confirm the conclusions drawn from those of other recent wells of Keokuk (pp. 234-8) and help to clear up a dubious geological section. They establish, in the log of the famous early Hubinger well, the reference by Gordon, Keyes and Norton of the heavy sandstone at 303 feet below sea level to the Saint Peter, and hence of the underlying dolomites to the Prairie du Chien. The ''Oriskany sandstone'' and the ''Niagara sandstone'' of Gordon,* however, are left entirely unsupported. Nor does the reference of these supposed ''sandstones'' and the ''sandstones'' of similar horizons of other well logs at Keokuk to an upper member of a bipartite Saint Peter sandstone fare any better. None of the four wells at Keokuk whose cuttings have been examined by the writer shows any trace of sandstone between the base of the Kinderhook and the summit of the Saint Peter, or, it may be added, of a Maquoketa shale. If any of the logs reporting ''sandstone'' and ''shale'' at these horizons are correct, there must be in this area an interesting unconformity which leaves in certain places the Maquoketa shale and Hoing sandstone more than 100 feet thick, while elsewhere within the city limits both have been entirely cut away.

It will be noted that in the absence of the Silurian and the Maquoketa the characteristic calcilutites of the Wapsipinicon stage of the Devonian rest directly on the rough dolomites of the Galena. As at Donnellson the Galena-Platteville is wholly dolomitized and embraces no shaly beds. The Glenwood shale, as at Donnellson, is absent, or represented by a thin dolomitic sandstone here placed with the Saint Peter.

Throughout the Keokuk area the Saint Peter sandstone is noteworthy for its thickness and in this well section for its fineness of grain, with secondary enlargements common, and especially for the exceptional and unpredictable fact that it was found dry. In the well of the Electro-Metals Co., for example, the Saint Peter's natural flow is 294 g.p.m. (p. 234). Thus it became unexpectedly necessary to drill to the water beds which supplied the once-famous wells of J. C. Hubinger & Co., wells whose natural flow at one time furnished power for a hydro-electric plant for city lighting.

The interpretation of the beds below the Saint Peter sandstone is made more difficult by two gaps in the sample cuttings aggregating 150 feet. As the Prairie du Chien thickens southward and at Burlington reaches a thickness of 565 feet, it may perhaps safely be assigned at Keokuk a thickness of 760 feet. The water-bearing sandstones from 1750 feet would thus fall in with the Jordan. Certainly the glauconitic beds of the Franconia, struck at Burlington 935 feet below the base of the Saint Peter, were not reached at Keokuk when the drill stopped 809 feet below the same datum.

* Gordon, C. H., Notes on the Geology of Southeastern Iowa: Am. Geol., vol. 4, pp. 237-9.

OGDEN, BOONE COUNTY

CITY WELL NO. 2—CONTINUED

Cambrian, continued:	
Saint Lawrence, Franconia beds, continued—	
Shale, gray and olive-green, hard, finely laminated; and sandstone, gray, glauconitic, grains minute, calcareous, of rapid effervescence, some finely laminated	2610–2620
Sandstone, gray, grains minute, glauconitic, calcareous; some shale; 3 samples	2620–2650
Sandstone, as above, grayish buff in mass	2650–2660
Sandstone, as above, greenish in mass	2660–2670
Sandstone, gray and light buff, grains minute, highly dolomitic; 2 samples	2670–2690
Sandstone, brown in mass, grains fine, rounded, highly dolomitic	2690–2700
Sandstone, light buff, gray in mass, grains fine, dolomitic	2700–2710
Sandstone, light gray, highly argillaceous, dolomitic, grains minute to fine; some dark fissile shale	2710–2720
Dresbach sandstone (90 feet thick, top 1626 feet below sea level)—	
Sandstone, very light gray, clean quartz grains, fine, not well rounded; 2 samples	2720–2740
Sandstone, yellow-gray, clean, larger grains up to 1 mm.; many well rounded	2740–2750
Sandstone, as above, coarse, grains up to 3 and 4 mm	2750–2760
Sandstone, as above, grains up to 1.5 mm.; some concreted friable masses of brown sandy shale at 2780; 5 samples	2760–2810
Eau Claire, or inferior Cambrian formation (42 feet penetrated, top 1716 feet below sea level)—	
Shale, or argillaceous sandstone, reddish buff, in friable masses, non-calcareous	2810–2820
No sample	2820–2830
Sandstone, buff speckled dark, fine to medium, mostly of broken quartz grains, some rounded, much ochreous material, some as spherical crusts inclosing sand grains, glauconitic, magnetic	2830–2835
Sandstone, as above, but darker; with a larger proportion of non-quartzose material	2830–2840 and 2845
No samples	2845–2852

The sample at 2845 was submitted to Professor A. C. Tester of the State University of Iowa, who writes under date of April 7, 1929:

"I believe you are right in calling this formation the Eau Claire.

I am satisfied that the material is from a sedimentary formation, that is a sandstone, which has been transported and deposited in this place with considerable sorting and reworking from its source. However, certain minerals indicate a contributing source of a rather basic igneous rock, possibly a gabbro intrusive type. I find some olivine, a very few grains of plagioclase feldspar (highly weathered), considerable serpentine and much well rounded or worn magnetite. Some of the grains of magnetite show weathering to hematite. Other minerals present in small quantities are, muscovite, garnet, zircon, titanite, ilmenite and leucoxene (?).

The quartz is both well rounded and pitted and fresh angular. Much of the latter is due to breaking of rounded grains. The large amount of rounded quartz I do not believe came entirely from overlying horizons, though there was undoubtedly some contamination of this horizon from above.

In addition to the minerals given above, I find good fresh glauconite in considerable abundance. I believe this is significant and indicates the accumulation of the materials in marine waters of moderate to shallow depth. The black clay also contains grains of glauconite. The sample also contains 15 to 20 per cent of magnetic iron and iron minerals. Some of this is readily recognized as fragments from the drilling tools or casing, but about 5 per cent is magnetite and considerable is a magnetic iron oxide scalelike concentration which I believe is a cementation or concretionary phenomenon. I have noted this condition in the field in sandstones of various ages.

I do not believe this horizon is closely associated with the pre-Cambrian rocks, but instead is a regularly deposited sandstone of characteristics slightly different from the normal type as already indicated. At the same time I would not be surprised if the pre-Cambrian rocks were encountered within a relatively short distance below this horizon, as igneous rocks were at hand not far distant when this bed accumulated."

WAUKEE, DALLAS COUNTY

Altitude of curb about 1020 feet.

In 1922 Thorpe Bros. Well Co. began drilling an oil prospect on the Forette farm, three miles south and one mile east of Waukee. Rose and Son were subcontractors for part of the work. The bore was sunk to a final depth of 2006 feet, this depth being reached on January 30, 1923. Six and five-eighths inch casing was set at a depth of 1786 feet. Drilling was carried on through a hole full of water from a depth of 1792 feet. These beds carried salt water.

Driller's log of Seibel oil well

	Thickness, Feet	Depth, Feet
Surface soil	3	0–3
Yellow clay	20	3–23
Sand and gravel—small amount of water	2	23–25
Yellow clay	15	25–40
Sea mud	20	40–60
Blue clay	1	60–61
Sea mud	11	61–72
Blue clay	8	72–80
Sand	20	80–100
Blue shale	20	100–120
Red shale	27	120–147

Blue shale	13	147–160
Red shale	27	160–187
Blue shale	15	187–202
Dark shale	28	202–230
Red shale	21	230–251
Blue shale	22	251–273
Light shale	32	273–305
Blue shale	19	305–324
Lime	61	324–384
Coal	1	384–385
Fire clay	1	385–386
Dark shale	19	386–405
Coal	2	405–407
Fire clay	2	407–409
Shale	20	409–429
Lime rock	11	429–440
Blue shale	10	440–450
Sandy shale	80	450–530
Blue shale	40	530–570
Dark sandstone—lots of water	26	570–596
Blue shale	9	596–605
Lime rock	65	605–670
Blue shale	8	670–678
Lime rock	8	678–685
Blue shale	4	685–690
Lime rock	8	690–698
Blue shale	10	698–708
Lime rock	50	708–758
White sandstone—top Kinderhook shale lots of water	40	758–798
Blue shale	4	798–802
Lime rock	72	802–874
Blue shale	20	874–894
Lime rock	140	894–1034
Blue shale	32	1034–1066
Lime rock—lots of water	138	1066–1204
Lime	103	1204–1307
Sand, carried a slight showing of gas	3	1307–1310
Lime, coarse to fine-grained	361	1310–1671
Sand, carried traces of oil, however slight were very good	6	1671–1677
Lime, white, somewhat chalky	15	1677–1692
Shale, red	35	1692–1727
Lime, white	10	1727–1737
Lime, reddish	10	1737–1747
Shale, red	41	1747–1788
Lime, white	4	1788–1792
Shale, blue	30	1792–1822
Lime, white, fine and hard	10	1822–1832
Shale, gray	8	1832–1840
Lime, blue, coarse-grained	65	1840–1905
Lime, white	17	1905–1922
Sand, white, very fine-grained	84	1922–2006

Notes.—The beds to 100 feet belong to the Pleistocene, those to 596 feet at least to the Des Moines, and those to 894 to the Mississippian. The lower beds are difficult of location, although the shales at 1692 feet may be Maquoketa. In that case the strata below are Galena-Platteville, leaving the eighty-four feet of "sand" at the base for the Saint Peter, assuming that it actually is siliceous material. Of course if it is crushed crystalline dolomite or limestone it may still belong to the Galena-Platteville. In that case the Saint Peter was not reached.

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