STATUS OF HYDROGEOLOGIC STUDIES IN NORTHWEST IOWA

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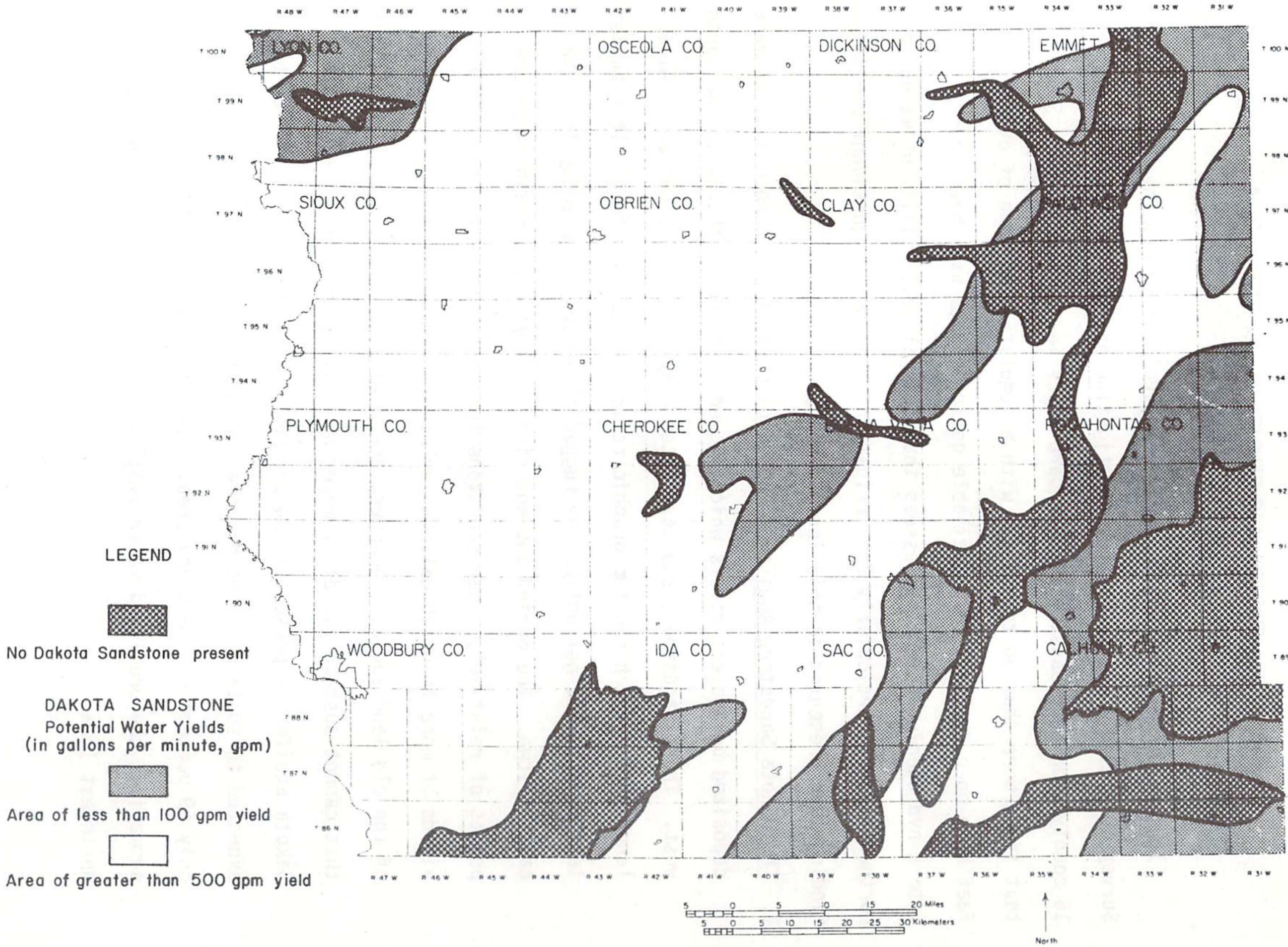
EXECUTIVE SUMMARY

In the summer of 1977, the Iowa Geological Survey and the U.S. Geological Survey initiated a comprehensive investigation of the water resources of a 16 county area encompassing 6,600 square miles in northwest Iowa. Since that time, more than 30 test wells with a cumulative footage of over 15,000 feet have been drilled. All available geologic data have been incorporated into a hydrogeologic model to assess the regional availability of water in northwest Iowa, particularly for irrigation. The more significant preliminary findings are presented in this interim report.

1. The Dakota Sandstone Aquifer - The sandstones of the Dakota aquifer were deposited by ancient rivers which flowed from the northeast to the southwest. These sandstones and associated clayey mudstones buried an older land surface which had topographic relief of over 500 feet. This buried land surface was not unlike the rugged topography seen today in northeastern Iowa. The buried ancient river valleys now contain thick deposits of relatively clean sandstone that can be expected to sustain yields of more than 500 gallons per minute. Parts of the upland areas of the old land surface, however, are covered by thin, clayey sandstones that cannot sustain yields of more than 100 gallons per minute. The Dakota aquifer is present in 84 percent of the study area, but can be expected to sustain yields of more than 500 gallons per minute over only 69 percent of the study area. The accompanying figure pictorially summarizes the predicted water availability from the Dakota aquifer in northwest Iowa.



Potential Water Yields from the Dakota Sandstone in Northwest Iowa.

2. Paleozoic Aquifers - The Dakota aquifer is underlain by many different older (Paleozoic and Precambrian) rock units. Some of these rock units are important sources of water in other parts of the state. Test wells drilled into these rocks have shown that, in some places, water is moving upward from the underlying Paleozoic aquifers into the Dakota aquifer. Very little is known about the distribution and composition of the Paleozoic rocks of northwest Iowa. They are deeply buried, and exposures of equivalent rocks occur many miles to the east. Preliminary studies of test cores prove that their water-yielding characteristics vary significantly from those known in eastern Iowa. For this reason, detailed core studies have been undertaken to outline their distribution, and to determine their relationship to controls on the underground movement of groundwater in northwest Iowa.
3. Research Well Registration Program - Three private land owners have been granted permission to irrigate crops from wells in the Dakota aquifer under contract arrangements with the Iowa Geological Survey (IGS). The contracts require drilling of production and observation wells under IGS supervision, and the completion of controlled pump tests that permit quantitative assessment of the water-producing capacity of the Dakota aquifer. Additionally, water level measurements have been obtained periodically at the observation wells since June 1, 1978. The current results show that, at the three sites tested, the Dakota aquifer is capable of sustaining current irrigation withdrawals without excessive drawdown. Water level records show that during the pumping season, static water levels decline approximately 5 feet in the immediate area surrounding the irrigation wells. Some of this decline is a naturally occurring seasonal fluctuation. During the winter and spring months,

water levels returned to pre-pumping levels. Measurements will be maintained at these sites, as further data will be needed to verify these preliminary findings.

4. Ongoing Research - The hydrogeologic model presented in this interim report is by no means complete. More data will be needed to test its validity, and to add further refinements. The present model is very general and qualitative. Detailed stratigraphic and sedimentological studies, and the acquisition of more hydrologic information will eventually permit quantitative modeling of the entire hydrologic system. This will permit a more accurate prediction of the response of the groundwater system of northwest Iowa to large withdrawals in concentrated areas. Among the continuing studies are:

   a. Regional inventory of current water levels - Now that the general geologic aspects of the major aquifers have been defined, the hydrologic relationships between them must be determined. This will require a regional field inventory of water wells and synchronous measurement of water levels in those wells.

   b. Test pumping of the Dakota and Paleozoic aquifers - More details and refinements are necessary to accurately predict water yields in the Dakota aquifer. The degree of interconnection between separate sandstone bodies within the Dakota aquifer, and between the Dakota aquifer and the various Paleozoic aquifers can only be determined by test pumping at carefully selected sites. Systematic water quality sampling of the various water producing horizons is an integral part of this program.

c. <u>Test drilling of glacial deposits</u> - Test holes at key locations are necessary to determine the control effected by glacial deposits on recharge to the Dakota aquifer.

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PART I: TEST DRILLING PROGRAM

The general geology and hydrology of the Cretaceous rocks of northwest Iowa have long been poorly understood. This lack of understanding was made especially apparent in the mid-1970's, when local drought conditions stimulated widespread interest in development of the Cretaceous Dakota aquifer as a water source for center-pivot sprinkler irrigation. The Iowa Natural Resources Council, charged with protecting and regulating use of the water resources of the state, placed a three year moratorium on new irrigation permits for Dakota wells in the summer of 1977. During this period, the Iowa Geological Survey and the U.S. Geological Survey have been engaged in a joint drilling program to better define the water resources of northwest Iowa.

The last published general geologic study of the Cretaceous rocks of Iowa appeared more than 85 years ago (Bain, 1893). The area of surface exposure of these rocks is extremely small in relation to the total area of occurrence. Because they are deeply buried in most places, previous workers had to depend primarily on logs of existing water wells to interpret the geology. This was difficult because: 1) most water wells in the Dakota aquifer do not fully penetrate the unit, and thus are of limited interpretive value; and 2) the Cretaceous rocks of Iowa are poorly consolidated sedimentary rocks that do not lend themselves to good sample recovery during drilling. For these reasons, a program of test drilling and detailed sample collection, including the use of borehole geophysical equipment, was designed and implemented in order to acquire quality data for interpetation.

To date, 23 test holes with a cumulative footage of 11,491 feet (3502m) have been drilled. Additionally, a total of 16,527 feet (5,037m) of IGS test holes and municipal, industrial and private wells have been logged with the borehole geophysical logging unit. The more significant results derived from this research program are summarized in this report.

PURPOSE

This report is limited to a discussion of the geologic controls on water availability from the Dakota aquifer. Other groundwater sources, including alluvial, buried channel, and deeply buried Paleozoic bedrock aquifers are available for use in northwest Iowa. These aquifers are hydrologically connected to the Dakota Formation in different places, and, dependent upon local conditions, either provide recharge to, or are recharged by the Dakota aquifer. Any complete assessment of regional groundwater supplies should document the extent and characteristics of all these aquifers, and detail their interrelationships. Subsequent publications will contain this information.

The quantity and quality of water produced from the Dakota aquifer varies widely over its area of occurrence. At the present time, we are not yet able to relate spatial variations in aquifer productivity and water quality to hydrologic connection with adjacent aquifers.

The following are basic to determinations on where the Dakota aquifer can sustain heavy water withdrawals without serious user conflicts, and where it cannot:

1) To what degree is the local water-producing potential of the Dakota aquifer related to regional changes in its thickness and textures (facies changes)?
2) Can these facies changes be predicted from one area to another?

The interpretations presented are based on extant data which have been used to develop a geologic model. Subsequently acquired data will almost certainly require modifications of these interpretations. Thus with time the geologic model will be increasingly refined, and continually raise the level of confidence in its utility for predicting actual groundwater conditions.

GENERAL GEOLOGY

Stratigraphy

Literature of the Cretaceous rocks on the North American continent is fairly extensive, dating back to the first recorded observations by the Lewis and Clark expedition of 1804-6 (Thwaites, 1904, p. 106). However, little detailed work has been done on the Cretaceous rocks of Iowa, due to limited exposure. The best exposures of Cretaceous rocks in Iowa are located north of Sioux City along the bluffs of the Big Sioux River. Several previous workers have visited these exposures, and it is their work combined with the present drilling program that has helped establish the terminology presently used by the Iowa Geological Survey.

Figure 1 is a natural gamma log and lithologic representation of the Cretaceous rocks encountered in Iowa. These Cretaceous rocks are subdivided into four separate and distinctive formations.

Dakota Formation: The Dakota Formation is the lowermost Cretaceous unit found in northwest Iowa. It was originally defined in 1861 by Meek and Hayden for a 400-foot (122m) sequence of yellowish, reddish, and occasionally white sandstone, with local interbedded varicolored shales and lignite beds, near Dakota City in northeastern Nebraska. This original description compares very well with that illustrated in figure 1.

Graneros Shale: The Graneros Shale overlies the Dakota Formation and reflects a gradational change in the environment of deposition (see later discussion). The Graneros consists mainly of dark gray calcareous shales with a few interbedded sandstones of limited lateral and vertical extent. It ranges in thickness from 45 to 55 feet (13.7 0 16.8m) where overlain by the Greenhorn Limestone.

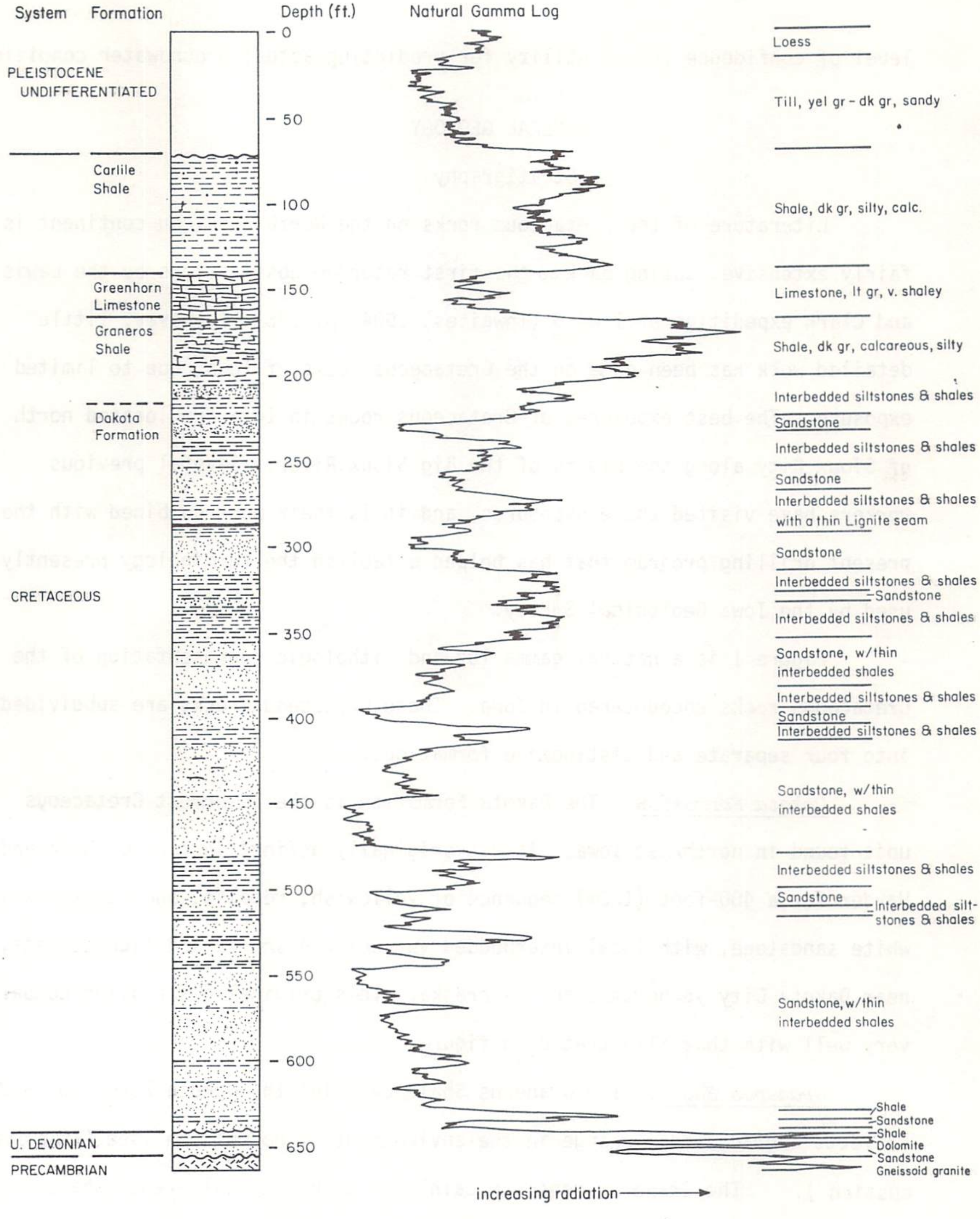


Figure 1. Geologic log, natural gamma log, and description of IGS-USGS core hole in the Cretaceous and underlying rocks near Hawarden in Sioux County, Iowa.

Greenhorn Limestone: The Greenhorn Limestone consists of thinly bedded to medium bedded, light gray to light yellow gray, chalky limestone, with a few thin seams of bentonite near the base. It is very fossiliferous, with abundant fragments of the pelecypod Inoceramus crowding the rock unit. The Greenhorn averages about 30 feet (9.1m) in thickness where overlain by the Carlile Shale and is a very consistent marker on natural gamma logs as shown in figure 1.

Carlile Shale: The Carlile Shale overlies the Greenhorn Limestone and is the youngest Cretaceous rock unit known in Iowa. It consists of dark gray silty hard shale that varies from 0 to 70 feet (0-21.3m) in thickness as a result of post-Cretaceous erosion. Exposures are limited to a few sites along the Big Sioux River north of Chatsworth in Sioux County. The rocks are preserved in this area because of post-Cretaceous structural deformation.

Structural Setting

Northwest Iowa is located on the southeastern flank of a major structural feature called the Transcontinental Arch (figure 2), which locally is defined by the erosional limits of the encircling Paleozoic rocks. These Paleozoic rocks dip away from the main axis of the arch, and in northwest Iowa they dip to the south-southeast (figure 3). Studies of the Paleozoic rocks surrounding the arch (Ham and Wilson, 1967; Witzke, 1979) have shown that this structure has a complex history and has played an important role in the depositional and tectonic development of the region.

The Cretaceous rocks of northwest Iowa were deposited on a previously deformed terrane of Precambrian rocks and northeast striking Paleozoic rocks. Intersecting with the Transcontinental Arch in southeast South Dakota and northwest Iowa is the Sioux Quartzite Ridge, an east-west trending positive topographic feature on the Precambrian surface (figures 2 and 3).

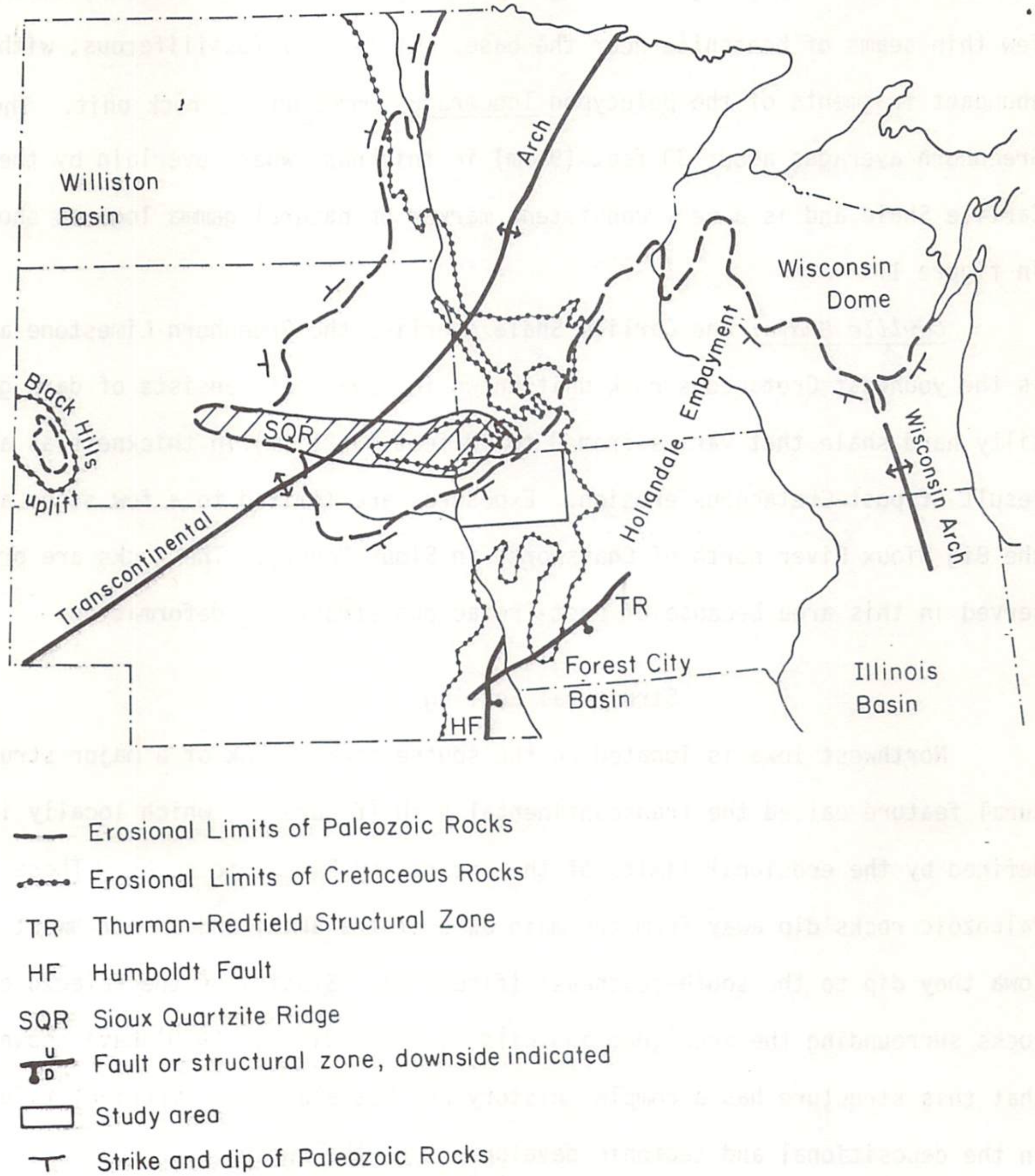
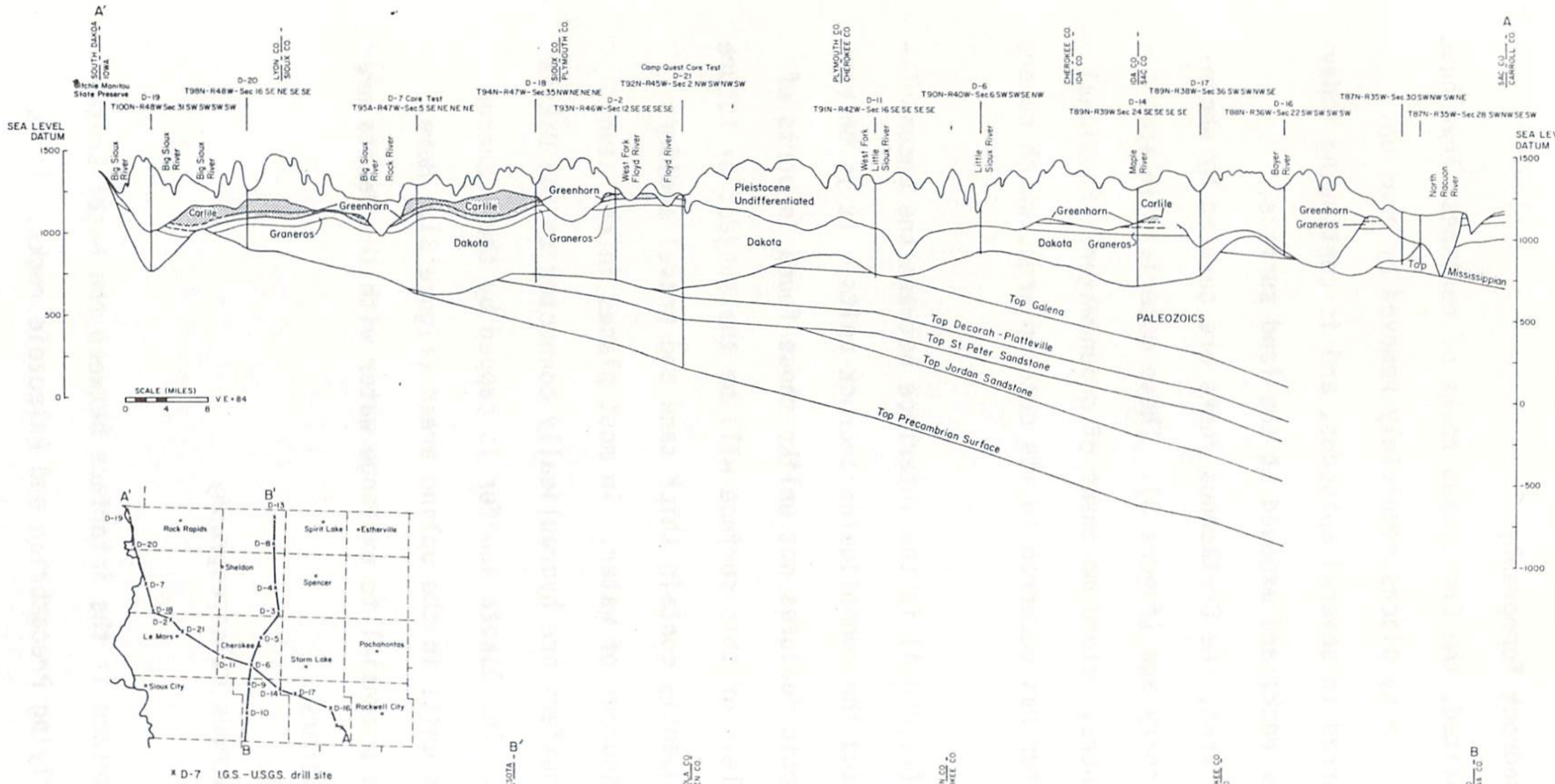


Figure 2. Structural geologic setting of the northwest Iowa project area.



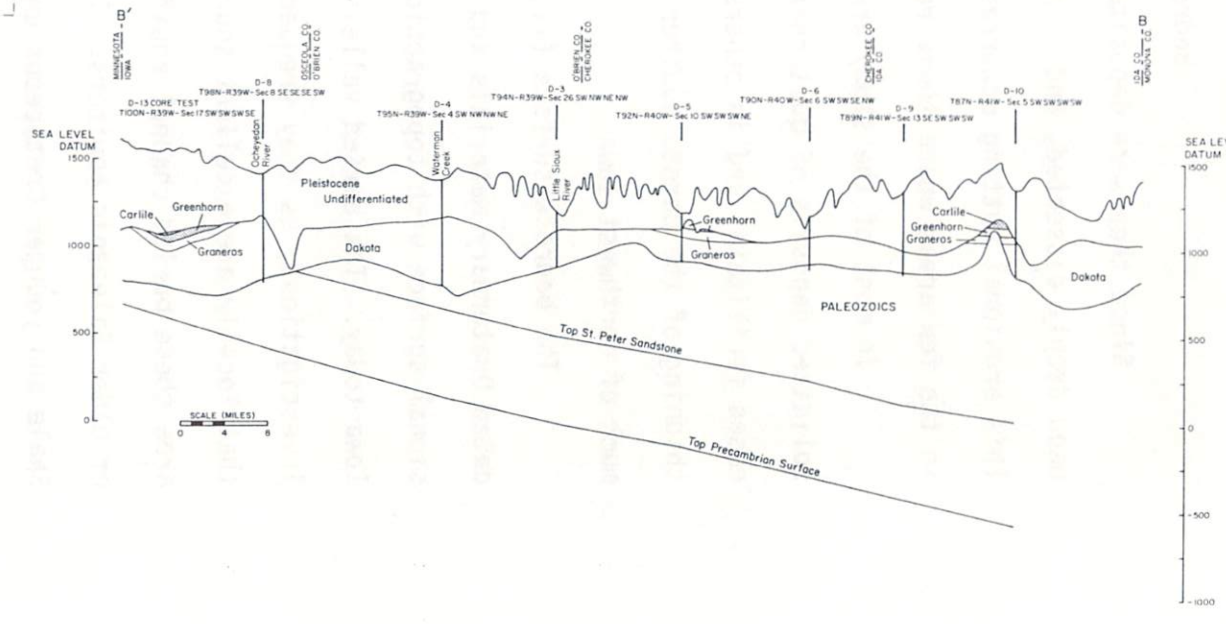


Figure 3. Geologic cross-sections of the project area.

GEOLOGICAL CONTROLS ON WATER AVAILABILITY

Bedrock Topography

Since they were deposited, the Cretaceous rocks of northwest Iowa have been deeply dissected, and in many places completely removed by erosion. This erosional cutting occurred in several episodes, and is continuing today in the few areas where these rocks are exposed at the land surface.

In most of the study area, the Cretaceous rocks are covered by unconsolidated deposits of Quaternary age (figure 3). These materials in some cases facilitate, and in others, retard movement of groundwater. Erosional thinning of the Dakota aquifer has occurred in its outcrop area, which covers much of northwest Iowa.

The bedrock surface (figure 4) is the interface between the unconsolidated Quaternary materials and the consolidated bedrock units. It is an erosional surface with topographic features not unlike those found in parts of Iowa today. The buried valleys of this surface will be the subject of future investigations, as they frequently contain thick sand and gravel aquifers that locally are excellent sources of water. In most places in the study area these buried channel aquifers are hydraulically connected to the Dakota or older Paleozoic aquifers. The Dakota aquifer is capped by the Graneros Shale and younger Cretaceous units in the upland areas (figure 3). Here, the only aquifers having the potential to exchange water with the Dakota are the underlying Paleozoic aquifers.

Cretaceous Paleogeography

Sub-Cretaceous Surface

The sub-Cretaceous surface is the interface between the basal Cretaceous deposits and the underlying Precambrian and Paleozoic rocks. It is an erosional unconformity of major significance, truncating Precambrian

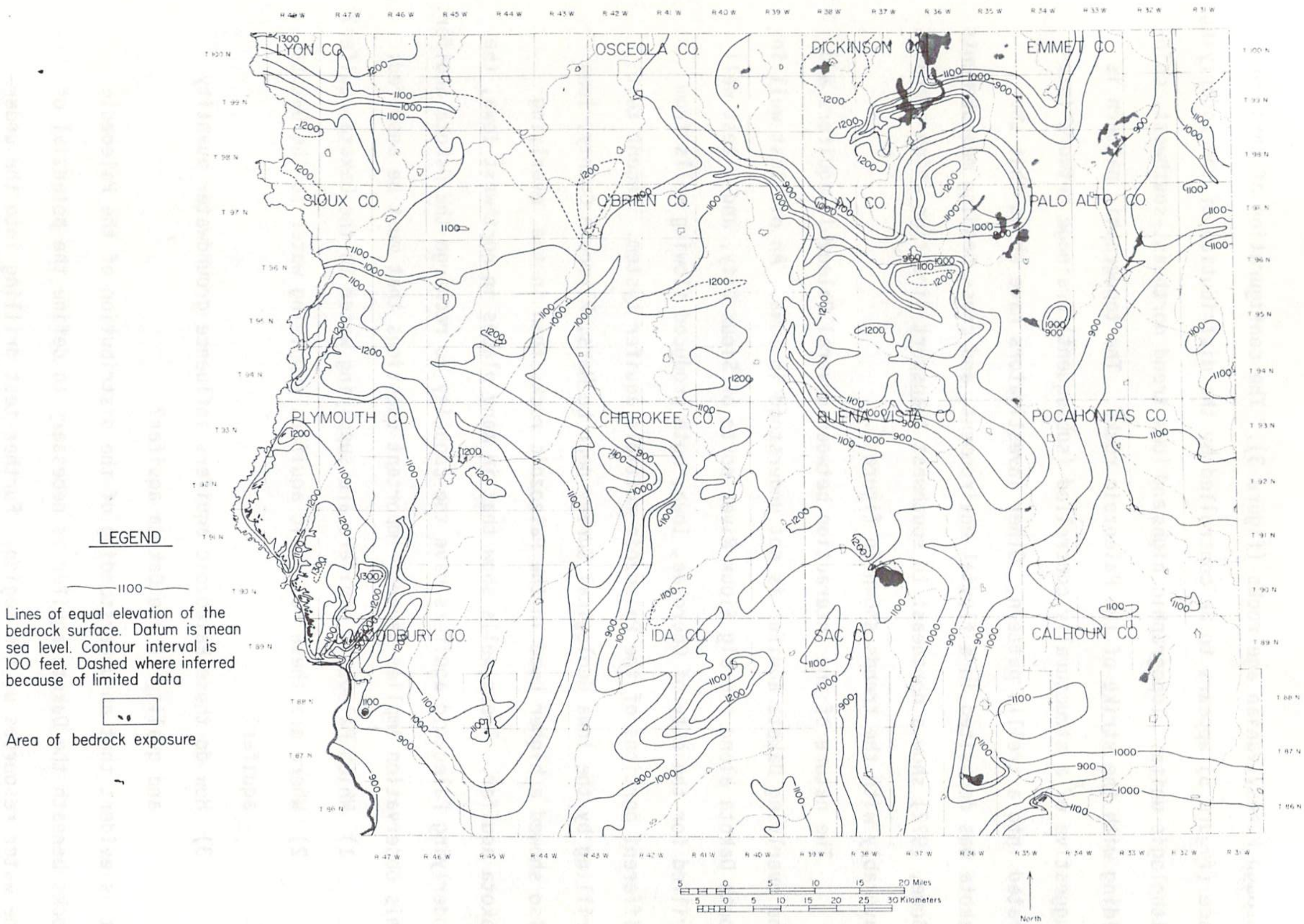


Figure 4. Bedrock topographic map.

through Pennsylvanian age rocks (figure 3). The configuration of this surface (figure 5) appears to be controlled by the distribution of the underlying lithologic units. Topographic highs and lows trend northeast-southwest, coinciding with the strike of the Paleozoic rocks. The topographic pattern is suggestive of a structurally controlled (subsequent) drainage network integrated into a trellis pattern. Other investigators have shown that the Dakota was deposited in a fluvial environment, and cross bedding measurements (Bowe, 1972) show a northeast to southwest transport direction which compares favorably with the trends shown in figure 5.

The nature of the interaction between several Paleozoic aquifers and the overlying Dakota aquifer is not understood in Iowa. An oil test well in South Dakota along the Big Sioux River north of Sioux City, and a test well drilled for the city of Cherokee, Iowa, both produced flowing wells from different portions of the Paleozoic multiple aquifer system. Recent test drilling by the Iowa Geological Survey near Le Mars, Plymouth County, Iowa also showed a higher head in the Paleozoic rocks than in the overlying Dakota aquifer. These wells show that in many places in northwest Iowa, the underlying Paleozoic aquifers have the capacity to recharge the Dakota aquifer. This observation implies several important questions that must be answered:

1) Which Paleozoic aquifers are supplying water to the Dakota aquifer?
2) Where are these Paleozoic aquifers supplying water to the Dakota aquifer?
3) How do these Paleozoic aquifers influence groundwater quantity and quality in the Dakota aquifer?

It is evident that an understanding of the distribution of the Paleozoic rocks beneath the Dakota aquifer is necessary to define the potential of the water resources of the region. Further test drilling into the underlying Paleozoics will permit refinements in the understanding of the

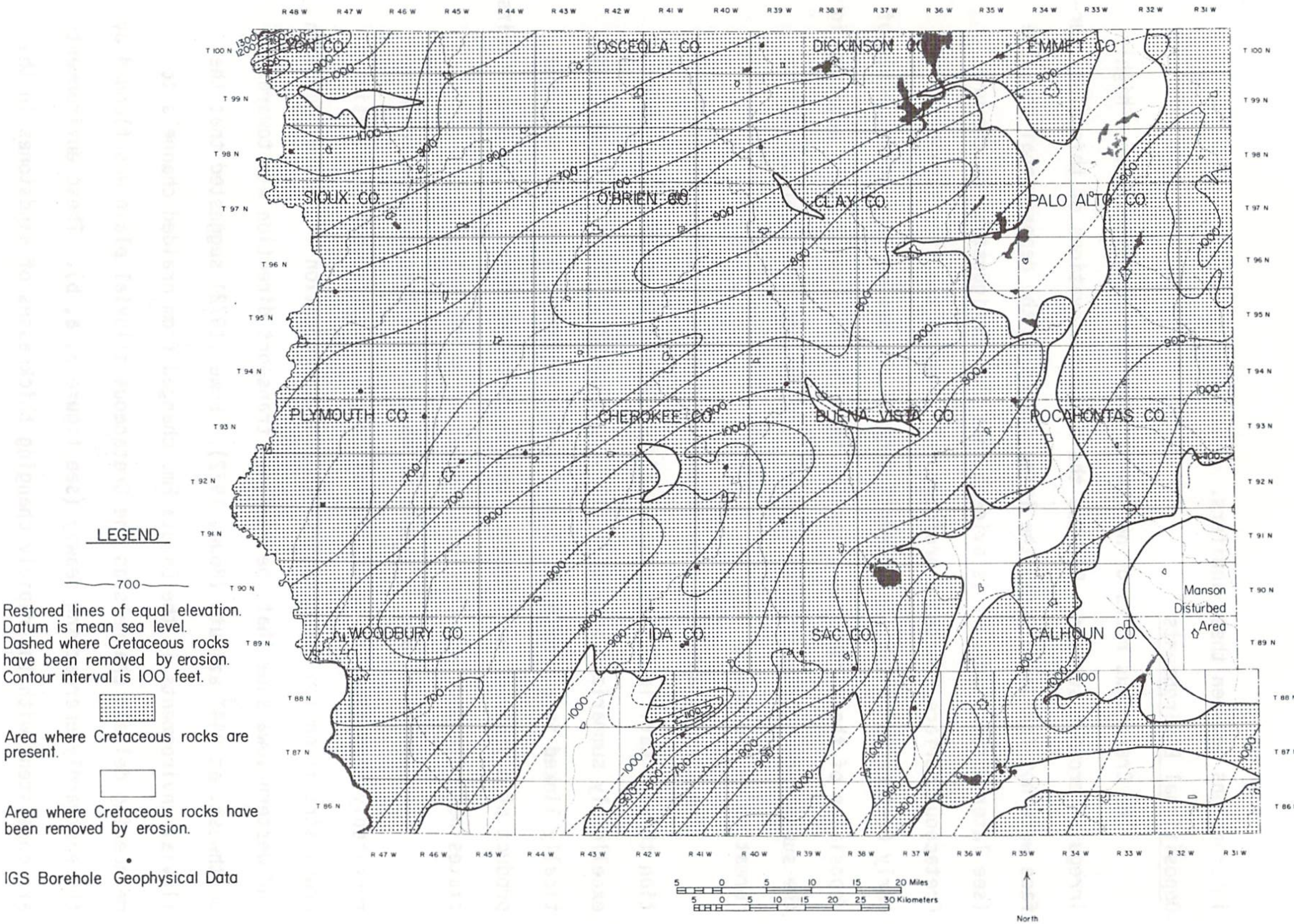


Figure 5. Contour map of the base of the Cretaceous system.

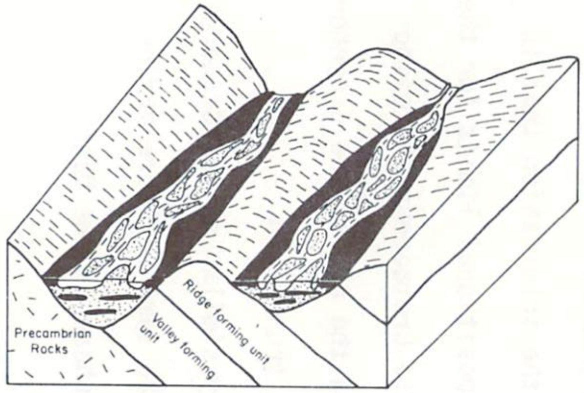
interactions between these aquifers.

Depositional Environments

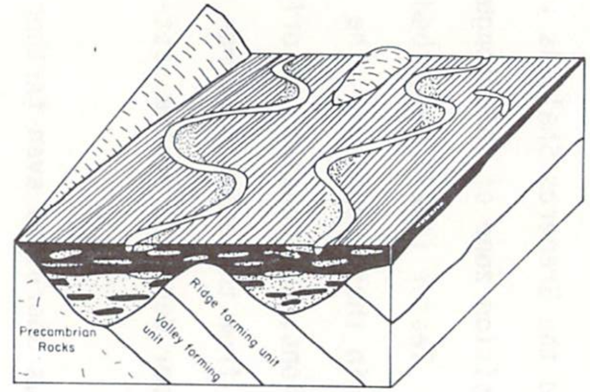
The Cretaceous rocks of northwest Iowa were deposited upon a highly irregular erosion surface. Because the highest elevations of this older surface were not inundated until the later stages of the depositional sequence (see later discussion), it is evident that the configuration of the pre-Cretaceous surface exerted a profound influence on the stratigraphy of the early Cretaceous units. An understanding of the sedimentary environments of deposition of these rocks is essential in order to predict their geometry in the subsurface. Of particular interest are the sandstones of the Dakota Formation -- the Dakota aquifer.

The stratigraphy and depositional environments of the Dakota Formation through Carlile Shale sequence of the Great Plains region has been excellently summarized by Hattin (1975, pp. 86-92). These units are genetically linked in a continuous depositional sequence, with each unit the product of a group of environments that migrated eastward as the Great Plains states were flooded by a Cretaceous seaway from the west.

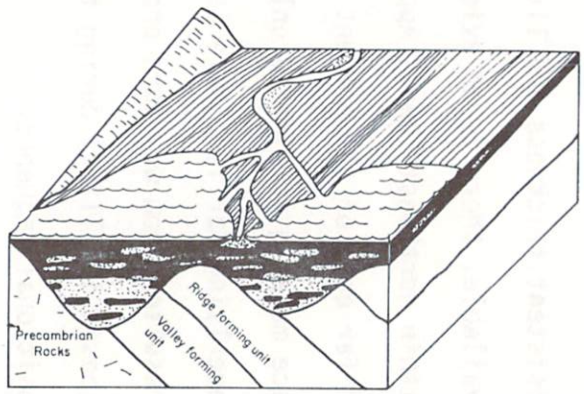
The sandstones and mudstones of most of the Dakota Formation have repeatedly been shown to be of fluvial origin. Statistical compilation of cross-stratification directions in the Dakota Formation of eastern Nebraska and western Iowa show that the regional transport direction was toward the southwest, at 244^0 azimuth (Bowe, 1972). Bowe (1972) suggested that the fluvial environments in the Dakota Fm. changed from braided channels to meandering deltaic channels as the Cretaceous alluvial plain was flooded by the eastwardly encroaching seaway (see figure 6, a, b). These environments are consistent with the rapidly changing thicknesses of sandstones in the Dakota Formation. Individual sandstone bodies are not laterally or vertically



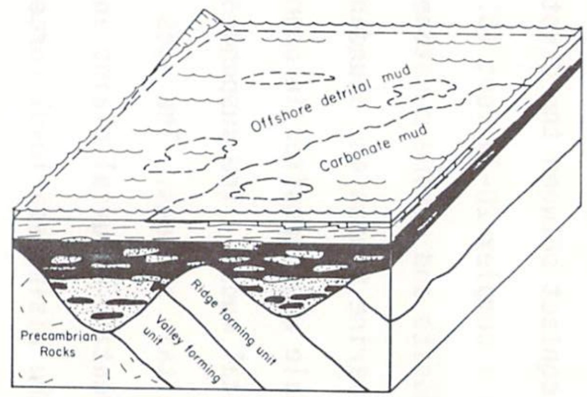
a) Lower Dakota Formation



b) Upper Dakota Formation



c) Dakota - Graneros Shale transition



d) Graneros Shale - Greenhorn Limestone transition

Figure 6. Block diagrams showing the sequence of environments of deposition from the Dakota Formation to the Greenhorn Limestone.

persistent, and rapidly interfinger with flood basin siltstones and claystones. Thus the local stratigraphy of the Dakota Formation can be unpredictable. The question is whether or not regional trends can be recognized.

The contact between the Dakota Formation and the Graneros Shale is represented by a complex 20-30 foot (6.1 - 9.1m) transition zone of intertonguing deltaic deposits and marine mudstones (figure 6c). Tester (1929) described restricted marine faunas and abundant plant debris in these deposits. The Graneros Shale was deposited in open marine conditions, and consists of offshore detrital muds -- the suspended sediment load from the eastwardly retreating deltaic systems. The muds covered the older deposits of the eastwardly retreating alluvial plains and deltas.

As the rising sea level forced the Cretaceous shoreline even farther to the east, detrital sedimentation steadily decreased, and open marine carbonate mud deposition became dominant (figure 6d). These carbonate muds are preserved today as the Greenhorn Limestone, a stratigraphic marker of remarkably persistent thickness and lithology. From the information that is presently available, there is no evidence of the depositional limits for the Greenhorn within northwest Iowa. Apparently the late Cretaceous shoreline transgressed far east of the present study area, and the use of the Greenhorn for subsurface mapping is limited only by erosional truncation.

The overlying Carlile Shale is depositionally similar to the Graneros Shale, and resulted from westward progradation of the same offshore marine mud facies (basin infilling) during the regressive phase of the Dakota-Carlile depositional sequence.

Pre-Cretaceous Topography

Isopach (thickness) maps show in three dimensions the thickness of rocks between any two horizons. If both surfaces were originally flat, a thickness map should reveal the total structural movement of the lower surface when the upper surface was deposited. However, if one of the surfaces represents an interval of topographic relief, and if structural deformation between the two surfaces was insignificant, a thickness map should roughly show the topography of the eroded surface.

As previously defined, the sub-Cretaceous surface of northwest Iowa shows a series of northeast-southwest trending topographic highs and lows, representing an eroded surface of strike-oriented valleys during deposition of the Dakota sediments. By the time of deposition of the Greenhorn Limestone this surface of topographic relief was mostly buried. Examination of geophysical logs, exposures and sample cuttings shows the base of the Greenhorn Limestone to be the best horizon in the Cretaceous system of northwest Iowa for structural mapping purposes. Apparent structures (Figure 7) of low relief are noted, which are oriented in a northeast-southwest direction paralleling the Transcontinental Arch, suggesting possible post-Greenhorn reactivation of the Arch.

Assuming that the base of the Greenhorn Limestone was a flat surface when deposited, a thickness map between this surface (figure 7) and the sub-Cretaceous surface (figure 5) should approximate the pre-Cretaceous topography. Figure 8 is a reconstruction of this interval. Areas where this interval is thick indicate topographically low areas on the Dakota drainage surface, and areas where the interval is thin indicate topographically high areas (see figure 3).

Examination of this map (figure 8) reveals two important aspects concerning the paleogeography of the area: 1) a thinning of this interval to the northwest suggests that the Sioux Quartzite Ridge stood as a feature of positive relief until buried by the Greenhorn Limestone. This contention is supported by biostratigraphic investigations of Cretaceous rocks on the north

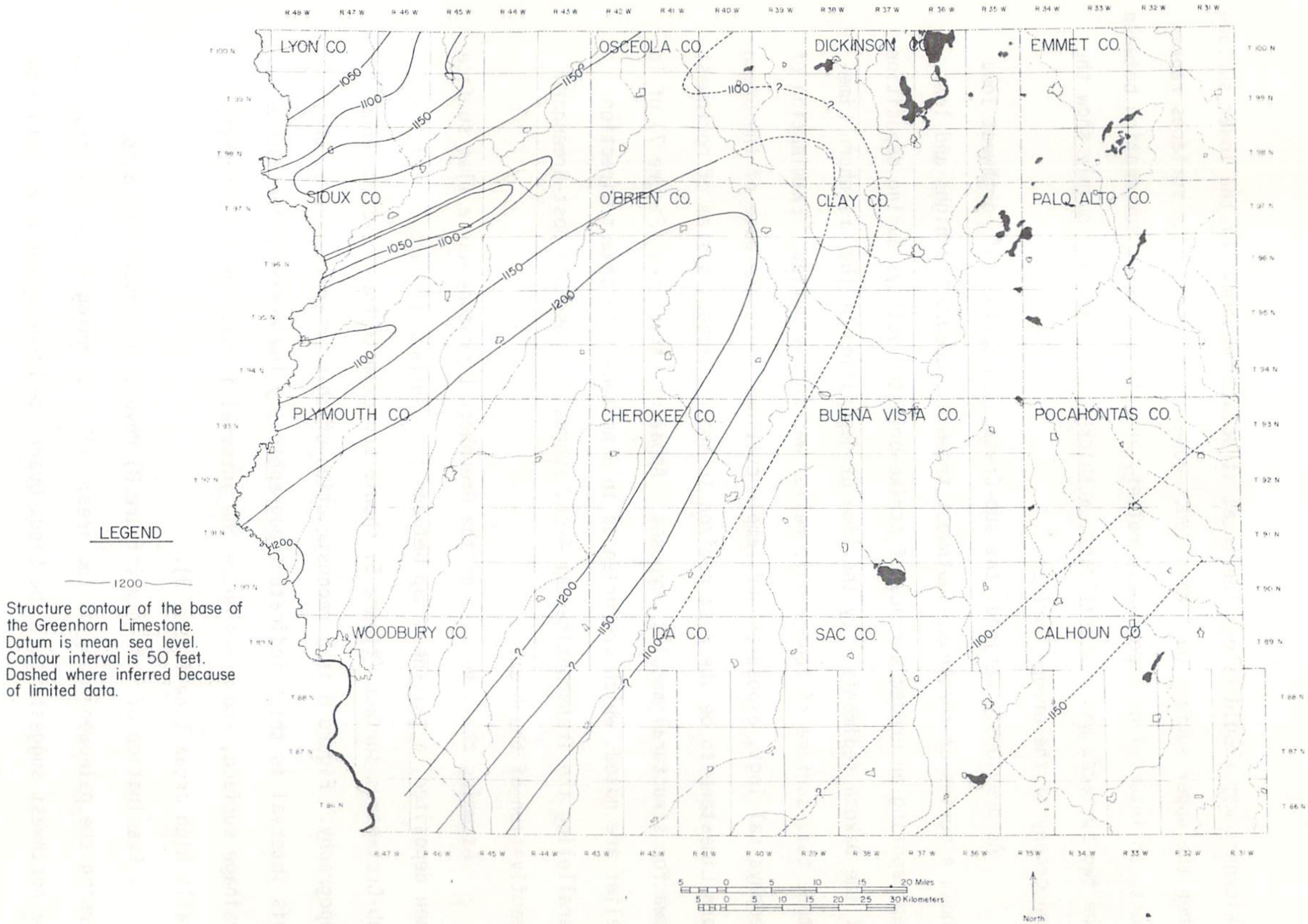


Figure 7. Structure contour map of the base of the Greenhorn Limestone.

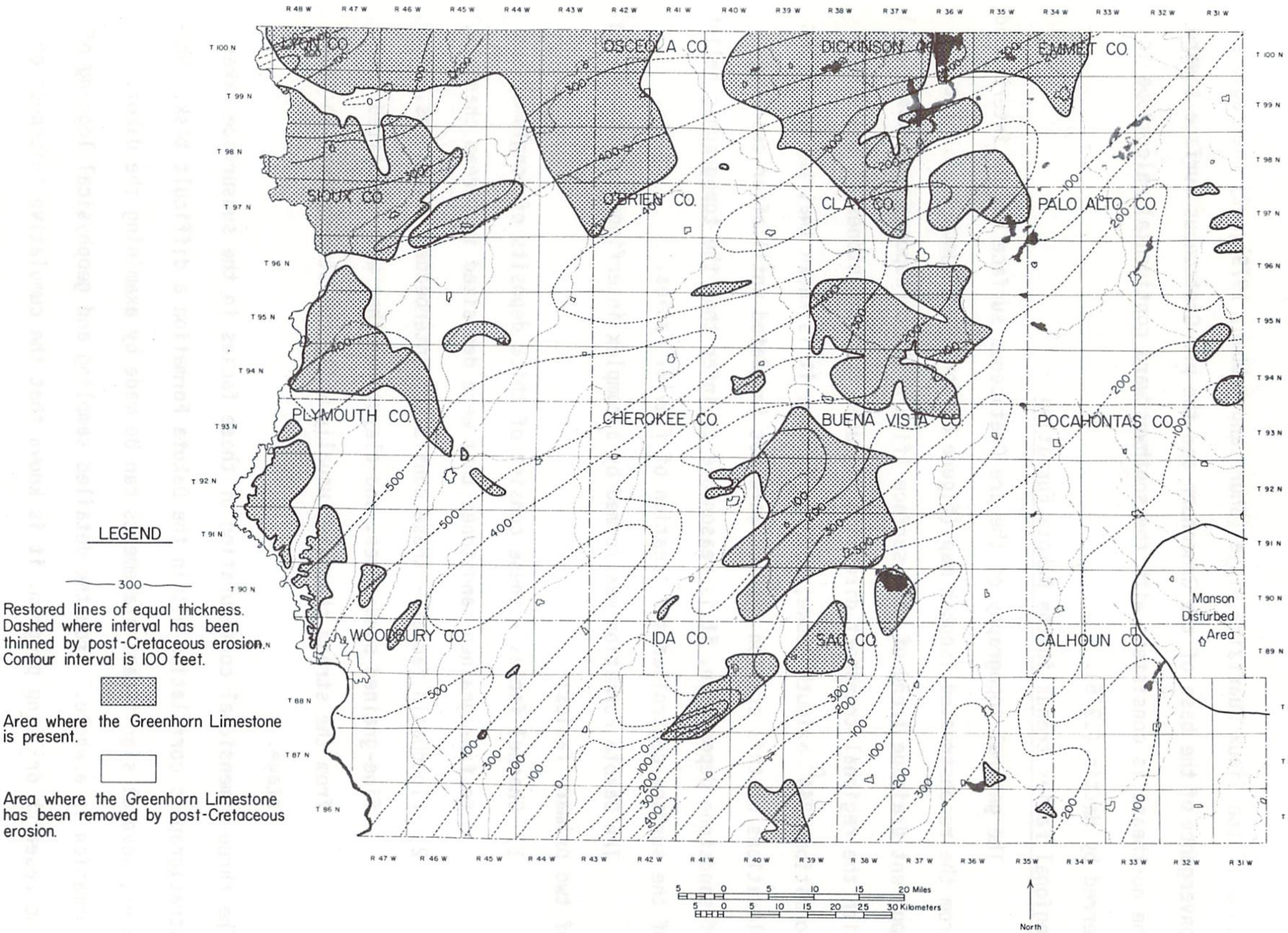


Figure 8. Isopach map of the base of the Greenhorn Limestone to the base of the Cretaceous system.

flank of the Sioux Quartzite Ridge (Shurr and Cobban, 1979); 2) the regional convergence of the base of the Greenhorn and the pre-Cretaceous surface toward the northeast is consistent with the southwestward continental paleoslope inferred by Hattin (1975).

<u>Regional Facies trends in the Dakota Formation</u>

The general topography of the pre-Cretaceous surface can be interpreted from the reconstructed isopach map (figure 8) for the project area. The apparent drainage trend of this surface (figure 9) corresponds remarkably well with the regional transport direction measured from sandstones in the Dakota Formation, 244^0 azimuth (Bowe, 1972). Because it is known that the uppermost elevations of this erosion surface were not inundated until after cessation of sandstone deposition, it is reasonable to infer that the topographic relief of the surface controlled the location of fluvial facies.

The Dakota Formation was formed by a complex interfingering assemblage of two primary facies:

1) Channel facies - these consist of thick deposits of conglomerates to fine-grained sandstones that were deposited in stream channels.
2) Floodbasin facies - these consist of interbedded siltstones, very fine-grained sandstones, and claystones that were deposited away from the stream channels, usually while the streams were in flood stage.

The three-dimensional configuration of these facies in the subsurface makes stratigraphic correlation within the Dakota Formation a difficult task. However, several significant statements can be made by examining the Dakota Formation as a whole. From the detailed sampling and geophysical logging of the research drilling program, it is known that the cumulative thickness of sandstone units in the Dakota Formation ranges from at least 66 to 341 feet

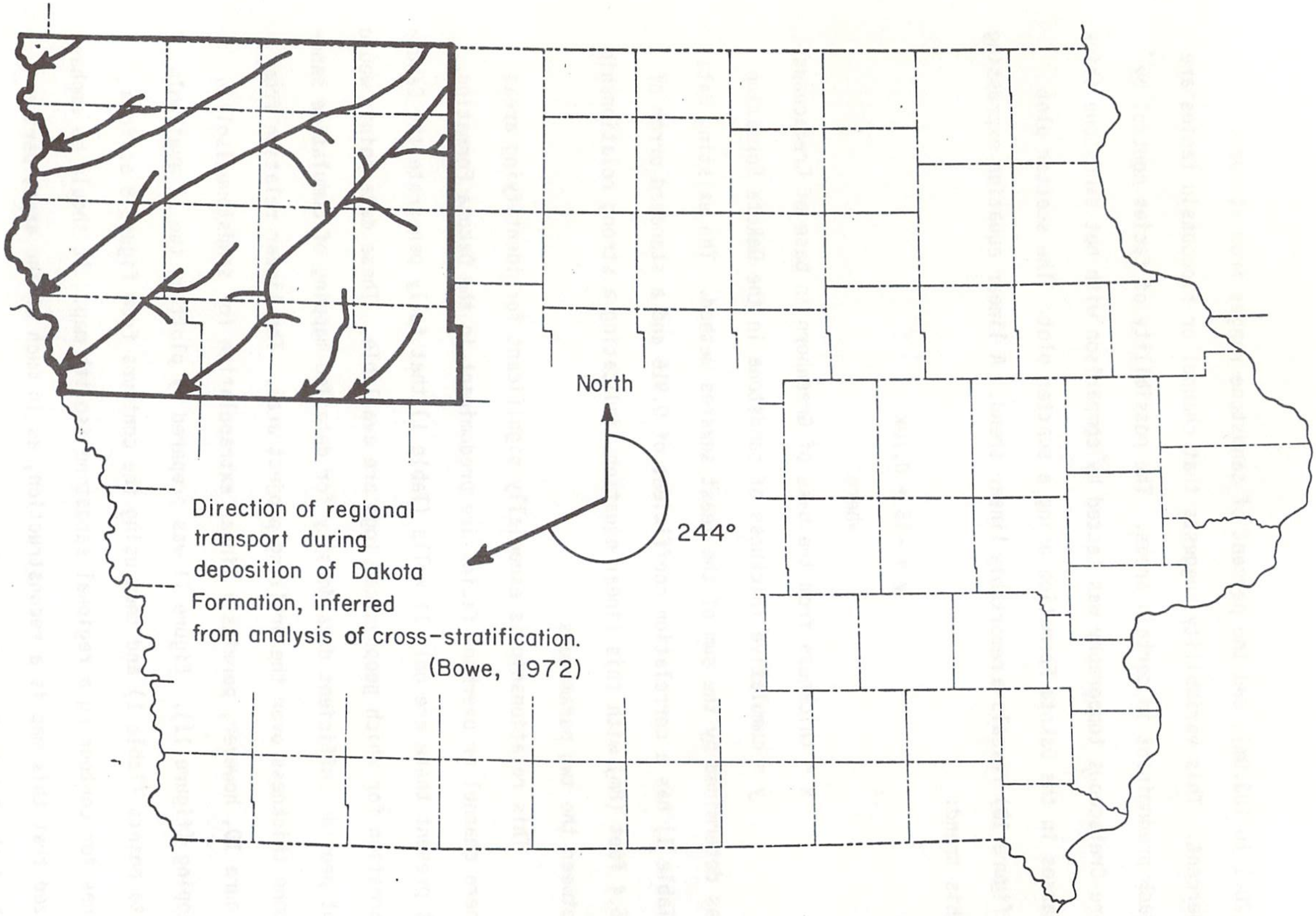


Figure 9. Relationship between Late Cretaceous paleodrainage inferred from well data, and the direction of regional fluvial transport inferred from outcrops in eastern Nebraska and western Iowa.

(20.1 to 103.9m), and the percent of sandstone ranges from at least 46 to 76 percent. This variability suggests that channel or floodbasin facies are each predominant in certain areas. The possibility of facies control by pre-Cretaceous topography was tested by comparison with net sandstone thicknesses in the Dakota Formation using a scatter plot. The scatter plot (figure 10) reveals a remarkably linear trend. A linear equation expressing this trend:

$$y = -45 + 0.70x$$

where

x = thickness from the base of Greenhorn to base of Cretaceous

y = cumulative thickness of sandstone in the Dakota Formation

was determined by the sum of the least squares method. The existing data (Table I) has a correlation coefficient of 0.916 and a standard error of 26.4 feet (8m) with this linear equation, indicating a strong relationship between the two parameters.

This relationship is especially significant for identifying areas where channel or overbank facies are predominant in the Dakota Formation. At present there are only 11 wells (Table 1) that fully penetrate the Dakota Formation for which geophysical logs are available. These data points would not provide sufficient data density for detailed mapping of cumulative sandstone thickness over the drilling project area. The linear relation from figure 10, however, permits a linear extrapolation for sandstone isolith mapping (figure 11). Figure 11 was prepared by plotting the 11 available data points (Table 1) and then using the contours from figure 8 as form lines for contouring a regional sandstone isolith map. It should be emphasized that this map is a reconstruction, as in much of the area, part or all of the Dakota Formation has been removed by erosion.

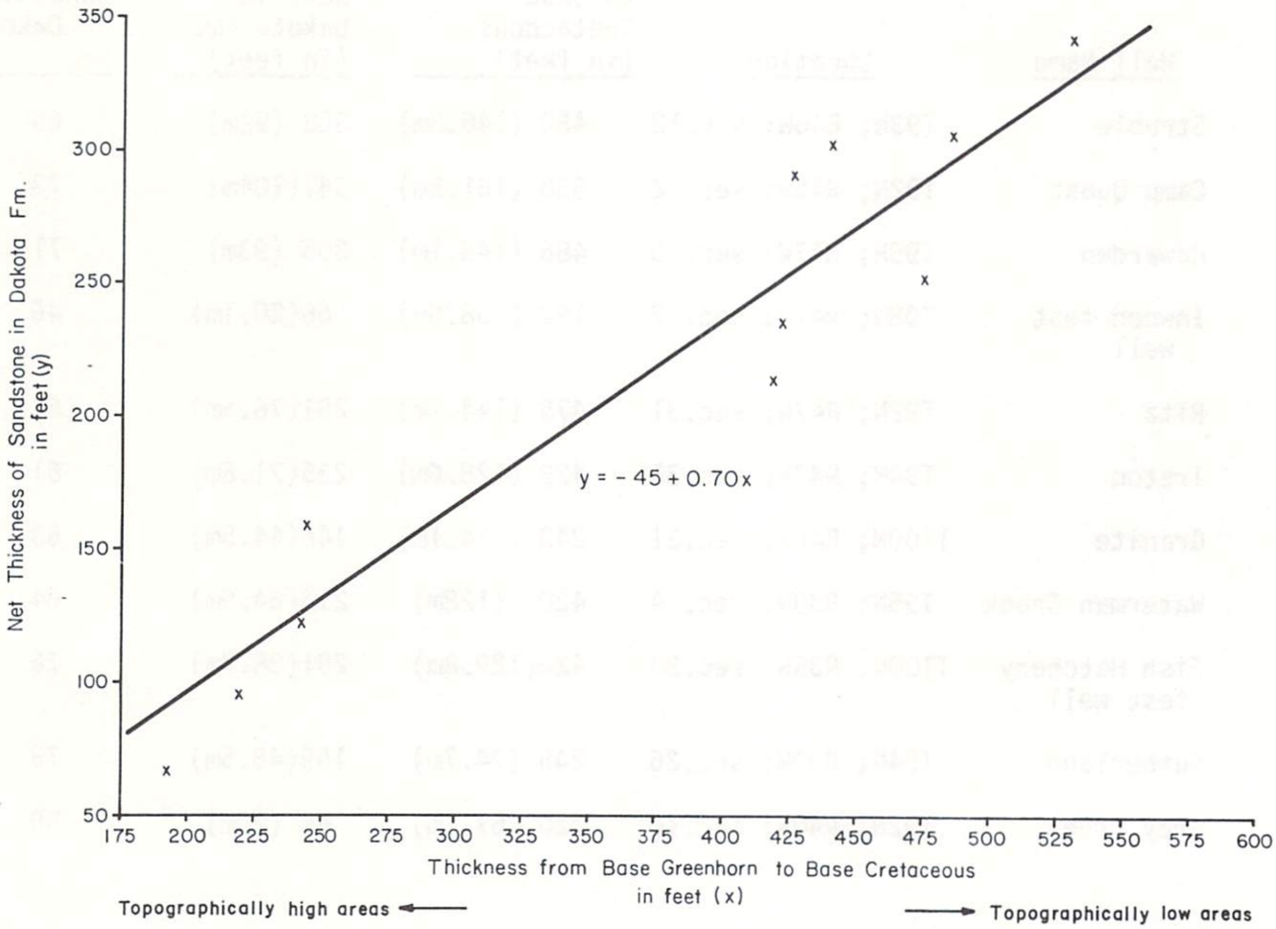


Figure 10. Relationship between net sandstone thickness in the Dakota Formation and thickness from the base of the Greenhorn Limestone to the base of the Cretaceous system.

Table I. Natural gamma log data used to interpret facies controls in Dakota Formation

Well Name	Location	Thickness from base Greenhorn to base Cretaceous (in feet)	Net sandstone thickness in Dakota Fm. (in feet)	Percent sandstone in Dakota Fm.
Struble	T93N; R46W; sec.12	480 (146.3m)	302 (92m)	69
Camp Quest	T92N; R45W; sec. 2	530 (161.5m)	341(104m)	73
Hawarden	T95N; R47W; sec. 5	486 (148.1m)	305 (93m)	71
Inwood test well	T98N; R47W; sec. 7	192 (58.5m)	66(20.1m)	46
Ritz	T92N; R47W; sec.31	475 (144.7m)	251(76.5m)	61
Ireton	T94N; R47W; sec.35	422 (128.6m)	235(71.6m)	61
Granite	T100N; R48W; sec.31	243 (74.1m)	146(44.5m)	63
Waterman Creek	T95N; R39W, sec. 4	420 (128m)	213(64.9m)	64
Fish Hatchery test well	T100N, R36W; sec.28	426(129.8m)	291(88.7m)	76
Sutherland	T94N; R39W; sec.26	245 (74.7m)	159(48.5m)	73
Gray Creek	T92N; R40W; sec.10	220 (67.1m)	95 (29m)	50

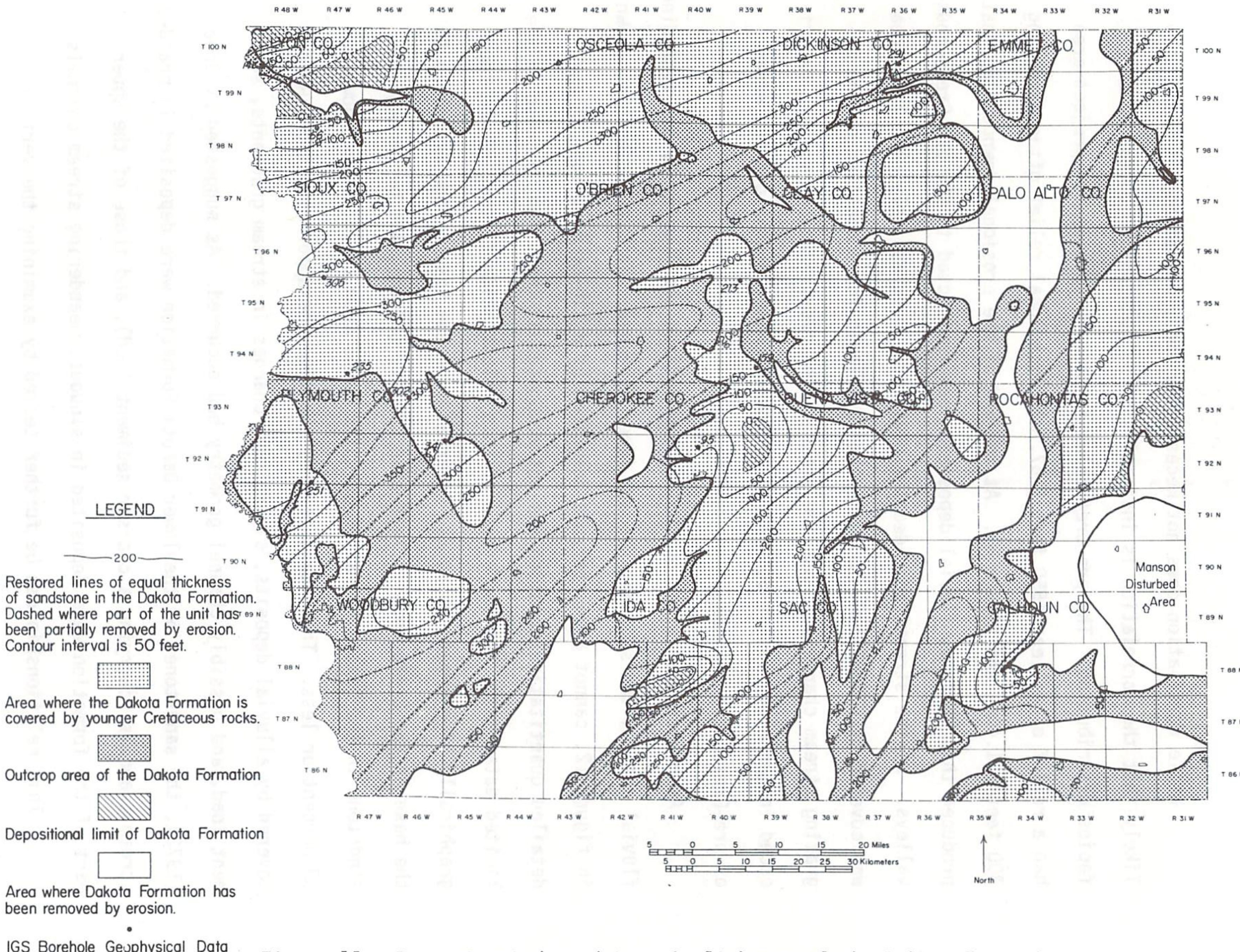


Figure 11. Reconstructed sandstone isolith map of the Dakota Formation.

While correlation does not necessarily imply causation, it seems very likely that the correlation is indicative of paleotopographic control of facies distribution. The pre-Cretaceous erosion surface in the project area had a relief of at least 550 feet (167.7m), with local relief often exceeding 300 feet (91.4m - see figure 8). At the end of the erosional downcutting that produced this surface, fluvial deposition was restricted to the pre-Cretaceous valleys. As the streams aggraded their valleys, progressively more land area was covered by alluvial plains and became available for occupation by the migrating stream channels. Thus the areas of the pre-Cretaceous valleys experienced longer histories of occupation by stream channels than did the areas of pre-Cretaceous uplands.

As higher elevations on the erosion surface were buried by the aggrading fluvial system, the sediments became finer textured. This relationship, shown in figure 12, cannot adequately be described by a linear equation. A more detailed quantitative solution was not attempted at this time, because of the limited data base. The importance of this illustration is that in the topographically high areas, where the interval from the base of the Greenhorn to the base of the Cretaceous is less than 225 ft. (68.6m), the percentage of sandstone in the Dakota Formation abruptly drops from 60-75 percent down to 50 percent or less. This means that by the time the upper elevations were covered by alluvial deposits, significant changes in stream gradients, sediment load, and possibly channel geometry had occurred. As suggested by Bowe (1972), the sandstones of the lower Dakota Formation were deposited in braided stream channels (carrying a coarser sediment load), and those of the upper part of the formation were deposited in sinuous, meandering stream channels.

This relationship can be further tested by examining the vertical lithologic sequence in the Dakota Formation. The left side of figure 13

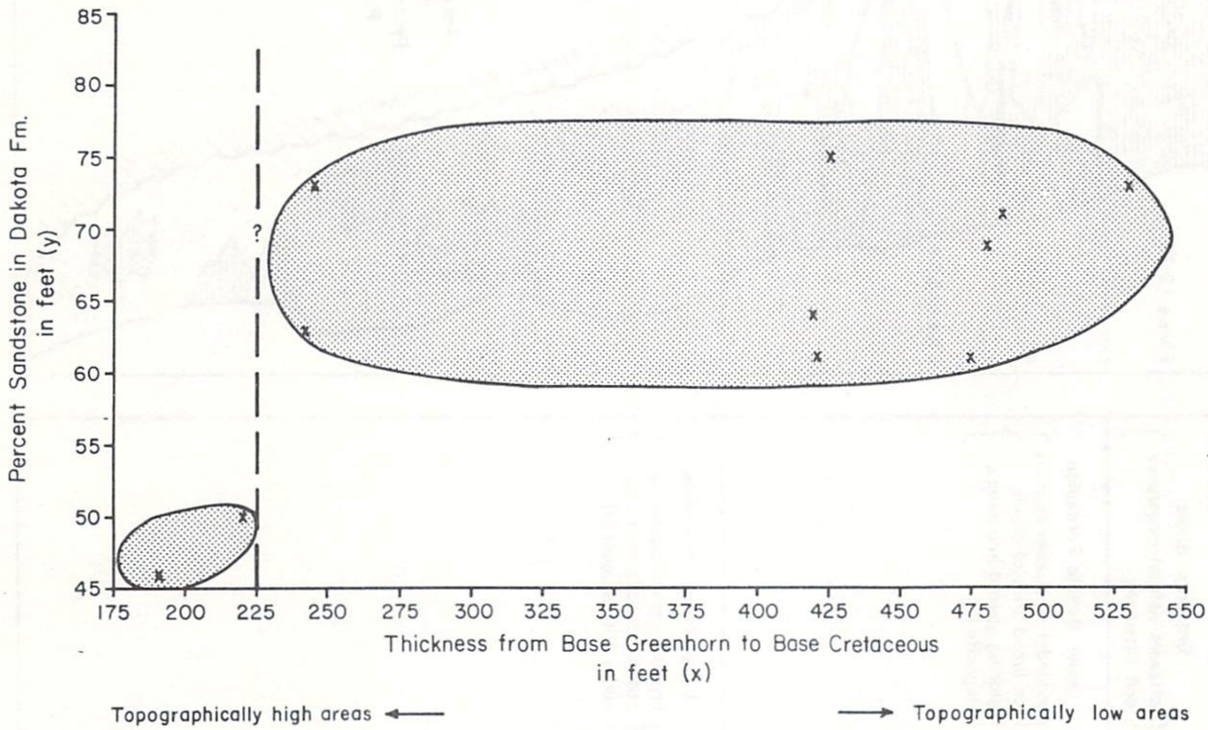


Figure 12. Relationship between percent sandstone in the Dakota Formation and thickness from the base of the Greenhorn Limestone to the base of the Cretaceous system.

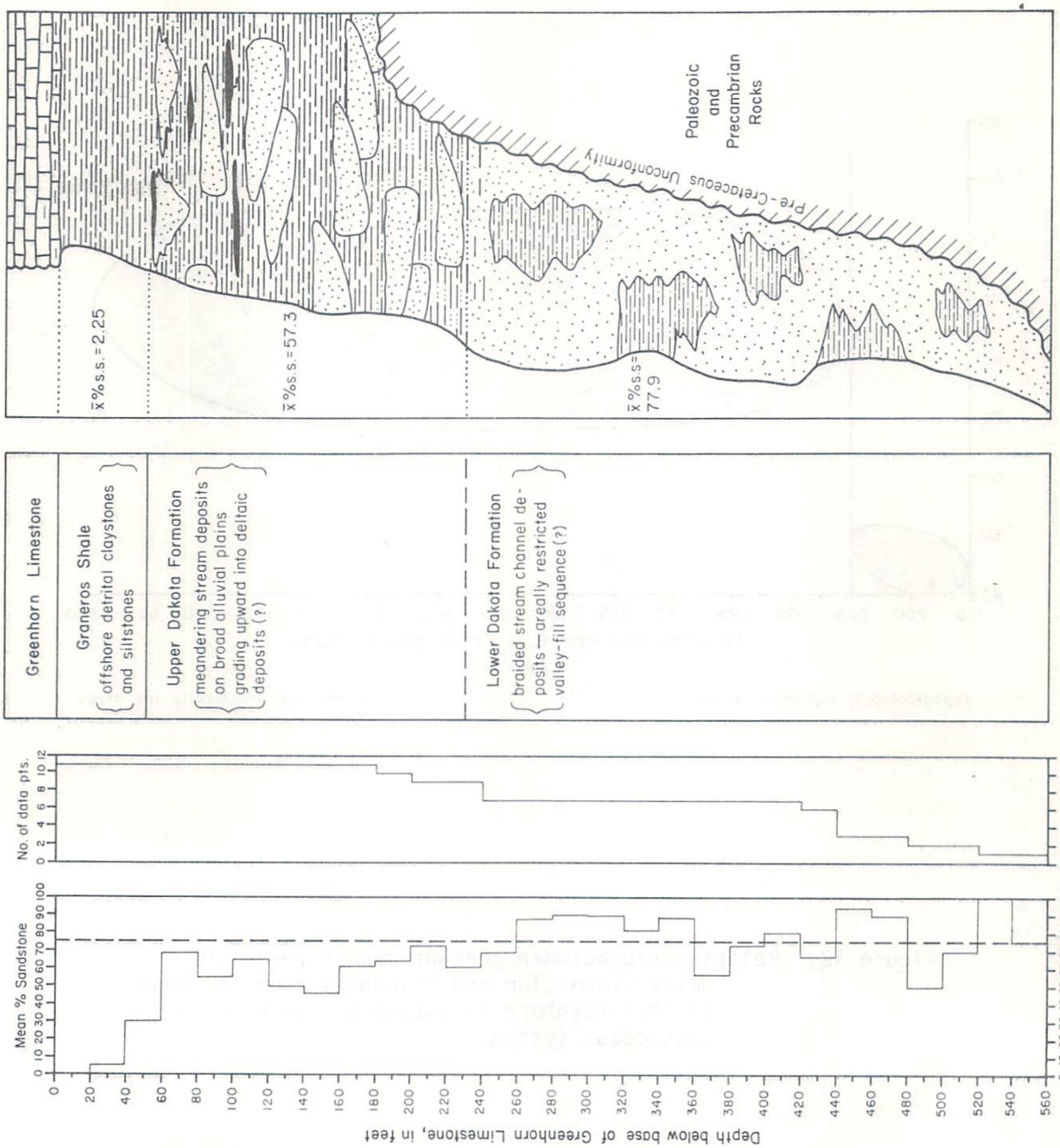


Figure 13. Vertical lithologic trends in the Graneros-Dakota interval of northwest Iowa, with inferred environments of deposition and spatial relationships. Interpretations based on natural gamma logs from test wells listed in Table I.

shows the mean percent sandstone in 20-foot (6.1m) intervals defined by depth below the base of the Greenhorn Limestone. The data for figure 13 was obtained from the 11 test wells listed in Table I. All of these test wells fully penetrate the Dakota Formation, but the total thickness measured in each varies because of the erosional relief at the base of the formation. As a consequence, some variability in percent sandstone near the bottom of the figure reflects unequal weighing from the small sample population, and is not indicative of a regionally persistent stratigraphic feature.

The lithologic sequence falls into three distinct units, based on the percentage of sandstone. The Graneros Shale, approximately 50 feet (15.2m) thick, consists of only 2% sandstone, the rest being claystone and siltstone. The upper 180 feet (54.9m) of the Dakota Formation has a lower sandstone percentage (57%) than the lower part (78%). This is consistent with the suggestion that the Dakota Formation may have been deposited by two distinct fluvial regimes. Higher sand/shale ratios generally are associated with braided channel environments, and lower sand/shale ratios generally are associated with meander belt environments. Figure 13 illustrates the importance of the pre-Cretaceous erosion surface in determining the areal distribution of fluvial facies in the Dakota Formation. In the areas of pre-Cretaceous valleys, the lithologic sequence in the Dakota Formation apparently consists of a thick succession of valley-fill braided stream channel deposits overlain by meandering stream deposits. In the upland areas of the old erosion erosion surface, however, the total sequence is greatly thinned and consists only of meandering stream deposits. Thus it can be inferred that the Dakota Formation in northwest Iowa can be separated into two different areal facies associations:

1) Thick valley-fill alluvial sequences consisting of approximately 70% sandstone.

2) Thin alluvial plain sequences consisting of less than 50% sandstone. The alluvial plain deposits appear to be nearly ubiquitous to the study area, but the thick valley-fill deposits are restricted to drainageways on the pre-Cretaceous erosion surface.

Hydrogeologic Significance

From the regional facies relationships that have been outlined, several qualitative statements can be made about variations in the water-producing potential of the Dakota aquifer. These statements refer to variations that occur because of internal changes in aquifer characteristics. It is known that hydraulic connection with overlying and underlying aquifers is also an important factor, but at present these conditions cannot be assessed with any confidence.

Figure 11 depicts the best predictor of water-producing potential in the Dakota aquifer that is presently available. In the areas where the cumulative thickness of sandstone is 100 feet (30.5m) or less, aquifer productivity appears to drop off rapidly. This dropoff is not simply a function of the net thinning of the aquifer. A portion of the decreased productivity is caused by lithologic changes. Where the net sandstone thickness is less than 100 feet (30.5m) the extant data shows that the sandstone percentage falls abruptly (figure 14). This again, is considered to be a reflection of changing stream hydrology in the later stages of deposition of the Dakota Formation (see figure 6b). Individual channel sandstone bodies within the Dakota Formation are known to be lenticular, and therefore of limited vertical and areal extent. In areas where sandstone comprises 70% of the vertical sequence, the degree of interconnection between sandstone bodies should be greater than in areas where 50% or less of the vertical sequence is composed of sandstone (see figure 13). Because they probably are better connected hydraulically, it

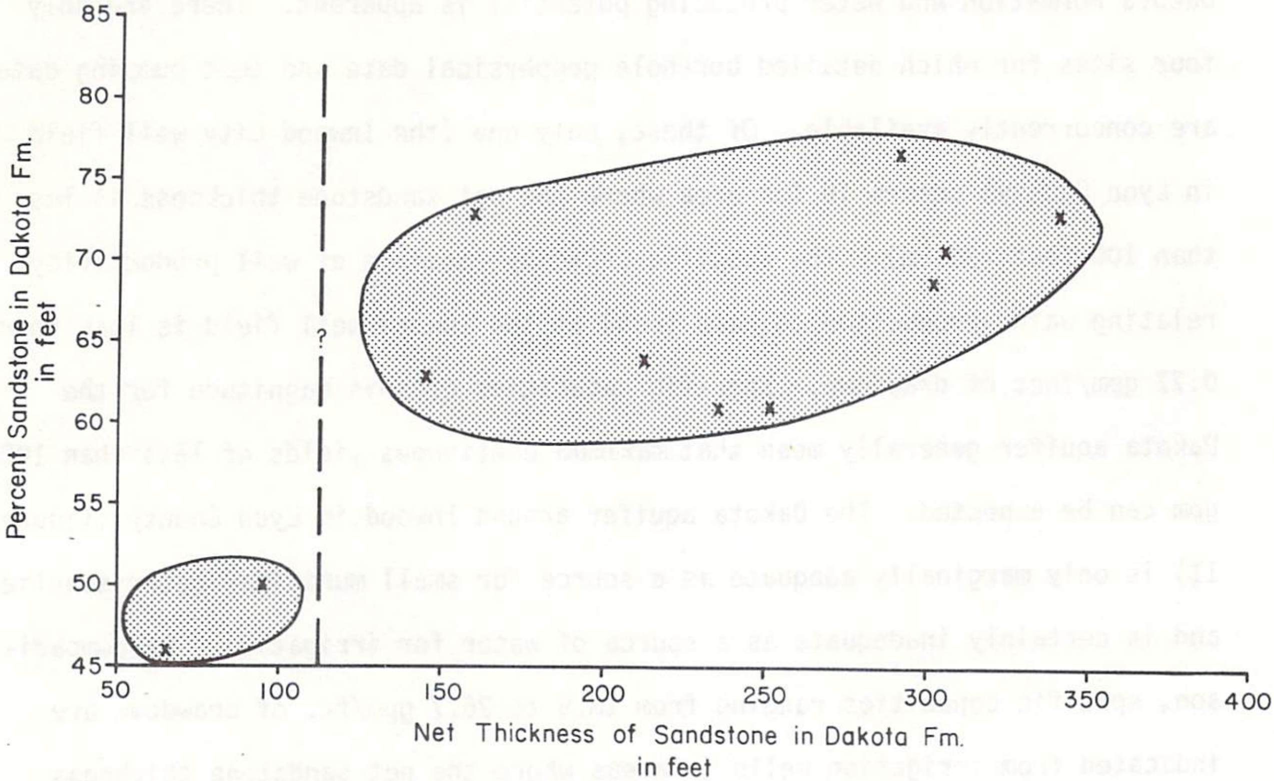


Figure 14. Relationship between percent sandstone and net sandstone thickness in the Dakota Formation.

seems likely that in areas where the net sandstone thickness exceeds 100 feet, (30.5m) much greater volumes of sandstone and aquifer storage are accessible for each foot of sandstone penetrated in a well.

Although the inferences that can presently be drawn must be tentative because of the limited data, a relationship between sedimentary facies in the Dakota Formation and water producing potential is apparent. There are only four sites for which detailed borehole geophysical data and test pumping data are concurrently available. Of these, only one (the Inwood city well field in Lyon County) occurs in the area where the net sandstone thickness is less than 100 feet (30.5m). The specific capacity (measure of well productivity relating water production to head loss) at the Inwood well field is less than 0.77 gpm/foot of drawdown. Specific capacities of this magnitude for the Dakota aquifer generally mean that maximum continuous yields of less than 100 gpm can be expected. The Dakota aquifer around Inwood in Lyon County (figure 11) is only marginally adequate as a source for small municipal water supplies, and is certainly inadequate as a source of water for irrigation. By comparison, specific capacities ranging from 18.9 to 26.7 gpm/ft. of drawdown are indicated from irrigation wells in areas where the net sandstone thickness exceeds 100 feet. Continuous yields of at least 500 gpm are available in this area.

Fortunately, the area where the Dakota aquifer has poor potential is relatively small. The study area encompasses 16 counties and approximately 6,600 square miles. The Dakota aquifer has been erosionally removed from only 16 percent of this area (figure 11). Of the remaining 5,525 square miles covered by the Dakota aquifer, only 18 percent of the surface area falls within the less than 100 ft. net sandstone thickness contour line (figure 11). This means that based on the geologic interpretation depicted in figure 11, the Dakota aquifer can be expected to be a highly productive source of water in 69 percent of the 16 county study area. In the remaining area, either its potential is limited or the unit is not present.

The tentative predictions made are based on the assumption that any wells drilled in the Dakota aquifer fully penetrate the unit and are properly developed. Unless this condition is met, wells drilled even in highly productive areas may yield poor results. Usually the most productive sandstones occur near the base of the aquifer.

CONCLUSIONS

1) The regional distribution of fluvial sedimentary facies in the Dakota Formation is the principal geologic control on water availability from the Dakota aquifer. The Dakota Formation was deposited unconformably upon an erosion surface that was controlled by the distribution of southeastwardly dipping Paleozoic strata. Southwesterly draining valley-fill sequences in the Dakota Formation contain thick accumulations of relatively clean, highly productive sandstone. The upland areas of the pre-Cretaceous drainage surface, however, were buried near the cessation of fluvial deposition, and are covered by thin, clayey sandstones that have limited water-yielding potential.

2) The study area, encompassing 16 counties, has a surface area of approximately 6,600 square miles, 84 percent of which is covered by at least part of the Dakota aquifer. Based on the geologic interpretation presented, the Dakota aquifer can be expected to be a highly productive aquifer in 69 percent of the total study area. Properly developed wells in these areas can be expected to yield at least 500 gpm.

3) In some areas, the Dakota aquifer is being recharged by underlying Paleozoic aquifers. The distribution and characteristics of these

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PART II: SUMMARY OF PUMP TEST DATA

In July 1977, shortly after a moratorium on new irrigation permits had been placed on Dakota wells, the Iowa Natural Resources Council (INRC) and the Iowa Geological Survey (IGS) initiated a research well registration program. This program allowed irrigation permit applicants who had completed INRC review procedures to develop irrigation systems using the Dakota aquifer under contract arrangements with the Iowa Geological Survey. The contracts required the drilling of an observation well in addition to the production well. IGS personnel collected samples during the drilling of these wells, and then logged the wells using borehole geophysical equipment. This program has provided additional drilling data on the Cretaceous rocks of northwest Iowa, and has made possible the collection of controlled pump test data.

The pumping of the irrigation wells, done under IGS supervision, has permitted the calculation of hydrologic characteristics of the aquifer, and will provide an opportunity to observe the long-term effects of pumpage for irrigation.

Four landowners have contracted with IGS under the research well registration program, three of which have already conducted the required controlled pump test. This summary will only list some of the hydrologic aquifer parameters for which values were determined. The period of record is not yet long enough to make definitive statements about long-term effects.

Hanson site (T 97N, R 46W, sec. 28)

A 72 hour pump test was conducted at the Hanson site in northwest Sioux County from June 7-9, 1978. During the pump test, a drawdown of 53 feet (16.1m) was measured at the pumping well, which was discharging at a rate of 1,000 gpm. The transmissivity of the aquifer at this site, calculated from this test, is approximately 29,000 gal/day/ft. Assuming that there will be no local interference from other irrigators, the maximum estimated drawdown at this site, as the pumping period approaches infinity, is 77 feet (23.5m).

Ritz site (T 92N, R 47W, sec. 31)

A 22 hour pump test was conducted at the Ritz site in Plymouth County during July 26-27, 1978. A total drawdown of 36 feet (11m) was measured at the pumping well, which was discharging at a rate of 881 gpm. From this test, the transmissivity of the aquifer at this site was calculated to be approximately 56,000 gal/day/ft. The maximum estimated drawdown at this site, again assuming that there will be no local interference from other users, will be 48 feet (14.6m) as the pumping period approaches infinity.

Hosteng site (T 87N, R 35W, sec. 30)

A 22 hour pump test was conducted at the Hosteng site in Sac County during July 27-28, 1978. A total drawdown of 44 feet (13.4m) was measured at the pumping well, which was discharging at a rate of 816 gpm. The transmissivity of the aquifer at this site, calculated from this test, is approximately 34,000 gal/day/ft. Assuming that there will be no local interference from other users, the maximum estimated drawdown at this site as the pumping period approaches infinity is 66 feet (20.1m).

Hydrographic Records

Water level measurements at the Hanson site observation well began in early June 1978. The observation well, separated from the irrigation production well by a horizontal distance of 2,500 feet, experienced a maximum static head loss of nearly 5 feet during the 1978 pumping season (figure 15). Three and one half months following the end of the pumping season, the static head had fully recovered to pre-pumping levels (figure 15). The impact of irrigation pumpage cannot be assessed from this record at present, because the

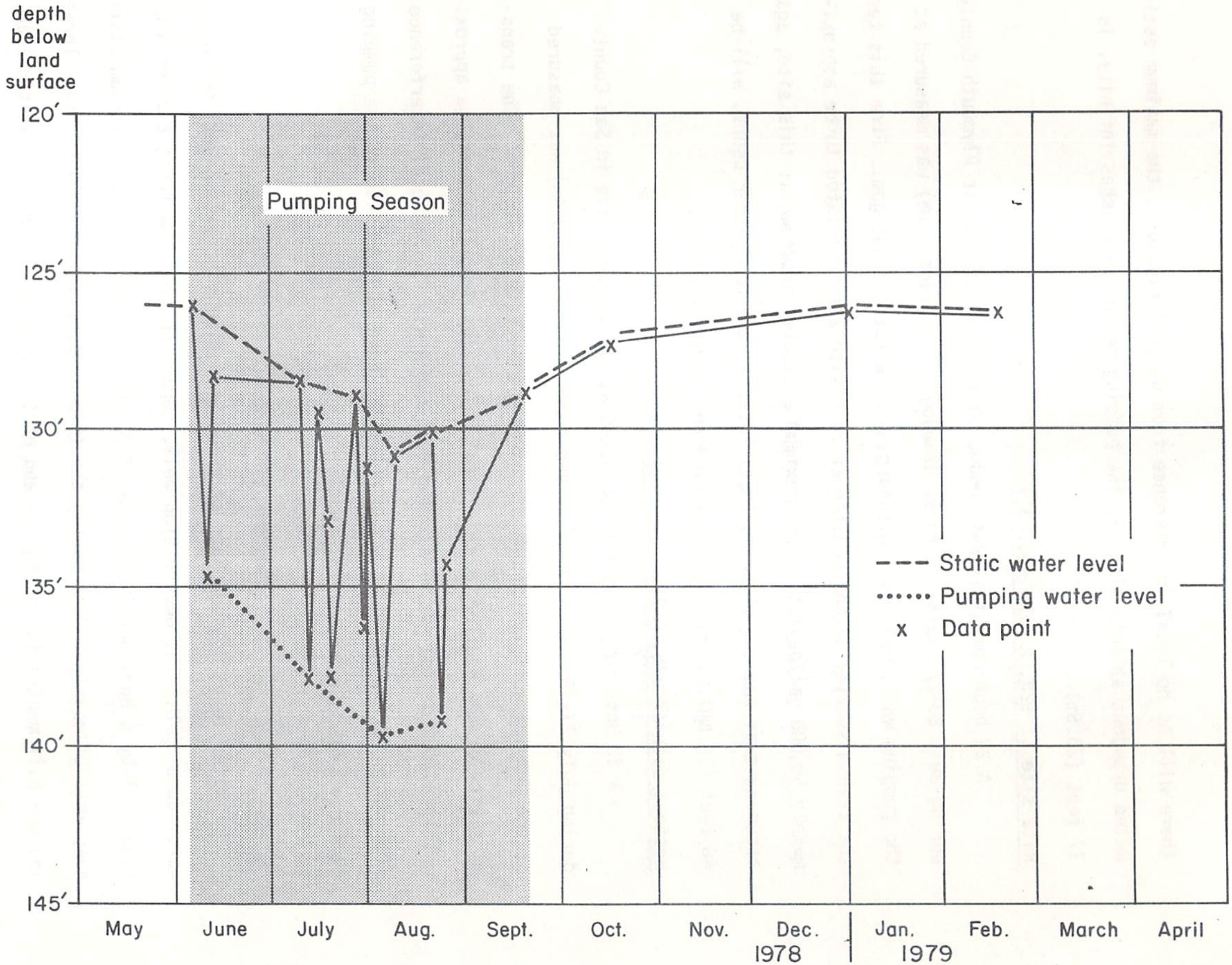

Figure 15. Hydrograph for Hanson site observation well.

magnitude of naturally occurring seasonal fluctuations in the static head of the Dakota aquifer are not yet known. The irrigation pumping season coincides with a period of naturally lower water levels, so all of the observed head loss cannot be attributed to pumping from the nearby irrigation well.

Conclusions

The controlled pump tests have shown in each case that the Dakota aquifer is capable of sustaining the required water withdrawals for sprinkler irrigation at the test sites. Long-term effects of high yield pumpage cannot yet be predicted with certainty, because of the relatively short period of record.

A program of regional hydrologic data inventorying is scheduled to begin during the 1979 field season. This program will result in the production of a regional head map of the Dakota aquifer, and perhaps of some adjacent aquifers. The ultimate goal will be to integrate the geologic and hydrologic data to define the regional and local characteristics of the entire ground water reservoir in northwest Iowa.