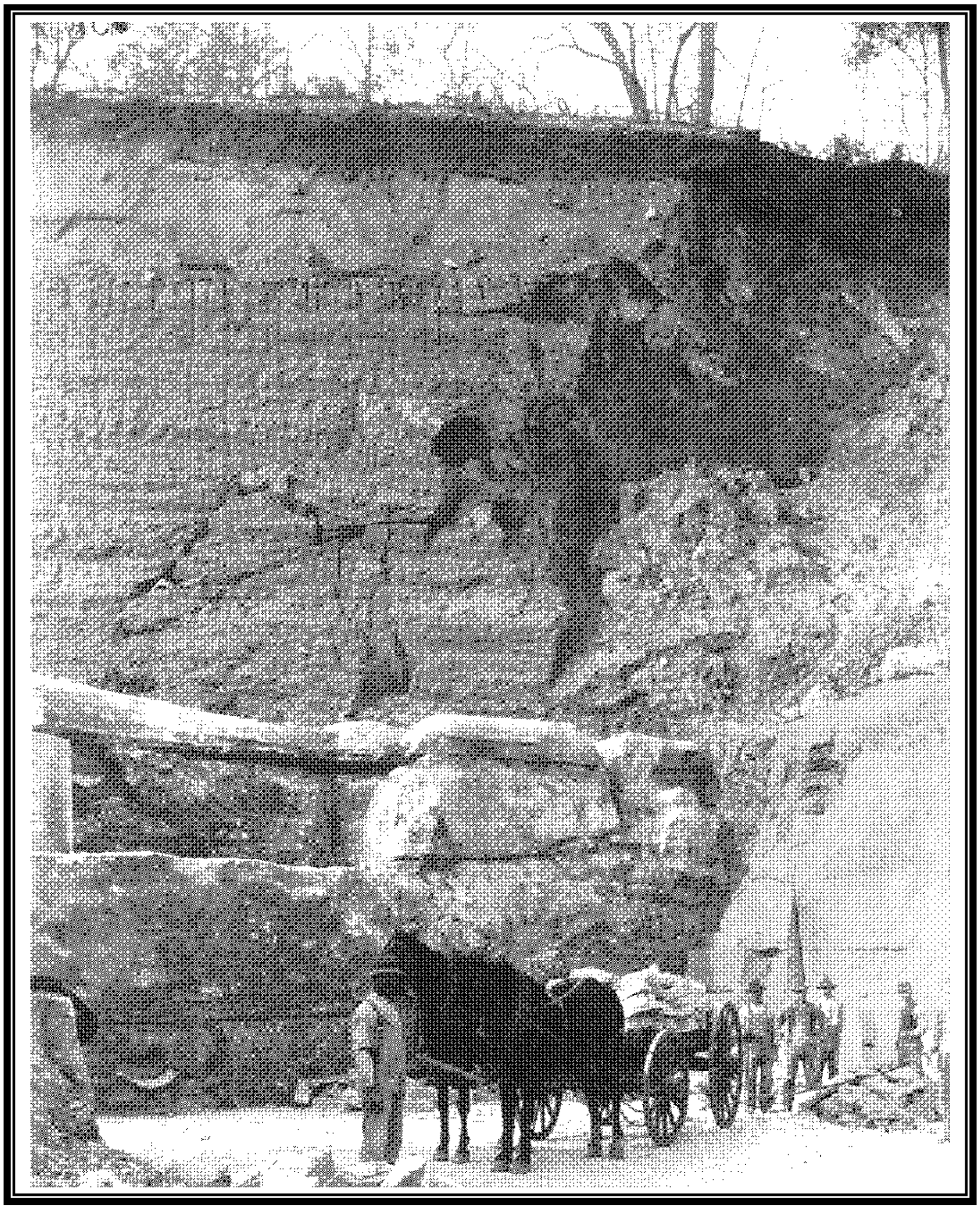
THE GEOLOGY OF THE JURASSIC FORT DODGE FORMATION, WEBSTER COUNTY, IOWA

by Raymond R. Anderson and Robert M. McKay



Geological Society of Iowa

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Cover photograph: Quarry in Gypsum Hollow that furnished gypsum for the Iowa Plaster Company, as it appeared in 1902. The overburden is glacial drift. Note the solution channels and the bedding and jointing which aided in the quarrying and mining. Photo published in Wilder (1919) courtesy of the Calvin Photography Collection, The University of Iowa Department of Geology

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THE GEOLOGY OF THE JURASSIC FORT DODGE FORMATION WEBSTER COUNTY, IOWA

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INTRODUCTION

The rocks of the Fort Dodge Formation (Upper Jurassic) constitute the most intensely exploited of the bedrock units in Iowa. The formation includes a basal conglomerate, a thick gypsum unit, and an upper suite of sandstones and mudstones locally referred to as the "Soldier Creek beds." The formation has an extremely restricted areal extent, with its only known occurrences in central Webster County, Iowa. The thick and exceptionally high quality gypsum unit that dominates the formation has been mined for a variety of economic products since the mid-1800's. The Fort Dodge Fm was the target of several early geologic investigations in the late 1800's and early 1900's. While these early studies discussed many details of the lithology, structure, and economic features of these strata, especially the gypsum beds, they failed to adequately answer many basic questions, such as the age, depositional environments, and the mechanics of their preservation. The high quality gypsum in the formation has been intensely mined for over 125 years, and recently the finite nature of this very limited resource has prompted a renewed interest in trying to better-understand this geologic unit before it is consumed by mining activity. In the last decade a number of geology students at Iowa State University have investigated various aspects of the formation as a part of their thesis and dissertation programs. Last year the Iowa Department of Natural Resources Geological Survey Bureau embarked on a detailed investigation of the formation. This investigation has concentrated on the "Soldier Creek beds" and their significance in understanding the depositional history of the Fort Dodge Fm as a whole. In 1996 a field trip associated with the 30th Annual Meeting of the North-Central Section of the Geological Society of America, hosted by the Department of Geological and Atmospheric Science of Iowa State University, visited some of the same sections that we will see today. This trip will provide an opportunity to update some of the information and interpretations presented during the 1996 trip, and to show this rock unit to the Iowa geologic community who may be seeing the formation for the first and last time, before the majority of the formation is mined away.

REVIEW OF THE GEOLOGY OF THE FORT DODGE FORMATION

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Introduction

The Fort Dodge Formation is an isolated outlier of Jurassic rocks, restricted to a 40 km^2 area in and around the town of Fort Dodge in Webster County, Iowa (Fig. 1). The unit consists of a localized basal fluvial conglomerate/sandstone interval overlain by a commercially valuable gypsum bed, and an upper mudstone and sandstone red-bed sequence informally known as the "Soldier Creek beds." The gypsum bed is one of the purest gypsum commercial deposits in the United States and has been mined for a variety of uses for over 125 years. The gypsum remains a valuable resource, with over 1.5 million tons mined every year. At this rate, the vast majority of the Fort Dodge Fm will be gone within about 50 years or so, the only geologic system in Iowa in danger of being almost totally mined.

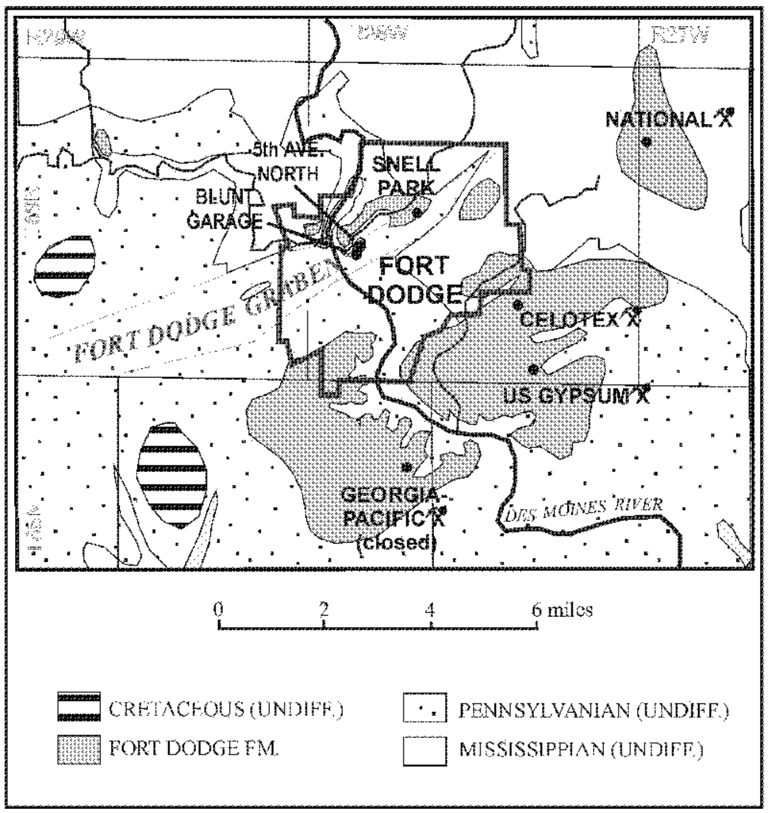


Figure 1. Bedrock geology in the Fort Dodge area.

Physiography of the Fort Dodge Area

Fort Dodge is nearly centrally located on the Des Moines Lobe (Fig. 2), a flat deposit of glacial drift left by the last continental glacier that retreated from central Iowa, between about 14,000 and 12,000 years ago. Although many rivers cut into the Des Moines Lobe, its young age has not allowed sufficient time for the development of a mature integrated drainage system. Consequently, the Lobe provides some of the flattest landscapes in Iowa. The major river on the Des Moines Lobe is the Des Moines River, which cuts through the glacial drift, exposing bedrock over much of its course. This includes the Fort Dodge area, where the river is incised over 150 feet into the Lobe, exposing rocks of the Fort Dodge Fm and underlying units, which were observed and reported by early visitors to the region, such as David Dale Owen in 1849. The Fort Dodge Formation is also exposed in the valleys of several tributary creeks that flow into the Des Moines River in the Fort Dodge area, including Soldier Creek, Gypsum Creek, and Lizard Creek. Early descriptions of these natural exposures, now mostly destroyed by mining, has provided valuable information about the distribution and thickness of the formation.

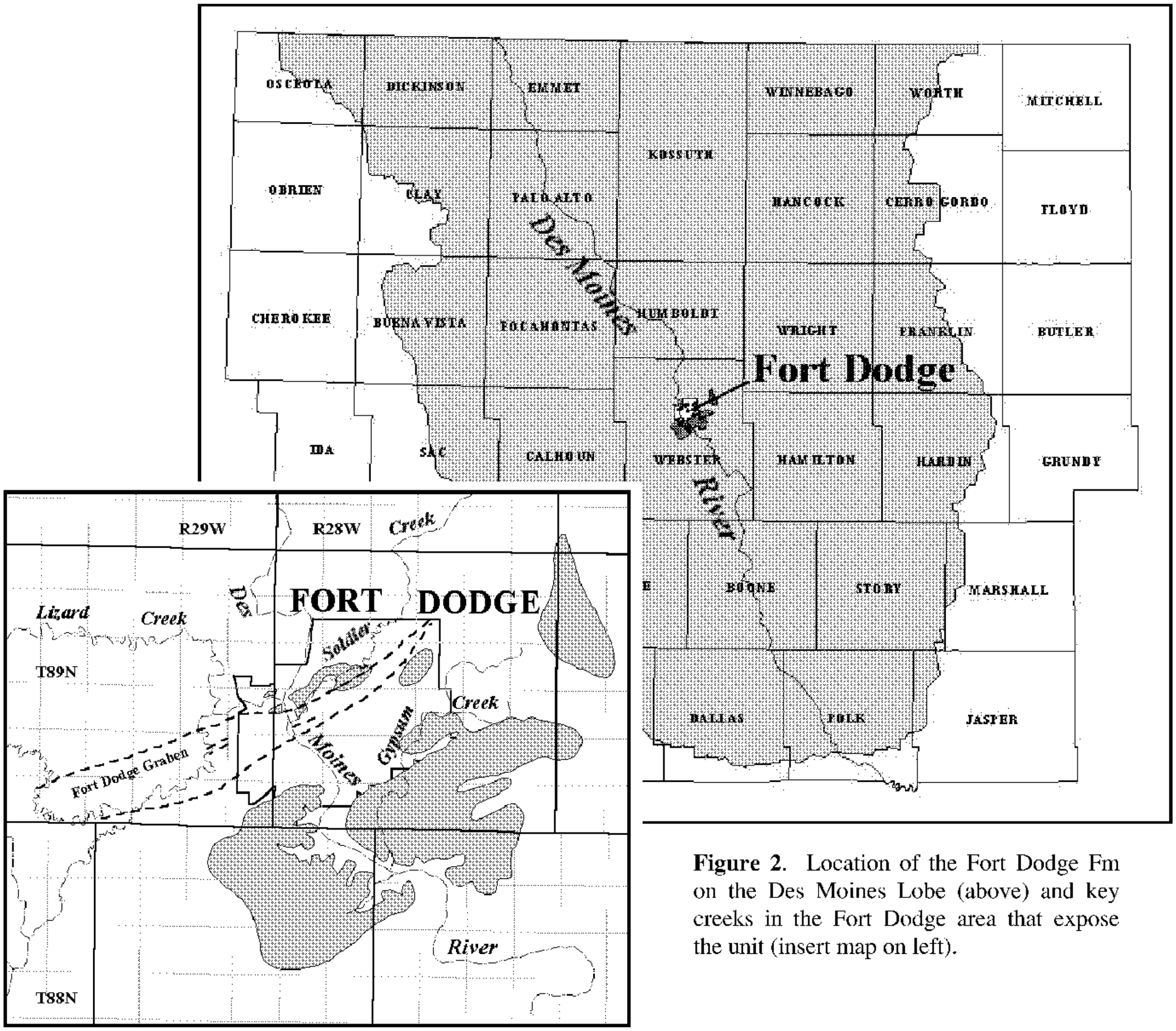


Figure 2. Location of the Fort Dodge Fm on the Des Moines Lobe (above) and key creeks in the Fort Dodge area that expose the unit (insert map on left).

Geology of the Fort Dodge Formation

The Fort Dodge Formation is composed of three distinct, stratigraphic units (Fig. 3): a thin, discontinuous basal conglomerate/sandstone, a thicker middle gypsum bed, and an upper succession of siltstone/mudstone/sandstone redbeds. Rarely are all three units exposed at the same location. These strata occur only in the vicinity of Fort Dodge, and rest unconformably on older rocks, generally of Pennsylvanian age and possibly, at rare locations, on Mississippian rocks. The Fort Dodge Fm is overlain

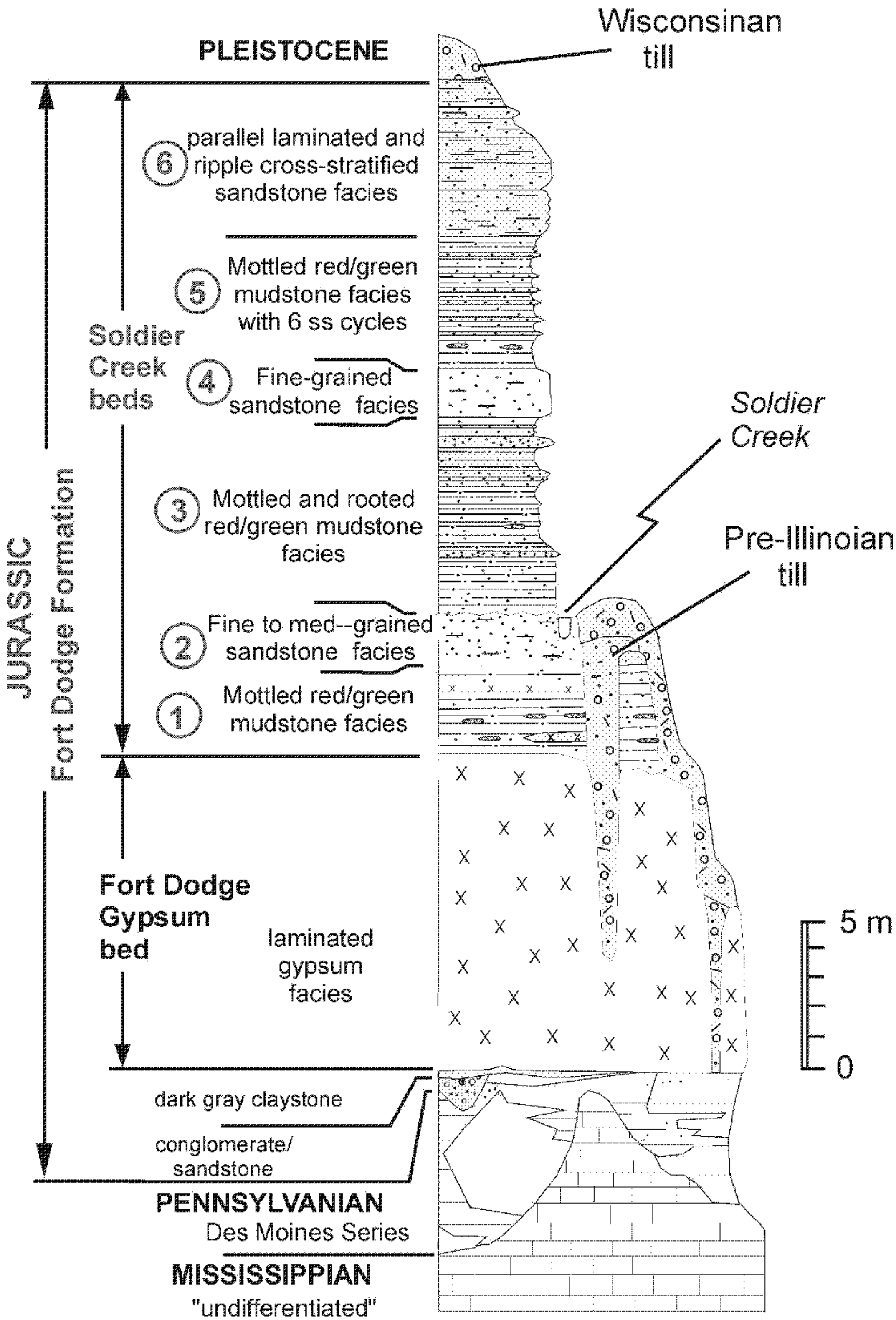


Figure 3. Composite section of the Fort Dodge Formation.

by about 10-20 m - of Pleistocene till over most of its area. Because of the pervasive cover of till, the only natural exposures are along the Des Moines River where it has eroded through the formation, and in tributary stream valley walls near their confluences with the larger river valley. One of the areas with the most extensive natural exposures was along Gypsum Creek at Gypsum Hollow, the site of the earliest quarries, but these exposures are now almost entirely lost to mining. Other exposures occur in the unnamed ravine immediately across the river from Gypsum Creek; along Soldier Creek near its confluence with the Des Moines River and upstream in Snell Park; along Lizard Creek and about 10 km west of the Des Moines River along the 219 ditch where it flows into Lizard Creek, and about 1 km up the 219 ditch.

In the following review the units that comprise the Fort Dodge Fm will be discussed in stratigraphic order from the base upward. The gypsum unit has been studied in more detail than the other units, and additional information is available in Iowa Geological Survey Bureau Guidebook Series No. 19, Geology of the Fort Dodge Formation (Upper Jurassic) Webster County, Iowa.

Basal Conglomerate

Outcrops of basal conglomerate have been reported only from the vicinity of the intersection of Gypsum Creek with the Des Moines River, on the west side of the river in what formerly was the Georgia-Pacific Quarry, and in the unnamed drainage to its south. At the Georgia Pacific Quarry, the lower contact of the basal conglomerate with underlying highly fractured Pennsylvanian strata was visible (Fig. 4). A thin blue-gray shale bed that lies above the conglomerate sequence and immediately beneath the gypsum in this area may constitute an additional unit.

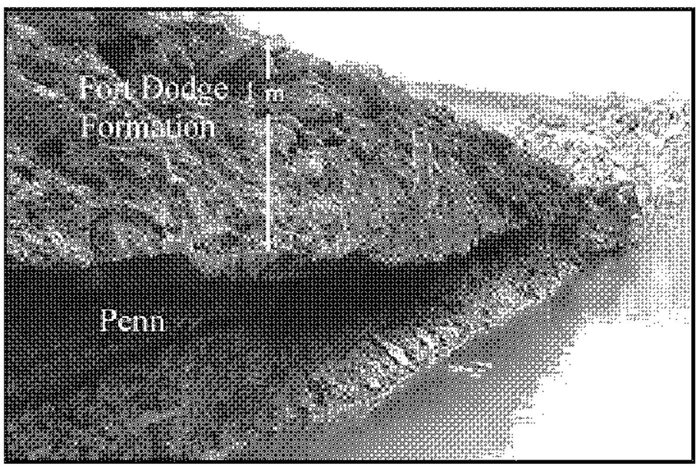


Figure 4. Fort Dodge Fm basal conglomerate as seen in a ditch at the Georgia Pacific quarry in 1996.

The conglomerate was also described along a valley, formerly used by a railway, along the west side of the Des Moines River opposite Gypsum Creek, about 1 km southeast of the former Georgia-Pacific Quarry. At this location, the unit is 0.7 m thick, overlies Pennsylvanian shales, and is separated from gypsum by about 15 cm of gray clay (Lees, 1918; Wilder, 1923). At nearby exposures in the ravine, the gypsum layer is missing and the basal conglomerate directly underlies glacial till. The best exposures of the basal, conglomerate-dominated unit were in the Georgia Pacific quarry in the NW¼ of the NE¼ of section 12, Township 88 N, Range 28 W. This quarry exhausted its gypsum resource in 1997 and is currently being reclaimed; however, Geological Survey Geologist geologists measured several sections and collected numerous samples and photographs before the exposures were buried. A typical section is reproduced in Figure 5.

At the Georgia-Pacific quarry (Fig. 5), the basal Fort Dodge Formation unit is composed of claystone, sandstone, and conglomerates resting unconformably on Pennsylvanian strata. The uppermost bed of the unit is a thin, gray, silty claystone which lies directly, and apparently conformably, beneath the gypsum bed. This clay ranges in thickness from 0 to over 0.2 m in the Fort Dodge area. This bed is underlain by a series of upward-fining units of sandstones and conglomerates with some mudstone lenses. The sandstones are mottled brick red to tan, calcareous, dominantly medium-grained to granular, horizontal to cross stratified, with quartz and carbonate grains. The basal bed is a brick red to tan sandy conglomerate,

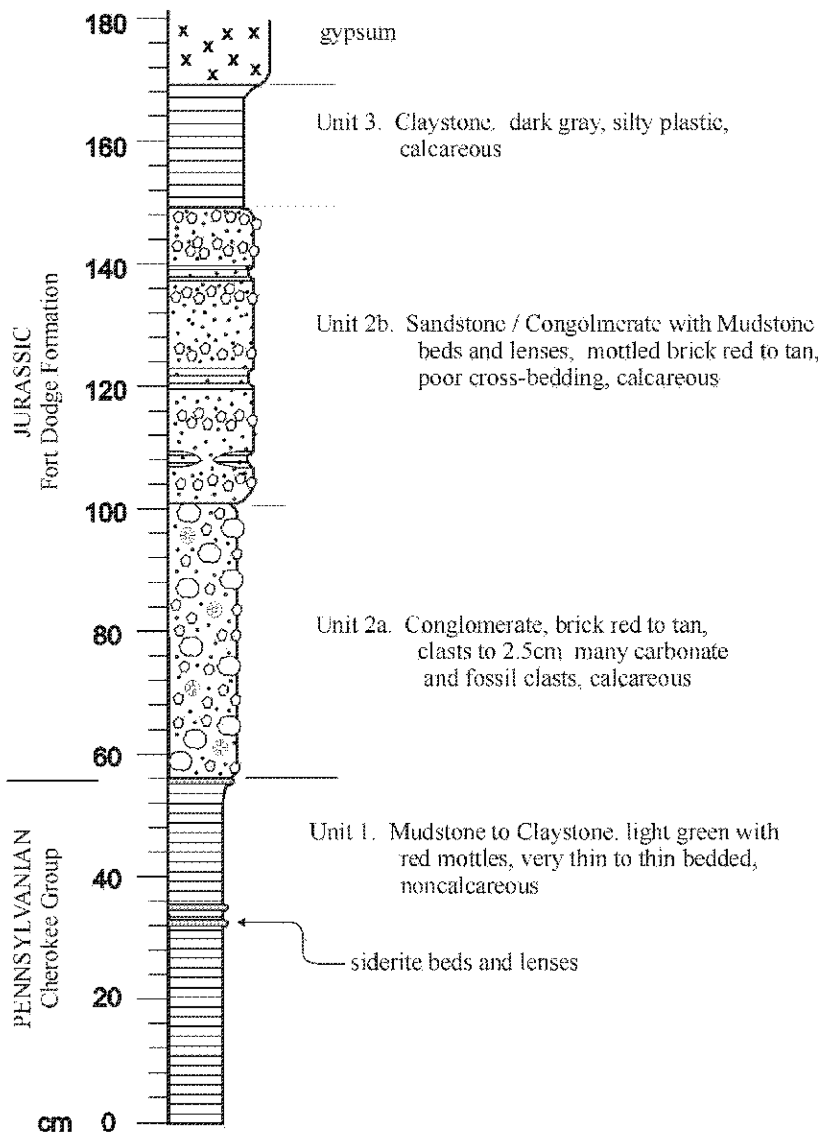


Figure 5. Measured section of Fort Dodge Fm basal unit in the Georgia-Pacific quarry.

poorly-sorted, and calcareous with rounded to angular clasts to 2.5 cm. Red mudstone rip-up clasts from the underlying Pennsylvanian strata are common, reaching lengths of several centimeters. Poorly-defined horizontal stratification was observed, and low angle cross-stratification is present. Coarse clasts include quartz, carbonate, and reworked Mississippian and Pennsylvanian fossils (foraminifera, echinoderms, brachiopods, and crinoids). The upper portion of this conglomerate is locally dominated by carbonate clasts, making this conglomerate a unique Iowa rock type, and providing evidence of the arid environment at the time of deposition (see Ludvigson on page 45 of this guidebook.) Below this interval is a light green to red-mottled, noncalcareous, thin-bedded mudstone with red sideritic bands. The contact of this unit and the overlying conglomerate is an erosional unconformity, and the underlying unit is interpreted as Pennsylvanian.

According to Wilder (1923), the conglomerate also occurs in Gypsum Hollow near the mouth of Gypsum Creek on the east side of the Des Moines River. Zaskalicky (1956) reported that the conglomerate was present in wells northeast of Fort Dodge in the vicinity of the town of Industry (about

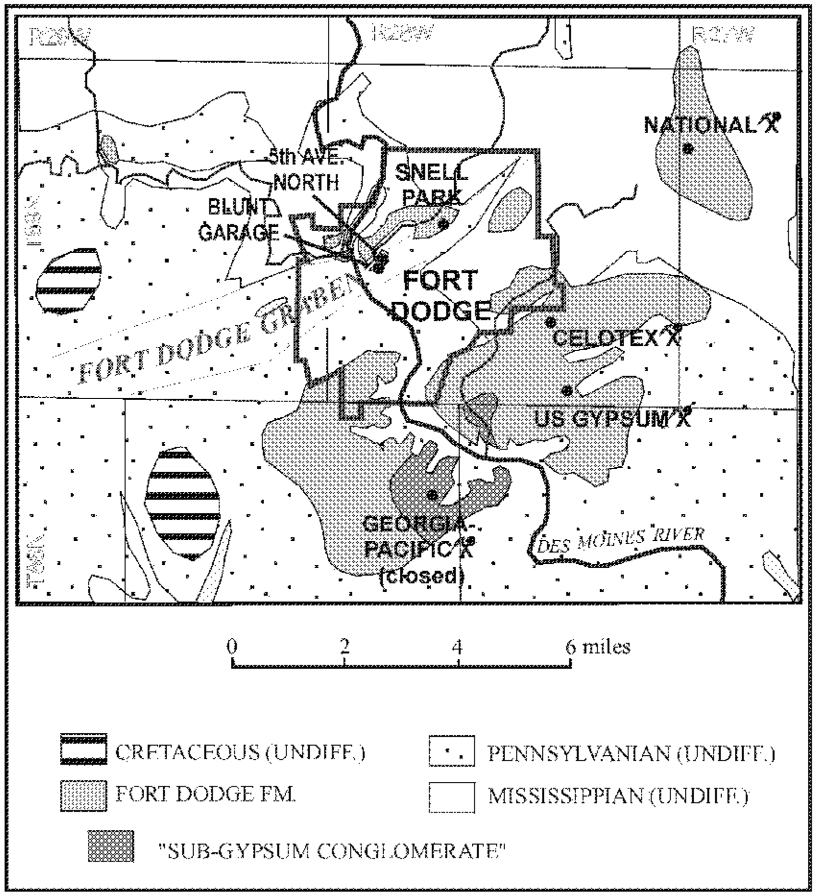


Figure 6. Known locations of Fort Dodge Fm basal conglomerate.

half-way between Fort Dodge and Vincent), and in the National Gypsum Quarry northeast of Fort Dodge (Fig. 6).

At most locations where gypsum occurs, there is no basal conglomerate or sandstone, and the gypsum and underlying dark-gray, sometimes scaly (from horizontal selenite flakes) basal shale lies unconformably on Pennsylvanian and possibly Mississippian rocks.

Gypsum Unit

Much of the following discussion of the Fort Dodge gypsum has been modified from Cody et al. (1996).

Introduction

The gypsum unit of the Fort Dodge Fm (Fig. 7) is generally bright white to gray banded, remarkably pure gypsum (>96% $CaSO_4 \cdot 2H_2O$). It is distinctly bedded, the layers ranging from 5 cm to 25 cm in thickness and separated by a thin clay band along which it is easily parted. Wilder (1923) reported that five "ledges" (or divisions) were recognized within the gypsum by miners (see Table 1). The Upper Rock unit is variable in thickness because its upper surface may have undergone exceedingly irregular dissolution (Fig. 8). This surface is especially evident at locations where the overlying "Soldier Creek beds" are missing and the gypsum is directly in contact with Pleistocene till, and it will be observable at

Table 1. Subdivisions of the Gypsum Bed from Wilder, 1923 (p. 201)

Ledge No.	Description	Thickness (m)
5.	Upper rock	1-4
4	Six-foot ledge	2.0
3.	Hard ledge	1.3
2.	Eighteen inch ledge	0.5
1.	Bottom ledge	1.5

the U.S. Gypsum quarry during the field trip. At the Georgia-Pacific Quarry location the basal 0.2 m thick gypsum ledge is dark brown and distinctively different from overlying gypsum. The rock is calcareous, and is composed almost entirely of tightly-packed, partly interlocking, buff, coarsely-crystalline gypsum nodules and clasts separated from each other by pronounced dark brown clay/silt impurities which gives a chicken wire appearance to the rock. Nodules usually are less than about 0.5 cm in diameter. The ledge has horizontal parting and contains short segments of thin, horizontal single-tier fibrous gypsum veins. The maximum thickness of the gypsum is about 10 m, but considerable variation exists because of topographic relief within the evaporite basin during deposition and because later erosion and dissolution differentially reduced thickness.

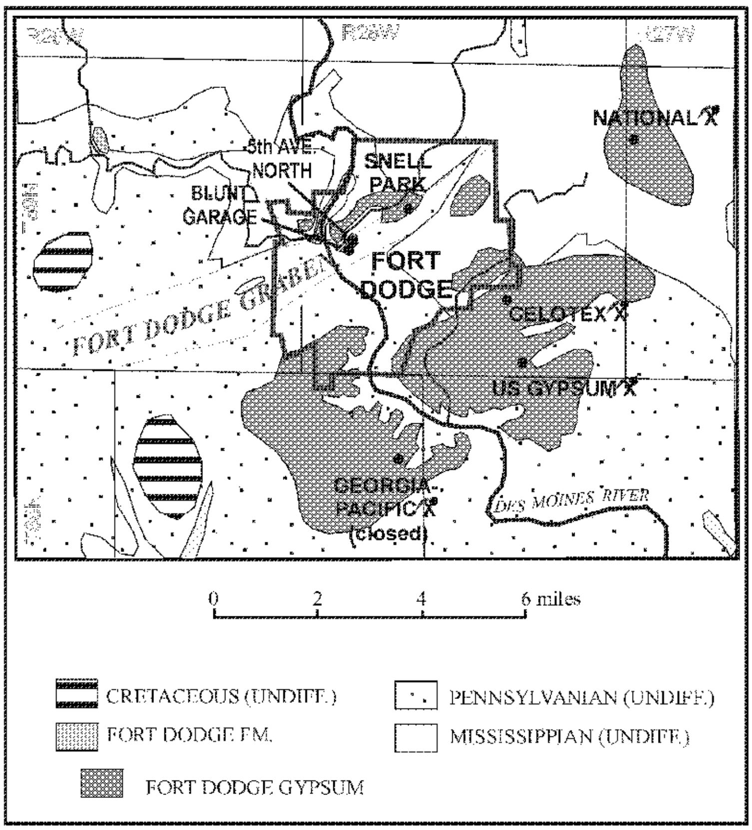


Figure 7. Known locations of the gypsum beds in the Fort Dodge Fm.

Chemistry and Mineralogy of the Gypsum Beds

As mentioned earlier, the Fort Dodge gypsum is characterized by only very small amounts of impurities, and contains between 89% and 96% $CaSO_4 \cdot 2H_2O$ (Bard, 1982). The high purity of Fort Dodge gypsum makes the rock particularly valuable for industrial use. Although present in small quantities, mineral impurities impart the distinctive banding and color to the rock. Major impurities are quartz, iron oxide, clay, and calcite/dolomite, as shown by USG Corporation chemical analyses (Table 2). Dolomite and calcite also are present in the gypsum, but are concentrated in marl stringers which are most abundant adjacent to fibrous gypsum layers (Dasenbrock, 1984). Minor amounts of illite and kaolinite are also present. Hayes (1986) performed dissolution of gypsum in a soxhlet extractor in order to precisely determine concentrations of mineral impurities. He found that extractor-insolubles constitute between 1.0% and 3.5% of the rock,

Figure 8. Eroded nature of the gypsum near limits of the Fort Dodge Fm, as seen at the Georgia-Pacific quarry in 1996.

and nodules contained < 0.5% insolubles. He confirmed the presence of the minerals observed by Dasenbrock (1984), and also detected pyrite, limonite, and possibly tourmaline. Quartz is the most abundant impurity, and is present both as detrital fine-sand and silt-size grains and as authigenic quartz crystals. Most of the detrital quartz is poorly sorted, angular to well-rounded, frosted, and stained yellow to orange by hematite coatings. Typically, it has a maximum diameter <0.1 mm. Surface textures of the detrital quartz exhibit aeolian features, indicating wind transport. Single crystals and clusters of authigenic quartz have a range between 0.1 mm and 0.3 mm length, but occasionally crystals as long as 1.0 mm were observed. Authigenic quartz is most common in the upper part of the section at the North Wells Quarry and was not found below about 3 m from the top. Calcite was next in abundance, but only the lower half of the deposit at the North Wells Quarry contained calcite crystals large enough to study with an optical microscope. These crystals were typically euhedral to subhedral in habit. Clay minerals were not observed in the soxhlet-extracted insolubles, although extremely fine clay may have passed through the cellulose filter used during extraction.

Laminations or Banding.

Probably the most striking feature of the gypsum is the distinctive and highly characteristic bands or laminations (Fig. 9) consisting of white lamina alternating with thinner dark ones. From a distance, the color banding gives an impression of continuous laminations but closer study shows that individual bands

Table 2. Major Element Chemistry of Fort Dodge Gypsum from U.S. Gypsum Corp.

Constituents	Sample I	Sample II	Sample III
CaO	32.48	32.30	32.20
SO_3	43.30	44.30	44.60
MgO	0.05	0.13	0.12
SiO_2	0.49	1.58	1.43
Fe_2O_3	0.03	0.11	0.11
Al_2O_3	0.09	0.32	0.28
CO_2	0.43	0.56	0.50
Free H_2O	18.8	0.02	<0.01
Combined H_2O	1.74	19.00	19.30
LOI*	1.73	1.50	1.30
$CaSO_4{\cdot}2H_2O$	94.58	95.60	96.10

Data from Bard (1982). * Loss on ignition.

extend only for a few meters or less before blending with others and disappearing. Lamina typically are irregular, and many are contorted to various degrees. Dark banding is predominately blue-gray, but yellow, red, or brown colors also occur.

Light colored bands

The white bands are of three types. The first is comprised of approximately horizontal laminations of single-tiered, vertically-oriented elongate gypsum crystals. These fibrous laminations occur throughout the section and typically extend laterally for < 15-20 m (Dasenbrock, 1984). The second type appears to result from the coalescence of small nodules concentrated in horizontal planes. This type has a mild to moderate contorted, or enterolithic, appearance (Fig. 10). Growth and coalescence of the nodules excluded mineral impurities so that these white lamina are particularly devoid of impurities (Dasenbrock, 1984). In thin-sections, nodular white laminations are invisible and cannot be distinguished from dark

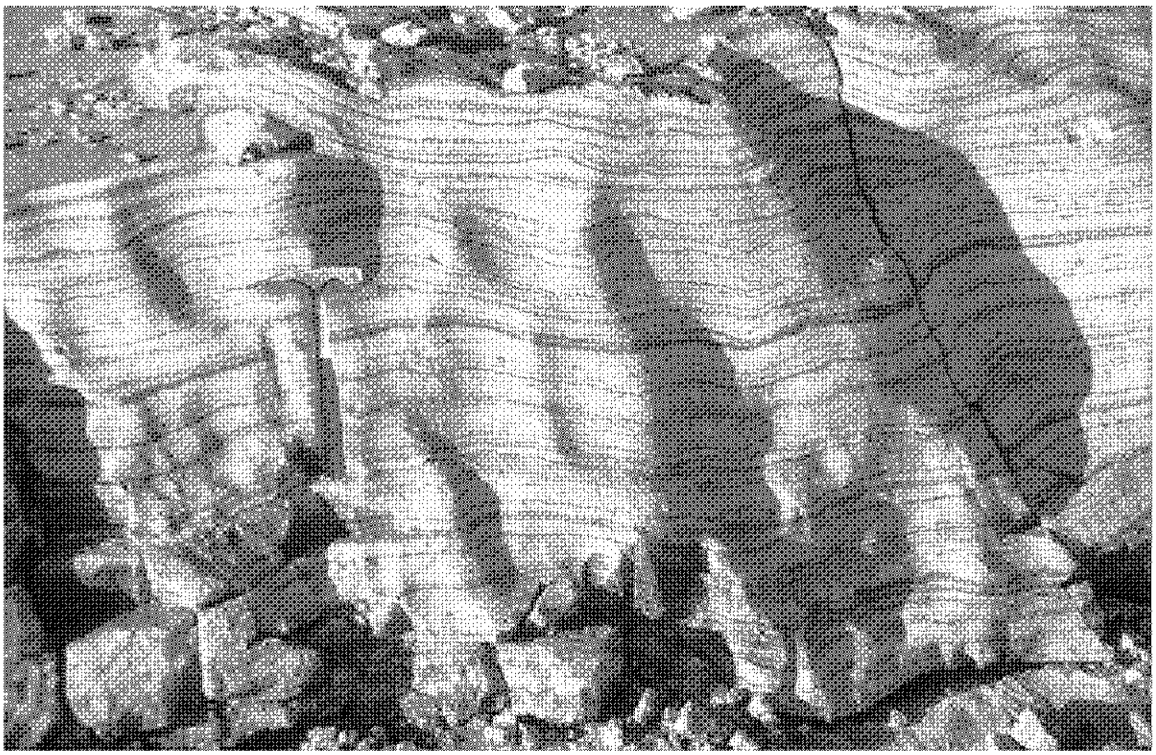


Figure 9. Horizonal banding in the Fort Dodge Gypsum.

laminations. A third and last type of light/dark banding results from intercalations of marl layers within the gypsum. Typically the marl layers are ≤ 2 mm thick and are usually light gray to yellow gray. Marl is most apparent on freshly-broken surfaces because weathering tends to rapidly erase its color distinction.

Dark colored bands

Each dark band is comprised of several very thin darker horizons separated by slightly lighter regions. The dark horizons appear to be composed of mineral impurities, but only discontinuous stringers of accessory mineral inclusions are visible in thin-sections. Part of the darkness in the wide dark laminations results from mineral impurities, but part seems be caused by larger gypsum crystals in dark lamina compared to those in nodular white ones. Larger crystals scatter less light and allow greater light penetration than smaller ones, so that bands composed of larger crystals appear darker than those composed of very small crystals.

The origin and significance of the banding in the gypsum is now well understood. Cody et al. (1996) noted that the lamina are at least partly diagenetic, and diagenesis may have caused expansion of thin primary layers. Wilder (1923, p. 201-202) suggested "The material in each one of these bands seems to have crystallized at one time and each band represents a period of some sort. He noted that their average thickness is about one-third on an inch and suggested that if they represent annual deposits, the interval required to deposit a foot of gypsum would represent thirty-six to forty years. Assuming an original thickness of thirty feet for the beds, "1200 years would suffice for their accumulation."

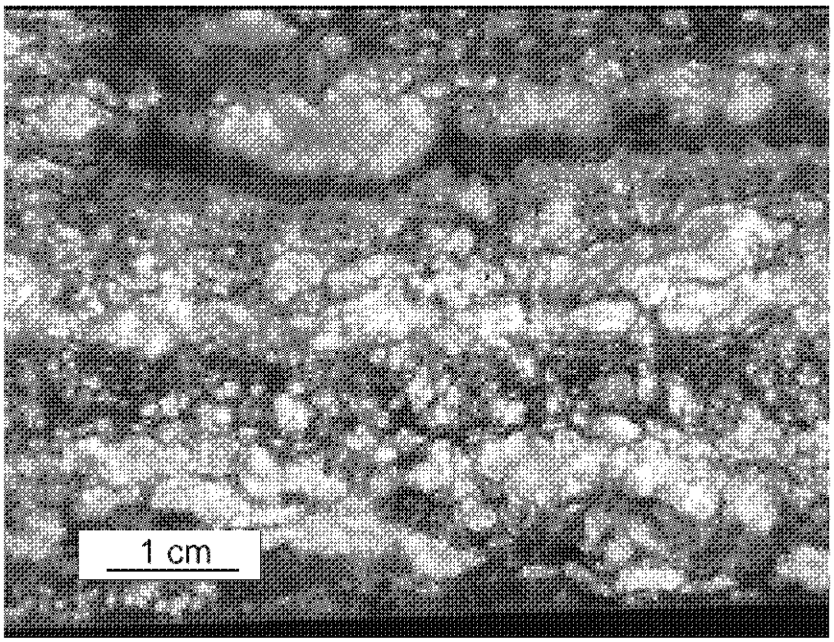


Figure 10. A "thick section" showing the smaller nodules that coalesce to form light colored banding in some areas.

Nodules

Two types of nodules occur in the Fort Dodge gypsum, both composed of fine-grained alabastrine gypsum. One distinctive type, occurring in the upper rock layer, consists of nodules typically up to about 20 cm in diameter, occasionally 1 m or more (Bard, 1982). Large nodules occur chiefly in horizontal to subhorizontal bands, and are typically composed of several smaller coalesced nodules separated from each other by a faint outline of darker material. In some nodules, however, evidence of coalescence is lacking. The second type of nodule is much smaller in size and occurs throughout the section (Fig. 10). This type has already been described in the preceding discussion of lamina. They occur in enterolithic bands formed by coalescence of nodules when viewed perpendicular to bedding. Often these nodules are most visible on bedding surfaces exposed by mining where the nodules appear as blisters. Both types of nodules often have relict anhydrite textures, that is, tiny blocky gypsum crystals aligned in a swirled pile of bricks texture (Dasenbrock, 1984).

Other Structures

Ripple marks occur at numerous locations in the Upper Rock layer (Fig. 11). They are most common on bedding planes adjacent to thin marl layers which typically are planes of weakness allowing the rock to split apart at those horizons. Ripple marks may occur at lower horizons in the section, but the rarity of marl stringers in those parts of the section may obscure their occurrence because the rock does not easily split apart at bedding planes without marl interlayers. Non-tectonic folds occur in the upper part of the section (Fig. 12). One example shows a gradual upward increase followed by a decrease in amplitude.

Figure 11. Ripple Marks on the surface of the gypsum, US Gypsum North Welles Quarry.

Figure 12. Folds in the gypsum were probably produced during a recrystallization event

Joint-Controlled Channels

Perhaps the most striking feature of the upper gypsum surface at most quarry locations is the presence of deep channels (or slips as they are called by miners) extending downward into the gypsum (Fig. 13). These fissures result from dissolution along earlier fractures. Channels often > 1 m wide may extend through the entire gypsum bed. According to miners, the channels are particularly well-developed at locations lacking a cover of Soldier Creek beds, where the gypsum is directly in contact with till. The enlarged fractures are filled with till or other Pleistocene materials, although in some locations they may be filled by red "Soldier Creek beds" material. Fractures are not always visible beneath channels so that gypsum recrystallization must have healed earlier fractures that controlled channel locations.

Figure 13. Solution-enlarged fractures (slips) in the Fort Dodge Gypsum

Channel orientation was studied by Hayes (1986) at three quarries. Orientation of the enlarged fractures is essentially random when all three quarries are compared, and was ascribed to the effects of underlying bedrock topography and differential compaction of underlying sedimentary rocks during stresses developed by glacier advances.

Textures of the Fort Dodge Gypsum

Pervasive diagenetic alteration and recrystallization since its deposition produce major difficulties in interpreting depositional environments of the Fort Dodge gypsum. In primary gypsum deposits such as those in the Mediterranean Miocene or the Paris Basin Eocene, a wide variety of bottom-growth and other types of gypsum textures are common. These features are completely lacking in the Fort Dodge gypsum. Originally, the Fort Dodge gypsum probably was similar to the Miocene or Eocene gypsum, but partial or complete dehydration followed by rehydration and recrystallization has obliterated primary textures. Dasenbrock (1984) outlined a possible sequence of primary deposition and diagenetic modifications. He concluded that the earliest gypsum would have resembled that of the Paris Basin gypsum with a variety of shallow-water bottom-growth crystals and early diagenetic shallow subsediment lenticular gypsum crystals. The dark, impurity-rich laminations probably precipitated during storm events that contributed wind blown dust, and the light laminations represent clear-water precipitation. Shallowing water depths developed during precipitation of the Upper Ledge, as evidenced by the presence of ripple marks, which are rare in underlying material. Porosity probably was high during this stage. Dasenbrock (1984) concluded that the gypsum then underwent a series of at least six sequential stages of diagenesis (Table 3).

The transition of gypsum to anyhdrite requires burial to depths of about 500 m or more for some period of time. The maximum depth of burial of the Fort Dodge Fm is not known, but can be estimated. A maximum of 15 m of the Upper Jurassic "Soldier Creek beds" above the gypsum, and it is unlikely that it was ever significantly thicker, so assume a maximum "Soldier Creek" thickness of 20 m. Anderson and Witzke (1994) calculated that a maximum of about 330 m of Cretaceous rocks were present in the area by the Late Cretaceous. With the uplift of the Rocky Mountains, Tertiary fluvial clastics such as the Ogalala Fm may have pushed into the Fort Dodge area, adding as much as an additional 100 m of strata. Totaling these estimates suggests that a maximum of only about 450 m of sedimentary rocks ever lay above the Fort Dodge gypsum. The fact that Pleistocene glacial till rests directly on the gypsum in some places indicates that most of this overlying strata was erosionally removed before the initial advance of the glaciers about 2.5 million years ago. At its maximum advance in the Pre-Illinoian, glacial ice above the gypsum reached an estimated thickness of many kilometers. With an average density of around 2.0 g/cc this thickness of ice would be equivalent to about several kilometers of sedimentary rock strata. However, this thickness of ice was present for only a few thousand years before retreat.

Table 3. Diagenetic Sequence Stages of Fort Dodge Gypsum (from Dasenbrock, 1984).

Stage I.	Compaction and Early Recrystallization.
Stage II.	Maximum Burial and Dehydration.
Stage III.	Uplift, Erosion, and Initial Rehydration. Porphyrblastic gypsum crystallized during slow hydration of deeply buried anhydrite phase.
Stage IV.	Later Rehydration. Alabastrine gypsum crystallized under relatively rapid rehydration of anhydrite with moderate burial depth.
Stage V.	Euhedral Gypsum Growth. Euhedral crystals formed at expense of earlier-formed crystals, probably being a more energetic habit than that of smaller highly-strained crystals.
Stage VI.	Fibrous Vein Formation. There may have been two stages in fibrous veins, older single-tier formed in fractures caused by pressure release during uplift and erosion, and more recent double-tier veins in fractures caused by pressure release during glacial retreats.
Stage VII.	Brecciation of Upper Gypsum Layers.

"Soldier Creek Beds"

Introduction

The informal name "Soldier Creek beds" is widely used by miners for the red to tan mudstones and sandstones that overlie the gypsum in the area. The name seems to have originated in an unpublished study by personnel of the USG Corporation (Zaskalicky, 1956) of outcrops along Soldier Creek in the city of Fort Dodge. The name, although quite appropriate because the best exposures of the rocks are found along Soldier Creek, is unfortunately preoccupied in Iowa by the Soldier Creek Member of the Bern Limestone, Pennsylvanian Wabaunsee Group. So, the unit will ultimately be renamed, but it is likely that the 5th Avenue North Section will be designated as its type section. The clastic units occurring above the gypsum are much thicker and more widely distributed than the basal conglomerate. They were apparently overlying the gypsum at all locations, but have subsequently been eroded from many areas. Additionally, the "Soldier Creek beds" are present in areas to the west of the gypsum basin where they rest directly on Pennsylvanian strata (Fig. 14). The clastic beds consist of up to 16 m of red, tan, and green mudstones, claystones, and red, highly calcareous, sandstones/siltstones. Several outcrops in the city of Fort Dodge have been described, especially along Soldier Creek near its confluence with the Des Moines River, and in Snell Park in the city. Nodules of celestite have been reported in the shales (Wilder, 1923), and for many years have been found by mineral collectors.

The extremely limited area of Fort Dodge Fm preservation does not allow for observation of the lateral facies changes that would constrain interpretation of "Soldier Creek beds" history. Two primaries facies tracts are preserved, the Gypsum Basin and Western (Fig. 14).

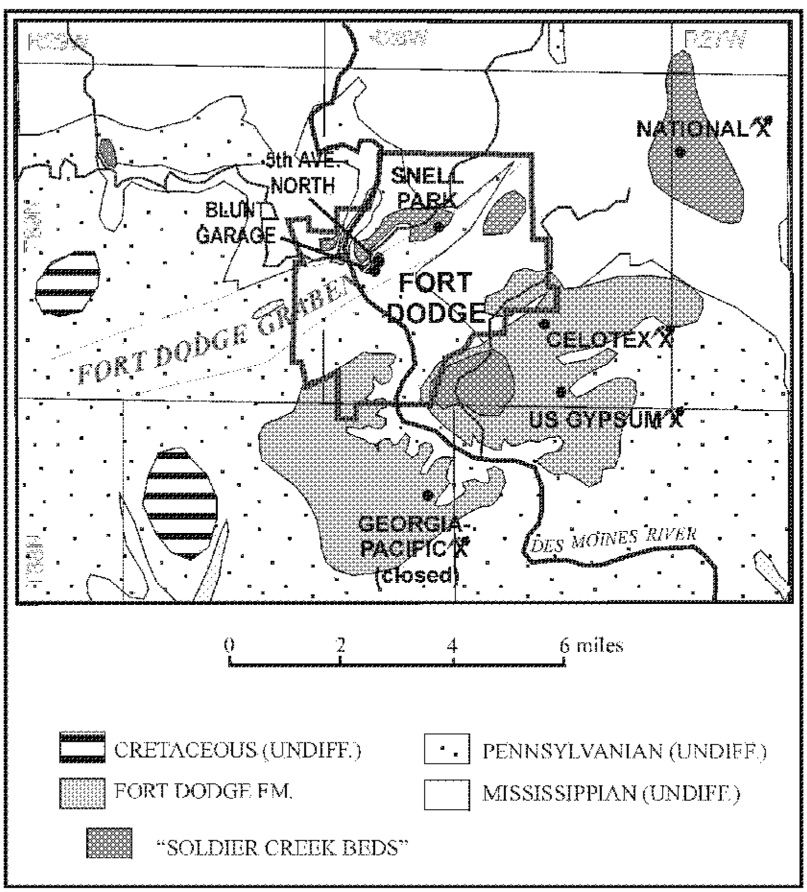


Figure 14. Distribution of "Soldier Creek beds" in Fort Dodge Fm.

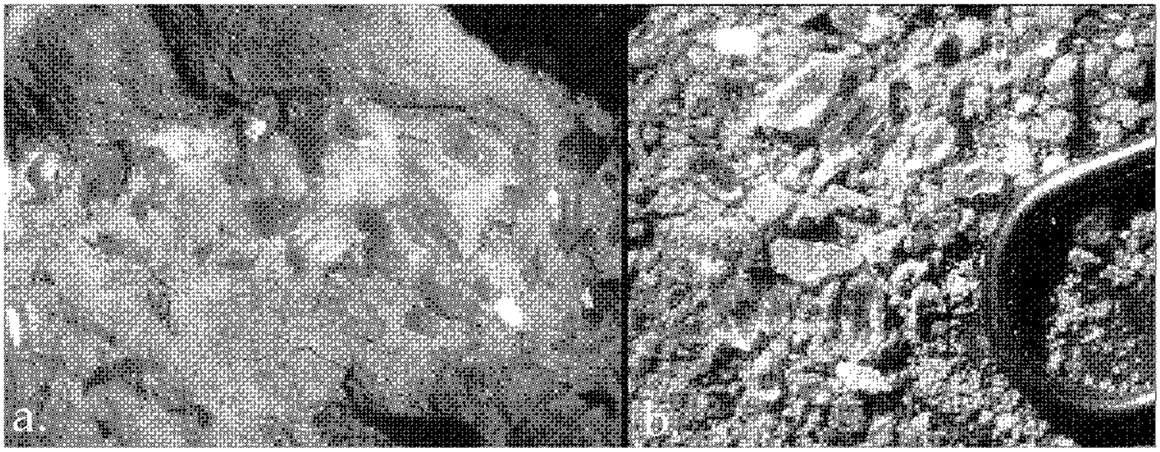


Figure 15. Doubly-terminated quartz crystals from bed 3 of the 5th Ave North Section. -- a. shows crystals in calcite matrix; -- b. shows desegregated crystals and paperclip for scale.

Gypsum Basin Facies Tract

The Gypsum Basin Facies Tract includes Soldier Creek units that overlie gypsum beds, by far the thickest and most complete section. The "type section" for this facies tract is the 5th Avenue North Section, located on the west bank of Soldier Creek where it would intersect a western extension of 5th Avenue North (Stop 1 on this field trip). This section also described by Meekins (1995, Section s1), exposes 15 m of sandstone, mudstone, and claystone that has been divided into five primary units. The units exposed at this section includes two laterally persistent sandstone units (units 2 and 4 of Fig. 17) separated by a red/green mottled, thin-bedded mudstone-dominated unit (unit 3) and an uppermost cyclic, upward-fining mudstone-sandstone set (unit 5). The upper unit is a tan to gray parallel-laminated and ripple cross-laminated sandstone (unit 6 of Fig. 17) that is truncated by Wisconsinan drift. A detailed description of these units is reproduced with the field trip Stop 1 description on page 67 of this guidebook. The green mottles in the red mudstone are horizontal to vertical, and some are interpreted as rooting structures. Millimeter-scale doubly terminated quartz crystals are scattered throughout unit 3 and are most abundant in the green-mottled areas where they are sometimes associated with sandy areas (Fig 15). Small halite casts (Fig 16) were found in sandstone float blocks, thought to have originated in unit 6. Exposures of "Soldier Creek" strata are poor and intermittent from the 5th Avenue North Section downstream (south) to its confluence with the Des Moines River. Upstream (north) from the 5th Avenue North Section most exposures are covered by fill material for about 100 m before a series of poor exposures on the western bank of Soldier Creek just south of the old Fort Dodge Culvert & Ironworks pit. The section is truncated on the north by the northern bounding fault zone of the Fort Dodge Graben, here referred to as the Soldier Creek Fault. The fault juxtaposes down- thrown Jurassic "Soldier Creek" strata with Mississippian carbonates

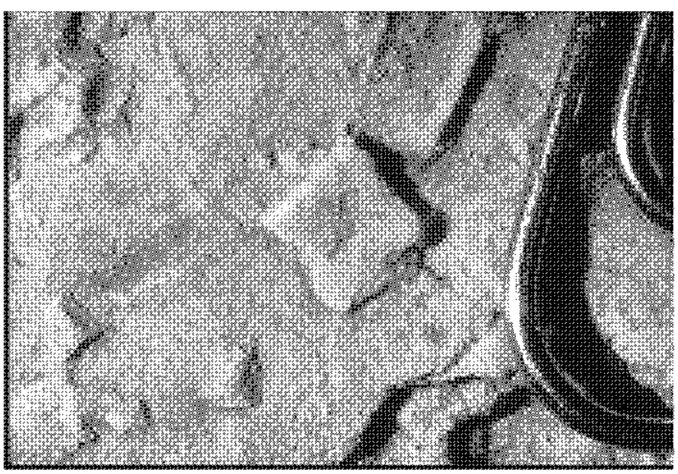
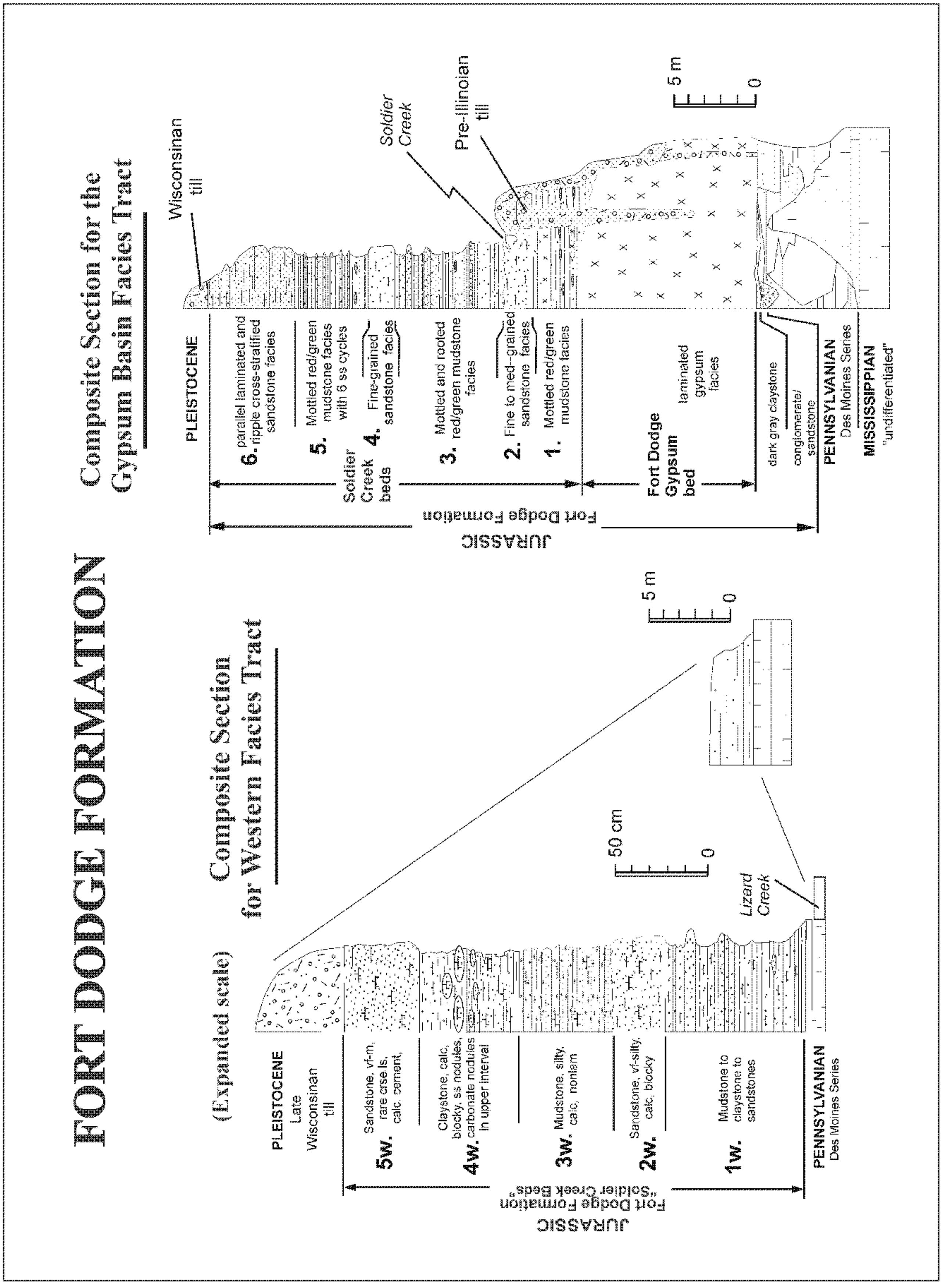


Figure 16. Halite crystal cast from unit 6 of the 5th Ave North Section (paper clip for scale).


FORT DODGE FORMATION
Composite Section for the Gypsum Basin Facies Tract
Wisconsinan till
Soldier Creek
Pre-Illinoian till
5 m
0
PLEISTOCENE
6. parallel laminated and ripple cross-stratified sandstone facies
5. Mottled red/green mudstone facies with 6 ss cycles
4. Fine-grained sandstone facies
3. Mottled and rooted red/green mudstone facies
2. Fine to med-grained sandstone facies
1. Mottled red/green mudstone facies
Soldier Creek beds
Fort Dodge Gypsum bed
laminated gypsum facies
dark gray claystone
conglomerate/sandstone
PENNSYLVANIAN
Des Moines Series
MISSISSIPPIAN
"undifferentiated"
JURASSIC
Fort Dodge Formation
(Expanded scale)
Composite Section for Western Facies Tract
50 cm
0
5 m
0
Lizard Creek
PLEISTOCENE
Late Wisconsinan till
5w. Sandstone, vf-m, rare crse ls, calc. cement,
4w. Claystone, calc, blocky, ss nodules, carbonate nodules in upper interval
3w. Mudstone, silty, calc, nonlam
2w. Sandstone, vf-silty, calc, blocky
1w. Mudstone to claystone to sandstones
PENNSYLVANIAN
Des Moines Series
JURASSIC
Fort Dodge Formation
"Soldier Creek Beds"

and shales of the St Louis and Pella fms. This exposure of the Soldier Creek Fault will be examined at Stop 2 of the field trip. About ½ mile further up Soldier Creek, a red/green mottled mudstone-dominated unit is exposed, lying above Fort Dodge gypsum on the east bank at Snell Park, field trip Stop 3, and further upstream on the west bank at the southern end of Oakland Cemetery. "Soldier Creek" mudstones are also exposed in the hillside on the north end of the cemetery. This mudstone represents the basal bed of the lower unit (unit 1 of Fig. 17), underlying the sandstone unit that serves as the bed for Soldier Creek at the 5th Avenue North Section.

Gypsum Basin facies tract "Soldier Creek beds" are also exposed in the National Gypsum Kaufman George Quarry (see Table 1 in Bettis et al., 1996). With a maximum observed thickness of 5.3 m, the section includes about 2.9 m of the basal red/green-mottled mudstone (unit 1 of Fig. 17) overlain by about 0.5 m of brown, fine-medium, calcareous sandstone (unit 2), continuous within the quarry, but varying in thickness from 0.5 to 0.3 m. The sandstone is cross-laminated to the north-northeast with faint ripples and minor flaser-like laminations. A thin, dark-gray plastic claystone was found in the western wall of the northern quarry (Fig. 18) in a single lens about 2 m wide with a maximum thickness of about 2 cm. This anomalous lithology, the only dark colored rock observed in any exposure of "Soldier Creek," proved upon x-ray analysis to be a rather pure calcium smectite. This bentonite, an altered volcanic ash, may ultimately provide an absolute age for the unit. Above the sandstone, about 2 m of red, fine sandy, green-mottled mudstone (unit 3) is overlain by Wisconsinan drift.

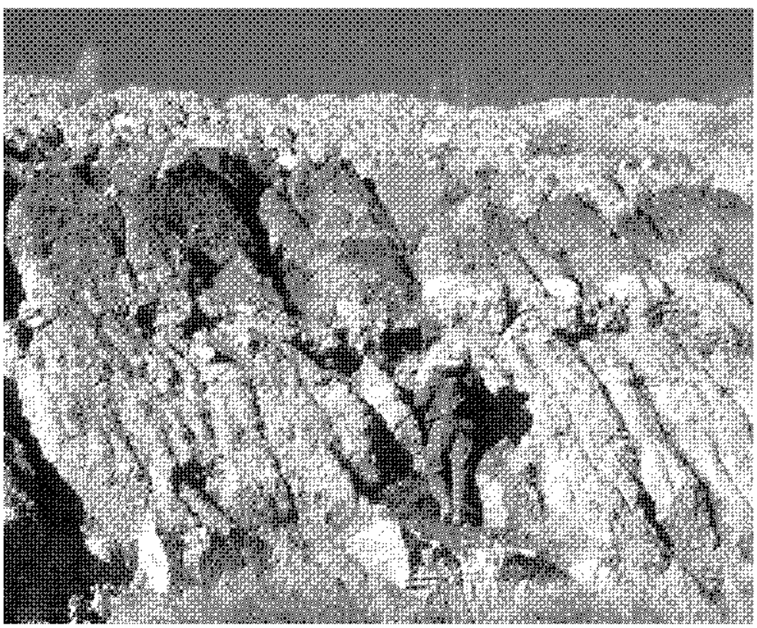


Figure 18. Co-author Robert McKay collecting samples of the bentonite from "Soldier Creek beds" on the west wall of the National Gypsum Company's Kaufman-George north quarry.

A similar succession of "Soldier Creek" strata was reported by Meekins (1995) and Cody and others (1996), both reporting on sections that were measured in the U.S. Gypsum North Welles Quarry in the mid 1980s. In 1984, Anderson and Farmer (Cody, 1996, p. 60-61) measured about 4 m of the strata (max. 5.5 m and a min. 2.7 m depending on the relief on the top of the underlying gypsum). The basal red/gray mottled siltstone (unit 1 of Fig. 17) averaged 2.7 m in thickness (max. 4 m, min. 1 m). It was overlain by about 0.5 m of tan calcareous sandstone (unit 2), and above that about 1 m of brick red/gray mottled mudstone that marked the top of the "Soldier Creek" section. No "Soldier Creek" strata have been observed in any of the quarries in the southeast part of the Fort Dodge Fm (Celotex quarries or U.S. Gypsum's Carbon, Collins, or Cardiff quarries) or the southwest (Georgia-Pacific Quarry). The beds are presumed to have been eroded from these areas.

Western Facies Tract

The Western Facies Tract of the Fort Dodge Fm "Soldier Creek beds" is known from a series of poor exposures along the eastern bank of the 219 Ditch near its confluence with Lizard Creek (Fig 14). The composite of these exposures totals about 2.5 m including five units (see Fig. 17) none of which can be confidently correlated to rocks in the Gypsum Basin Facies Tract. The basal unit (unit 1w. of Fig. 17) includes about 0.7 m of red mudstone with thin tan fine- to medium-grained sandstone lenses resting directly on Pennsylvanian black shale. Unit 2 (unit 2w.) is a light tan to gray, very-fine to silty, moderately calcareous sandstone 0.3 m thick. It has a blocky fracture and displays no sedimentary structures. Above the sandstone lies a light gray silty to clay-rich mudstone 0.5 m thick (unit 3w.). The rock is calcareous and is not laminated, displaying a blocky fracture. The upper 0.1 m grades into a tan, calcareous siltstone with a blocky fracture. Above a sharp contact, the next unit (unit 4w.) is a light brown-gray to tan calcareous claystone, about 0.5 m thick with a blocky fracture. An interval about 15 cm above the base contains very fine to fine, well-cemented calcareous sandstone nodules about 5 cm in diameter. From 26 to 35 cm above the base of the unit a number of light gray carbonate nodules to lenses are present. These nodules include rare to scattered quartz granules but no apparent fossils although the fabric appeared to be bioturbated.. The upper part of unit 4 grades into unit 5 (unit 5w), 0.4 m of tan, very fine to medium sandstone with some coarse grains. The unit is well cemented, calcareous, and contains no sedimentary structures, but does contain rare very coarse sand grains similar to those in the limestone nodules in the underlying unit.

Depositional Environment of the "Soldier Creek Beds"

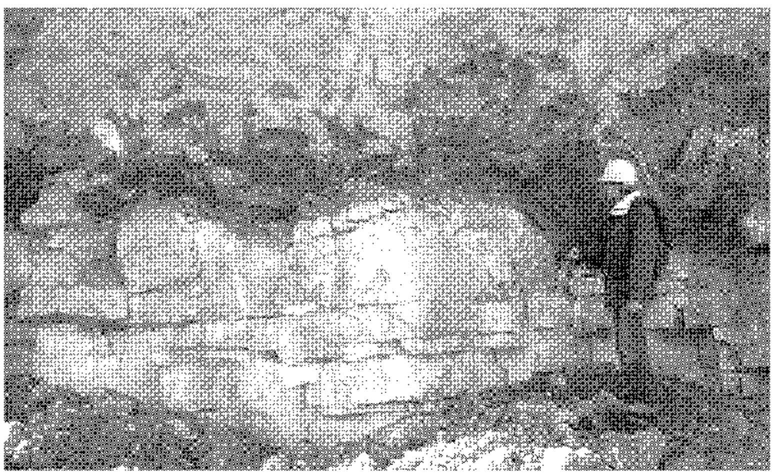


Figure 19. Relief on the upper surface of the gypsum where it is overlain by "Soldier Creek" strata at the National Gypsum Kaufman-George North Quarry.

The "Soldier Creek beds" appear to represent a sequence of fluvial clastics that were deposited in the gypsum basin after the basin had dried out and the gypsum had undergone a short period of erosion. The upper layers of the gypsum display the highest concentration of ripple marks and rare desiccation cracks, indicating a shallowing and periodic drying of the brines in the basin. Relief up to about 1.5 m on the gypsum surface below "Soldier Creek" strata was observed at the U.S. Gypsum North Welles Quarry and the National Gypsum Kaufman-George Quarry. This relief is present as an undulating surface on the gypsum surface and as "Soldier Creek" fill in solution enlarged channels. Some evidence was observed for post-depositional collapse of "Soldier Creek" strata into dissolution depressions in the gypsum, but some of the relief on the contact between the units is believed to be primary. The contact between the "Soldier Creek beds" and the gypsum is sharp, with no increase in clastic content of the gypsum in the upper layers. An olive drab basal siltstone ranging in thickness from about 2-10 cm was observed directly above the undulating gypsum surface in the Kaufman-George Quarry. The lower-most millimeter of this siltstone, where it was in contact with the gypsum, is dark gray.

A variety of structures observed in the "Soldier Creek beds" provides clues to its depositional history. The upward-fining sequences of sandstones, siltstones, and mudstones, lens-shaped sand bodies and cross stratification suggest a fluvial environment, and the fact that no sandstone unit is much more that a meter in thickness suggests that no large channel has been observed. The current interpretation is deposition by a series of minor channels and overbank deposits on a very low relief surface. The lack of bedding or other structures in most of the sandstones suggest bioturbation, probably by rooting. This idea is supported by the mottling in the mudstones which also has the appearance of rooting structures. So, the region was apparently well vegetated during "Soldier Creek" deposition.

The discovery of halite casts in float blocks, apparently from the upper part of the section (unit 6 of Fig 18), and adhesion ripples also discovered in float blocks suggests the evaporation of shallow saline groundwater. Of note is the preservation of thin bedding in the unit, suggesting that vegetation was much sparser shortly after its deposition.

These observations and interpretations are consistent with fluctuations during the retreat of the nearby Sundance Sea. The beginnings of the westward retreat of the sea would cut off the source of brine to the gypsum basin allowing it to dry up and a fluvial system to develop on the coastal lowland and the deposition of the lower part of the "Soldier Creek." Then, a minor transgression would move saline groundwater into the area, reducing the vegetation to more salt tolerant forms and providing the brine for crystallization of halite on or near the surface.

Age of the Fort Dodge Formation

Interpreted of the age of the Fort Dodge gypsum have spanned several eras of geologic time. Age assignments ranging from the Pennsylvanian to the Cretaceous, have been proposed. The first was by Owen (1852), who observed that the gypsum overlies Pennsylvanian rocks, suggested that its contact was conformable, and concluded that the gypsum was Pennsylvanian. In 1858 Worthen interpreted the contact relationship as unconformable. Keyes (1895) agreed that an unconformity exists between gypsum and underlying rocks, and interpreted the gypsum as correlative with the Cretaceous Niobrara chalk to the west. Later he speculated (Keyes, 1915) that the gypsum might be Miocene. Wilder (1903) conducted the first detailed geologic investigation of the formation. From outcrops that can no longer be found along Soldier Creek, he reported thin gypsum layers in red shales above the main body of the gypsum and observed that the "Soldier Creek beds" must be closely associated with the gypsum. He concluded that the overlying "Soldier Creek" red shales and sandstones were only slightly younger than the gypsum, presumably representing a gradual waning of conditions favoring gypsum precipitation. He noted (Wilder, 1903) that the combination of the red beds and gypsum at Fort Dodge was similar to Permian lithologic relationships in Kansas, and he concluded that the most probable age of the gypsum and overlying red "Soldier Creek" clastics was Permian. Moore and others (1944) cited Pennsylvanian fusulinids collected from the Fort Dodge Formation as evidence of a mid-Virgilian age, but Hale (1955) pointed out that these fossils are worn and may have been reworked from older beds, and he cautiously agreed with the Permian age.

The Permian age interpretation remained widely accepted until Cross (1966) published an abstract on the results of a palynologic investigation of the gypsum. He noted that the Fort Dodge gypsum was probably coeval with a sequence of gypsiferous gray-red shales in the Michigan Basin thought to be Kimmeridgian (Upper Jurassic). He based this interpretation on the presence of *Clasopollis* (now better known as *Corollina*) (Fig. 19) in profusion, the abundance of primitive gymnospermous pollen (podocarps, tsugoid, laricoid), a paucity of *Anemia*-type ferns, and the absence of angiospermous pollen in both deposits. He noted that these plants clearly contrasted with the underlying mid-Pennsylvanian

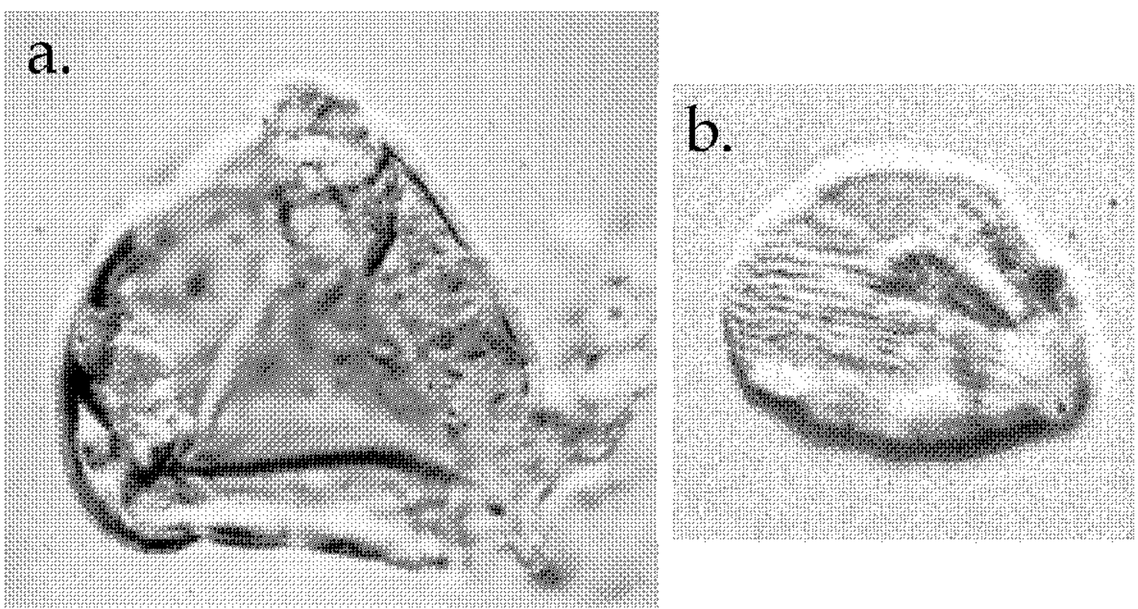


Figure 19. Two key pollen grains that constrain the age of the Fort Dodge Fm. **a.** *Duplicisporites* sp. *A*. Srivastava (1987) (Toarcian to Oxfordian); **b.** *Corollina toros (*a.k.a. *Clasopollis torosaa)* (Lias to Cenomanian), from Klug (1996).

floras, and that none of the identified genera bridged the unconformity.

Cody and others (1996) reported that in a personal letter to Cody, Cross (1984) stated "***I have spent some time on the problem of the age of the Fort Dodge Beds as compared with the MichiganRedbeds and I have not yet come to any final decision ... However, it looks like it very well could be older than Kimmeridgian (=Morrison) and might be as old as Gypsum Springs (for which there is no conclusive palynological study at this time).***"

In 1996, Klug reported on an investigation of palynomorphs from the Fort Dodge gypsum. He noted that the palynofloras are dominated by coniferous pollen (Table 4), with one of these taxa, assigned to the genus *Corollina* (a.k.a. *Classopollis*; Fig. 19b), the most common. He also noted that bisaccate pollen grains (gymnosperms) are also well-represented as are monosulcate pollen grains. Fern or fern-like miospores are also very common in most samples, however no angiosperm pollen (with the exception of a few modern contaminants) were present. Of special interest was the observation that no marine palynomorphs, such as dinoflagellates and acritarchs, have been recovered from either the gypsum or the adjacent clastics. These fossils would be expected in a marine evaporite.

Klug (1996) concluded that the abundance of palynomorphs in the gypsum beds suggested derivation from local floras. The common occurrence on non-obligate tetrads in many of the samples argued against long-distance transport. However, he also be noted that plant material, other than palynomorphs, is very poorly represented in the sampled gypsum.

Although the palynoflora reported by Klug does not allow a tightly constrained biostratigraphic determination, the overall impression given is for a Late Jurassic age. The apparent absence of younger forms such as the very distinctive *Cicatricosisporites*, suggests deposition of the gypsum prior to the latest Jurassic and Early Cretaceous. The presence of *Duplicisporites* sp.*A.* Srivastava (1987) (Fig. 19a) provides the best constraint of the forms identified to date, suggesting that the gypsum was deposited in the period from the upper Lower Jurassic Toarcian Stage (c.a. 190 Ma) to the lower Upper Jurassic

Table 4: Tentative identifications and ranges of select palynomorphs from Fort Dodge gypsum beds by Klug (1996).

TAXON	**RANGE**
Corollina torosa	Lias to Cenomanian
Vireisporites pallidus	U. Permian to L. Triassic
Eucommiidites troedssonii	Jurassic to L. Cretaceous
Exesipollenites tumulus	Jurassic to L. Cretaceous
Araucariacites fissus	Jurassic
Leptolepidies major	Rhaetian to U. Cretaceous
Retitriletes reticulumsporites	Jurassic to Cretaceous
Duplicisporites sp. A. Srivastava (1987)	Toarcian to Oxfordian
Deltoidospora minor	Rhaetian to Cretaceous

Oxfordian Stage (c.a. 155 Ma).

Most recently, Ludvigson (1996) interpreted paleogeographic reconstructions by Scotese (1991) as indicating that North America was moving northward from the Middle Jurassic through the Lower Cretaceous, and that the Fort Dodge area was at dry, evaporitic latitudes (~10-30° north) during the Upper Jurassic. This agrees with Klug's interpretation that the Fort Dodge Formation is probably an Upper Jurassic unit. The distance between the outliers at Fort Dodge and the main body of similar-age rocks to the west further suggest that the Fort Dodge gypsum was probably deposited at a time of near maximum marine transgression, probably coeval with the deposition of the Sundance Formation (or possibly basal Morrison Formation) and equivalent strata of the Rocky Mountain states. A more complete discussion of this work can be found on page 45 of this guidebook

The best age assignment of the gypsum at this time is probably Kimmeridgian (≈ 155 my BP) but it might be as old as Bajocian (≈ 180 my BP), the age of the Wyoming Gypsum Springs Formation (Imlay, 1956). Personnel of the Iowa Geological Survey are currently engaged in a more detailed palynological study of the gypsum and associated sediments.

Jurassic Strata of the Midcontinent

The Jurassic was marked with the beginning of the breakup of the Pangean supercontinent. In general, the Jurassic is characterized by significant marine transgressions on a world-wide scale, with seaways advancing into the heartlands of the existing continents. Seas transgressed onto the North American craton from three sides during the Jurassic, the north, the west, and the south. From the north the Western Interior Seaway, known as the Logan or Sundance sea, extended southwards as far as New Mexico and Arizona along the trend of the modern Rocky Mountains (Sellards et al., 1981). Periodic transgressions of these seas were followed by regressions and erosional episodes that divide the three major subdivisions of the Jurassic, the Lower, Middle, and Upper. Surviving strata show progressive overlap by each successive sequence.

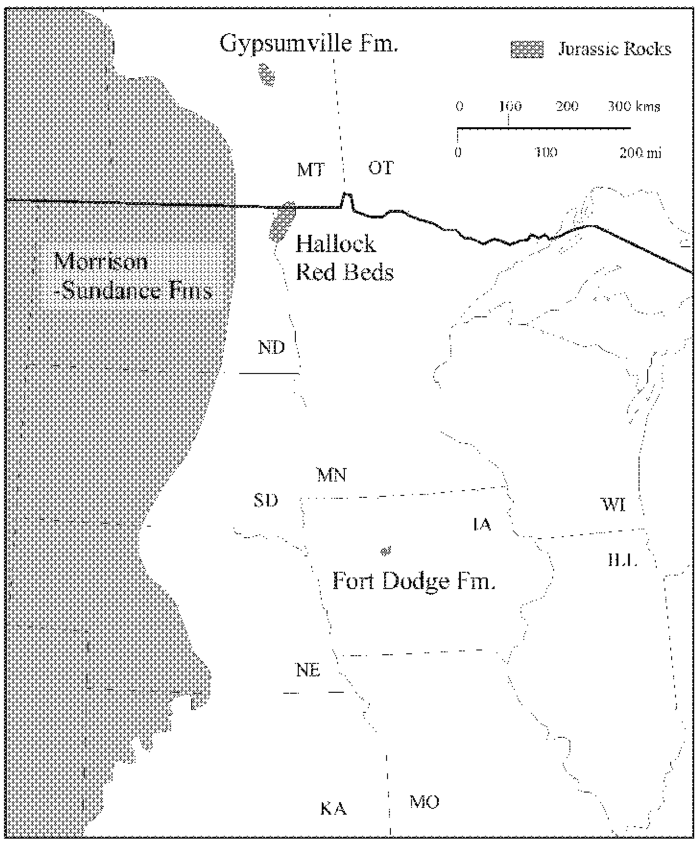


Figure 20. Location of Jurassic rocks in the Midcontinent.

The climate in central North America appears to have been relatively uniform throughout the 64 million years of the Jurassic (208--144 Ma). Circulation through the oceans that lay at both the north and south polar regions probably prevented the formation of polar ice caps accounting for this general climatic amelioration (Sellwood, 1978). However, the onset of the Late Jurassic was marked by a significant climatic change, expressed by overall warming of the climate in the Northern Hemisphere (Vakhrameev, 1988.). Vast areas of the continent were flooded by shallow epicontinental seas during the Middle and Late Jurassic, but the seaways regressed from continental interiors by end of the period. Evaporite deposition was extensive in North America in the areas marginal to the inland seas (see Brenner, 1983).

The maximum limits of the Jurassic marine transgressions are not known due to extensive post-

Jurassic erosion. However, the presence of a limited number of outliers of Jurassic evaporites and other strata provides minimum limits. The Fort Dodge beds are one of only a few of the remnants of these formerly extensive evaporite deposits to survive subsequent erosion. Others include the Hallock Red Beds (Mossler, 1978) in northwestern Minnesota, and the Gypsumville Gypsum (Banatynee, 1959) in east-central Manitoba (see map, Fig. 20). These outliers are located hundreds of kilometers east of the main body of North American Jurassic strata in the western plains states and Rocky Mountains (Bunker et al., 1988; Brenner, 1983). The Fort Dodge Formation was probably deposited contemporaneously with the vast, dinosaur-bearing strata of the Morrison-Sundance formations of the western interior.

Origin of the Fort Dodge Gypsum

Some aspects of the deposition of the Fort Dodge Gypsum are fairly well understood and are not controversial. It is clear that the gypsum was deposited in a closed or restricted basin or basins in an arid climate where evaporation exceeded precipitation. Beyond those generalities, however, many aspects of the history of the Fort Dodge gypsum are not unambiguous. Was it a marine or inland continental lake deposit, and was the evaporite basin originally much larger than the gypsum's currently known extent or did it approximately coincide with the present-day extent of gypsum?

Among the difficulties in trying to answer these questions are: (1) the lack of autochthonous marine or continental fossils; (2) the complete lack of time-related strata in nearby areas, the nearest being in the subsurface of central Nebraska, Michigan, or northwest Minnesota; (3) unconformable upper and lower surfaces; (4) underlying shale and basal conglomerate and overlying 'Soldier Creek beds' also lack autochthonous fossils and other marine/continental indicators; (5) pervasive gypsum recrystallization; (6) near absence of primary structures and textures, even in relict form.

In contrast with these problems, several known features place restrictions on proposed hypotheses. These are: (1) purity of the gypsum; (2) apparent lack of lateral facies differences from one gypsum location to another; (3) near absence of vertical facies changes, with the exception of shallow water indicators in upper one-third of the section; and (4) similarity of sulfur isotope $\delta^{34}S$ ‰ values to those of the marine Jurassic isotope age curve (Claypool et al., 1979; Hansen, 1983).

Marine or Continental Deposit?

Probably the fundamental question relating to the deposition of the Fort Dodge gypsum is whether the deposit originated in a marine or continental environment. A marine gypsum deposit would utilize ocean water as the source of calcium sulfate. Deposition would have occurred in an evaporite basin with restricted connection to an open ocean, presumably to the west in the case of the Fort Dodge gypsum, or in a deep open sea basin with poor circulation. If the Fort Dodge gypsum was of marine origin, then the Late Jurassic shorelines must have been farther to the east than is indicated by the current main body of preserved Jurassic strata (Fig 20). If the Fort Dodge gypsum was deposited in an inland continental lake, then calcium sulfate must have been derived from dissolution of older nearby evaporites. Both Devonian and Mississippian gypsum/anhydrite deposits occur in southern Iowa (McKay, 1985). South of Fort Dodge, gypsum/anhydrite deposits occur in Devonian rocks that lie about 200 - 400 m below the Fort Dodge beds, but shallower Mississippian gypsum may have once been present and subsequently disappeared through dissolution. Widespread brecciation of buried Mississippian limestones may be evidence of collapse resulting from subsurface evaporite dissolution.

Deposition probably occurred in a large evaporite basin, but there is no evidence available to confirm the geometry of the gypsum basin or the lateral extent of evaporite deposition. The purity of the gypsum and the lack of preserved lateral facies change support the contention that gypsum deposition was once more widespread than its present-day occurrence alone would suggest. Both factors argue against an inland continental lake setting. In inland continental lakes distant from an ocean, evaporite deposition utilizes groundwater supplemented by $CaSO_4$-bearing surface water as a source for the $CaSO_4$. Gypsum precipitation would be relatively slow, and wind-derived and seasonal river clastic input would prevent pure gypsum from being deposited. Fort Dodge gypsum contains wind-blown silt as a minor component, but no larger silicate particles that might have been transported by rivers. The silt usually constitutes < 4% of the rock, and seems insufficient in concentration for a continental groundwater-fed evaporite lake with slowly precipitating gypsum.

The only 90%+ pure gypsum lake deposits we know of occur in a few, relatively small, sea-marginal lakes. Thick, relatively pure, laminated gypsum deposits occur in the sea-marginal dune lakes of South Australia (Warren, 1982, 1989). In sea-marginal Lake MacLeod in northwest Australia (Logan 1987), halite deposits are relatively clean because the NaCl concentration in seawater seeping through permeable coastal sediments requires that relatively small volumes of water evaporate to produce thick salt deposits. Rapid precipitation of halite, therefore, easily overwhelms clastic input from wind and other sources. In comparison to halite, seawater contains relatively small amounts of $CaSO_4$, so that large amounts of seawater must evaporate to form thick pure gypsum deposits. This process can be relatively rapid in sea-marginal lakes supplied by seawater flowing through permeable coastal sand dunes, but gypsum in these lakes is not always of high purity. Lake MacLeod gypsum is mixed with clay and aragonite (Logan, 1987).

Other problems related to a continental lake origin are the absence of carbonates which would be expected in lakes fed largely by groundwater. Fort Dodge area Devonian and Mississippian gypsum was closely associated with limestone/dolomite, and groundwater rich in calcium sulfate would be expected to carry abundant carbonates in solution. Carbonates are abundant in both the underlying conglomerate and in the Soldier Creek beds however, and lake margin carbonate deposits may have once been present but might have been eroded in pre-Pleistocene times.

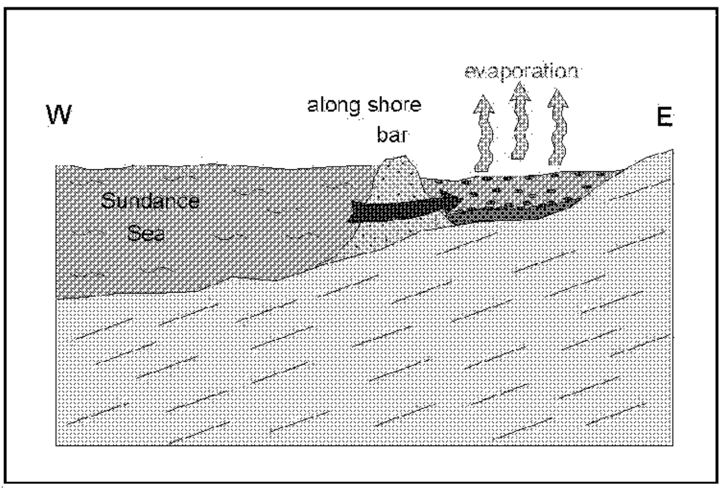


Figure 21. Possible model for recharge of brines in the Fort Dodge gypsum basin.

The similarity of $\delta^{34}S$ ‰ of the Fort Dodge gypsum to marine Jurassic values seems surprising if the sulfate were derived from buried Devonian or Mississippian gypsum, but this evidence could be stronger because sulfur isotope values of both Devonian and Mississipian Iowa sulfates overlap those of the Jurassic (Hansen, 1983).

Deposition of the Fort Dodge gypsum in a deep-sea basin with poor circulation and vertical communication with surface waters is ruled out by reconstructions of Late Jurassic paleoenvironments. The Fort Dodge area lay at the eastern-most limits of the Sundance Sea, as indicated by the very limited number of preserved outliers, the characteristics of the rock in these outliers and the main body of Jurassic strata, and the lack of evidence of a Jurassic structural basin in the region. All these data indicate that the Sundance Sea of the central midcontinent transgressed eastward over a very flat, very low-relief surface, reaching its maximum transgression somewhere in the Iowa area. There is no evidence that its depth in the area reached hundreds of meters or that any significant basins were present.

In summary, lithologic features and regional interpretations suggest that the Fort Dodge gypsum was deposited in a relatively large sea-marginal lake or restricted marine evaporite basin. However, the lack of marine palynomorphs in the gypsum place some major constraints on the configuration of the depositional basin. The basin must have been large enough to trap any sediment contributed by rivers and most other terrestrial sources near its margins (now lost to erosion.) Also, some barrier must have restricted or very seriously limited the direct communication of water from the open sea to the west and the gypsum basin. Normal surface circulation of water, as would occur over a submarine barrier, would allow for the movement of planktonic and other shallow water palynomorphs into the basin. The barrier separating the Fort Dodge gypsum basin from the Sundance Sea may have risen above the surface of the water, and recharge of $CaSO_4$ rich water may have by percolation through a permeable barrier such as an along-shore sand bar (see Fig. 21).

Erosion and Preservation of the Fort Dodge Formation

Recent studies of Cretaceous strata in Iowa and surrounding states by a consortium of geologists led by Iowa Geological Survey Bureau and University of Iowa geologists has provided critical information in our understanding of the erosion and preservation of the Fort Dodge Fm (see Ludvigson, page 45 of this volume). With the onset of the Cretaceous, North America had drifted northward into latitudes with higher precipitation, and soon two major southwest trending rivers developed (Fig. 22). These paleo valleys were filled by sand and gravel deposits now exposed in the Guthrie County area (southern valley) and in a sequence of water and research wells across the main body of the Iowa Cretaceous (northern valley). These rivers were large, as is demonstrated by the size of the clasts that they transported, including quartz cobbles to 5 cm in diameter apparently transported from headwaters areas in Wisconsin and Canada. They cut deeply into existing strata, removing much of the Fort Dodge Fm, with only the portion of the formation centered on the interfluve between the paleovalleys preserved. Finally the eastern transgression of the Western Interior Cretaceous Seaway reduced the rivers' gradients and changed it from an erosional to a depositional mode in west-central Iowa and the surviving rocks of Fort Dodge Fm were buried by Dakota Fm fluvioclastics (Fig. 23) and by subsequent Cretaceous marine strata. Post-Cretaceous erosion then stripped off these Cretaceous strata exposing the Fort Dodge Fm just prior to the Quaternary glacial advances that again buried the units.

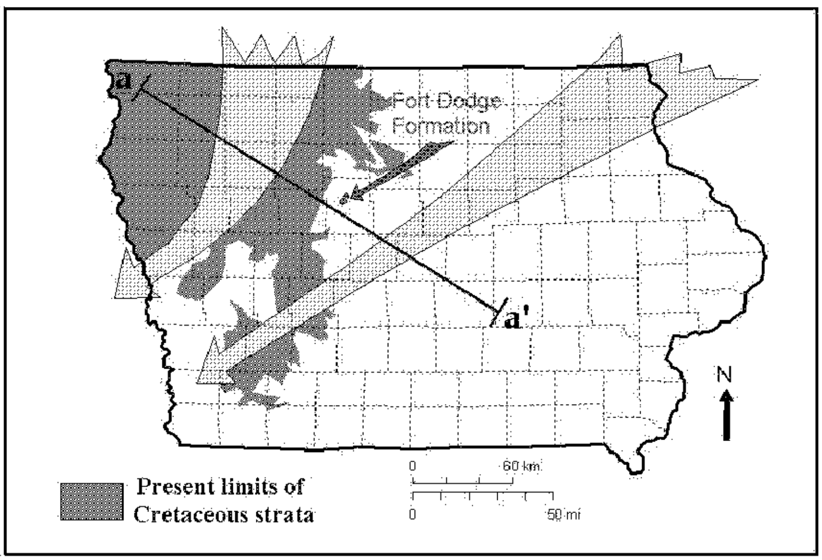


Figure 22. Location of two (Late Cretaceous) fluvial channels in Iowa. Line a-a' is line of cross section for Figures 22 & 23.

Other factors influenced the details of Fort Dodge Fm preservation. Structural features exerted some control over the distribution and thickness of surviving strata. There was some variability in the geometry and depth of the basin in which the lower shale and associated gypsum were deposited, although the details of this geometry has not yet been determined. Also, it is clear that there was faulting and local graben development in the region, and it appears the Fort Dodge Fm sediments were faulted

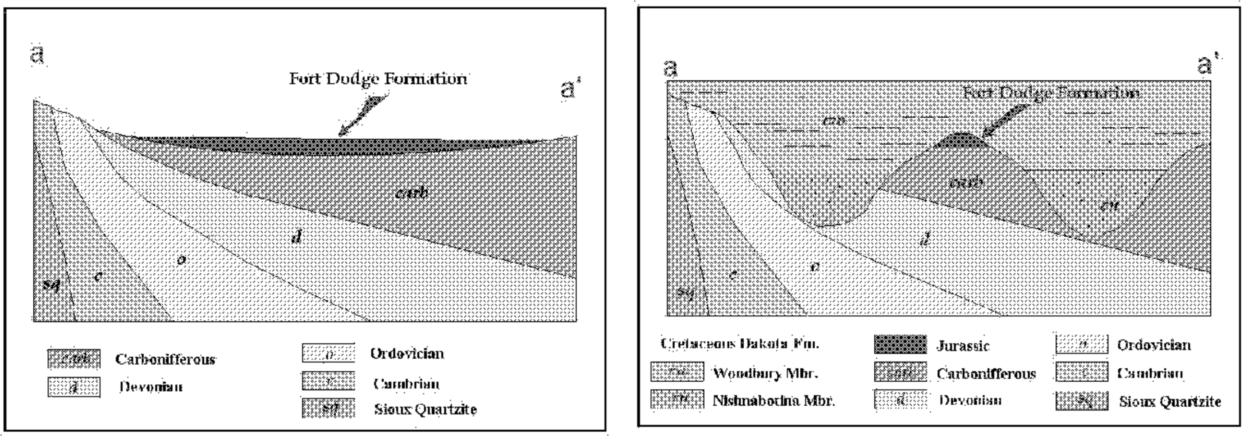


Figure 23. Northwest-trending cross section across Fort Dodge Formation showing geologic relationships immediately after deposition (left) and after incision of Cretaceous channels then burial by later Cretaceous fluvioclastics in advance of transgressing seas.

and structurally preserved in some areas, although the vast majority of the gypsum lies outside of any known grabens.

Fort Dodge Graben

The presence of faults cutting the Paleozoic and Mesozoic rock formations in the Fort Dodge area has been addressed by several authors during this century. Prior to that Keyes (1895) was the first geologist to discuss the structural relations of outcropping bedrock units in the Fort Dodge region. He did not note any faulting in the area, but did recognize and illustrate the significant unconformable relationships between the Mississippian, Pennsylvanian and gypsum-bearing formations.

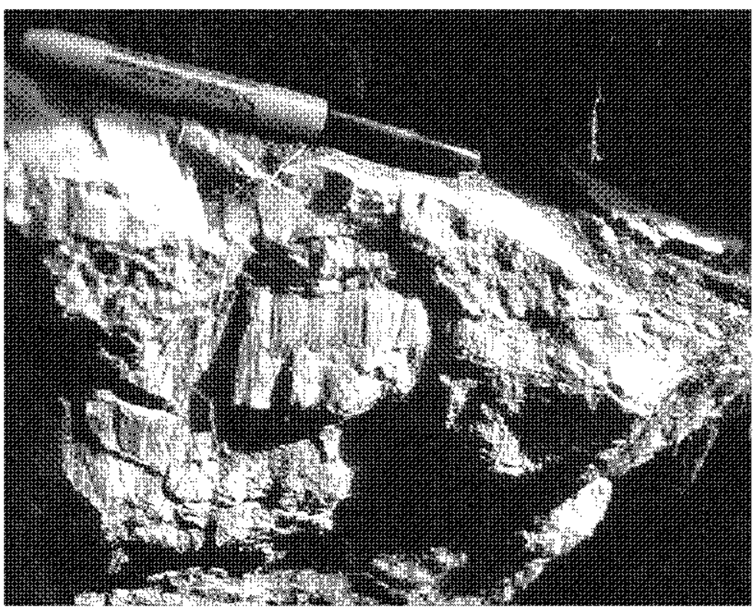


Figure 24. Slickensides in Mississippian carbonates along Soldier Creek (Field Trip Stop 2).

Some years later Keyes (1916) presented data to support a new interpretation of faulting in the Fort Dodge region, and he attributed the preservation of the Fort Dodge formation to faulting in the area. A few years later Lees (1924) reexamined bedrock exposures in and near Fort Dodge and concluded that no faulting of either Paleozoic or Fort Dodge beds was present. Lees attributed the elevation differences of the gypsum beds to be the result of deposition within a steep-walled paleovalley and subsequent irregular erosion during the incision of the modern drainage system.

Faulting was first clearly documented by Hale (1955) who used newly acquired data from the Fort Dodge Limestone Mine and deep city water wells to show that a small east northeast trending faultbounded graben extended through the Fort Dodge well field located near the mouth of Soldier Creek. Hales' interpretation of well data suggested that two faults define a wedge-shaped graben (see Fig. 1) with maximum stratigraphic displacement of 175 feet on the south and 250 feet on the north. City wells in this area show that Mississippian St. Louis Formation strata, which outcrop at the mouth of Lizard Creek and in the valley of Soldier Creek, are down-dropped about 250 feet and in juxtaposition with Mississippian Maynes Creek strata near the mouth of Soldier Creek. Tilted and slickensided St. Louis strata (Fig. 24) in the vicinity of the 7th Street bridge over Soldier Creek (Stop 2 of this field trip) suggests that the north graben-bounding fault probably trends slightly more to the northeast than originally mapped by Hale (1955). Small faults with displacements of a few feet within the redbed sequence of the Fort Dodge beds along Soldier Creek suggest that minor displacement of Jurassic strata has occurred. Small-scale faulting of the Fort Dodge beds in this area appears to account for the approximately 55 foot difference in elevation of the gypsum between the mouth of Soldier Creek and the main gypsum district southeast of the city.

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QUATERNARY STRATIGRAPHY OF THE FORT DODGE, IOWA AREA: UNITED STATES GYPSUM CO. QUARRIES

by
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Authors Note: *The following section is taken from Geological Survey Bureau Guidebook Series No. 18, p. 95, and provides a detailed discussion of Des Moines Lobe stratigraphy, paleo-climatic conditions and insect, plant and macrofossil records from the Fort Dodge, Iowa area. Unfortunately, the section described below no longer exists. However, the section we will be visiting today is quite similar to the National Gypsum pit exposure and will display all of the key elements of the Quaternary stratigraphy of the area*

NATIONAL GYPSUM CO., KAUFFMAN-GEORGE PIT, FORT DODGE, IOWA

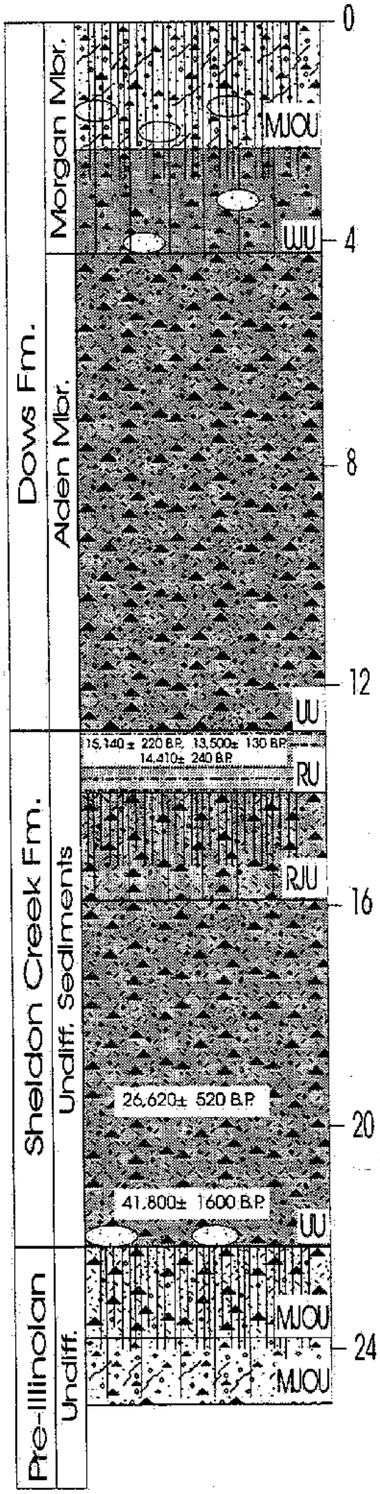
Leaders: E. Arthur Bettis III, Deborah J. Quade, Donald P. Schwert,
Holly J. Torpen, and Richard G.Baker

PLEASE STAY AWAY FROM THE VERTICAL WALLS EXPOSED ON EITHER SIDE OF THE RAMP AT THIS STOP. THE QUARRY OPERATORS HAVE GRANTED US PERMISSION FOR THIS VISIT CONTINGENT ON NO ONE BEING NEAR THE HIGH WALLS.

INTRODUCTION

The Kauffman-George Quarry is the only quarry currently supplying the Georgia-Pacific Corporation's mill south of Fort Dodge. The quarry was opened in 1973 and has been in continuous operation since. Gypsum produced at the Kauffman-George Quarry is trucked about 9 miles to the Georgia-Pacific mill and wallboard plant south of Fort Dodge.

At this stop we will examine the Morgan and Alden members of the Dows Fm., examine and discuss the Dows Fm./Sheldon Creek Fm. contact, as well as paleoenvironmental interpretations derived from fossil plant and insect assemblages preserved in sediments at the Dows/Sheldon Creek contact. Several active gypsum pits in the Fort Dodge area, outcrops along Brushy Creek southeast of Fort Dodge, and excavations for an earthen dam at Brushy Creek State Recreation Area, located 19 km south of Stop 2 have provided us with a good look at the complete sedimentary sequence of the Dows Formation in a low-relief plain with irregular surface patterns (PU) landform area of the Lobe. This area is within the part of the Lobe covered by the Altamont advance, and a few kilometers southeast of the Clare Moraine.



Name: **94 NATIONAL** *County:* **WEBSTER**
Company: **NATIONAL GYPSUM (KAUFFMAN-GEORGE PIT)**
Parent Material: glacial diamicton *Vegetation:* none
Loc. (Q's): **SE, NW** *Sec.* **7** *T.* **89N** *R.* **27W**
Quad: **VINCENT** *Elevation:* **1125 FT.**
Landscape Position: low relief till plain
Date Described: 7/24/95
Descrip. By: E. A. Bettis III, exposure on active ramp on north side of pit

Depth (meters)	*Soil Horizon (w. zone)*	*Description*
		DOWS FORMATION
		Morgan Mbr.
0-2.4	MJOU	loam diamicton [Dms(r)], stratified, with deformed (by collapse) lenticular bodies of stratified pebbly sand, sand, and silt [PGcs(pl)] and S(m-pl), gradual to clear boundary
2.4-4.3	UJU	loam diamicton [Dms(r)-Dmm], with fewer lenticular bodies of stratified pebbly sand, sand and silt than above, abrupt lower boundary
		Alden Mbr.
4.3-12.8	UU	loam diamicton (Dmm), abrupt boundary, C-14 ages on wood from lower 30 cm., 15,320± 180 B.P. (B-10838)
		SHELDON CREEK FORMATION UNDIFF.
12.8-14	RU	shallow troughs filled with finely planar bedded to laminated silt and fine to medium sand [S(pl-h) and F(sc)], these shallow troughs are organic-rich in their upper few decimeters and contain macrofossils and beetles, abrupt undulatory lower boundary. C-14 dates: wood at top of unit, 14,410± 240 B.P.; macrofossils in upper 10 cm., 13,500±130 B.P. (B-10835); macrofossils 0.8 below top of unit, 15,140±220 B.P. (B-9797)
14-15.9	RJU	loam diamicton (Dmm), gradual lower boundary
15.9-22.3	UU	loam diamicton (Dmm), with a zone of small lenticular bodies of shallow trough-crossbedded pebbly sand 0.6 to 2.1 m above the lower contact, these pebbly sand bodies are undeformed and are interpreted as subglacial channels, C-14 dates: wood collected 4.0 m below top of unit, 26,620±520 B.P. (B-100004); wood collected 0.3m above base of unit 41,800+1600 B.P. (ISGS-3200) abrupt lower boundary
		PRE-ILLINOIAN UNDIFF.
22.3-23.8	MJOU	loam diamicton (Dmm), gradual lower boundary
23.8-25	MJOU	loam diamicton [Dms(s)], weakly stratified with common streaks and blobs of reworked Soldier Creek Formation siltstone and sandstone, abrupt lower boundary
Base		***Jurassic (rocks of the Fort Dodge Beds)***

Figure 1. Graphic log of the stratigraphic sequence exposed in the National Gypsum Quarry, Fort Dodge, Iowa

STRATIGRAPHY

Figure 1 presents a graphic log of the stratigraphic sequence exposed in the National Gypsum pit in late July 1995. The quarry is active and lateral expansion is at a fast rate, so the details of the stratigraphic sequence, and the nature and occurrence of sub-Dows deposits during the field trip visit may differ from those depicted in Figure 1. In this area the Dows Fm. consists of relatively thick, dense, uniform Alden Mbr. diamicton that changes abruptly upward to stratified diamicton and sorted sediments of the Morgan Mbr. Morgan Mbr. deposits exposed in the eastern wall of the ramp in 1995 consisted primarily of sorted sediments--trough cross-bedded medium to coarse pebbly sands with interbedded lenses and pods of diamicton. Individual beds of the sorted sediments were offset by normal faults, probably formed by collapse of underlying sediments during melting of buried ice.

The Morgan Mbr. is jointed through its vertical extent (4.3 m), with thin discontinuous coatings of iron and reduction zones along some joint faces in the oxidized zone of the weathering profile. The oxidized/unoxidized weathering zone transition is rather abrupt here and coincides with the lower boundary of abundant sorted sediments in the Morgan Mbr. Jointing continues into the unoxidized weathering zone, but at an intensity much less than higher in the weathering profile. In the unoxidized zone thin oxidation fronts extend from joint faces into the unoxidized matrix.

Dows Fm. deposits abruptly overlie planar bedded to laminated silt and fine to medium sand that were deposited in small, shallow ponds on the pre-Des Moines Lobe surface of the Sheldon Creek Fm. These pond sediments fill shallow troughs that range from about 40 cm to 1.5 m in depth. Small-scale deformation structures (water escape features, small normal faults and small folds), formed when the area was overridden by the glacier that deposited the Dows Fm. are common in these sediments.

The pond sediments contain at least two horizons of organic enrichment that include plant and insect fossils. The upper-most organic horizon gives way laterally to an A/C soil profile developed on thin silty sediments that grade downward into Sheldon Creek Fm. diamicton. The upper two meters of the Sheldon Creek Fm. is jointed and reduced. The organic horizons, interpreted as incipient soils, jointing, and a reduced (as opposed to unoxidized) weathering zone indicates that Sheldon Creek Fm. deposits were exposed to subareal weathering and soil development before they were buried by Dows Fm. diamicton. The nature of the soils developed in and on the pond sediments, and the presence of jointing (formed by desiccation of the clay-rich diamicton), and a reduced weathering zone (originally an oxidized zone that was later subjected to an oxygen-poor environment) in the underlying Sheldon Creek Fm. diamicton suggest that the conditions on the pre-Lobe landscape became more poorly drained as the glacier advanced into this area. The presence of these soils and weathering profile also indicate that little or no subglacial erosion or deformation took place as the Lobe advanced across this area. Other gypsum pits in the Fort Dodge area, clay pits along the Des Moines Valley south of Fort Dodge, and outcrops in Brushy Creek State Recreation Area expose Dows Fm./Sheldon Creek Fm. sequences very similar to that exposed at the Kauffman-George pit. This preservation of the pre-Dows Fm. surface over a relatively large area (at least 150 km^2) indicates similar, non-erosive conditions at the base of the Des Moines Lobe glacier as it advanced across this area.

Radiocarbon ages on organic remains collected during 1984 at this stratigraphic position by George Hallberg from the lower 20 cm of the Dows Fm. (15,310 $\pm$80 B.P.-- B-10838 on wood) and in the pond sediments below the Dows Fm. (15,140$\pm$220 B.P.-- B-9797 on macrofossils) indicate that the Lobe advanced across this area about 15,200 years ago. Younger radiocarbon ages from the pond sediments (13,500$\pm$130 B.P.--B-9796 and 14,410$\pm$240--B-9877) are judged erroneous in the regional chronologic context. These "too young" ages may be a product of abundant moss in the dated samples; mosses are known to yield young radiocarbon ages (McDonald et al., 1987).

Beneath the pond sediments, the Sheldon Creek Fm. consists of massive, uniform, dense diamicton interpreted as basal till. The lower 2.1 meters of the unit contains small, lenticular bodies of shallow trough cross-bedded pebbly sand that are interpreted as subglacial channels. Wood collected by Hallberg in 1984, 2.3 m above the base of the Sheldon Ck. Fm., yielded a radiocarbon age of 26,620±520 B.P. (B-10004) while another wood sample collected in 1995, 0.3 m above the base of the unit yielded a radiocarbon age of 41,800±1600 BP (ISGS-3200). Sheldon Creek Fm. diamicton abruptly overlies oxidized, jointed, and unleached Pre-Illinoian diamicton, which in turn buries Fort Dodge Fm. rocks comprised of reddish siltstone (Soldier Creek beds) and the underlying Fort Dodge gypsum (Figure 1).

INSECT REMAINS: A FACETED EYE'S PERSPECTIVE ON THE ADVANCE OF THE DES MOINES LOBE INTO NORTH-CENTRAL IOWA

Donald P. Schwert and Holly J. Torpen

INTRODUCTION

The organic-rich sediments underlying the Dows Fm. contain remarkably rich quantities of beetle (Coleoptera) chitin. Also present in these sediments are remains of other insect orders (Hemiptera, Homoptera, Trichoptera, Ephemeroptera, Diptera, and Hymenoptera), erigonid spiders, oribatid mites, cladoceran ephippia, and aquatic snails. Schwert (1992), in a preliminary report on the fauna, listed some of the beetle species identified from the quarry's sediments.

The insect assemblages at Fort Dodge are among the most stratigraphically significant yet encountered in the late Wisconsinan record. Their occurrence immediately below the Dows Fm. implies that they are evidence of insect faunas that occupied the landscape of north-central Iowa as ice of the Des Moines Lobe advanced into this region. Indeed, at one of the sites (Section II), insect-bearing organics appeared to be sheared into the diamicton. Collectively, the Fort Dodge assemblages thus present a perspective on the environment and climate of this region prior to and during ice advance.

SAMPLE SECTION, AGES, AND PROCEDURES

Sampling of sub-diamicton organics at the National Gypsum Quarry for insect analyses occurred on two occasions. In July 1984, a team (D.P. Schwert, G.R. Hallberg, R.G. Baker, A.C. Ashworth, D.G. Horton, and others) obtained organics from two sections of freshly-stripped quarry overburden. The first (Section I) section of organic sands from the east wall was sampled in bulk; fragments of wood and of mosses (Scorpidium scorpoides; field determination by D.G. Horton) were encountered in these samples. The second section (Section II) of organic silts from the central portion of the north quarry wall was sampled in 10-cm intervals, from 0 cm (diamicton contact) to 50 cm. In 1995, Art Bettis sampled sub-diamicton organics from fresh exposures in the quarry overburden; these samples are still being processed for insect remains.

As of this writing, radiocarbon dates have been obtained from organics derived from the July 1984 sampling, but not the 1995 sampling (Table 2). Included in this list are ^{14}C-AMS dates on minute quantities (0.20 - 0.31 mg) of unidentifiable beetle chitin, undertaken to test whether chitin is appropriate for dating. In addition to these four dates, two others exist on sub-diamicton organics sampled by G.R. Hallberg in June 1984, from exposures on the east wall of the quarry: 14,410 ± 240 B.P. (Beta-9877; wood and plant fragments at contact with diamicton) and 15,140 ± 220 B.P. (Beta-9797; plant debris and disseminated organic carbon 0.8 - 1.0 m below contact with diamicton). G.R. Hallberg (pers. comm., 1984) estimated that the organic units for these latter two dates were approximately stratigraphically equivalent (in their relationships to the overlying diamicton) but about 20 m distant from those of Section I due to active stripping of the quarry overburden. Overall, the precise relationships among the three sections sampled in 1984 remain unclear.

Insect chitin was isolated from the July 1984, and 1995 samples utilizing standard kerosene flotation procedures (Elias, 1994). Chitinous remains were sorted under binocular dissection microscope, with the diagnostic beetle remains being mounted with gum tragacanth onto micropaleontological slides for identification purposes. Other chitinous remains were stored in ethanol. All insect fossils are reposited in the Quaternary Entomology Laboratory, North Dakota State University.

Taxonomic analysis of the chitinous remains was accomplished through morphologic comparison with modern, pinned specimens of beetles. The remains of several taxa were submitted to expert systematists for identification or verification.

FAUNAL SYNTHESES

A comprehensive list of Coleoptera identified from Fort Dodge is presented in Table 3. Included are the results of our recent reevaluation of beetle chitin obtained during the 1984 sampling

Seventeen families of beetles have been identified. A strong aquatic element is represented, particularly in the Section II and 1995 assemblages, with the rich presence of dytiscids (predaceous diving beetles) and hydrophilids (water scavenger beetles), plus water-marginal taxa of Carabidae (ground beetles), Staphylinidae (rove beetles), Limnebiidae (minute moss beetles), and Heteroceridae (variegated mud-loving beetles). These taxa are regularly associated with pools and shallow ponds bordered by open silty-sand margins, where the surface is only sparsely covered by sedges, grasses, and mosses; such habitats are common on floodplains. Present as well at Fort Dodge is the carabid Opisthius richardsoni, a large, riparian beetle today common only on sandy-gravels of braided stream and point bar deposits (Ashworth and Schwert, 1991).

Wood was encountered as bits of twigs and other pieces in both the Section II and 1995 samples, suggesting only a minimal regional presence of trees, possibly dwarfed. This conclusion is supported by the profound open-ground nature of the beetle assemblages. Of the hundreds of chitinous remains so far analyzed, only three are of scolytids (bark beetles); of these, Polygraphus rufipennis is regularly associated with conifers (Bright, 1976).

Despite the implied differences in the ages of the Section I and Section II assemblages, the taxa represented are remarkably consistent. Except for its lower diversity and sparser occurrence of water beetles, nearly all of the Section I taxa are present in Section II. Likewise, all of the taxa so far identified from the 1995 samples are represented in Section II.

Table 2. Coleoptera identified from sub-diamicton sediments at the National Gypsum Quarry, Fort Dodge, Iowa.[a]

	Skeletal parts:	Minimum # of individuals:					
			Section II Interval (cm)				
		Section I	0-10	10-20	20-30	30-40	1995
Carabidae:							
Opisthius richardsoni Kby.	P L			1			
Notiophilus aquaticus (L.)	H P L R	1		1			
Elaphrus americanus Dej.	R				1		
Elaphrus californicus Mann.	H P L R			5	3		
Elaphrus sp.	P		1				
Loricera pilicornis (F.)	H P L			2	2		
Dyschirius spp. (2)	H P L R	5	1	2			
Miscodera arctica (Payk.)	H P	1					
Bembidion grapii Gyll.	P L R	3		7	3		
Bembidion sordidum (Kby.)	H P L R	5		8	4		
Bembidion petrosum Gebl.	H P L R			5	2		
Bembidion nigripes (Kby.)	H P L R			7			
Bembidion mutatum G. & H.	P L R	4		2			1
Bembidion morulum LeC.	P L R	5		2			
Bembidion spp. (6)	H P L R	5		7	6		5
Agonum anchomenoides Rand.	H P L R		1	7			
Dytiscidae:							
Hydroporus cf. *griseostriatus* (DeG.)	H P L R			7	3		
Hydroporus spp. (2)	H P L R			5			
Agabus arcticus (Payk.)	H P L R			8			1
Colymbetes sp.	L			1			
Hydrophilidae:							
Helophorus sempervarians Angus	H P L R			16			
Helophorus arcticus Brn.	H P L R	1		4			
Helophorus sp.	P L R			2			2
Laccobius sp	H P L R			11			
Cercyon sp.	L R			2			
Limnebiidae:							
Ochthebius sp.	H P L R		2	72	5		12
Staphylinidae:							
Oxytelus or *Anotylus* sp.	H P				1		
Olophrum consimile Gyll.	P L R			2			
Bledius spp. (2)	H P L R	5		14	1		
Stenus spp. (3)	H P L R		1	45	2		1
Philonthus cf. *subvirescens* Thoms.	H P L R				5		
Philonthus sp. (*aurulentus* grp.)	H P L R			8	9		
Philonthus spp. (2)	H P L R			2			
Mycetoporus sp.	L R	3				1	
Tachinus jacuticus Popp.	tergite			5			
Tachinus elongatus Gyll.	tergite			1			
Tachyporus sp.	tergite	1					
Aleocharinae gen. indet.	P L R						
				20			
Silphidae:							
Thanatophilus sp.	H P R		1	2			

Table 2. contd.

	Skeletal Parts:	Minimum # of individuals:					
				Section II Interval (cm)			
		Section I	0-10	10-20	20-30	30-40	1995
Scarabaeidae:							
Aphodius spp.	H P L R	5	1	5			1
cf. Cyphon sp.	L R				1		
Byrrhidae:							
Simplocaria sp.	P L R			4			
Curimopsis sp.	L R			2			
Heteroceridae:							
Gen. indet.	P L R		1	10	10		4
Elateridae:							
Negastrius sp.	P			1			
Gen. indet.	P L R			2	1		
Cantharidae:							
Gen. indet.	P L			6			
Coccinellidae:							
Hippodamia caseyi Johns.	L R			1			
Chrysomelidae:							
Plateumaris sp.	R			1			
Phaedon sp.	P R						1
Altica spp. (2)	H P R			3			
Gen. indet.	L R	2					
Curculionidae:							
Bagoini gen. indet.	L R			3			
Gen. indet.	H P L R	2		6	4		
Scolytidae:							
Polygraphus rufipennis (Kby.)	L			1			
Pityophthorus sp.	P L			1			

[a]Numbers in parentheses refer to the number of indeterminate species within a taxon. Skeletal parts are abbreviated: H = head, P = prothorax, L = left elytron, R = right elytron. Minimum number of individuals listed are based on the most abundant skeletal part.

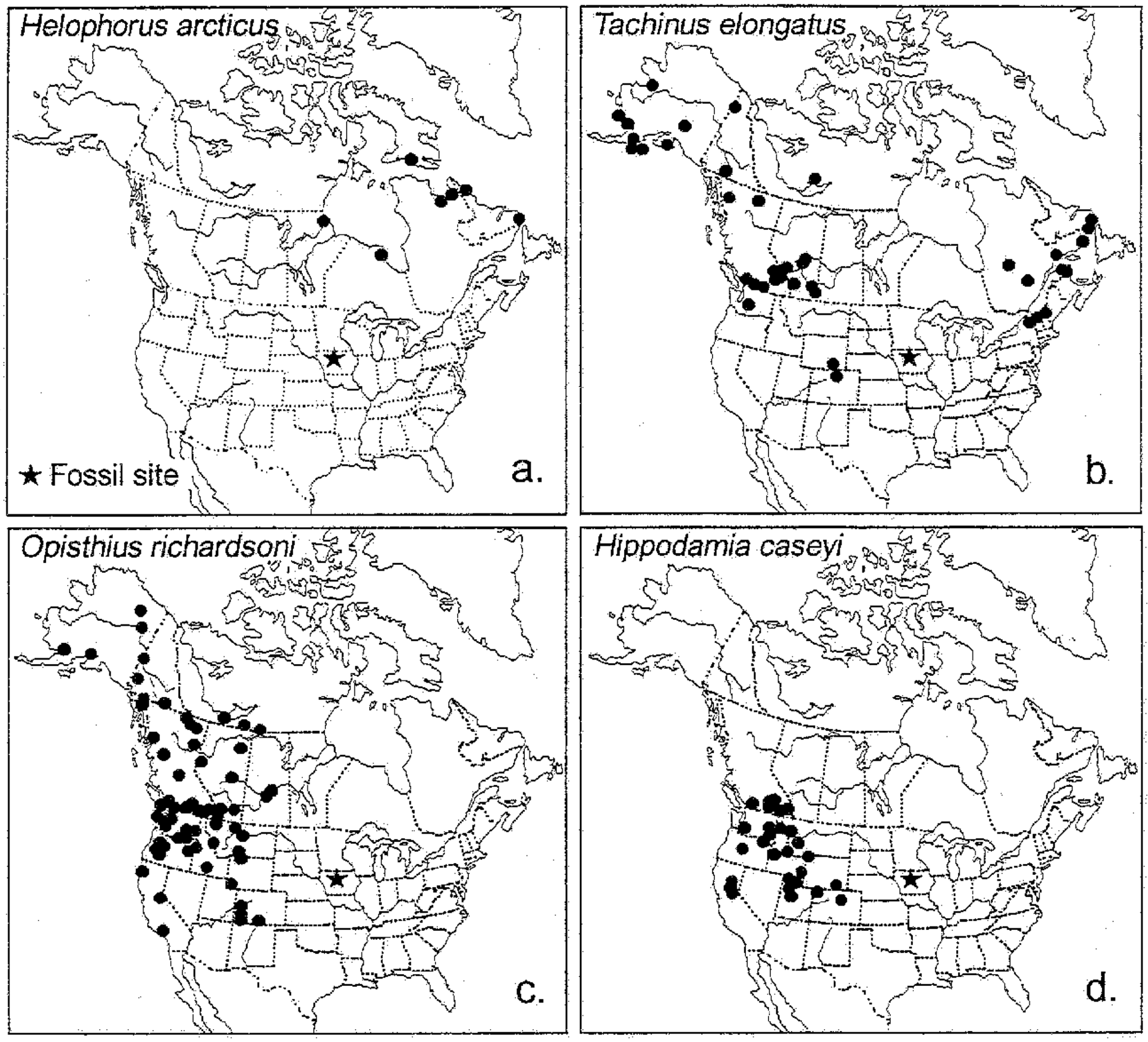


Figure 2. Modern distribution of beetles represented as fossils at Fort Dodge, Iowa. (sources: Campbell, 1973; Gordon, 1985; Ashworth and Schwert, 1991).

In contrast to other, older late Wisconsinan assemblages within the region (Elkader, IA - Woodman et al., in press; Conklin Quarry, Iowa City, IA - Baker et al., 1986; lowermost Saylorville, IA - Schwert, 1992), the assemblages at Fort Dodge are nearly devoid of obligate arctic (Type I, per Schwert, 1992) beetles. The only such taxon represented is the hydrophilid Helophorus arcticus (Figure 2a), a species that has been reported from numerous full-glacial and late-glacial assemblages in the Midcontinent (Morgan, 1989). More typical of the Fort Dodge beetle assemblages are species, such as the staphylinid Tachinus elongatus (Figure 2b), with ranges throughout boreal and montane forest zones but not onto tundra.

A Cordilleran element is likewise present in the Fort Dodge assemblages. The carabid Opisthius richardsoni (Figure 2c) today is common along the margins of cold, meltwater-fed rivers in western North America (Ashworth and Schwert, 1991) - environments that would have been common in a landscape flushed with glacial meltwaters associated with the Des Moines Lobe advance and retreat.

Less easily explained is the occurrence of the coccinellid (ladybird beetle) Hippodamia caseyi (Figure 2d), a predaceous beetle of western, montane distribution whose biology remains poorly known.

DISCUSSION

The Fort Dodge insect assemblages provide evidence that regionally the Des Moines Lobe advanced into an open, almost treeless landscape of shallow pools and meltwater-fed streams. Although the vegetational structure must have resembled taiga or tundra, the Fort Dodge insects show few affinities to these biomes. The profoundly "cold" and "arctic" aspect demonstrated by the full-glacial faunas at Elkader, IA (Woodman et al., in press) and Conklin Quarry, Iowa City, IA (Baker et al., 1986) is absent in the assemblages at Fort Dodge. Instead, those at Fort Dodge share close affinities to late-glacial faunas, such as those represented at Norwood, MN (Ashworth et al., 1981), Two Creeks, WI (Morgan and Morgan, 1979), Kewaunee, WI (Garry et al., 1990), and Ontario E-13 (Schwert, 1992), where non-arctic, open-ground elements are mixed with those of Cordilleran affinities. In our preliminary analyses of insect assemblages at other sub-diamicton sites (Alden and Brushy Creek) within the region, we have likewise encountered only beetle assemblages of late-glacial affinities.

Thus, present in this "glacial" setting of continental ice advancing into a tundra-like landscape were insect faunas of distinctly "non-glacial" affinities. The arctic insect species that had characterized the late Wisconsinan, full-glacial climate of the Midcontinent had by now been extirpated by climatic warming (Schwert and Ashworth, 1988; Schwert, 1992). From refugia to the south, insect faunas of more temperate affinities advanced northward, probably to the ice margin, itself.

Although paleoentomological analyses can obviously have no direct application to glacial physics or the dynamics of ice response, those at Fort Dodge and associated sites nonetheless provide strong evidence that the advance of the Des Moines Lobe was triggered by the termination of full-glacial climatic conditions. Exactly when and how quickly this climatic transition occurred remains equivocal. "Arctic" insect faunas were present at Conklin Quarry (Iowa City, IA) through at least 16,700 B.P. (Baker et al., 1986). If the 15,310 ± 180 B.P. (Beta-10838) date of Section II organics and associated, non-arctic insects at Fort Dodge is validated by future dating at this site, it temporally delimits both the extirpation event and the termination of late Wisconsinan full-glacial climatic conditions.

POLLEN AND PLANT MACROFOSSILS

Richard G. Baker

INTRODUCTION

The organic loams at the Dows-Sheldon Creek contact contain locally abundant plant macrofossils and sparse pollen. These plant remains must represent the vegetation present as glacial ice of the Des Moines Lobe advanced across the site. The plant record is of interest not only for revealing the vegetation of this interesting time, but also for how it compares with the insect record.

The sites were sampled first by R.G. Baker, G.R. Hallberg, D.P. Schwert, A.C. Ashworth, D.G. Horton, with help from students from North Dakota State University. Art Bettis resampled the sediments at the same stratigraphic horizon in 1995 after the original section had been cut back considerably.

The plant macrofossils were soaked in water with detergent, washed through sieves (0.5 and 0. mm mesh), and picked by hand using a dissection microscope. All samples collected in 1984 were 300 ml in volume; the 1995 sample was 100 ml. The samples are listed per these volumes. The pollen sample was treated in standard fashion using KOH, HCL, acetolysis solution, and HF, stained with safranin, and mounted in silicone fluid (Faegri et al., 1989). Both pollen and macrofossils were identified using reference collections at the Geology Department, University of Iowa, Iowa City, Iowa, and fossils specimens are reposited in the Repository there.

Radiocarbon ages on the organic remains have been discussed previously. Ages of 15,310 ±80 BP (Beta-10838) and 15,140±220 BP (Beta-9797) are considered to represent the age of these fossils.

RESULTS

The pollen spectrum of the one sample counted is simple: 55% Cyperaceae (sedge) and 45% *Picea* (spruce). No other pollen type makes up even 1% of the sample. These very minor types include *Alnus* (alder), *Betula* (birch), *Salix* (willow), Poaceae (grass family), *Artemisia* (sagebrush), and Asteraceae (daisy family).

The plant macrofossil samples include analyses from four sections from the 1984 collections (one with five levels) and the 1995 collection. The taxa in these analyses are arranged by ecological grouping, so that readers can understand their significance (see Table 3). The groupings are arctic, boreal, wetland, aquatics, and other.

DISCUSSION

Comparison of the pollen and plant macrofossils shows some interesting patterns. The pollen sample yields quite a different picture from the plant macrofossils. The dominance of spruce pollen is in contrast with the almost complete lack of spruce needles (one needle out of 2500 ml of sediment). Where spruce is present, it is common to find hundreds to thousands of spruce needles/liter of sediment. This assemblage suggests that spruce was not growing in the immediate vicinity, but it was probably present on some upland areas in the vicinity.

The high sedge pollen fits well with the many *Carex* and *Eleocharis* (spike-rush, another sedge genus) macrofossils. These, along with such wetland taxa as *Equisetum* (horsetail), *Scheuchzeria palustris* (scheuchzeria), *Triglochin maritimum* (arrow-grass), *Juncus triglumis* (rush), *Juncus* sp. (rush), and *Ranunculus cymbalaria* (seaside crowfoot) suggest that a wetland complex was present. The diverse moss flora indicates that many of the low-lying areas supported rich fen vegetation (D.G. Horton, personal communication), which is where many of the sedges, arrow-grass, scheuchzeria, and rushes probably grew. Both upland and pond environments also existed locally, as indicated by both sediments and beetle remains. *Dryas integrifolia* (mountain avens) is a typical pioneer on calcareous gravelly upland habitats, and *Vaccinium uliginosum* var. *alpinum* (bilberry) grows in both upland and moist sites. Pond sites are recorded by *Myriophyllum* (water-milfoil), *Potamogeton* spp. (pondweeds), *Ranunculus aquatilis* (an aquatic crowfoot), and *Chara* (an algae). Several of the wetland and aquatic taxa tolerate relatively high alkalinity (Kantrud et al., 1989), suggesting that runon may have been composed of fairly hard water. This is not surprising considering the proglacial setting.

Table 3. Plant macrofossils at the 1995 Fort Dodge exposure, Sheldon-Dows Contact (R.G. Baker, analyst).

level		Dows/Sheldon contact		0-10	10-20	20-30	30-40	40-50		
Date collected		1995	1984	1984	1984	1984	1984	1984	1984	1984
Sec. no.		EAB	Sec. 1	Sec. 2	Sec. 2	Sec. 2	Sec. 2	Sec. 2	Sec. 3	Sec.4
Arctic	**fossil type**									
Dryas integrifolia	leaves	12	1						58	16
Dryas integrifolia	stems + leaves	2							some	
Juncus triglumis (s.l.)	seeds	53								
Salix arctica type	leaves	15								
Salix sp. A	microphyllous leaves	5								
Salix sp. B	microphyllous leaves	8								
Vaccinium uliginosum var. alpinum	leaves								5	2
cf. Vaccinium uliginosum var. alpinum	leaf fragments	8							30	
other small leaf fragments		25							4	3
immature small leaves (2mm long)	whole leaves	11								
small twigs		27								
Boreal										
Picea	needles					1				
Wetland										
Carex aquatilis type										1
Eleocharis palustris type	fruits	1 cf.	1	9		13				4
Equisetum subgen. Hippochaete	stem fragments	common								
Juncus sp.	seeds	9	7	1		122	57		2	1
Ranunculus cymbalaria		1 cf.				74	9			
Scheuchzeria palustris	fruits		2							
Triglochin maritimum	fruits	10		2		1			1	
Aquatics										
Myriophyllum	fruits			1						
Potamogeton alpinus	fruits			8		3				
Potamogeton filiformis	fruits	1			1	13	7			
Potamogeton sp.	fruits					1				1
Ranunculus aquatilis	fruits			1			1			4
Chara								present	present	present
Other										
Carex (biconvex)	fruits	69		177	4	234	66		30	1
Carex (trigonous)	fruits	27	3	2		2			65	
small composite	fruits	1								
Draba	siliques									2
grass	caryopsis						1			
Rumex	fruits						2			
Salix	buds	2				19			7	
Salix	capsule bases	33				7			17	
Salix	stipules	4								
unknowns		27								

The macrofossils of arctic species do not show up in the pollen record at Fort Dodge, but that is fairly typical. These include *Dryas integrifolia* (mountain avens), *Vaccinium uliginosum* var. *alpinum* (arctic bilberry), *Juncus triglumis* (rush), and *Salix arctica* type (arctic willow). These and many other arctic species produce very little pollen. Thus, the species that do produce great amounts of pollen (e.g., the sedges), and pollen fallout from trees some distance from the point of deposition, easily overwhelm the local pollen production.

As with the insects, the combined pollen and plant macrofossil record differs significantly from records from both older and younger sediments. Sites dating from about 16,500 to 21,000 B.P. have a more diverse flora of arctic plant macrofossils, and a pollen record dominated by pine, spruce, and sedge, rather than just spruce and sedge (e.g., Baker et al., 1986). This has been interpreted as a much more open landscape, because 1) insects, vertebrates, and plant macrofossils from that time are all treeline to arctic, and 2) pine apparently was absent from the Midwest, and pollen production was low enough that pine pollen blowing in from the southeastern U.S. comprised 20-30 percent of the total pollen counted. At least that much pine presently is found well beyond treeline in the arctic.

Between about 11,000 and 14,000 B.P., both pollen and plant macrofossils are dominated by spruce and sedge in Iowa (e.g. Baker et al., in press) and across much of the Midwest (e.g., Watts and Winter, 1966). Arctic macrofossils are limited to sites near the ice margin in Minnesota, and in southern Minnesota they are minor elements of a mainly boreal biota (Ashworth et al., 1981).

There are few sites dating from the 14,000 to 16,500 B.P. range, and the Fort Dodge site suggests that this was a period of transition. Although the Des Moines Lobe was advancing, the pollen and plant macrofossil record suggests that "arctic" conditions were no longer present, and that spruce was probably abundant on many upland sites. This transition may be a continental expression of the climatic and oceanographic changes seen in oceanic sediments and ice cores at about 14,500 B.P., resulting in the last major Heinrich event in the North Atlantic (Bond et al., 1992; Mayewski et al, 1994).

The contact between the Dows and Sheldon Creek Formations appears to be marked by surfaces with some plants in growth position. These suggest that the local landscape was a mosaic of small ponds, fens, other wetlands, and drier upland surfaces that were seldom flooded. The continued presence of arctic plant macrofossils may have depended on more local conditions of disturbance and perhaps cold microhabitats. These microhabitats may have been caused by cold air drainage down local lows, or by cooler conditions adjacent to meltwater streams.

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COMPOSITIONAL DIFFERENCES BETWEEN JURASSIC AND CRETACEOUS SANDSTONES OF WESTERN IOWA, WITH COMMENTS ON THE CONTROLLING FACTORS

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Introduction

As a long-time student of the bedrock geology of western Iowa, I recall being asked many years ago how one could distinguish between the then-putative Jurassic sandstones and conglomerates in the Fort Dodge area from Cretaceous sandstones and conglomerates that also occur in the same area. Given the lack of any systematic investigations of the compositional characters of these sandstone deposits, the question couldn't be answered with any sense of confidence. At first look, sandstone units in both rock intervals are interstratified with red-colored or red-mottled mudrock units suggesting paleosol formation in continental environments. What differences are there, if any, between these roughly similar deposits?

Continuing studies of the Mesozoic geology of western Iowa have gradually built a data set on the detrital modes of sandstone units in the Dakota and Fort Dodge formations, enabling a direct comparison and a definitive assessment of the compositional differences between these units. Ludvigson et al.(1987) and Witzke and Ludvigson (1994) showed that sandstones of the Dakota Formation are ultramature quartzarenites, representing an extreme end-member concentration of siliceous resistates.

Systematic investigations of the geology of the Fort Dodge Formation in the mid-1990s (summarized in Cody et al., 1996) led to development of a data set on detrital modes of sandstones in that unit (Ludvigson et al., 1996), providing opportunity for direct comparison to other deposits. These studies have shown that sandstones of the Fort Dodge Formation are calclithites that preserve a record of sediment eroded from Paleozoic carbonate bedrock terranes and other cratonic sources. The profound compositional differences between Jurassic and Cretaceous sandstone suites in the region provide an interesting topic for contrasting the tectonic, paleogeographic, and paleoclimatic settings of western Iowa during the time intervals in question.

Detrital Modes of Sandstones in the Jurassic Fort Dodge Formation

Standard ternary plots of the framework grain compositions of sandstones in the Jurassic Fort Dodge Formation show that these clastic sediments contained substantial proportions of lithic grains (Fig. 1a), especially in the units preserved beneath the bedded gypsum deposits. Also noteworthy is the trend toward an increase in the abundance of detrital feldspar grains as lithic grains decrease in abundance in sandstone units above the bedded gypsum.

A consideration of the sedimentary lithic grain types (Fig. 1b) shows a great predominance of sedimentary carbonate rock fragments over polycrystalline quartz (mostly microcrystalline chert grains) and siliciclastic shale/mudstone rock fragments. This is the case in all stratigraphic positions within the Fort Dodge Formation. These components are sufficiently abundant that the sandstones of the Fort Dodge Formation can be classified as calclithites. Larger carbonate rock grains in the conglomerate facies show that most were eroded from local Pennsylvanian and Mississippian strata, which is consistent with the general principle that soft carbonate rock grains do not survive the abrasion of long-distance sedimentary transport. While total quartzose grains become a volumetrically important component in the upper part of the Fort Dodge Formation (Fig. 1c), siliciclastic sedimentary rock fragments remain a very minor component througout. The presence of calclithite sandstones in the Jurassic Mistuskwia Beds of the Moose River Basin of northern Ontario (Norris, 1993) suggests that this compositional character might have been of widespread occurrence in Jurassic depositional systems of central North America.

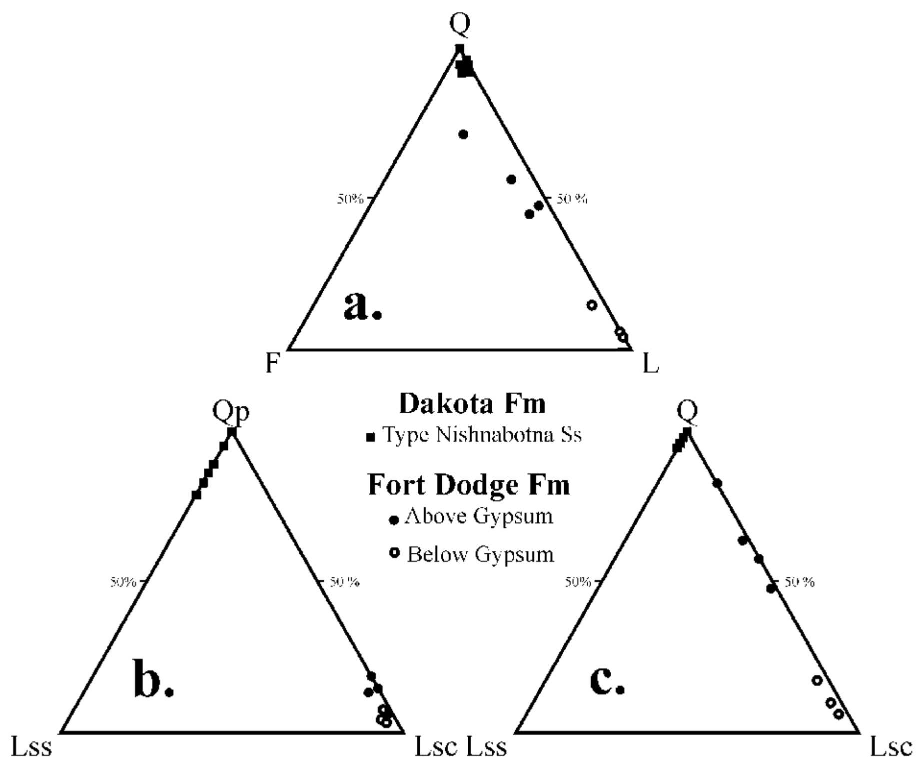

Figure 1. Ternary plots comparing the detrital modes of sandstones in the Jurassic Fort Dodge Formation and the Cretaceous Dakota Formation. **a.** QFL plot. **b.** QpLssLsc plot. **c.** QLssLsc plot. Grain parameters and plots are adapted from Ingersoll et al. (1987). Grain parameters are: Q, total quartzose grains; Qp, polycrystalline quartz; F, total feldspars; L, total lithic grains; Lss, sedimentary siliciclastic rock fragments; and Lsc, sedimentary carbonate rock fragments. Data from the type Nishnabotna Member of the Dakota Formation are from Witzke and Ludvigson (1994), and data from the Fort Dodge Formation are from Ludvigson et al. (1996).

Detrital Modes of Sandstones in the Cretaceous Dakota Formation

Standard ternary plots of the framework grain compositions of sandstones in the basal Nishnabotna Member of the Cretaceous Dakota Formation show that these clastic sediments are almost exclusively composed of monomineralic quartzose grains (Fig. 1a). A plot of sedimentary lithic grain types in sandstones of the Nishnabotna Member (Fig. 1b) shows that they are principally composed of polycrystalline quartz (mostly microcrystalline chert grains), indicating that carbonate rock terranes were a sustantial detrital source for these sediments. Tabulation of macrofossils contained in chert clasts from Dakota conglomerates in Guthrie County (Witzke and Ludvigson, 1996, p. 45-46.) showed that many of these clasts were eroded from lower Paleozoic bedrock terranes in the Upper Mississippi Valley region or yet even more distant sites, although local Pennsylvanian bedrock sources were also evident. Especially noteworthy is the fact that carbonate rock fragments, a major component in the Jurassic sandstones of the Fort Dodge Formation, are completely lacking in the Cretaceous sandstones of the Dakota Formation.

The other lithic component consists of siliciclastic mudstone intraclasts that are preserved as remnants of overbank fluvial mudstone deposits in the depositional system (Fig. 1b and 1c).

Tectonic Setting of Jurassic and Cretaceous Depositional Systems in Western Iowa

In order to appreciate the possible relevance of tectonic controls on the compositional variations of Mesozoic sandstones in western Iowa, a larger continental-scale perspective is needed. The Jurassic and Cretaceous history of North America is interwoven into the larger picture of the mid-Mesozoic breakup of the northern Pangean and southern Gondwanan supercontinents. Of special note is the rifting apart of North America and Africa that opened the central Atlantic Ocean basin (figs. 2 and 3). Along the western border of North America, convergent plate tectonic activity resulted in a rising Cordillera, and crustal thickening in this mountain belt caused isostatic subsidence of the continental foreland area inboard (just to the east) from the mountain belt. This actively subsiding Mesozoic foreland basin was flooded by epeiric seas during the sea-level highstands of the Jurassic (Fig. 2) and Cretaceous (Fig. 3), respectively.

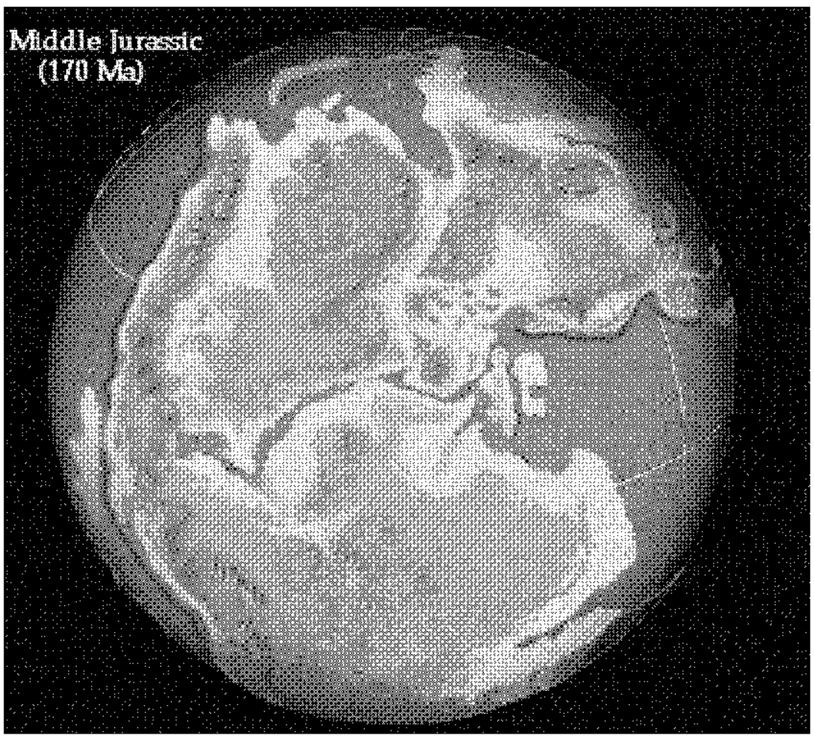

Figure 2. Paleogeographic global reconstruction for the Middle Jurassic (170 Ma) from Blakey (1999; used by permission). Note the initial rifting apart of North America (upper left) from Africa (lower right). Mountain-building activity along the western coast of North America resulted in subsidence of the Western Interior Foreland Basin to the east, subsequently flooded by a shallow epeiric sea (light tone).

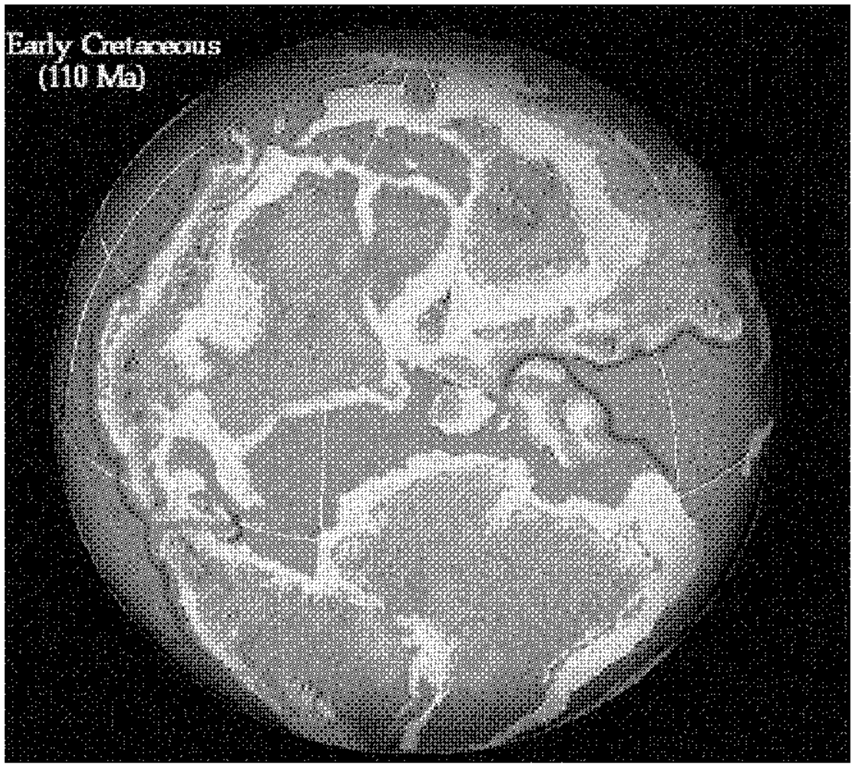

Figure 3. Paleogeographic global reconstruction for the Early Cretaceous (110 Ma) from Blakey (1999; used by permission). Note the opening of the central Atlantic Ocean basin by sea-floor spreading along the site of rifting between North America (upper left) and Africa (lower right). Also note the flooding of the North American Western Interior Foreland Basin by a shallow epeiric sea (light tone).

The Jurassic and Cretaceous sedimentary rocks of the central United States represent the far eastern erosional limits of a once-continuous sedimentary cover in the Western Interior Foreland Basin. These Mesozoic strata accumulated on the cratonic, or tectonically inactive side of the foreland basin, in the area of the stable continental interior. The net accumulation and preservation of these rock strata do attest to limited tectonic subsidence in the more distal portion of the basin, and thus indicates that the region was part of a large, westward-sloping continental surface during deposition. This westward-sloping continental surface extended from the far eastern reaches of the basin all the way into the deep, more rapidly subsiding north-south trending basin axis just to the east of the rising Cordillera. The regional transport of fluvial sediment, including most of the sandstone units currently under consideration, was governed by this gently sloping continental surface.

Importantly, these considerations dictate that compositional variations between the Jurassic and Cretaceous sandstones in western Iowa were not related to any major change in the regional tectonic setting. Both suites show evidence of sedimentary recycling of older cratonic, particularly sedimentary carbonate rocks, but the products of these two episodes of sedimentary cycling are remarkably different. What other factors came into play?

Evolution of Major Mesozoic Erosion Surfaces in Western Iowa

While the overall tectonic setting of western Iowa appears to have been relatively stable throughout the Mesozoic, there are apparent differences in the relief and configurations of erosion surfaces that were buried by Jurassic and Cretaceous strata. The total surface area still buried by the sub-Jurassic unconformity in Webster County is relatively small, but within that area, a total relief of only a few tens of feet is evident. This is far smaller than the magnitude of several hundred feet of relief known on the sub-Cretaceous unconformity elsewhere in western Iowa. Witzke and Ludvigson (1994, p. 58) presented a transverse cross section across a major paleovalley in the sub-Cretaceous unconformity that was subsequently filled by the Nishnabotna Member of the Dakota Formation. Nishnabotna sandstones filling this paleovalley are characteristic of the "northwest petrofacies" (Witzke and Ludvigson, 1994, p. 61-63) of first-cycle quartzarenites that probably were eroded from thick Cretaceous lateritic weathering profiles on the Precambrian basement surface of Minnesota, in the headwaters area of the paleovalley.

Witzke and Ludvigson (1994, p. 61-63) also noted a "southwest petrofacies" in the Nishnabotna Member that is characteristic of exposed sections in Guthrie County and the type sections in the Nishnabotna River Valley in western Iowa. This sandstone suite contains a major component of Paleozoic chert from provenance areas far to the east-northeast. The presence of estuarine facies in the more distal reaches of this sandstone interval (Witzke et al., 1996) suggests that the "southwest petrofacies" also accumulated in a major paleovalley on the sub-Cretaceous unconformity, one that was flooded by rising sea-levels during the initial regional Cretaceous aggradation in the Late Albian.

The drainage divide between the two paleovalleys filled by the "northwest petrofacies" and "southwest petrofacies" was shown in the cross section of Witzke and Ludvigson (1994, p. 58) as a cuesta of southeastward dipping Devonian and Mississippian carbonate strata in north-central Iowa. The Jurassic outlier of the Fort Dodge Formation is located astride the summit elevations of this cuesta where it has been exhumed from beneath the erosional edge of the Cretaceous Dakota Formation. This relationship logically leads to the suggestion that the Fort Dodge Formation was preserved as an erosional remnant on the interfluve between two major paleovalleys on the sub-Cretaceous unconformity, a concept that is schematically illustrated elsewhere in this guidebook (see page 26 of this volume). This interpretation also suggests that a major base level drop and episode of fluvial incision occurred between the deposition of Late Jurassic and Early Cretaceous strata. A similar relationship has been recognized in western Saskatchewan, where latest Jurassic deposits are preserved on interfluves between major paleovalleys on the sub-Cretaceous unconformity, all of which was buried by Aptian-Albian strata (Leckie et al., 1997).

Changes in Paleoclimate

The plate tectonic changes attending the breakup of the Pangean and Gondwanan supercontinents in the mid-Mesozoic (figs. 2 and 3) had major consequences for paleoclimatic regimes in North America. Irving et al. (1993) showed that during the Late Jurassic-Early Cretaceous interval, the area of Saskatoon, Saskatchewan drifted northward by about 30 degrees of paleolatitude. Some of this drift resulted from a clockwise sense of rotation that carried western portions of North America even farther to the north. An interpolation from the modern coordinates for the Fort Dodge area (42.5 °N, 95 °W), using the maps of Scotese (1991) indicates that between the deposition of the Jurassic Fort Dodge Formation and the Cretaceous Dakota Formation, western Iowa drifted northward by about 15 degrees of paleolatitude (Fig. 4).

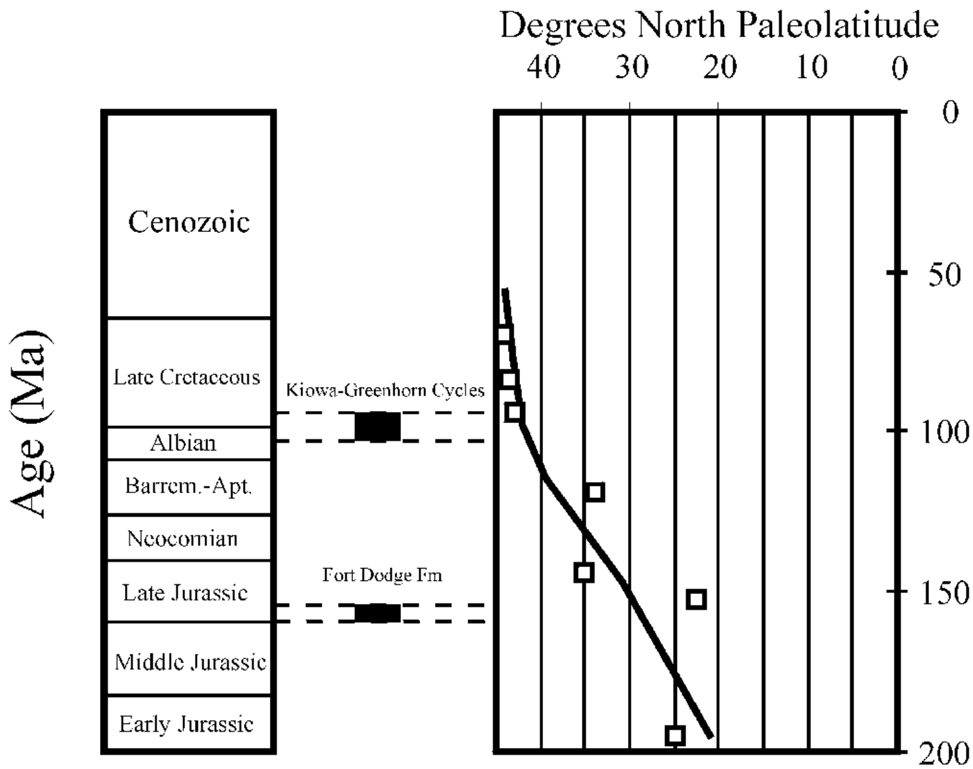

Figure 4. Changes in the paleolatitudes of the Fort Dodge area during the Jurassic-Cretaceous interval, based on maps published by Scotese (1991). About 15 degrees of northward drift is indicated for the time interval spanning from deposition of the Fort Dodge Formation (160 Ma) to deposition of the Dakota Formation (100 Ma).

This northward drift transported the western Iowa area from a position in dry belt latitudes less than 30º north of the equator to a position located in humid temperate climates greater than 40º north of the equator (Fig. 5).

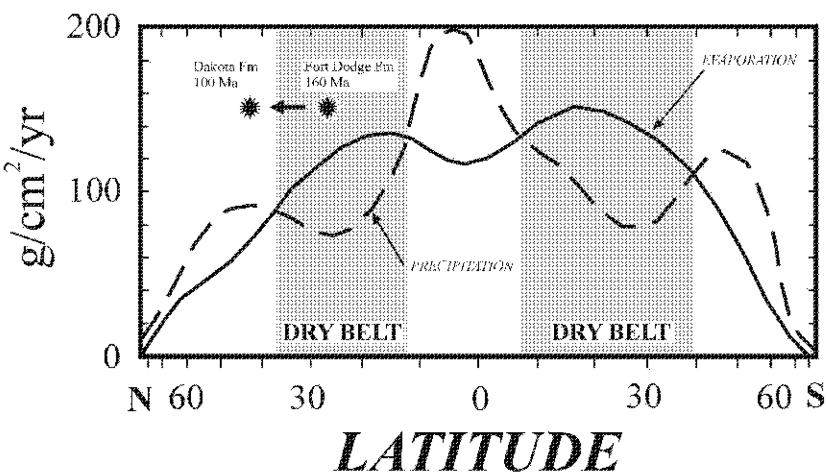

Figure 5. Zonally averaged precipitation and evaporation with respect to latitude (after Barron and Moore, 1994, p. 20), showing the northward drift of western Iowa from a Jurassic location with a net rainfall-evaporation deficit during deposition of the Fort Dodge Formation, into a Cretaceous location with a net rainfall-evaporation surplus during deposition of the Dakota Formation.

The deposition of Jurassic bedded gypsum evaporite deposits, preservation of crystallotopic halite casts, and presence of authigenic doubly-terminated quartz crystals in mudrocks described from the Fort Dodge Formation elsewhere in this guidebook all provide independent empirical evidence that the unit was deposited in an area of net rainfall deficit. The xeric Jurassic landscapes indicated from these observations would not be expected to experience high rates of chemical weathering or leaching of local carbonate bedrock terranes, and the deposition of calclithite sandstones is entirely consistent with all other data.

In contrast, independent empirical sedimentologic evidence (Witzke and Ludvigson, 1994) and climate model simulations (Slingerland et al., 1996) indicate that mid-Cretaceous paleoenvironments of the western Iowa area were located in an area of net rainfall surplus. Moreover, increased rates of global ocean crust production during the mid-Cretaceous are believed to have led to elevated concentrations of volcanically-derived CO_2 in the Earth's atmosphere, and resulted in an episode of global greenhouse warming (Caldeira and Rampino, 1991). Increased atmospheric moisture transport in this mid-Cretaceous "Greenhouse World" has been proposed to have resulted in a 28 % increase in globally-averaged precipitation over that of current levels, based on climate model simulations (Barron et al., 1989). Independent global marine phosphorus burial data suggests that the mid-Cretaceous, especially at about 100 Ma, was a time of greatly accelerated continental weathering (Fölmi, 1995). These works collectively lead to the expectation that the sediment source areas for the Albian Nishnabotna Member sandstones were subjected to intense chemical weathering in very humid subtropical paleoenvironments. The interpreted intense chemical leaching of these terrestrial landscapes is entirely consistent with the observed complete absence of any carbonate lithic detritus, despite the abundant evidence for erosion from carbonate bedrock terranes in the form of chert clasts.

Conclusions

Sandstones of the Jurassic Fort Dodge Formation in Webster County, Iowa are calclithites that contain abundant and well-preserved lithic detritus eroded from local Paleozoic carbonate bedrock terranes. Pennsylvanian and Mississippian bedrock lithoclasts in these sandstones resemble local bedrock units, and could not have survived the abrasion of long-distance fluvial transport. These sandstones probably accumulated in both ephemeral streams and related shallow paludal settings in xeric terrestrial paleoenviroments.

Sandstones of the basal Nishnabotna Member of the Cretaceous Dakota Formation are quartzarenites that contain abundant chert grains indicating erosion from Paleozoic carbonate bedrock terranes, but are completely lacking in carbonate lithic detritus. These sandstones probably accumulated in large stream systems draining intensely-leached terrestrial environments that received abundant precipitation.

Acknowledgments

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GYPSUM MINING IN THE AREA OF FORT DODGE, IOWA

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Introduction

The Fort Dodge area is one of the leading gypsum producing regions in the United States. About 1.5 million metric tons of gypsum (with a raw value of $10 million) was mined and processed in the area in 1994 by four companies: United States Gypsum Corporation, National Gypsum Company, Georgia-Pacific Corporation, and the Celotex Corporation. This production accounts for about 75% of the total gypsum mined in Iowa, making Iowa second only to Oklahoma among the states in annual gypsum production. Most (over 70%) of the gypsum mined in the United States (and in the Fort Dodge area) today is used to produce plaster of Paris, primarily for production of wallboard (drywall). Most of the rest of the gypsum (18%) is used as a retarder to slow the setting of portland cement. Gypsum is also used as plaster, soil conditioner, inert filler in pharmaceuticals and foods, and a small amount is carved into ornaments and sculptures (including the Cardiff Giant).

The history of gypsum production in the Fort Dodge area was most recently summarized by McKay (1985). He reported that gypsum had been utilized by people in the Fort Dodge area since the 1850s. The gypsum occurrence was first reported in the geologic literature by geologist David Dale Owen (1852, p.98) who reported exposures along the Des Moines River, and estimated that 190 million tons of gypsum was present, a "supply (that) may be considered as almost inexhaustible.". Keyes (1893) described the gypsum beds at Fort Dodge as "by far the most important bed of plaster-stone known west of the Appalachian chain, if not in the United States." At first Fort Dodge residents used gypsum only for building stones which they "preferred to the limestone of good quality" that also existed in the area (White, 1870). The building stone was quarried from the first known gypsum quarry in the area, the Cummins Quarry.

In 1872 Captain George Ringland, Web Vincent, and Stillman T. Meservey built the Fort Dodge Plaster Mill, first gypsum mill in the area, to grind gypsum for commercial products. The success of this mill led to the construction of others, and by 1902 seven mills were operating in the area, producing a variety of products including building blocks, mortar, plaster, roofing, and flooring products.

The original quarrying operations soon gave way to underground mining, Although most of the underground mine areas have subsequently been stripped and the remainder of the gypsum removed, some areas south of Fort Dodge are still undermined. Collapse in these mined areas, with only a few feet of gypsum left as a roof beneath the glacial drift, is not uncommon. In some places the landscape takes on the appearance of a karst terrain. Today all mining is done by open pit operations, using a variety of equipment to strip off the glacial till, blasting the gypsum, and hauling it to the mills.

The four gypsum-producing companies that currently operate in the Fort Dodge area run their mills 24 hours a day and most of the quarries run two shifts seven days a week. The gypsum resource at Fort Dodge is extremely limited, existing as a small outlier of about 20 km^2, and completely isolated from other Late Jurassic deposits by several hundred kilometers. Gypsum reserves are sufficient for about 30 years at the current rate of extraction for some of the companies, others have only minimal reserves that will be depleted in a few years.

Early Uses of Gypsum

The earliest mining of gypsum in the Fort Dodge area was for building stone. There is no record of the date of first use, but it was certainly before 1868 since an early lithograph (Fig. 1) from White (1870) depicts an 1868 quarry located on Two Mile Creek (now Gypsum Creek) and mentions Cummin's quarry which was operating in 1870 on Soldier Creek in sec. 17, T89W, R28W, considerably north of the city limits at that date. The stone being soft, easily mined, and exposed in creek valleys was used in place of limestone for both exterior and interior use (Fig. 2). According to McGee (1884) it was extensively used twenty or so years earlier. Well-known gypsum structures included an arched culvert over Two-Mile Creek (Gypsum Creek) on the Illinois Central railroad and the depot building for the company. Both were built in the 1860's. McGee (1884) observed in 1880 that the culvert was in good condition, and the depot building appeared to be in good condition in 1883. He noted, however, that gypsum was poorly suited for foundations because of its solubility, and foundation failures were common. By the 1880's gypsum building stone was rarely used because of its poor reputation for durability. Gypsum block can still be found in basement walls of older homes and in a few small old retaining walls, but none of the buildings with exterior gypsum block walls are still standing.

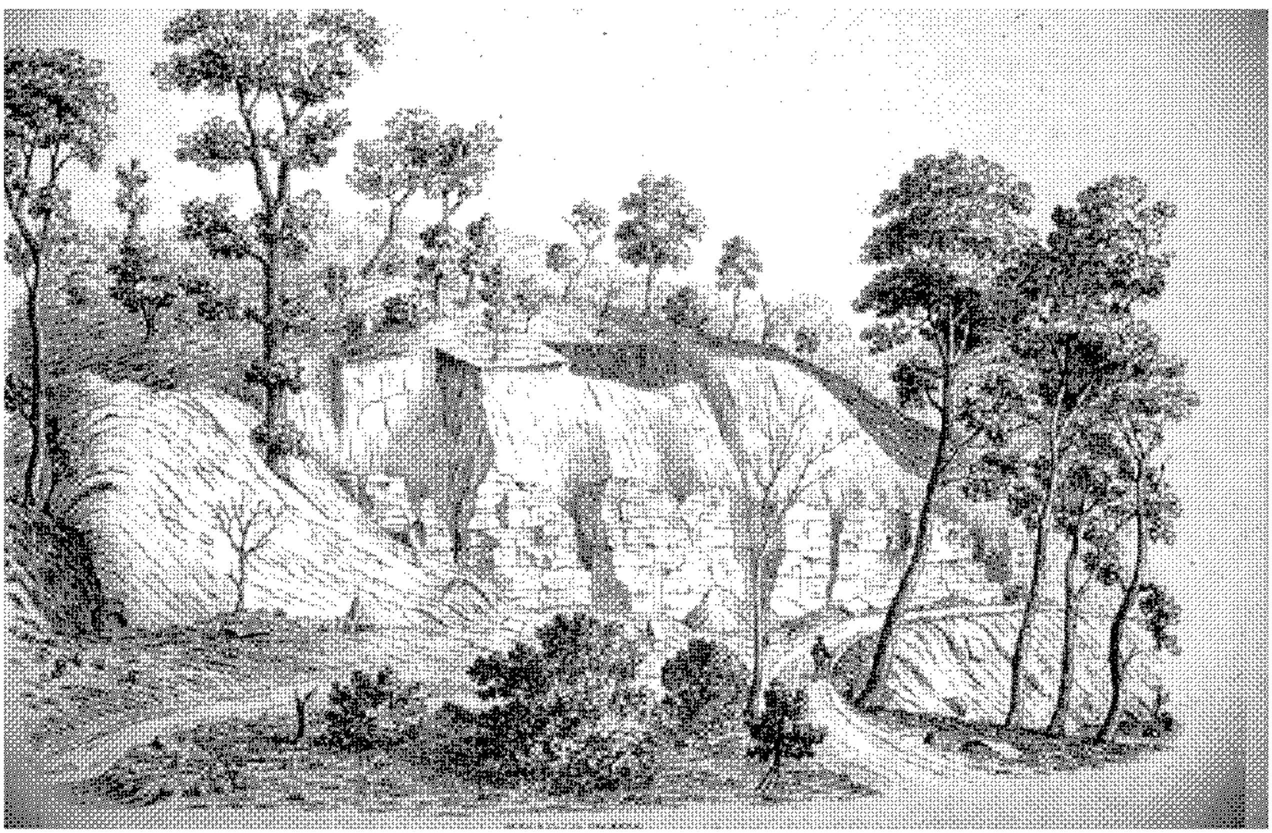

Figure 1. Sketch of one of the quarries that was operating along Two Mile Creek (now Gypsum Creek) in 1868. From White (1870, facing p. 297).

Plaster Industry

The first calcining mill in the United States began in 1835 on Staten Island in New Brighton, New York. By the late 1860's investors saw the potential of the Fort Dodge gypsum for plaster of Paris, and three wealthy local businessmen formed a partnership, and in May, 1872 started work on the first commercial gypsum mill, the Fort Dodge Plaster Mills. It was located in sec. 33, T89N, R28W overlooking Gypsum Hollow and began operations in October 1872. Later in 1873, the name of the plant was changed to the Cardiff Mills (Roddenborn 1972), presumably from the fact that the block used for the Cardiff Giant came from the vicinity. This mill has the distinction of being the first gypsum calcining plant west of the Mississippi River. In 1881 the original partnership was dissolved and a new one, the Iowa Plaster Company, was formed. This company, and later ones usually owned quarries or underground mines to supply gypsum to their calcining plants. In the following years a complex series of new companies and mergers formed, and by 1972 a total of at least 30 different business entities related to gypsum mining had existed in the Fort Dodge area during the first one hundred years (Rodenborn, 1972).

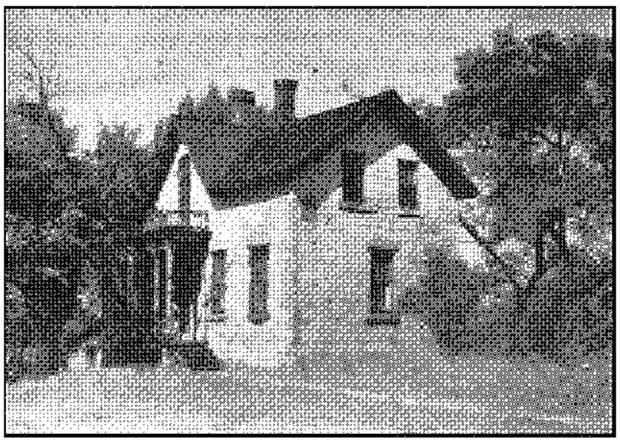

Figure 2. House in the Fort Dodge area constructed of gypsum blocks. All such houses have either been destroyed or the gypsum blocks have been covered with siding. No information is available about when the house was built. Picture originally published in Wilder (1923, p. 201).

Because of easy access to gypsum all of the initial gypsum material was taken from quarries, most of which were located near Gypsum Creek or along the Des Moines River. Later, underground mines were often used because most of the gypsum occurred away from river valleys. In these areas gypsum was covered by 20 meters or more of glacial till which at the time was considered too deep for stripping. Apparently the cost of underground mining was competitive with stripping at this time. According to Rodenborn (1972), the first underground mine was opened in 1896 by the Cardiff Gypsum Plaster Company, the fifth milling company in the area. The Fort Dodge Plaster Company opened the Crawford Mine in 1893 (Fig. 3), and the Iowa Hard Plaster Company started an underground mine in 1906. Certain-Teed Corporation, which began operations in Fort Dodge in 1923, operated an underground mine until 1945 when three miners died in a severe underground accident. This led to permanent closing of the mine. In these mines the room and pillar method was employed after sinking a shaft to within a few feet of the gypsum base. The underlying material was left as mine floor and enough gypsum was left in the ceiling for roof support. After the mine had nearly exhausted all the rock on company property, the floor, walls, pillars, and ceiling were removed, as far as possible. The unsupported roof of these mines was highly unstable and eventually most of the mines collapsed, with the location of the mines marked by sinkholes. One such collapse occurred near the entrance to the USG Corporation wallboard plant, and several other sinkholes will be visible during the field trip.

After 1900, large out-of-state corporations became interested in the Fort Dodge gypsum. The most successful of these companies was the United States Gypsum Company, later to become a subsidiary of USG Corporation, which was incorporated in New Jersey in 1901 with the purpose of merging or otherwise consolidating the gypsum plaster industry. Several local companies merged with it in 1902 and subsequent years. In 1902 USG acquired the plant and land of a local company, the Mineral City Plaster Company, and commenced operations. In September 1907 the Sackett Plaster Board Company of New York began mining and producing plaster and plaster board near the city. The Sackett plaster board was the first plaster board manufactured in Fort Dodge, and resembled modern wallboard but contained six cores of gypsum separated by seven paper layers compared to the single core and inner and outer paper layers of modern board. After being pressed between rollers, the Sackett board was 5/16" thick. It was used in place of wood lath as a base for application of conventional gypsum plaster, and it differs from modern wallboard which eliminates plastering. Sackett was a relatively large company with plants in Grand Rapids, Michigan, and Rochester, New York. It was purchased by USG in 1913. Prior to its purchase, the USG had supplied calcined gypsum to the Sackett plaster board plant in Fort Dodge (Rodenborn 1972).

By 1923 six companies operated mills in the area. Listed in order in which they began operations, they were The Cardiff Gypsum Plaster Company, United States Gypsum Company, Universal Gypsum Company, American Cement Plaster Company, Wasem Plaster Company, and the Iowana Plaster Company (Wilder, 1923). Of these companies, only United States Gypsum is still in operation.

Figure 3. Photograph underground in the mine of the Fort Dodge Plaster Company, C.C. 1900 (from Rodenborn, 1971, p. 69).

By 1972, only four companies were operating quarries and mills (Rodenborn, 1972). They were USG, National Gypsum, Georgia Pacific, and Celotex. USG Corporation, with its main office in Chicago, is by far the largest operator in Fort Dodge. Georgia Pacific Corporation was incorporated in Georgia in 1927 and became involved in plaster production when it merged with Bestwall Gypsum Company in 1965. Bestwall had previously bought all the gypsum operations of Certain-Teed Corporation in 1956. Celotex was incorporated in Delaware in 1935 after reorganization of the company which first began in Louisiana in 1920. It began gypsum operations after buying part of the American Gypsum Company of Ohio, and in 1950 purchased the Wasem Plaster Company in Fort Dodge. Celotex, in turn, was purchased by Jim Walter Corp., a private company based in Florida. National Gypsum Company, incorporated in Delaware in 1924, and began Fort Dodge operations in 1935 when it purchased the assets of another company. The current mill and plaster board plant was built in 1956. National, in turn, was purchased in September 1995 by Delcor, Inc., an investment concern controlled by a former chairman of the company. In 1995 the same four companies as in 1972 were still located in Fort Dodge, although under different ownership (with the exception of USG).

Gypsum Production

The gypsum industry in Fort Dodge is an excellent example of current trends in gypsum production in the United States. During the early days of production, numerous small local companies started, with later consolidation taking place as more successful companies merged or purchased less successful or wealthy ones. At the current time, a few companies are predominant and most are involved in both mining gypsum and producing gypsum products. According to Stone and Jakacki (1989) there are 10 major companies in the United States that produce wallboard and plaster systems, but 5 of these mined 80% of the total crude gypsum and 6 produced over 85% of calcined products (McKetta, 1987). Raw material is generally obtained from captive mines/quarries closely associated with calcining plants, but plants on the east coast often import gypsum from Canada and those of the west coast from Mexico. In 1986, USG operated 12 mines and 22 calcining plants; National gypsum, 7 mines and 18 plants; Georgia-Pacific, 6 mines and 9 plants; Celotex, 3 mines and 4 plants.

Fort Dodge gypsum meets all requirements for an ideal source. It is exceptionally pure, is located close to markets including Minneapolis, Omaha, and Kansas City, and can be mined by inexpensive stripping. Consequently it has been a significant source in the United States since 1900. Table 1 presents data on production from 1905 through 1990. In all years after about 1900 Iowa was either second or third in U. S. gypsum production, and most of that gypsum came from the Fort Dodge area. Generally Iowa gypsum constituted about 12% - 13% of U. S. production. Although the nominal values of gypsum produced in Iowa were highest in 1980 and 1990 (Table 1), when corrected for inflation 1960 was the best year. The 1990 inflation-correction production value of crude gypsum was less than that in 1925.

Table 1. Production of Iowa Gypsum*

Date	Iowa Production, 10^3 metric tons	Value 10^3 $	Value, in 1990 $***	% of US Production
1905	179	344	4,813	18
1910	323	436	5,668	15
1915	496	486	4,433	22
1920	572	2,236	13,818	20
1925	800	2,174**	15,348	14
1930	322	437	3,240	13
1934	180	276	2,558	12
1940	487	587	5,183	13
1950	982	2,507	12,011	12
1960	1,283	5,428	22,743	13
1970	1,136	4,223	13,471	9
1980	1,486	13,136	19,704	12
1990	2,192	14,243	14,243	13

* Data from Minerals Yearbook, for each year.

** Values prior to 1935 in Mineral Yearbooks included both calcined and uncalcined gypsum, whereas those after that date are for crude gypsum before calcining. An attempt was made to correct for this change by assuming all produced gypsum had the value of uncalcined ground agricultural gypsum, but this approach may not be very accurate.

*** Corrections for inflation used the composite consumer price index data from Derks, 1994. Inflation for commodities will be slightly different than given by the CPI.

The future of gypsum mining in Iowa is probably good because of the abundance of subsurface Mississippian gypsum in southern Iowa, although the cost of locating and mining this gypsum must be evaluated. Gypsum produced during flue gas desulfurization may create severe competition in the future. Unless new deposits are located, gypsum mining in Fort Dodge is limited to less than about 30 years for USG and probably even less for the other three companies that have less reserves.

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USES OF GYPSUM IN TODAY'S SOCIETY

exurpted from

MODERN AND ANCIENT USES OF GYPSUM

Geology of the Fort Dodge Formation, Webster County, Iowa

IDNR Geological Survey Bureau Guidebook Series No. 19

by

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INTRODUCTION

Much practical understanding of the use of gypsum for construction and other purposes was achieved early in the history of civilization as discussed in the second section of this paper, but very little scientific knowledge was achieved until the middle 16th century. In his first scientific publication, Lavoisier (1768) determined gypsum solubility, the presence of water of crystallization, and confirmed that heating gypsum to very high temperatures prevents plaster hardening (Wilder, 1923). In 1883, Le Chatelier published a notable research study of gypsum and plaster from Paris. When heating gypsum in an oil bath and observing two temperature halts at $\approx$ 128 ºC and at $\approx$ 165 ºC during heating of gypsum, he concluded that gypsum dehydrated in two stages, with most of its water lost at the lower temperature and the remainder at the higher temperature. These values compare well with those obtained by modern methods. He also accurately determined the amount of water in the hemihydrate. Since then there have been an immense number of studies of all aspects of gypsum, including its crystallography, dehydration behavior, geology, product technologies, and current and past uses.

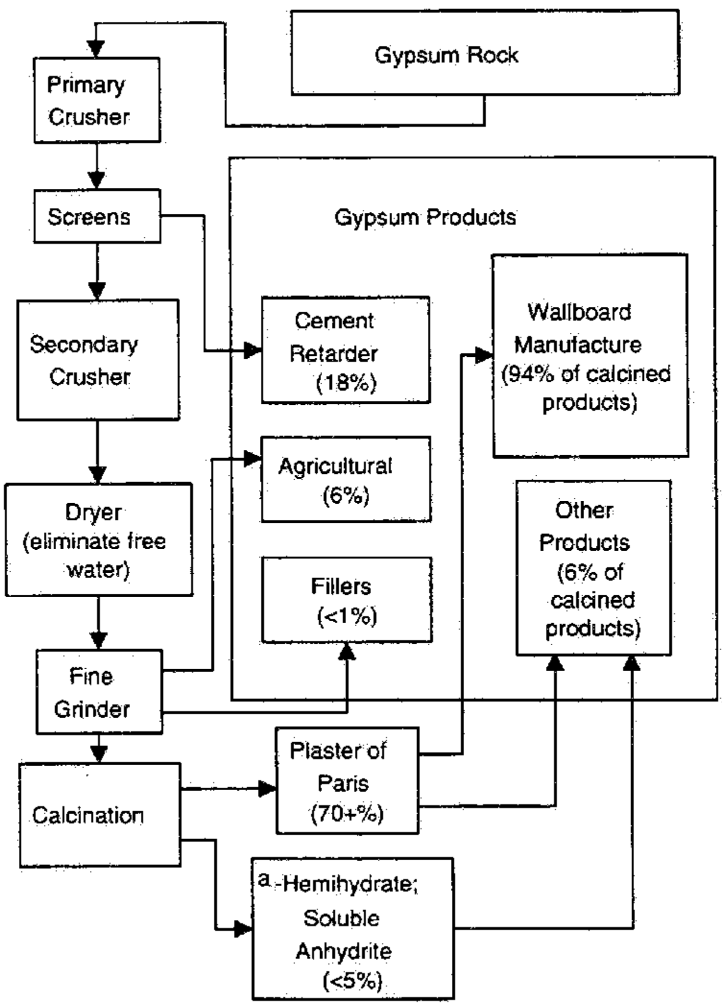
Today, the largest use of gypsum is based on its property of giving up, or taking on, water of crystallization. Over 70% of the gypsum mined in the United States is to manufacture plaster of Paris manufacture, with most of this material used in wallboard (drywall) manufacture. Another 18% of mined gypsum is used as a retarder to slow the setting of portland cement (concrete), with 4% to 6% by weight of gypsum being mixed with the cement to provide sufficient time for working the concrete. Five to six percent of mined gypsum is powdered and used as a soil conditioner, a minor amount is used as an inert filler in pharmaceuticals and foods (Appleyard, 1983b), and a small quantity of alabaster is carved into ornaments and sculptures. In Europe where masonry construction is more common than in the United States, a relatively large portion of gypsum is used in hand and machine applied wall coatings or plasters.

Plaster of Paris

The material used for plaster is called plaster of Paris (the name being derived from the occurrence of large gypsum deposits in the Montmartre district of Paris, France), or gypsum plaster if there is any possibility of confusing it with other types of plaster. Rock gypsum is ground and heated to relatively low temperatures, between about 110 ºC and 165 ºC where gypsum loses one and one-half of its two water of hydration molecules and forms the mineral, bassanite, also referred to as hemihydrate or more precisely β-hemihydrate. When water is added to the hemihydrate, it rapidly dissolves and elongate gypsum crystals slowly form (Montgomery, 1987). Hardness of the set plaster results from the interlocking character of the newly formed needle-shaped gypsum crystals. The initially-set plaster contains an excess of water and is damp. Evaporation of water from the damp material, however, has nothing to do with setting of gypsum plaster.

Wallboard

Plaster wallboard or *drywall* was invented in the United States about 1890 and became widely used in the construction industry after WW II. It has almost entirely taken the place of applied plaster in construction because of its versatility, fire-retarding properties, and rapid installation with greatly reduced the labor costs. When wallboard is exposed to fire or extreme heat, the gypum loses water and changes back to the hemihydrate releasing steam that provides a natural fire damper. Many building codes recognize the value of gypsum wallboard and require its use between potential fire hazards and apartments or other living spaces.



Modified from McKetta, 1987; Wenk & Henkels, 1978

Figure 1. Flow diegram for gypsum production and use.

The modern industrial mining and manufacture of gypsum products follows the flow-chart sequence shown in Figure 1. The basic wallboard processing methods involve (1) rock preparation, (2) calcining or heating to cause partial dehydration, and (3) processing into wallboard (Appleyard, 1983a). Rock preparation chiefly involves crushing, grinding and sieving, and drying to remove excess water. Beneficiation methods may be required at some locations because of excess contamination by quartz, limestone, or anhydrite. To keep costs low, however, beneficiation is avoided unless absolutely necessary for very high-grade products. Most gypsum such as that at Fort Dodge does not require beneficiation.

Calcining is the industrial term for the dehydration of gypsum to hemihydrate or to other partially or completely dehydrated calcium sulfate phases. It is performed in vessels called kettles, of which there are many designs. Both batch and continuous kettles are used. In a batch operation, ground gypsum, of -100 mesh (<.15 mm), designated as land plaster (any type of ground and uncalcined gypsum is land plaster, regardless of use) is introduced into the top of the kettle, heated and stirred, and the calcined material is dumped by gravity into a holding bin called the hot pit. About 2-3 hours are required from filling to dumping of a batch kettle. The kettle at USG Corporation in Fort Dodge is a continuous type and requires about 1 hour retention time (Hollender, USG Corp., pers. comm. 1996). Temperatures in the calcining kettle must be closely controlled in order to obtain the proper degree of dehydration. Figure 3 shows a schematic temperature/time curve for the kettle during a batch operation. In the figure, point A is the introduction point of land plaster. Introduction of cold gypsum causes the temperature to drop to about 75 ºC and then to rise. At about 43 ºC gypsum begings to dehydrate, and the kettle temperature is kept at 104 ºC during this first dehydration. As the temperature rises, the gypsum passes through an interval known as 'first boil', between 116 ºC -121 ºC, where the gypsum mass appears to boil because of released steam. After boiling ceases, the material consists chiefly of β-hemihydrate together with small amounts of α-hemihydrate, soluble anhydrite, and undehydrated gypsum. The latter three phases are present because conditions are not precisely the same in different parts of the kettle. This stage is referred to as first settle because the solid phases settle to the bottom of the heating vessel when boiling no longer helps keep them in suspension. The kettle temperature is then increased to 150 ºC -166 ºC at which point the solids are dumped. The volume of solid material at this point is about 15% less than the original volume. After dumping, the cycle may be started over.

Dumping is omitted if further dehydration is required to produce soluble anhydrite (Anhydrite III). The kettle is will continue to heat to about 177 ºC when a second boil occurs until hemihydrate is completely dehydrated, at which a second settle occurs. Heating is continued to about 204 ºC after which Anhydrite III is dumped (Appleyard, 1983a; Wenk and Henkels, 1978).

Wallboard is manufactured by pouring a water slurry of β-hemihydrate (referred to as stucco in the wallboard industry) onto a continuous strip of special paper with turned-up edges forming a broad, shallow, trough. The hemihydrate rapidly reacts with water in the slurry to produce tiny, needle-shaped gypsum crystals, and these crystal grow and interlock with each other to form a rigid sheet. The solidifying gypsum layer is covered with another paper layer, and rollers and other guides insure the proper width and thickness of the paper/plaster sandwich. Bonding of the newly-formed gypsum layer to the top and bottom paper occurs because gypsum crystals penetrate into and interlock with the porous paper fibers (Appleyard, 1983a). The soldified wallboard is then heated to remove excess moisture but without dehydrating the newly formed gypsum. Finally it is cut into proper lengths and stacked for delivery.

One of the early problems with wallboard manufacture was that plaster set too slowly for efficient industrial production. This problem was solved by the addition of certain chemicals that accelerate setting. Accelerators such as powdered gypsum or potassium sulfate when added to the initial stucco/water slurry reduce setting time from ≈ 30 minutes to ≈ 5 minutes. Other additives such as foaming agents are usually added to increase operational efficiency by reducing the amount of water required to produce a rapidly flowing slurry. The time required to manufacture a single piece of wallboard, from initial pouring of the stucco slurry to final drying generally is less than about 10 minutes. Special types of wallboard may be manufactured using a wide variety of additives and/or coatings.

As in so many industries wallboard has become a significant problem in groundwater contamination. Nearly 30 million tons of wallboard are manufactured in North America each year, but about 3% to 5% of wallboard is wasted during construction because trimming and breakage of sheets. According to Musick (1992) about one pound of wallboard scrap will be created for each square foot of house floor area, so that about one ton of waste wallboard is generated for each home built. This large volume of waste wallboard is buried in landfills, and plays an important part in the tremendous volume of waste material that is rapidly exhausting the landfill capacity in highly urbanized regions. Although the gypsum wallboard material itself is harmless, after burial the sulfate may be reduced to sulfide gas which is both noxious and toxic. Decay of wallboard paper and binders also may accelerate the reduction of sulfate to sulfide. The problem has not passed unnoticed by municipalities. For example, as a result of major groundwater contamination problems in British Columbia, in 1984, Vancouver banned all waste gypsum wallboard from municipal landfills. This ban has stimulated efforts to recycle waste wallboard into new wallboard manufacture, and some observers believe that recycled gypsum will soon become a signficant part of new wallboard.

Other Dehydrated Gypsum Products

In the late 19th and early 20th century, calcined gypsum was largely used in plasterwork and related uses (Wilder, 1923) that were similar to its uses in antiquity. Extensive practical experimentation, led to greater diversity of use and materials. One was the development of denser plaster products produced by calcining gypsum to much higher temperatures than required for producing plaster of Paris. Normal gypsum plaster has up to 45% porosity. This relatively low density material is ideal for wallboard because the relatively lightweight sheets can be handled more easily that those composed of heavier, denser material. Low density material also reduces the cost of raw materials. However, low density gypsum plaster is not suitable for high wear area such flooring because it abrades easily. It was discovered that high temperature calcining, between about 900 ºC and 1400 ºC, produces a material that forms very dense gypsum plaster. The high-calcined material is known as hydraulic gypsum, or Estrich gypsum in Germany (Appleyard, 1983a). High temperatures produce complete dehydration of gypsum with the formation of insoluble anhydrite (Anhydrite II). Some of the sulfur is also expelled so that the product contains both insoluble anhydrite and quicklime, CaO. Addition of water to this calcined material causes slow rehydration to gypsum with setting taking several days. Further hardening develops over several weeks as the lime slowly reacts with air to form calcite crystals. $Ca(OH)_2$ which forms from CaO on addition of water to the dry material acts as an accelerator to promote hydration to gypsum (Wirsching, 1985; Kawiak, 1991), although other accelerators such as potassium sulfate, aluminum sulfate, or borax may also be added to increase hydration rates. Without an accelerator, hydration of Anhydrite II is extremely slow and will take many years in a damp environment to develop. Insoluble anhydrite was found persisting in mortar of a 12th century church in Poland. Change from insoluble anhydrite to gypsum does not involve an intermediate hemihydrate stage (Wirsching, 1985). The product requires tamping of the almost hardened paste so that there is a significant reduction of intial porosity. Because setting does not involve the growth of needle-like crystals, tamping does not damage further setting as it would for normal gypsum plaster. Tamping facilitates development of hard setting by bringing newly-formed gypsum crystals into close contact with each other so that their continued growth results in an interlocking texture. The texture of hardened hydraulic gypsum is much different than that of traditional low-temperature calcined gypsum plaster, in that hydraulic gypsum is composed of almost equant gypsum/calcite crystals with an interlocking texture compared to the porous intergrown elongate crystals of set plaster of Paris. Unlike set plaster of Paris, hardened hydraulic gypsum is relatively resistant to damage by short-term exposure to water. Hydraulic plaster is not widely used in the United States, but normal β-hemihydrate plaster is used as flooring in commercial building in the United States as long as it is covered with carpet, tile, or other material. Hydraulic plaster was widely and successfully used for flooring and other purposes in Germany during the early 20^{th} century, and is still used there for a variety of purposes. It is commonly used in Europe for gallery and roof supports in subsurface mines where a relatively hard and dense material is needed (Wirsching, 1985).

Keene's cement is a closely related commercial product sometimes used for molding statues and similar items. It is produced by heating gypsum to ≈ 900 ºC and combining it with accelerators which induce rapid hardening after addition of water. The hardened material will take a high polish and has a relatively high density that resembles marble. The resemblance to natural marble often is enhanced by additions of pigments.

α-Hemihydrate is occasionally used for special plasters because it has lower water demand for mixing into a slurry, so that less excess heat is required to dry the hardened product. It sets more slowly and produces a denser product than that from β-Hemihydrate. It is more expensive to produce, and consequently, is not used for standard wallboard (Wenk and Summerfield, 1987).

Gypsum in Agriculture

Although the major uses of gypsum are in construction, a large amount of gypsum is also used for soil conditioning on farms and ranches. Gypsum is a key ingredient of proper maintenance of soil fertility. It increases stability of soil organic matter, produces more rapid seed emergence, improves water penetration, and helps in the reclamation of alkaline saline sodium-rich soils by replacing Na with Ca on the exchange sites of soil clay minerals (Davis, 1994). It provides sulfur to plants and aids fertilizer utilization and production of legumes. Wallace (1994) listed 33 agricultural benefits of gypsum application for specific types of soils.

Gypsum applications on certain soils may also help reduce global warming. Although most of the current attention on global warming focuses on carbon dioxide, methane is also an effective green house gas. Calculations indicate it may have been responsible for about 17% of greenhouse warming in the 1980's (Lelieveld et al., 1993). Experiments on Phillilpine rice paddy soils which emit large quantities of CH_4 found that 6.6 tons/hectare of ground gypsum reduced methane emission by 55-70%. (Denier van der Gon and Neue, 1994). It was concluded that methane reduction was due to inhibition of methanogenesis by sulfate reducing bacteria.

Other Uses

Another use of gypsum is in the manufacture of molds and casts. Molding and casting plaster is similar to wallboard plaster, but requires much greater production control to insure high purity, close tolerance for its expansion/shrinkage properties, and very rapid setting. The advantage of plaster of Paris for molding and casting is that it expands during setting and facilitates complete filling of molds with preservation of detail without shrinkage cracks. During the setting of plaster of Paris, the hemihydrate becomes rehydrated to gypsum which has a crystal volume that is $\approx$ 7% less than the original hemihydrate plus the water required (Paffenbarger and Rupp, 1979). On the basis of these volume comparisons, a logical conclusion would be that plaster should shrink during setting. The unexpected expansion during setting results because the growing needle-like gypsum crystals push away from each other and create voids between the growing crystals. The void space in hardened plaster of Paris typically is as high as 45% of the total volume, and the linear volume increase is about 0.5% (Paffenbarger and Rupp, 1979) and gypsum plaster is typically much less dense than solid gypsum.

A wide variety of special plasters are also produced by mixing calcined gypsum with various additives which increase the strength or change the properties of the material upon rehydration. Included in these special plaster are those used in the oil and gas industry as a cementing material to seal porous rock layers encountered during drilling.

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FIELD TRIP STOPS

STOP 1. SOLDIER CREEK BEDS AT THE 5th AVENUE NORTH SECTION

by
Raymond R. Anderson and Robert M. McKay
Iowa DNR Geological Survey Bureau

THIS EXPOSURE IS VERY STEEP AND POTENTIALLY DANGEROUS.

DO NOT ATTEMPT TO CLIMB ON THE EXPOSURE.

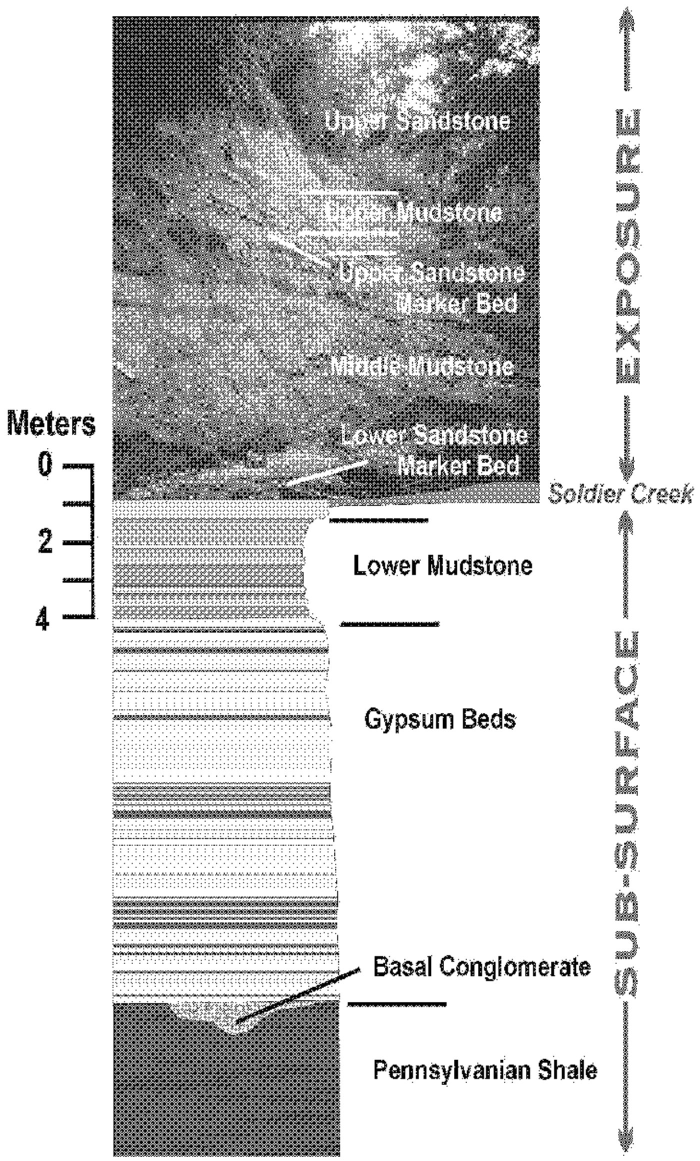


Figure 1. Annotated photograph of 5th Ave North Section with reconstruction of probable Fort Dodge Fm and underlying strata in the subsurface.

The 5th Avenue North Section is located on the west bank of Soldier Creek, at a location where an extension of 5th Avenue North to the west of 5th Street would intersect the creek. The section exposes the thickest-known sequence of "Soldier Creek beds", the informal name assigned to the mudstone and sandstone redbeds that lie directly above the Fort Dodge gypsum. The name "Soldier Creek" was apparently first applied to the beds by Zaskalicky (1956) in an unpublished report on the gypsum resources of the area prepared for the U.S. Gypsum Company. The name, although quite appropriate because the best exposures of the rocks are found along Soldier Creek, is unfortunately preoccupied in Iowa by the Soldier Creek Member of the Bern Limestone, Pennsylvanian Wabaunsee Group. So, the unit will ultimately be renamed, but it is likely that the 5th Avenue North Section will be designated as its type section.

A total of 14 m of "Soldier Creek" sandstones, mudstones, and claystones are exposed at this section. Thirteen beds were described, tentatively grouped into 5 informal units. Comparing the rocks at 5Th Ave. N. with the section at Snell Park (Stop 3) and a section at the Kohl Brevery (about 0.6 km down Soldier Creek) published by Wilder (1919, p. 137-138), an additional 3-4 m of "Soldier Creek" strata are present in the subsurface (Fig. 1). This constitutes the entire "Soldier Creek" section in the Gypsum Basin Facies Tract. At this section the "Soldier Creek beds" rest on at least 2 m (as seen at Snell Park) and probably 10 m (the thickest observed gypsum). It is unlikely that the gypsum is underlain by the basal Fort

Dodge Fm sandstone and conglomerate unit in this area. The gypsum probably rests on Pennsylvanian strata. Pennsylvanian rocks can be observed about 0.2. km up Soldier Creek from Snell Park, within 100 yards of "Soldier Creek" exposures (although the contact has not been observed). A graphic section of the 5th Ave. N. section provides a brief description of each bed and the tentative unit associations. A more detailed description as measured in June of 1996 appears on the following pages. For additional information on the "Soldier Creek beds," see page 15 of this guidebook.

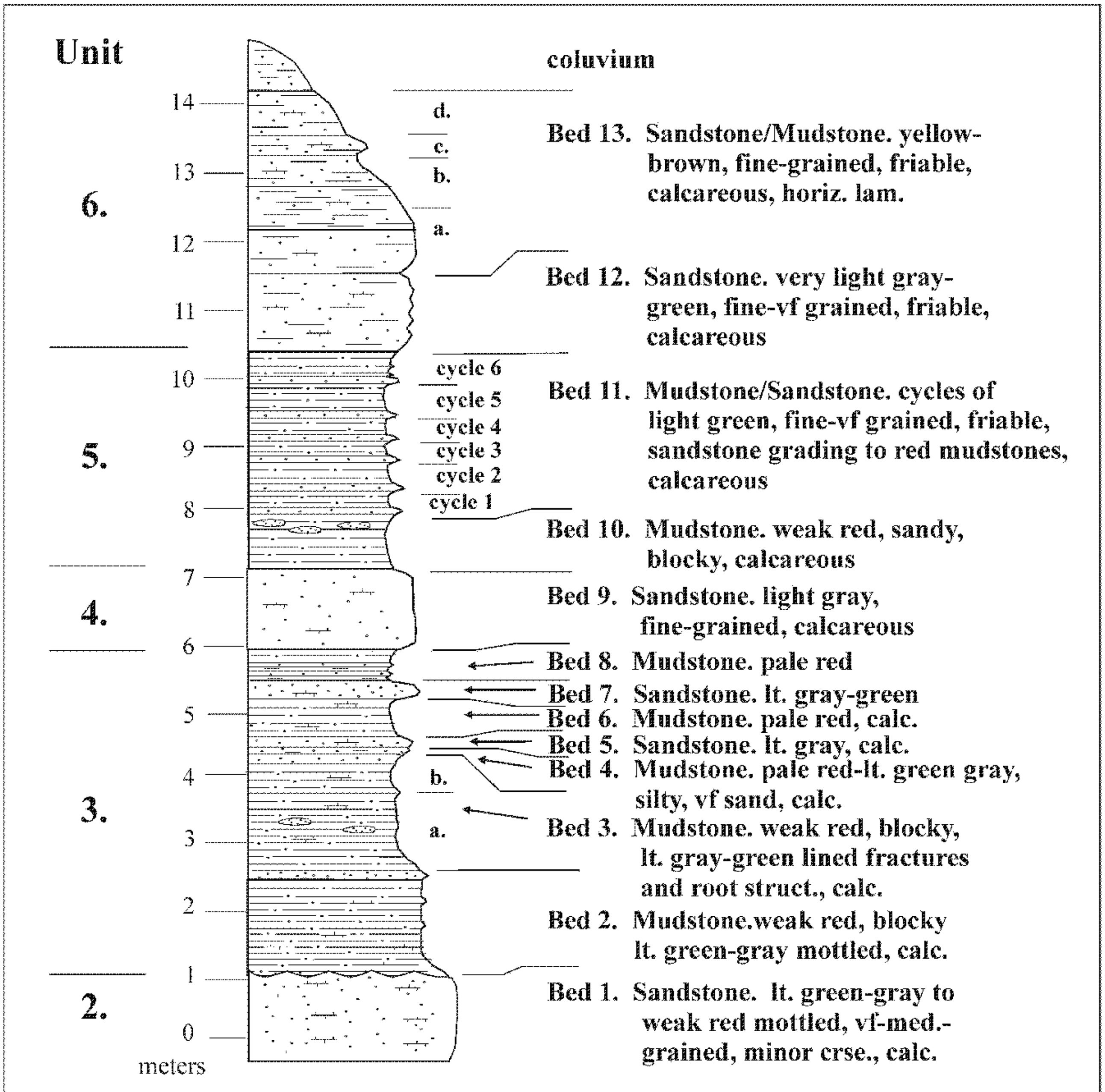


Figure 2. Graphic representation of the "Soldier Creek beds" at the 5th Avenue North Section. See the following pages for a detailed description of the units.

Detailed description of the "Soldier Creek beds" exposed at the 5th Avenue North Section Description by Robert McKay and Ray Anderson, 14 June, 1996

Location of Section:
NE¼, SW¼, NE¼, sec 19, T89N, R28W
A bluff exposure on the southwest bank of Soldier Creek in Fort Dodge, at the intersection of the creek and an imaginary western extension of 5th Avenue North, about 250 yards up-stream from the 7th Street viaduct

LOWER TRENCH

Bed 1. 58 cm of unit above creek level
· **Sandstone**, varies in color from light green-gray (5GY7/7) to weak red (10R5/3)
· calc, vf-m-grained, minor crse, m & crse grains round to sub-round
· in trench breaks out in flat, platy angular fabrics
· no fine laminations, upper contact appears sharp
· coloration anastomosing molting, diffuse mottling dominantly lt green-gray
(photos of trench and contact)

Bed 2. 170 cm
· **Mudstone**, weak red (10R4/3 - 4/4) with 5-10% lt green-gray (5GY7/1) planar linear mottles, appear to be rooting structures
· red mudstone breaks into angular blocky fabric
· mottles horizontal to sub horizontal, sub-vertical, maximum thickness of planar mottles 2-3 cm
· maximum width up mottles up to about 8 cm (perhaps some greater)
· planar mottles dominantly mudstone
· some mottled areas display well developed prismatic gypsum and mm-scale doubly-terminated quartz crystals, dominantly in center of mottles
· quartz crystal aggregates with silty intercrystalline matrix of calcareous mudstone
· also, subordinate zones of harder moderately cemented mudstone trending in color toward pink (10YR7/3 - 7/4), occur as horizontal oriented subtubular cemented nodules 3-4 cm in diameter, ellipsoidal in x-section, to at least 9 cm long, also contain tubular quartz crystal aggregates
(photos of crystal aggregates and mottles)

UPPER TRENCH

· (upper 132 cm of unit)
· week red mudstone as below, <5% lt green mottles
· 103-103 cm - sub vertical fractures with lt green fills - strike 225°, dip 60-70° S
· 110-132 cm - ~5% lt green rooting structures as below with quartz crystals
· 125-132 cm - zone of pale red (10R6/2 - 6/3) mudstone, lt green - gray rooting structures 5-10%, thin lenses of fine sandstone, fires prominent greenish sand at 132 cm

Bed 3a. 153 cm
· **Mudstone**, week red, angular blocky fracture
· lower 1/2 <5%verticle to sub-vertical, lt green-gray lined fractures and less root structures
· minor subhorizontal lt green sandy nodular zones, nodules to 25 cm diam, 13 cm in height, irregular boundaries, dominantly well sorted vf-f sandstone, weakly cemented, common pale red mottles, section also contains near vertical fracture planes with lt green color, strike 270°
· upper 60 cm lt green-gray mottles increase to 10%, mottles appear sandier, not necessarily connected, x-sec shape circular to elliptical, some highly irregular elliptical, common 0.5-3 cm width, lesser number of green fractures
(photo of elliptical mottle)
· upper 15-30 cm lt green-gray mottles 15-20%, strong horizontal fabric, sharp upper contact

Bed 3b. 36 cm
· **Mudstone** weak red as below 0-30 cm
· 30-40 cm, weak red mudstone with 5-15% lt green mottles increasing upward, mottles contain vf sandstone no quartz crystals, various mottle shapes include (1-common) large equant, 1-2 cm thick and 2-6 cm wide subhorizontal to subvertical, (2-common) tube-like subvertical to subhorizontal, 3-8 mm diameter, (3-rare) subcircular concentric 2-3 cm diameter and 3-4 interbands of pale red-lt gray green

· upper 5-15 cm grades to sandstone (sample), dominantly lt green-gray with less pale red mudstone laminae, sandstone vf-f-grained, small-scale trough cross-strata and ripple-form structures with common clay drapes, ripple crest orientations 2 strikes @ 220°, sharp upper contact, upper part of sandstone is cross-stratified, lower (thickest) non-stratified irregular loaded to nodular basal section.

Bed 4. 7-8 cm
· **Mudstone**, (sample) silty to vf sandstone, lateral color variation from pale red to lt green-gray, calc, angular blocky fabric, prominent horizontal bed appears as wet zone
· basal contact wavy over sand below
· upper contact sharp, wavy - sandstone above

Bed 5. 0-11 cm
· lenticular **sandstone**, lt gray, vf-f-grained, pinches out horizontally, but moderately persistent
· calc, friable with common lt green-gray mudstone-claystone drapes and flasiers
· small-scale ripple forms, ripple crests strike 220-230°
· domal features at base (3 within 4 m zone) ~30 cm wide, 10-12 cm high, very sandy (as below), sand is non-laminated, non stratified, mod well cemented, possible root/trunk/log cast?? (photos of features), dominantly lt green-gray clay laminae that drape over

Bed 6. 60 cm
· lower 20 cm **mudstone**, pale red, angular as below
· 20-40 cm, 50%pale red, 50%green gray, prominent 1-6 cm horizontal and irregular zones of lt green-gray with common quartz crystals, quartz-calcite nodules 0.5-1.0 cm and linear nodules to 10 cm (photo and samples)
· 40-60 cm, pale red mudstone, 5-10%lt green-gray sandy red mudstone lenses and mottles, rare subvertical rooting structures, upper contact very sharp (photo of contact)

Bed 7. 36 cm
· **sandstone**, moderately prominent ledge-former
· lt green-gray, vf-f
· appears as one massive bed
· clay laminae and flasiers in lower 5 cm
· trace of pale red horizontal mottling,
· prominent, closely-spaced vertical fractures similar to talus at base of section

Bed 8. 62cm
·**mudstone**, pale red with 12 prominent thin interbeds of lt gray-green ss in lower 45 cm, ss occurs as continuous thin beds to lenses with ripple-form structures, thin beds have clay laminae to clay drapes
· upper 15 cm dominantly red mudstone with 10-20% lt green-gray ss as lenses and irregular nodules up to 9 cm x 6 cm (photo)

Bed 9. 88cm
· **sandstone**, (sample) one thick prominent bed, very light gray with pale red exterior
· fine-grained, very well sorted quartzose
· slightly-moderately cemented, calc
· no x-strat or other structures observed
· upper 12 cm poorly cemented, friable, recessive
· sharp upper contact

Bed 10. 85 cm
· lower 50 cm **mudstone**, weak red, blocky angular with 5% lt green-gray subhorizontal to subvertical, 1 cm x 18 cm, sandier, well cemented nodular (to 6 cm x 10 cm) in places, quartz crystals and calcite in nodules (photos taken)
· sharp upper contact

Bed II. 250 cm
· 6 prominent sandstone-based mudstone cycles average ~40 cm thick, ss at base 5-12 cm, thick-bedded, rippled with interbedded heavily flasiered ss, ss rippled, clay forset drapes, ss vf-f, clay in ss lt green-gray with much less weal red to pale, ~70-80%ss, 20-30%clay, ripples where visible <1cm amplitude, significant component horizontally laminated (sample from cycle 2)
· 2-3 discontinuous ss lenses (isolated ripples) may occur between cycle sands

· prominent vertical fractures strike 295°
· ss bases become thinner near top of unit
· mudstone portions dominated by blocky angular red mudstone with 5% or less lt green-gray vertical fracture fills and minor horizontal to subvertical sandy mottles (1.0-0.5 cm wide), oval-circular-tubular (sample of red mudstone from top of cycle 4, sample of sandstone from 5th cycle)

Bed 12. 121 cm
· **sandstone**, f-vf-grained some m-c subrounded to rounded frosted quartz and carbonate(?)
· very light green-gray with minor pale red as horizontal streaks and mottles
· cross-stratified
· some color mottling is coincident with cross-strata foreset laminae
· foreset dip direction=N20°E, fa (foreset azimuth)=20° from lower 20 cm of unit, minimum of 15 cm thick sets (sample)
· remainder of unit is very thin-bedded, horizontally stratified to small-scale lenticular (lenses 0.5 cm thick)
· trace of clay lamellae
· minor lenticular zones are better cemented (base middle top) are week red in color (sample)
· middle part oxidized tan color with a few prominent horizontal wavy lt gray-green ss laminae

Bed 13a. 110 cm
· lower 60 cm **sandstone** (90%) tan-yellow-tan-pale red, mudstone (10%) very thin bedded, horizontal laminated with 10% discontinuous mudstone laminae
· well stratified, very poorly cemented

Bed 13b. 50 cm
· 70% **mudstone**, 30% sandstone, weak red to yellow tan, sandstone yellow-tan, mottled, horizontal lenses, vertical mottles, strong horizontal fabric, cemented ss-mudstone nodules in upper 10 cm (samples)

Bed 13c. 28 cm
· **sandstone** (70%) interlaminated (well developed)with mudstone (30%)
· sand layers 3 mm - 1.5 cm ripple forms and small scale ripple cross-laminae, one ripple crest strikes 170° (photos, sample)

Bed 13d. 75 cm
· **mudstone** dominated with common to discontinuous tan sand lenses
· minor lt green-gray tube-like structures, subhorizontal to subvertical

Bed 14. 1 m
· Quaternary sandy gravelly **coluvium**

STOP 2. FORT DODGE FAULT ZONE AT SOLDIER CREEK

by
Raymond R. Anderson and Robert M. McKay
Iowa DNR Geological Survey Bureau

Field trip Stop 2 is located less than ¼ mile up Soldier Creek for the 5th Ave. North Section. At this stop the presence of the Fort Dodge Fault is demonstrated by the exposure of Jurassic "Soldier Creek " clastics and Mississippian St. Louis Fm carbonates and sandstones at similar elevations within about 100 feet of one another. St. Louis Fm strata on the up-thrown block forms a low waterfall and a high bluff on the west bank of the creek, just downstream from the 7th Street bridge. "Soldier Creek" strata form a bank about 100 feet downstream. The Fort Dodge Fault crosses the creek between.

The most complete section of St. Louis Fm strata is present on the west bank of the creek, in the area of the waterfalls (Fig. 1). The carbonates of the Croton Mbr are overlain by Yenrougis Mbr sandstone and Verdi Mbr limestone (see Fig. 2 graphic section and detailed description on following pages). Minor satellite faults to the main Fort Dodge Fault can be observed producing tilted and slickensided St. Louis strata on the east bank of the creek. The strata within the graben appears to dip to the west (likely the result of a series of step faults paralleling the Fort Dodge Fault), with displacement of approximately 55 feet observable in the elevation of the gypsum from the mouth of Soldier Creek to the main gypsum district

Figure 1. View looking up stream at Mississippian strata exposed on the west band of Soldier Creek, just west of the Fort Dodge Fault.

southeast of the city. Faulting at the waterfall was observed to strike 176° and dip at 58° E. Vertical fractures near the fault display a strike azimuth of 53°, dipping 79° to the northwest.

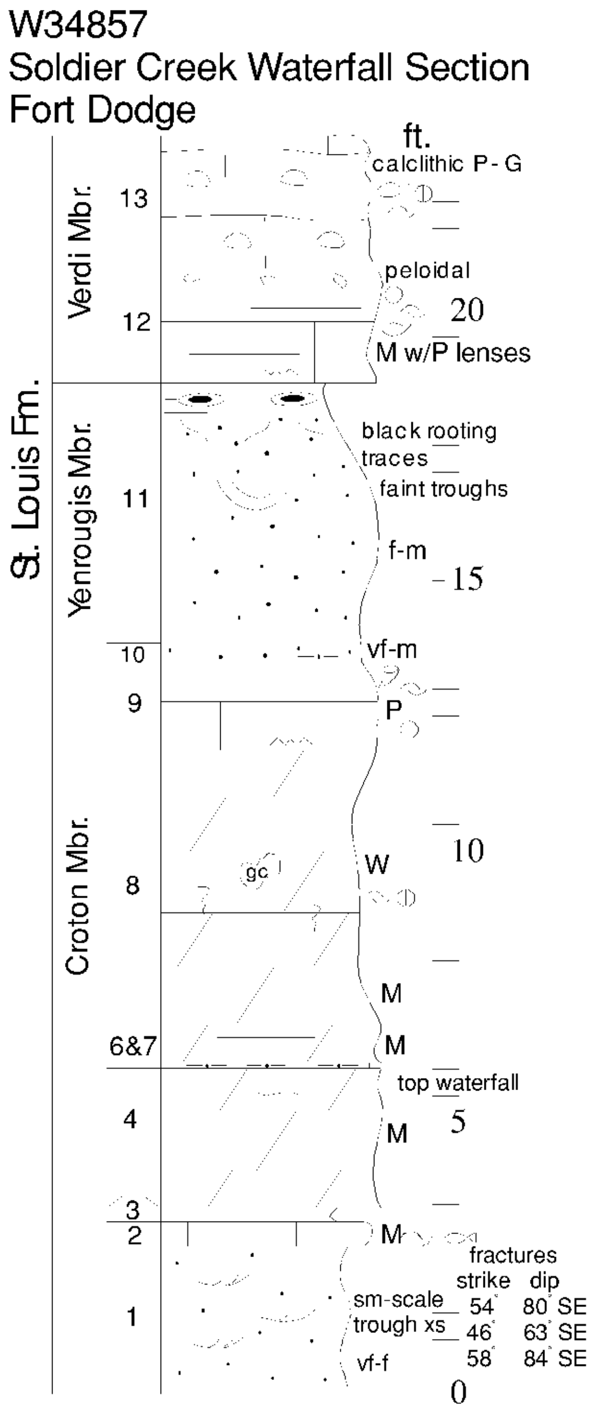


Figure 2. Graphic section of the Mississippian rocks exposed along Soldier Creek on the up-thrown block of the Fort Dodge Fault. A detailed description follows.

Name:	**SOLDIER CREEK WATERFALL SECTION (SCWS)**	*County:*	**WEBSTER**
Company/ Owner:	**FORT DODGE, CITY OF**		
IDALS Reg. #:	**NOT APPLICABLE**	*IDOT Code #*	**NOT APPLICABLE**
Loc. (Q's):	**NE SE SE NW NE**	*Sec.* **19** *T.* **89N**	*R.* **28W**
Quad:	**FORT DODGE NORTH (I21)**	*Elevation:*	1033 ft. at top of outcrop 1010 ft. at base of outcrop
Loc. Rmrks:	Along Soldier Creek & about 150 ft downstream of new 7'th Street Bridge over Soldier Creek.		
Descrip. By:	R. McKay & R. Anderson	*Date(s):*	11/24/1998
Descrip. Rmrks:	Begin main section 60 ft downstream of most prominent waterfall. Section exposed in creekbed and in west cutbank. Additional notes taken on the slickensided & dipping part of section on the east bank of the creek at the same location.		
Previous Descrips. & Other Remarks:	Lees & Wilder have a description very close by that they called the "Stone Bridge Section" of IGS A.R. v. 28, p. 140		

Unit #	*Description*	*feet*	*meters*
	MISSISSIPPIAN		
	ST. LOUIS FORMATION		
	Verdi Member		
13	Limestone, light gray, peloidal skeletal mudstone to wackestone with brachs, echinoderm plates, and ostracode valves that has been weathered and recemented into a calclithic packstone to grainstone especially in upper part. Sample 13. Soil above.	2.62ft	0.80m
12	Limestone, light gray, laminated mudstone (in lower 10 cm) to skeletal mudstone with skeletal peloidal packstone laminae, prominent ledge former across top of main exposure, mildly styolitic, skeletal grians include brachs, echinoderm plates, and whole valve & articulated ostracodes. Highly fractured in upper part. Samples 12 and 12 top	2.16ft	0.66m
	Yenrougis Member		
11	Sandstone, light gray, f, minor m, calcareous, faint x-strata of 20 cm thick trough sets, lower 30-40 cm uncmted and friable; main portion cemented and ledge forming; upper 25 cm poorly cemented, recessive. Upper 10 cm of recessive zone displays small diagonally to subhorizontally oriented black mottling approx 5 cm wide by 2-4 cm long. These are possible rooting traces. Immediately above zone of black mottling structures the unit grades rapidly to claystone that is light greenish gray and partially oxidized to orangish tan. Claystone contains discontiuous thin lenses of light gray to brownish black laminated chert 4-5mm thick. Chert contains some disseminated marcisite xtls. Sample 11 of chert lenses.	4.85ft	1.48m
10	Sandstone, light gray to mottled green & oxidized orange, vf-m, quartzose, sa-sr, silty to clayey matrix, sticky, forms first layer in prominent recessive portion of exposure. Sample 10	0.33ft	0.10m
	Croton Member		

9	Limestone, light gray, skeletal peloidal packstone, whole and broken brachs, echinoderm debris, solitary rugose corals, dense, conchoidal fracture, dolomitic in lower 10 cm, styolitic especially at basal contact with dolostone. Thickens to 70 cm upstream just above water level where the lower 30 cm is mudstone to wackestone that grades upward to skeletal wackestone with whole valve brachs and upper 10 cm to skeletal pakstone with common solitary rugose corals and echinoderm plates. Sample 9	1.31-1.61ft	0.40-0.70m
8	Dolostone, light medium brown, prominant medium-bedded unit forming main part of cliff, vf-f xtln, conchoidal fracture, moderately to very porous dolostone, mostly appears to be a dolomudstone but towards middle at about 75-85 cm above base is zone of skeletal dolowackestone with moldic partial & whole valve brachiopods & moldic echiniderm debris, burrow traces especially common near brach zone, common irregular shaped green clay filled molds of both burrows and brachs and vugs. Sample 8	5.12ft	1.56m
7	Dolostone, light medium brown, dolomudstone, f xtln, abundant submm moldic porosity in lower 3/4s and laminated in upper few cm, possible ostracode molds	0.19-0.36m	0.06-0.11m
6	Dolostone, light brown to light gray, dolomudstone, f xtln, slightly pyritic, undulose wavy lower contact, flat upper contact. Sample 6	0.43ft	0.13m
5	Siltstone, light gray, slightly micaceous, calcareous, laminated, laterally persistant. Sample 5	0.06ft	0.02m
4	Dolostone, waterfall unit, light gray in lower half grading up to light brown in upper half. Lower part is dolomudstone with a disturbed to mottled fabric, nonsandy with minor submm moldic porosity. Upper part is dolomudstone, medium-bedded, nonsandy, chonchoidal fracture, vf-f xtln, very slightly argillaceous with faint discontinuous argillaceous laminae. Sample 4a from 20 cm above base; sample 4b from 50 cm above base.	2.59ft	0.79m
3	Shale, recessive unit, lt gray, slightly silty, dolomitic, laminated. Sample 3	0.23ft	0.07m
2	Limestone, very light gray, lime mudstone, fine xtln, slightly very fine sandy, dolomitic, light medium green clay flakes/accumulations up to a few mm long by 1mm thick, trace fish scale/bone, trace brachiopod skeletal debris, slightly pyritic, ledge former. Sample 2	0.46ft	0.14m
1	Sandstone, vf-f, v light gray, calcareous but only moderately cemented and moderately hard, thin-bedded with thin discontinuous lensatic structure with discontinuos lenses up to 50 cm long; possible small-scale ripple structure. Occurs in stream bed as ledge former. Prominent near vertical fractures: Strike 234 Az with 80 degree dip SE; Strike 226 Az with 63 degree dip SE; Strike 238 Az with 84 degree dip SE.	2.72ft	0.83m
	TOTAL THICKNESS	23.4ft	7.1m

Additional section along east bank 33ft (tape) across creek from main section and just downstream of main waterfall.

Section exposes 2.0 m of units 4 through 8, 45 cm of unit 9 limestone, and 80 cm of brecciated sandstone of units 10 & 11. Upper 60 cm is breccia of with sandstone clasts and lessor limestone clasts having a silty/sandy/shaly matrix. Strike on top of unit 9 limestone of 193 Az with dip of 43 degrees east; bearing of 143 to Corpus Christie church steeple. Strike on unit 8 dolomite of 173 AZ with dip of 21 degrees east. Strike on slickensided surface in unit 8 of 176 Az with dip of 58 degrees east. Sample of slickensides developed in unit 8.	9.18ft	2.8m

STOP 3. SOLDIER CREEK BEDS AND FORT DODGE GYPSUM AT SNELL PARK

by
Raymond R. Anderson and Robert M. McKay
Iowa DNR Geological Survey Bureau

Introduction

The exposures in Snell Park present one of the few opportunities to observe the Soldier Creek beds overlying the Fort Dodge gypsum. The area of the exposures (Fig. 1) was the site of the Old Cummins Quarry, where 7 m of gypsum was present at the time the quarry was described by Keyes (1895).

THIS EXPOSURE IS VERY STEEP AND POTENTIALLY DANGEROUS.

PLEASE OBSERVE THE SECTION FROM ACROSS SOLDIER CREEK.

<u>DO NOT ATTEMPT TO CLIMB ON THE EXPOSURE.</u>

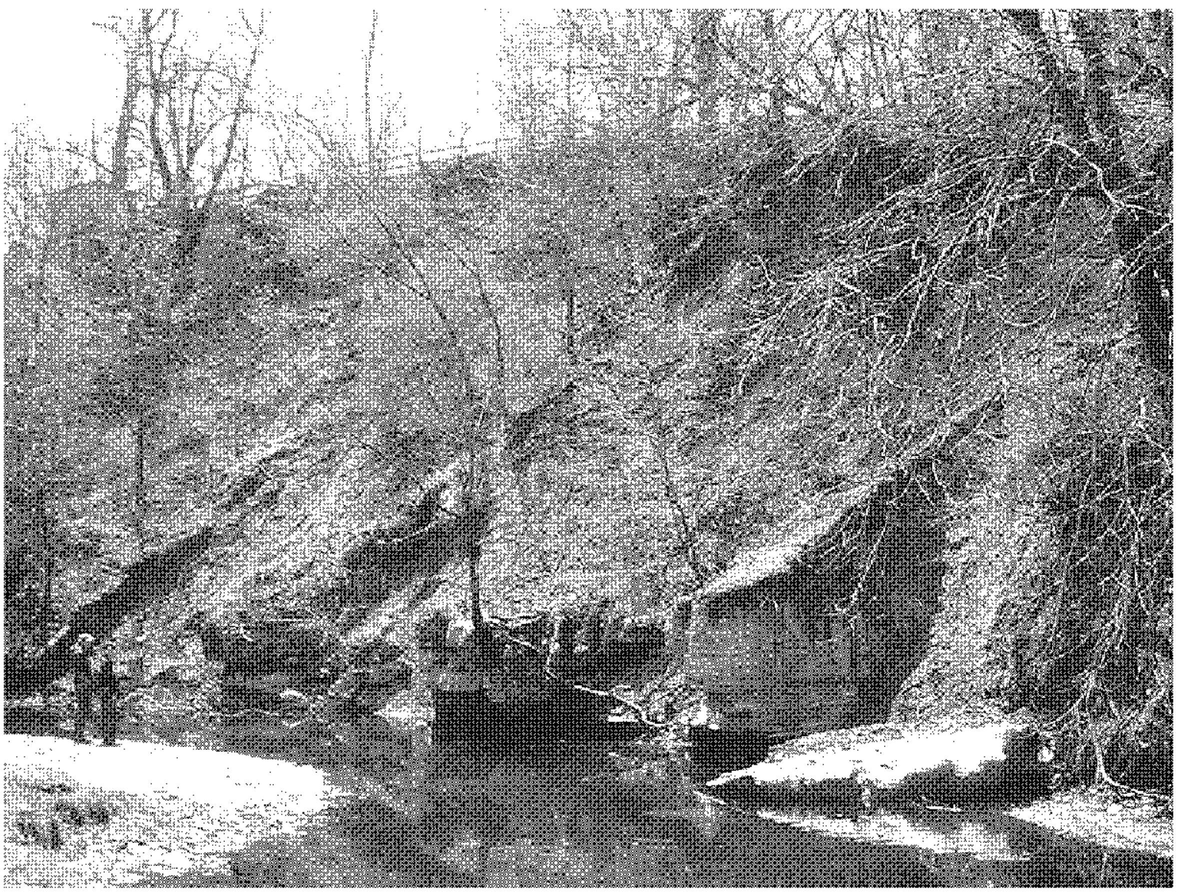


Figure 1. Exposure of "Soldier Creek beds" overlying Fort Dodge gypsum at Snell Park.

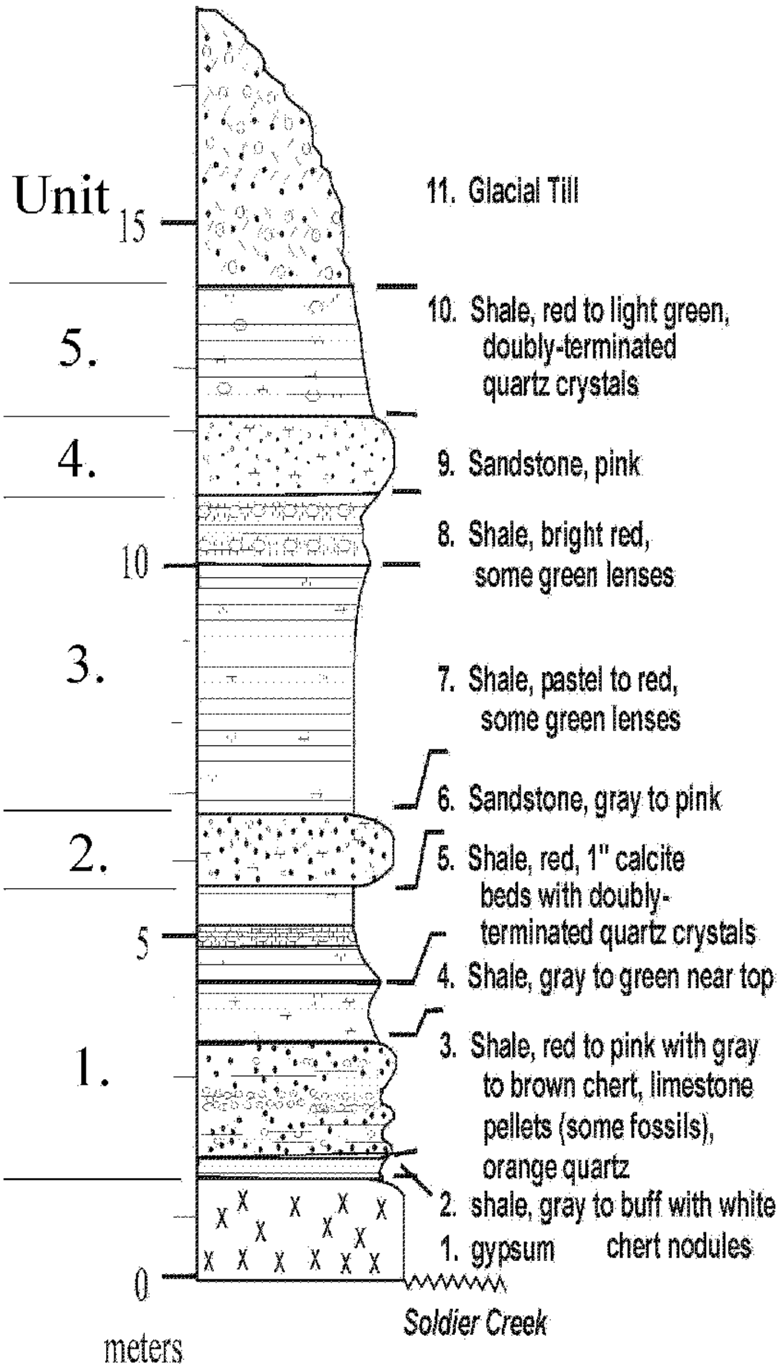


Figure 2. Graphic section of the Fort Dodge Formation at Snell Park. Description from Hale (1955, p. 131-132).

One of the best exposures of the rocks of the Fort Dodge Fm lie along Soldier Creek at Snell Park. The bluff at the park exposes about 1.5 m of Fort Dodge gypsum and an additional 12.5 m of the overlying "Soldier Creek beds", including units 1 through 4 and most of unit 5 (Fig. 2). This is one of the few remaining exposures of the gypsum that is not threatened with destruction by mining.

STOP 4. QUATERNARY MATERIALS OVERLYING THE FORT DODGE GYPSUM AT THE U.S GYPSUM QUARRIES

by
[1] E. Arthur Bettis III and [2] Deborah Quade
[1] The University of Iowa Department of GeologyIowa City, Iowa 52242-1379
[2] Iowa DNR Geological Survey Bureau, Iowa City, Iowa 52242-1319

Only a limited portion of Iowa's rich Pleistocene history is preserved in the materials above the gypsum in the Fort Dodge area. Many gypsum pit sections are often characterized by thin exposures of Pre-Illinoian glacial sediments (2.5 million to 500,000 years old). Pre-Illinoian sediments fill in the irregularities in the gypsum surface (where there is no "Soldier Creek" present) and are sometimes preserved as a thin layer above the "Soldier Creek beds." Pre-Illinoian till exposed in these sections is heavily oxidized and has a caramel brown color. Mid to Late Wisconsinan-age tills, associated with the latest glacial advance into the state, the Des Moines Lobe, overlie Pre-Illinoian age sediments in the Fort Dodge area. The Sheldon Creek Fm. was deposited by several earlier advances into Iowa, dates from these deposits cluster around 40,000 to 26,000 years before present. In the Fort Dodge area, Sheldon Creek deposits have been documented by radiocarbon dating at the National Gypsum Kauffman-George pit and at Brushy Creek Recreation Area. Sheldon Creek age sediments are overlain by the younger Dows Fm. which was deposited as the Des Moines Lobe advanced into Iowa approximately 15,200 years ago. The Dows Formation consists of several till members, the Alden Mbr. (basal till), a unoxidized,

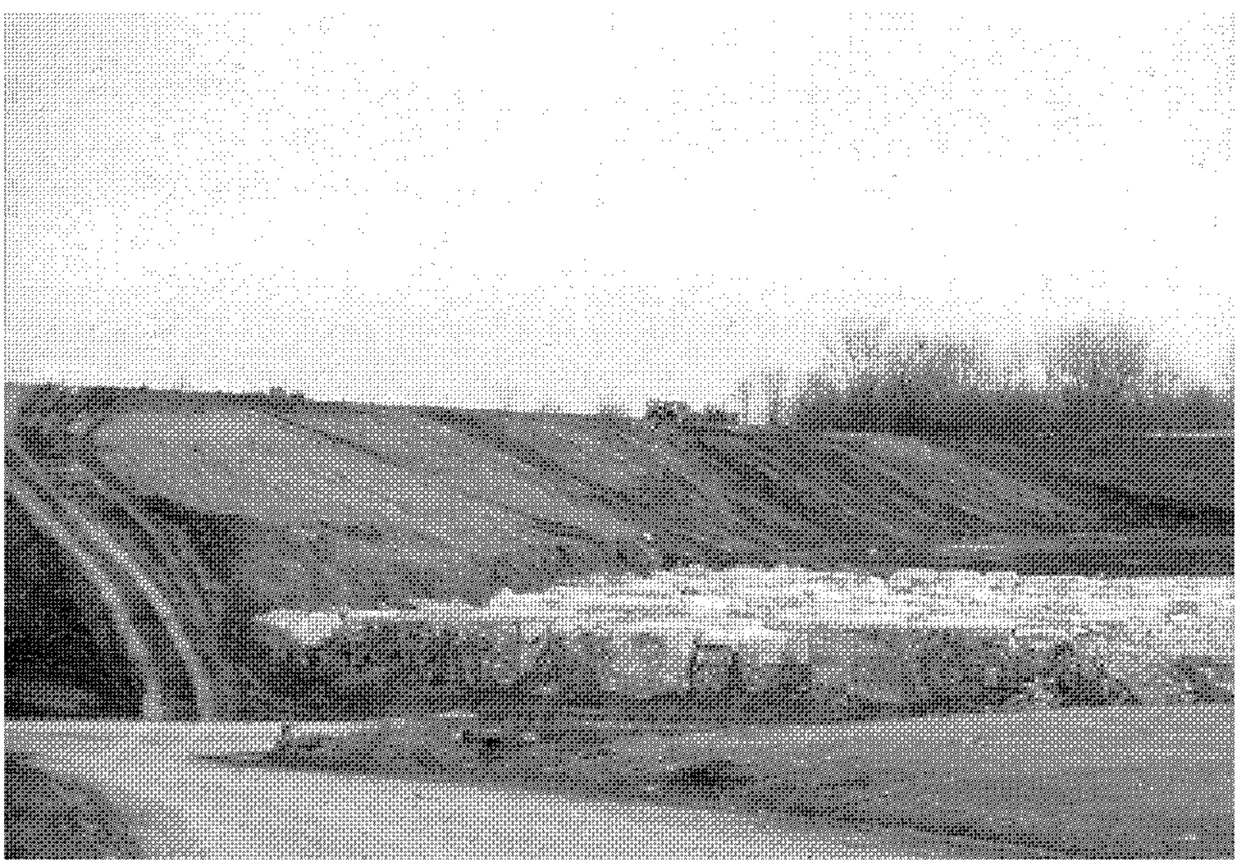


Figure 1. Quaternary section exposed at the U.S. Gypsum Corp. Carbon-Cardiff Quarry.

uniform loamy till unit and Morgan Mbr. (supraglacial till), a usually oxidized, much less uniform till with associated lenses of sand, silts and clays. Both the Sheldon Creek and Dows (Alden Mbr.) are unoxidized, dark gray, in sharp contrast to the underlying oxidized, brown Pre-Illinoian tills. The contact between the Sheldon Creek and Dows fms is usually difficult to identify, but sometimes is evident by the presence of a boulder pavement or a weathered Sheldon Creek horizon. The contact between the Alden and Morgan mbrs is usually marked by a change in oxidation and color as well as a change to a fairly uniform texture. We will be examining these units in either the Carbon-Cardiff (Fig. 1) or North Welles (Fig. 2) quarries, depending on the conditions.

Figure 2. Quaternary deposits above gypsum at the U.S. Gypsum North Welles Quarry.

STOP 5. FORT DODGE GYPSUM AT THE U.S. GYPSUM COLLINS QUARRY

by
[1] Raymond R. Anderson, [1] Robert M. McKay, and [2] Larry Pawlosky
[1] Iowa DNR Geological Survey Bureau
[2] U.S. Gypsum Corporation

YOU MUST KEEP YOUR HARD HATS ON AT ALL TIMES

The Fort Dodge gypsum is mined in a number of quarries in this area by the U.S. Gypsum Co. We will be examining gypsum beds in the Collins Quarry, just northeast of the mine office building. The gypsum is prepared for mining by first removing the overlying Quaternary materials down to the gypsum. Then, backhoes with specially designed buckets are used to clean glacial materials from the solution-enlarged fractures (called slips by the miners). Once the gypsum is cleaned off it is drilled and blasted, then loaded into trucks for shipment to the processing plant. For more information on the Fort Dodge gypsum see page8 of this guidebook

You may climb up on the gypsum to examine it more closely, but be careful, **THE GYPSUM CAN BE SLIPPERY IF IT IS WET**. You may collect samples or take photographs if you wish.

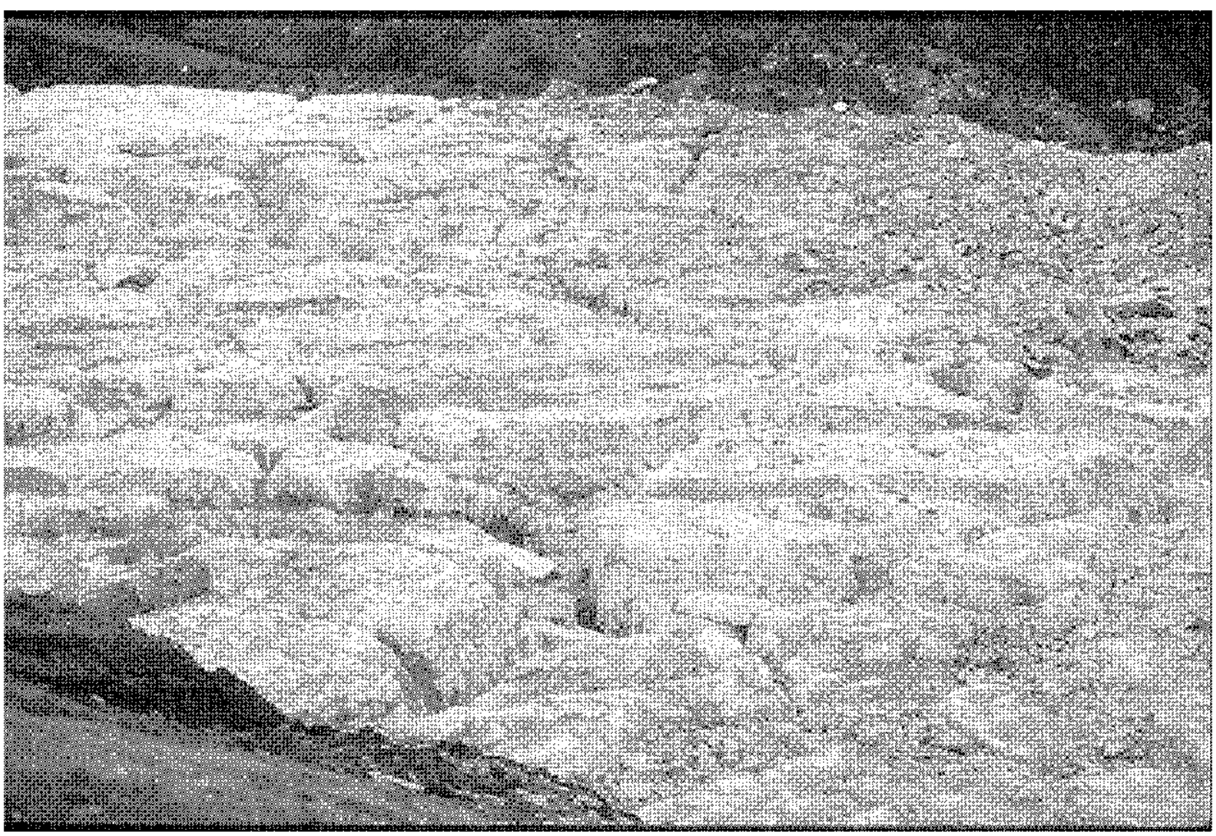


Figure 1. Fort Dodge gypsum exposed prior to mining at the U.S. Gypsum Co. Collins Quarry.

STOP 6. MINING RESTORATION AT THE U.S. GYPSUM SOUTH WELLES QUARRY

by
[1] Raymond R. Anderson and [2] Larry Pawlosky
[1] Iowa DNR Geological Survey Bureau
[2] U.S. Gypsum Corporation

TO REACH THIS STOP, WE WILL BE DRIVING ON THE U.S. GYPSUM CO. HAUL ROAD

DRIVE ON THE LEFT SIDE OF THE ROAD AT ALL TIMES WHILE IN THE QUARRY AND YIELD TO THE MINING VEHICLES

WHEN WE STOP,
PLEASE PULL OVER TO THE LEFT SIDE OF THE ROAD AS FAR AS POSSIBLE AND STAY OFF THE ROAD AND AVOID THE MINING VEHICLES.

Overview of Mine Reclamation Law

In 1968 the State of Iowa enacted legislation requiring that mined areas be reclaimed. The law was amended in 1985, and with a few subsequent minor changes now exists as Iowa Code Chapter 208. The law forbids the burial of topsoil during the mining process. Upon completion of the mining, it requires mine operators to grade affected lands (except for impoundments), pit floors, and highwalls to slopes having a maximum of one foot vertical rise for each four feet of horizontal distance, or to conform with surrounding terrain in areas of greater relief. They must provide for the approved vegetation of the affected lands. And, all of this reclamation must be completed within three years of the completion of mining activities in the area. Mining, crushing areas and spoil piles that were operated prior to 1968 are exempt from these laws.

South Welles Reclaimation Area

Looking due west from the road, a large area of reclaimed quarry pits can be observed. The gypsum in this quarry, the South Welles Quarry, was removed about 20 years ago, with the area then reclaimed to as near original condition as possible. The area has become a very well used recreational area for local hunting, fishing, hiking and nature observation. A wide variety of flora and fauna are thriving in the area. The area has also been cited by the Iowa Department of Natural Resources as an excellent example of reclamation practices and results.

On the other side of the road, the unreclaimed mined area at the south end of the North Welles Quarry can be observed. This provides a good contrast with the reclaimed area to the west.

STOP 7. ABANDONED UNDERGROUND MINE ADITS AT THE U.S. GYPSUM NORTH WELLES QUARRY

by
[1]Raymond R. Anderson, [1] Robert, M. McKay, and [2]Larry Pawlosky
[1]Iowa DNR Geological Survey Bureau
[2]U.S. Gypsum Corporation

REMEMBER, DRIVE ON THE LEFT SIDE OF THE ROAD AND YIELD TO MINING VEHICLES

PLEASE PULL OVER TO THE LEFT SIDE OF THE ROAD AS FAR AS POSSIBLE AND STAY OFF THE ROAD AND AVOID THE MINING VEHICLES.

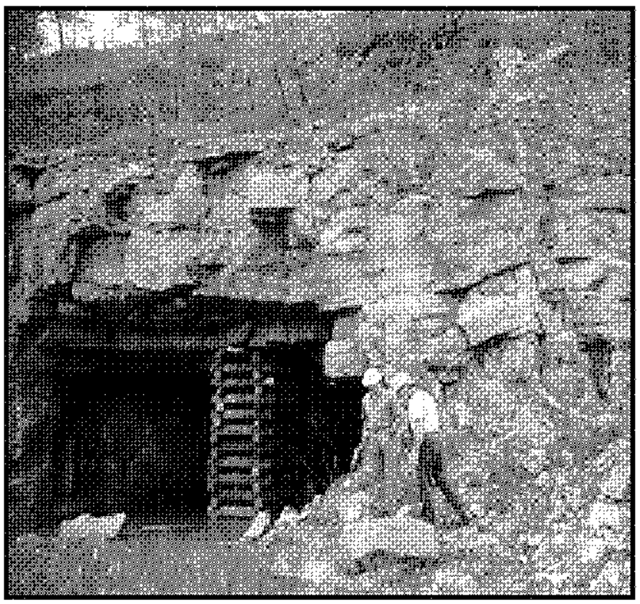


Figure 1. Photograph of an abandoned adit in the U.S. Gypsum North Welles Quarry. Wood cribbing can be seen holding up the roof.

Looking north-northeast from the haul road, two large mine openings can be observed. These adits are part of an extensive underground mine complex located directly under the U.S. Gypsum plant and property east of the Mill Road. These openings were exposed during more recent open pit quarrying activity during the last 20 years. However, the openings have been maintained to provide access to the complex of underground workings for de-watering of the underground mined areas. The original vertical access shaft to this underground mine complex still exists on the plant grounds, but is no longer active. U.S. Gypsum ceased underground mining in 1927 when they switched all of their gypsum production to quarry operations. These and other underground mine workings have officially been closed, and access by U.S Gypsum employees is strictly forbidden due to current mining laws. Most of the exposed adits have been filled, or at least access has been blocked with fill material (such as the adits exposed in the Cardiff Quarry.) However, in an effort to control mine de-watering and sink hole subsidence in the area of their wallboard factory, U.S. Gypsum has arranged to use a contract mine service to enter the mines when necessary. For more information on the history of gypsum mining in the Fort Dodge area, see page 53 of this guidebook.

Please feel free to photograph the adits from the road and ask any questions, but stay near the cars; do not hike down into the mining area or wander out into the haul road.

STOP 8. TOUR OF THE U.S. GYPSUM WALLBOARD PLANT

by
[1] Raymond R. Anderson, [1] Robert M. McKay, and [2] Larry Pawlosky
[1] Iowa DNR Geological Survey Bureau
[2] U.S. Gypsum Corporation
Ron Hollander, Wallboard Plant Manager

NO PHOTOGRAPHY IS ALLOWED IN THE WALLBOARD PLANT.
LEAVE CAMERAS IN VEHICLES

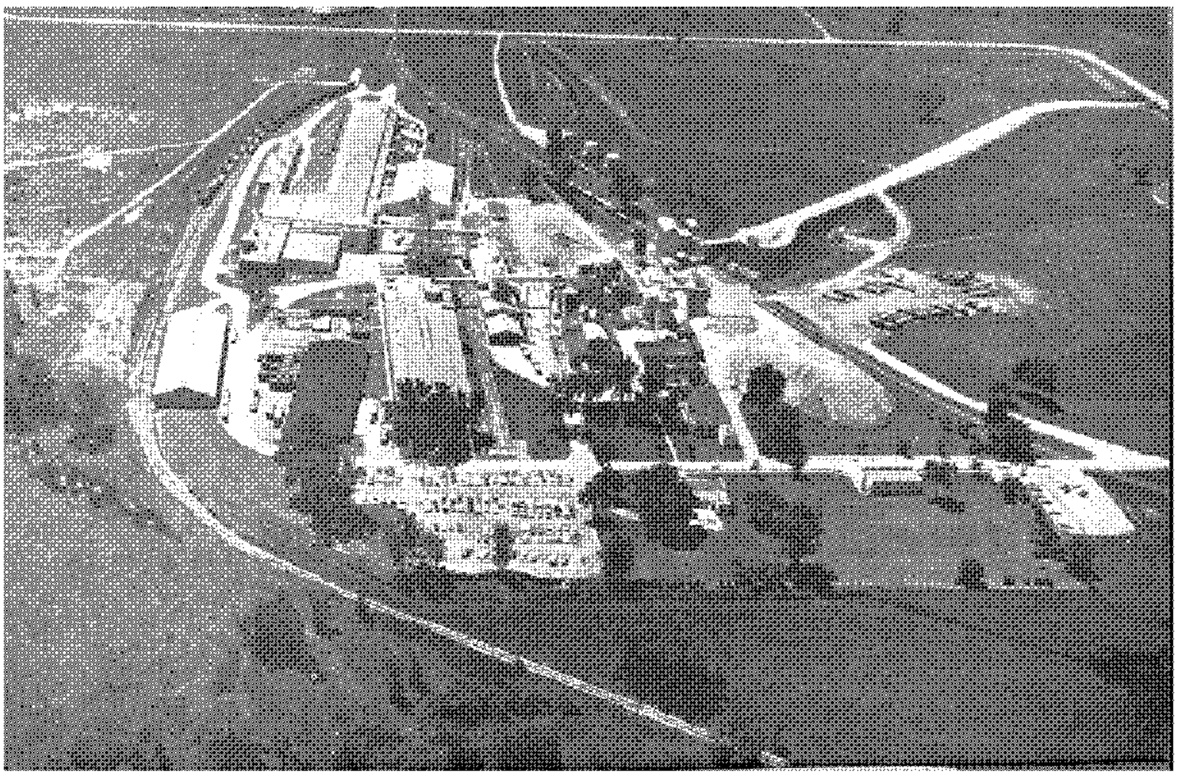


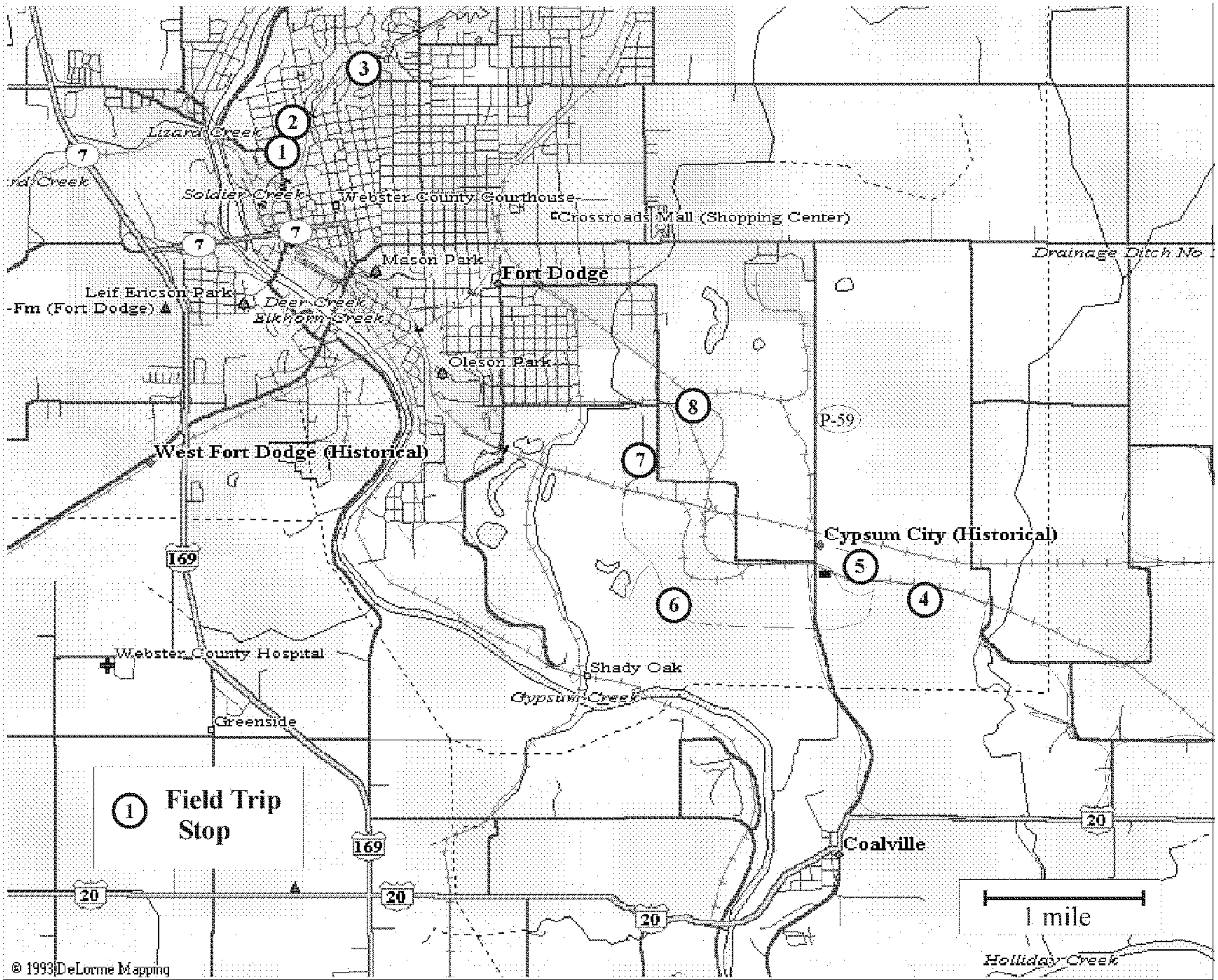
Figure '. Aerial photograph of the U.S. Gypsum Corporation wallboard plant. Modified from Rodenborn (1972).

The United States Gypsum Company was incorporated in New Jersey on December 27, 1901. with its corporate offices in Chicago, Illinois. The company became a leading gypsum producer in 1920 when it was consolidated with 34 other gypsum companies, and it has been the top gypsum producer in the Fort Dodge area for many years.

U.S. Gypsum has been making gypsum building products in Fort Dodge since 1902. The plant operates 24 hours a day, and last year it produced 65 million square feet of wallboard. In addition to wallboard, the factory produces industrial plasters and joint compounds. Please refer to the accompanying guidebook article on the Uses of Gypsum (page 59) for a discussion of wallboard manufacturing.

THIS IS THE LAST STOP OF THE FIELD TRIP. HAVE A SAFE DRIVE HOME.

Geological Society of Iowa
109 Trowbridge Hall
Iowa City, Iowa 52242-1319


Lizard Creek
Soldier Creek
Webster County Courthouse
Crossroads Mall (Shopping Center)
Drainage Ditch No
Mason Park
Fort Dodge
Leif Ericson Park
-Fm (Fort Dodge)
Deer Creek
Elkhorn Creek
Oleson Park
P-59
West Fort Dodge (Historical)
Gypsum City (Historical)
Webster County Hospital
Shady Oak
Gypsum Creek
Greenside
Field Trip Stop
Coalville
1 mile
Holliday Creek
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