MINNESOTA GEOLOGICAL SURVEY

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DEEP STRATIGRAPHIC TEST WELL NEAR HOLLANDALE, MINNESOTA

G. S. Austin

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DEEP STRATIGRAPHIC TEST WELL NEAR HOLLANDALE, MINNESOTA

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DEEP STRATIGRAPHIC TEST WELL

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by
G. S. Austin

ABSTRACT

A deep stratigraphic test well, the Hollandale No. 1, in Freeborn County, Minnesota was drilled in rocks that range in age from Devonian to Precambrian in search for reservoirs suitable for the underground storage of natural gas. The porous St. Peter Sandstone of Ordovician age and the Mt. Simon Sandstone of Cambrian age are potentially good reservoir rocks. The Ordovician Decorah Shale overlies the St. Peter Sandstone and probably is the most suitable cap rock in southeastern Minnesota. However, the Decorah is restricted geographically and generally lies relatively near the surface. The Eau Claire Formation, above the Mt. Simon Sandstone, also has been considered as a possible cap rock, but it is composed of shales that are interbedded with sandstones and is vertically permeable.

As this was the first cored well in this part of southeastern Minnesota, a study was undertaken of the lithic units penetrated during drilling, and interpretations were inferred for the depositional environment of each unit. The rocks of Paleozoic age were deposited in a shallow-water environment in cyclic fashion. Four recurrent lithotopes that characterize the rocks are (1) quartzarenite, (2) poorly sorted lithotope with strata composed of clastic particles ranging in size from silt to granule or with arenaceous carbonate strata, (3) shale or argillaceous sandstone, and (4) carbonate rock. The recurrence of these lithotopes in the Paleozoic column in southeastern Minnesota has led to the identification of nine sedimentary rock cycles. Several of the cycles are bounded on their upper surfaces by unconformities; in others, rocks occur that appear to have been deposited by both transgressional and regressional seas.

The general trend in the depositional cycles of Cambro-Ordovician rocks of southeastern Minnesota is from predominant sandstone and subordinate carbonate in the older cycles to subordinate sandstone and predominant carbonate in the younger cycles. This progression reflects the gradual degradation of the Precambrian surface and the covering of these basement rocks and older Paleozoic rocks by younger sediments.

INTRODUCTION

The search for underground reservoirs suitable for storage of natural gas in Minnesota south of the Minneapolis-St. Paul area resulted in the drilling and coring in 1967-68 of a deep stratigraphic test well, the Northern Natural Gas Company's Hollandale No. 1 (fig. 1), about 2 miles east of Hollandale, Minnesota, in SE ¼, SE ¼, SW ¼, sec. 7, T. 103 N., R. 19 W., in Freeborn County.

Basic requirements for the underground storage of gas include (1) a doubly plunging anticline having adequate closure, (2) rock layers having sufficient porosity and permeability to serve as a reservoir for the gas, (3) an impermeable cap rock overlying the reservoir, and (4) the absence of open faults or joints in the cap rock that would allow escape of the gas. It has been assumed that structures suitable for storage in southeastern Minnesota are most likely to occur on the steep flanks of the Midcontinent Gravity High. It is probable that Paleozoic bioherms have not produced adequate domed structures. Hence, in Minnesota, Paleozoic isostatic adjustment along the Midcontinent Gravity High is the most likely cause of large domal structures. The porous St. Peter Sandstone of Ordovician age and the Mt. Simon Sandstone of Cambrian age (fig. 2)

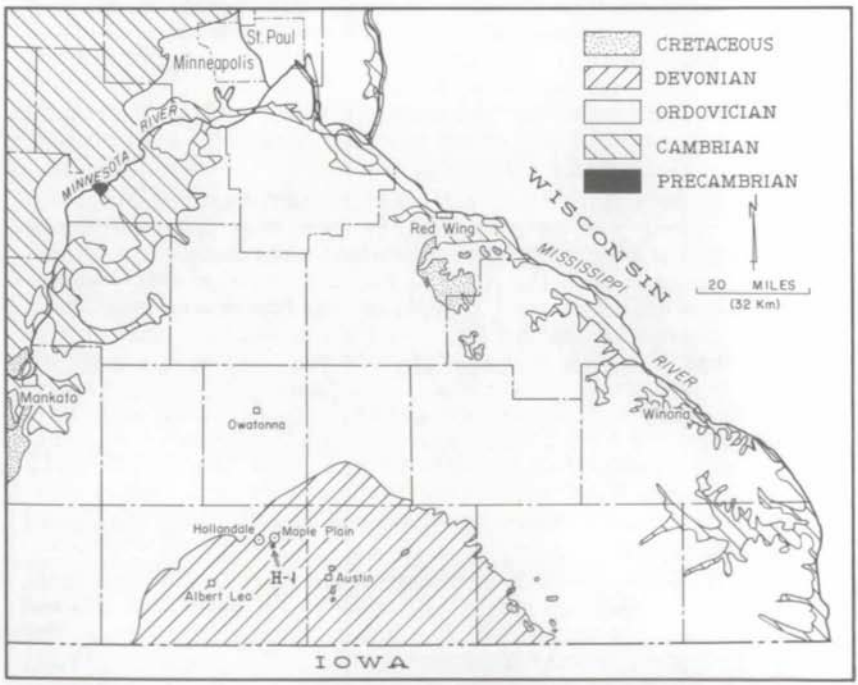


Figure 1 — Generalized geologic map of southeastern Minnesota showing the location of Hollandale No. 1 well.

SYSTEM	SERIES	GROUP	FORMATION	MEMBER
QUATERNARY	Pleistocene			
CRETACEOUS	Upper		Windrow	Ostrander
				Iron Hill
DEVONIAN	Middle		Cedar Valley	Solon
ORDOVICIAN	Cincinnatian		Maquoketa	
	Champlainian		Dubuque	
			Galena	Stewartville
				Prosser
				Cummingsville
			Decorah	
			Platteville	Carimona
				McGregor
				Pecatonica
			Glenwood	
			St. Peter	
	Canadian	Prairie du Chien	Shakopee	Willow River
			Oneota	
CAMBRIAN	St. Croixan		Jordan	
			St. Lawrence	Black Earth
			Franconia	Tamah
				Birkmose
			Ironton	
			Galesville	
			Eau Claire	Sandy Unit Shaly Unit Greensand Unit Red Unit
			Mt. Simon	
KEWEENAWAN			Red Clastics	"Type 3"

Figure 2 — Stratigraphic classification used in this report.

potentially are suitable as reservoir rocks for gas storage. The sedimentary rock units most likely to form an adequate cap rock are (1) the Decorah Shale above the St. Peter-Glenwood-Platteville sequence and (2) the Eau Claire Formation above the Mt. Simon Sandstone. The Decorah is restricted geographically to the center of the structural lowland in southeastern Minnesota and the center of the Twin City Basin and probably is too shallow to serve satisfactorily as a cap rock. Accordingly, most of the search for a suitable cap rock to date has involved the Eau Claire Formation; however, the shales in this unit are interbedded with sandstone and the formation seems to be permeable vertically.

The ground elevation at the drill site is 1,201.98 feet above sea level and all footages in this report are given in feet below the surface. The initial hole, H-1, begun on October 24, 1967, was drilled to a depth of 725 feet, where a bit became stuck, forcing abandonment. A second hole, originally called H-1A, was started 20 feet away from H-1 and drilled to a depth of 1,905 feet. The cores from these two holes were later combined and are identified now as from Hollandale No. 1, or H-1. The interval from 0 to 212 feet was not cored in H-1, and the interval from 470 to 532 feet did not core well and only cuttings were taken from these two sections. Coring began in H-1A at 1,005 feet; consequently, only cuttings are available for the interval from 725 to 1,005 feet.

As this is the first cored well that has penetrated the Precambrian rocks in this part of southeastern Minnesota, a study of the lithic units penetrated here provides useful detailed information about the succession of strata in this region and about lateral changes that occur between the well and outcrop areas mainly to the east and north. The vertical and lateral changes in sorting, grain size, and mineralogy of the clastic particles in the sedimentary rocks of southeastern Minnesota are taken as indicative of relative changes in the depth of the Paleozoic sea and the nearness to shore. Furthermore, the vertical repetition of changes of the various sedimentary rock types provides a means whereby the sedimentary cycles proposed in this report can be identified.

GEOLOGIC SETTING

The Hollandale hole was drilled near the center of a depositional lowland that extends northward from the ancestral Forest City Basin into southeastern Minnesota (fig. 3). That part lying within southeastern Minnesota and western Wisconsin has been designated the Hollandale embayment (Austin, 1969). The Hollandale embayment is bordered on the west and north by the Transcontinental Arch, on the northeast by the Wisconsin Dome, and on the east by the Wisconsin Arch. The only major Paleozoic nearshore deposits are preserved

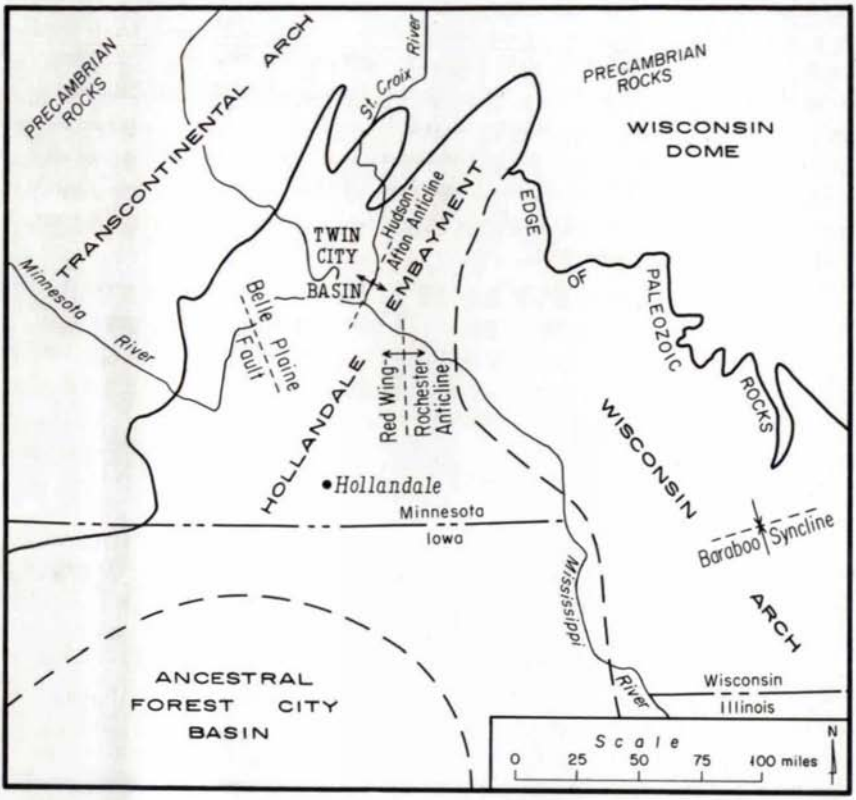


Figure 3 – Map showing the location of the Hollandale embayment and other structural features in Minnesota, Wisconsin, and Iowa.

on the Wisconsin Arch; post-Paleozoic erosion has removed correlative units to the north and west. The embayment is superimposed upon more restricted Precambrian structures, such as the River Falls syncline and the St. Croix horst in eastern Minnesota, western Wisconsin and central Iowa, which contain Keweenawan sedimentary and extrusive rocks and are cut by large-scale Precambrian faults (G.B. Morey, oral comm., 1969). Post-Precambrian movements along these faults produced relatively minor, but nevertheless significant, disruptions in the embayment – such as the Hudson-Afton anticline and the Belle Plaine fault – which have affected the thin but widespread Paleozoic shallow-water shelf deposits. The smaller basinal depressions within the embayment have been formed as a result of irregularities on the underlying

Precambrian surface. Only a few, such as the Twin City Basin, have been specifically named.

The surface of the Precambrian rocks is depressed within the Hollandale embayment. In southwestern Minnesota, on the Transcontinental Arch, the Precambrian surface ranges in altitude from 700 to 1,750 feet above sea level. At the Hollandale well, near the center of the embayment, the same surface is at an altitude of about 420 feet below sea level. East of the embayment, at Winona along the Minnesota-Wisconsin border, Precambrian rocks are penetrated at an altitude of 155 feet above sea level.

Although the Paleozoic rocks are nearly flat-lying in the center of the embayment, bedding in the underlying Red Clastic Series of Precambrian age (Kirwin, 1963) in the Hollandale hole is inclined at least 45° and in many places is vertical with respect to the core axis, indicating deformation prior to the deposition of the Upper Cambrian sedimentary rocks.

STRATIGRAPHY AND DEPOSITIONAL ENVIRONMENT

The following is a description of the stratigraphy and inferred environment of deposition of the rocks in the Hollandale area as determined from the cuttings and core. The stratigraphic succession, together with geophysical logs for H-1, is illustrated in Figures 4a and 4b. The relatively minor lateral lithologic changes within the early Paleozoic rocks of the upper midwest permit thin lithic units to be traced for hundreds of miles (Berg, Nelson, and Bell, 1956; McGannon, 1960). Consequently the lithology of the core has been compared with outcrops of the correlative rocks in order to postulate depositional environments.

Quaternary System

The bedrock in the Hollandale area is covered by approximately 70 feet of Pleistocene glacial drift. The drift is composed of a lower interval of about 10 feet of sandy gravel overlain by about 60 feet of gray, silty, calcareous till.

Cretaceous System

Windrow Formation

Some pink and white quartz pebbles are associated with weathered pieces of carbonate rock in the cuttings taken at a depth of 70 feet in H-1. The pebbles were derived from a thin layer of the Windrow Formation, which lies just below the drift.

Nonmarine rocks of Cretaceous, and perhaps Tertiary, age (Bleifuss, 1966), cover much of southeastern Minnesota in thin discontinuous beds that lie disconformably on rocks ranging in age from Cambrian to Devonian. The lower member of the Windrow Formation, the Iron Hill Member, is composed of a

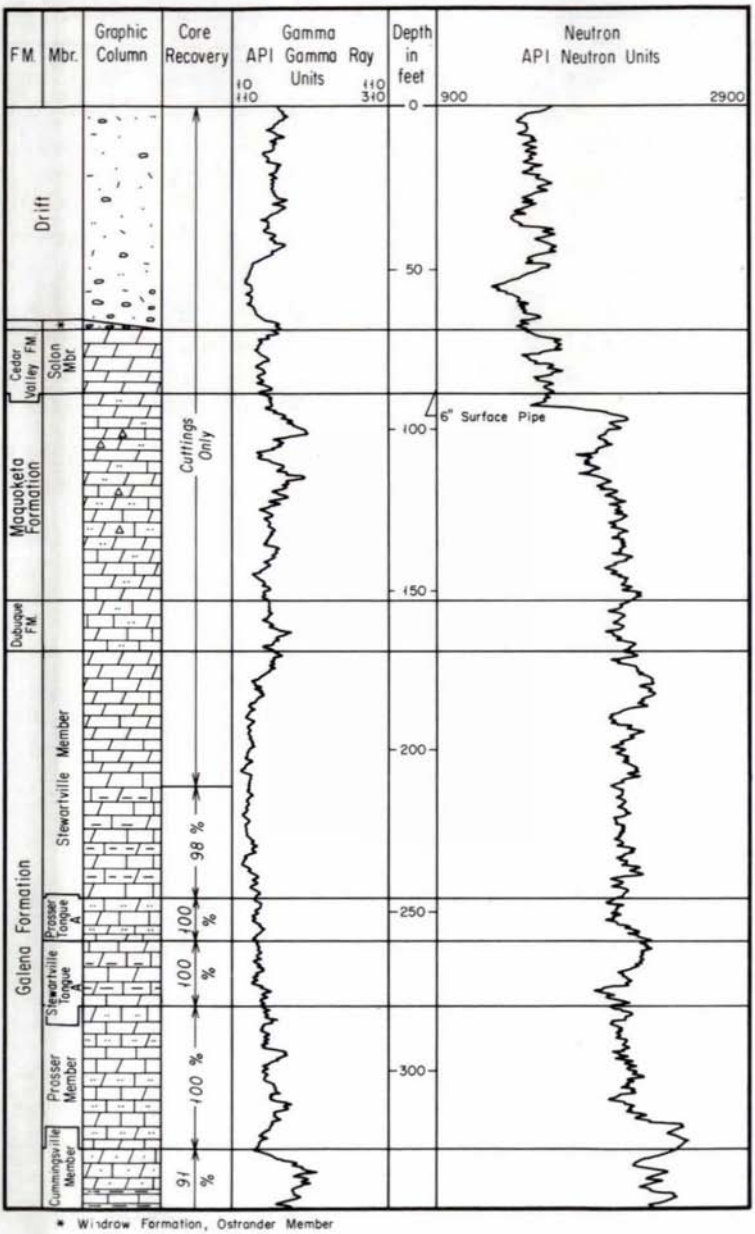
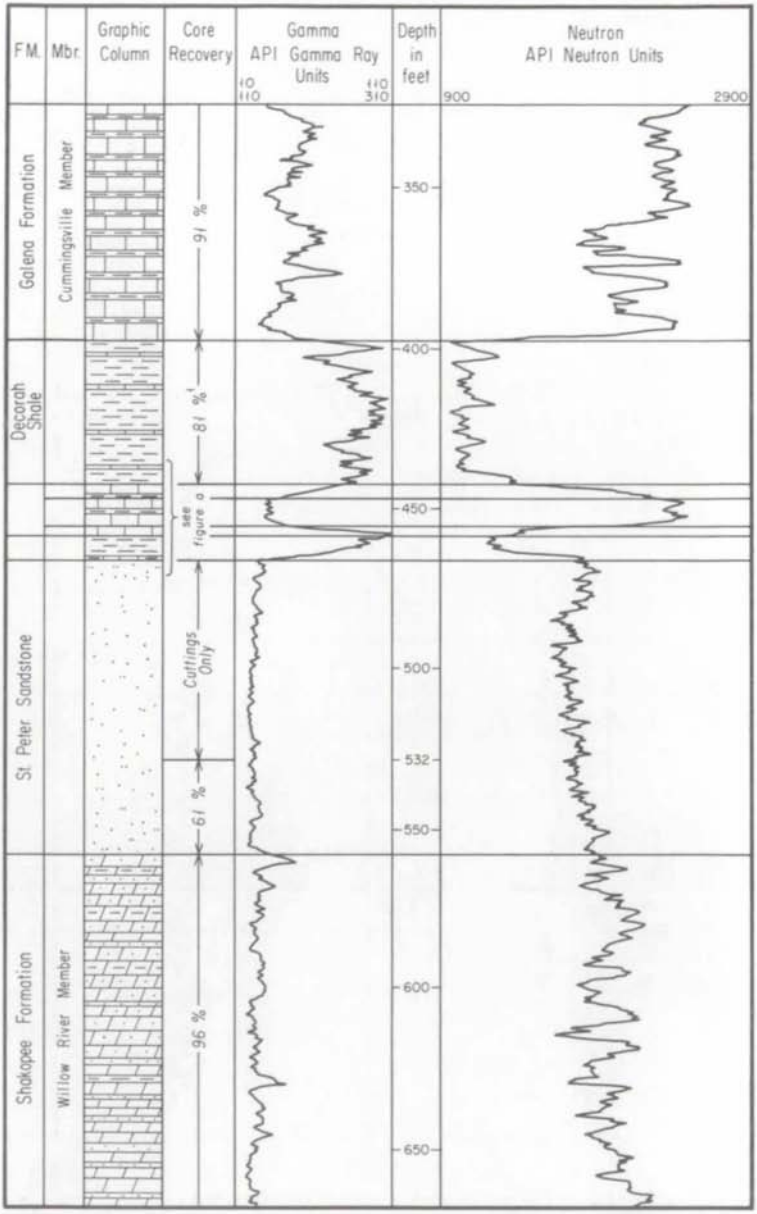


Figure 4a– Graphic column, core recovery, and geophysical logs, Hollandale No. 1 well.



[1] Some of core (20 %) removed before core was delivered to M.G.S.

Figure 4a continued

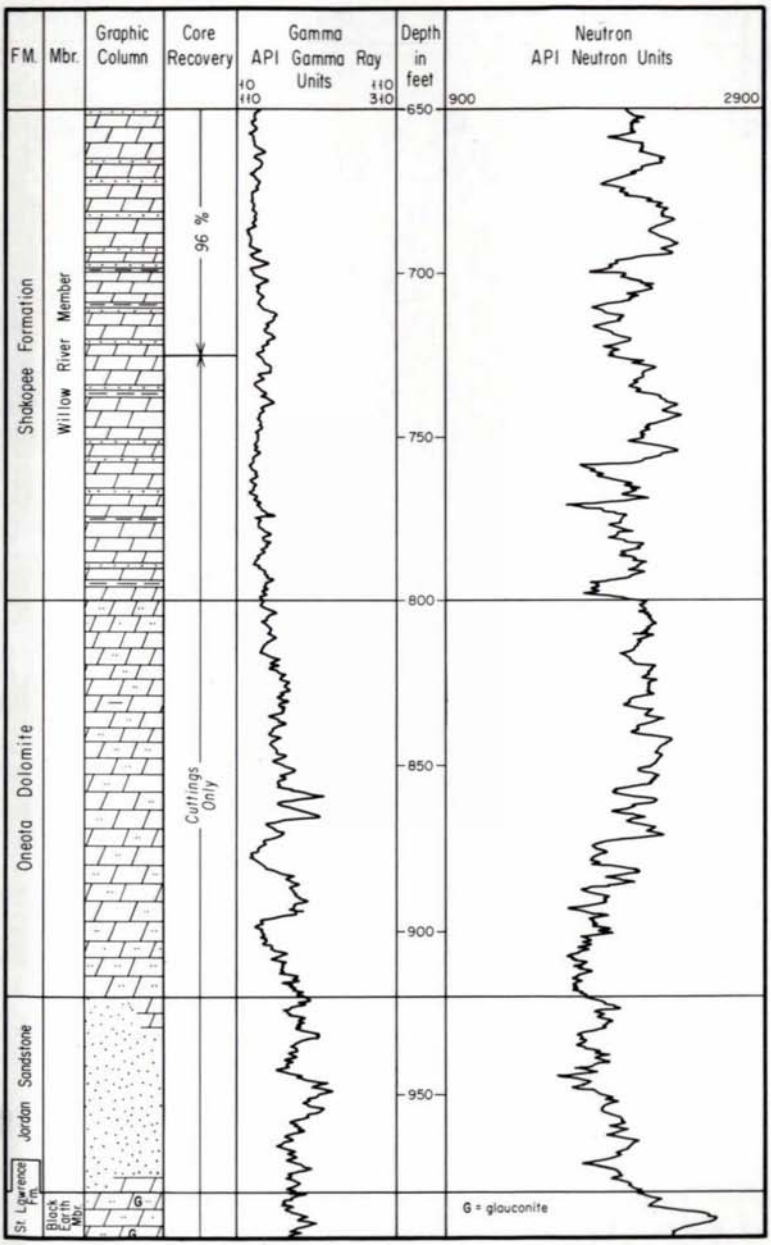


Figure 4a continued

HOLLANDALE TEST WELL

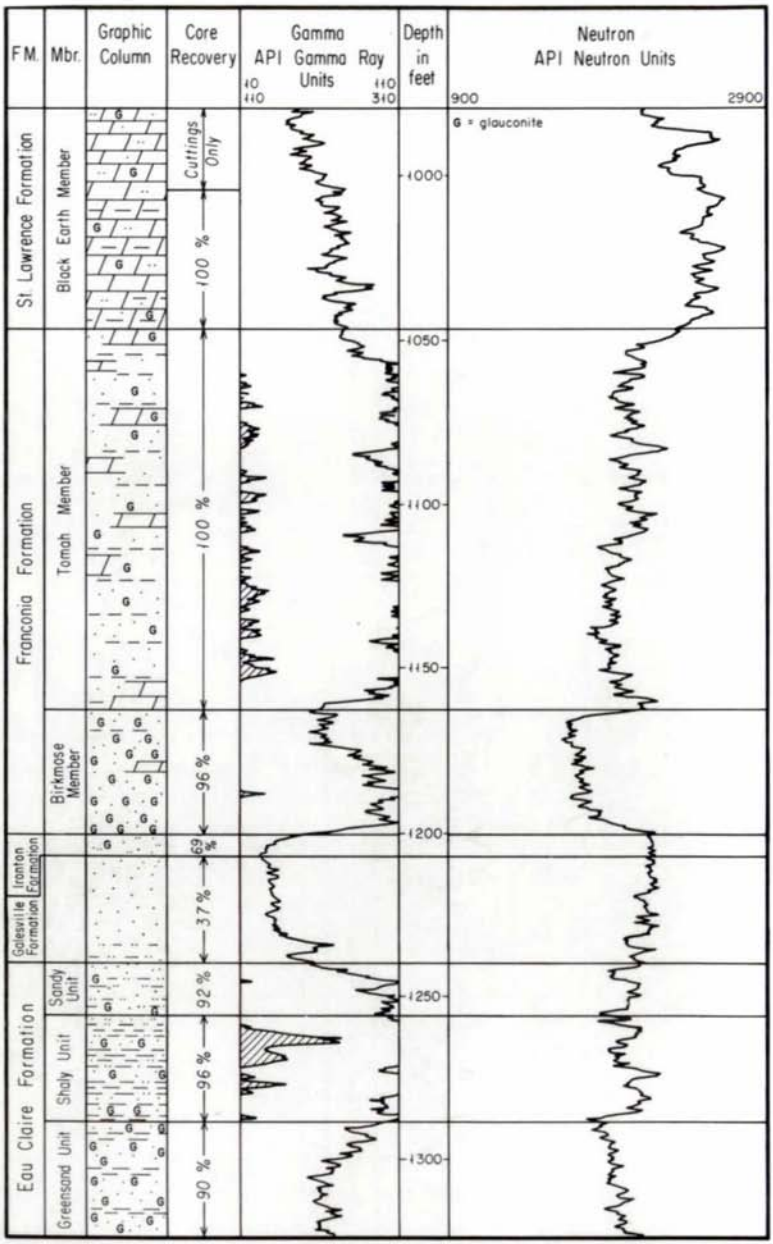
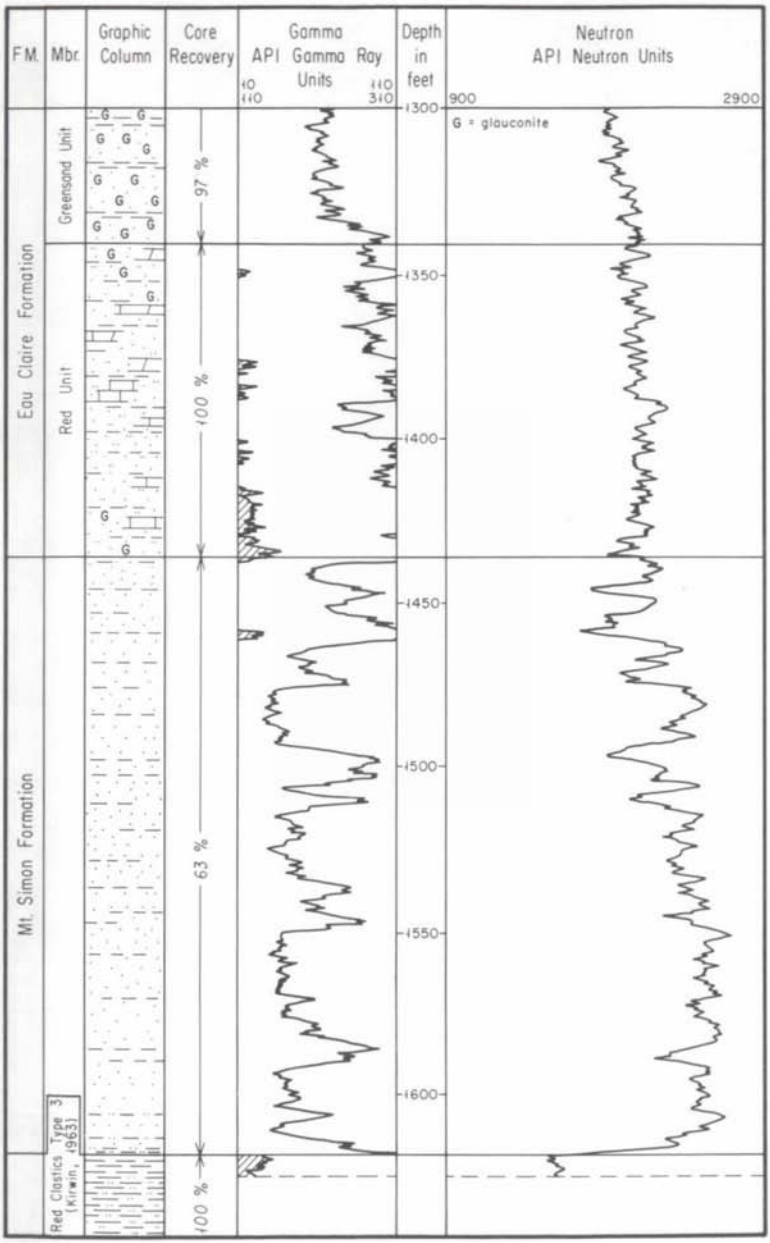


Figure 4a continued



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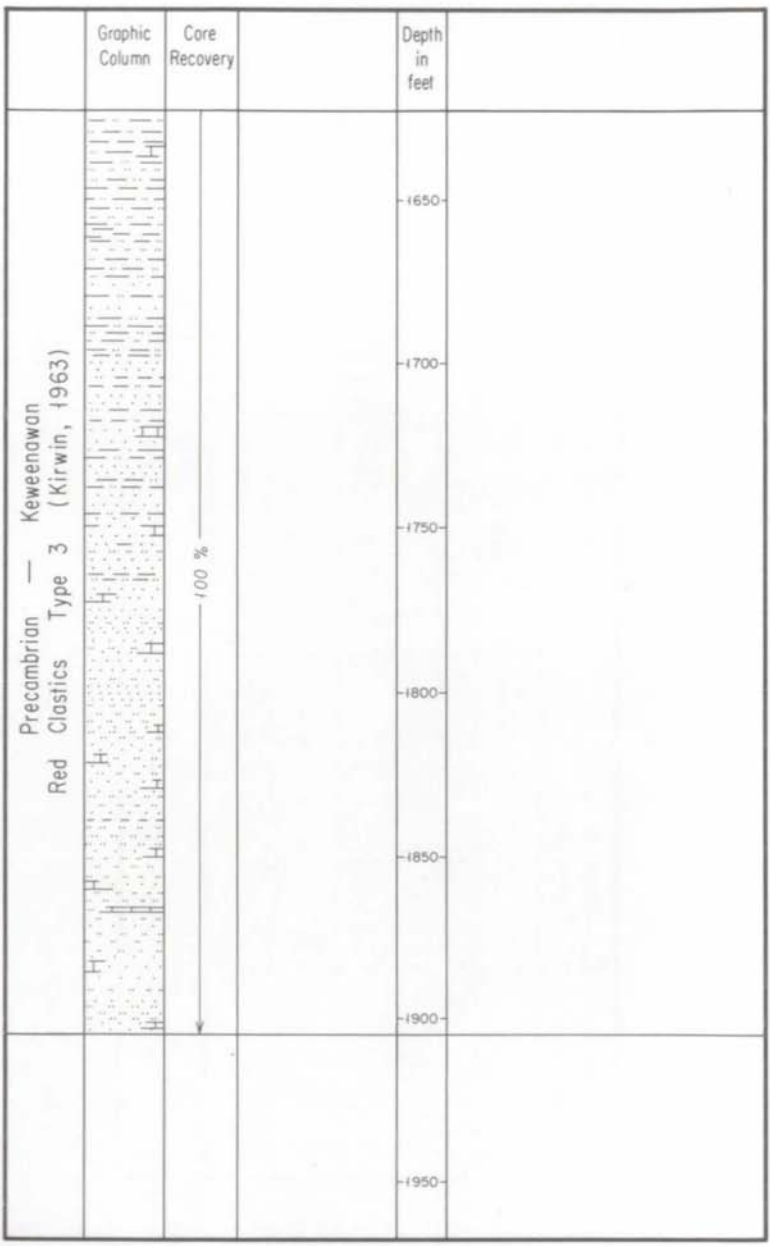

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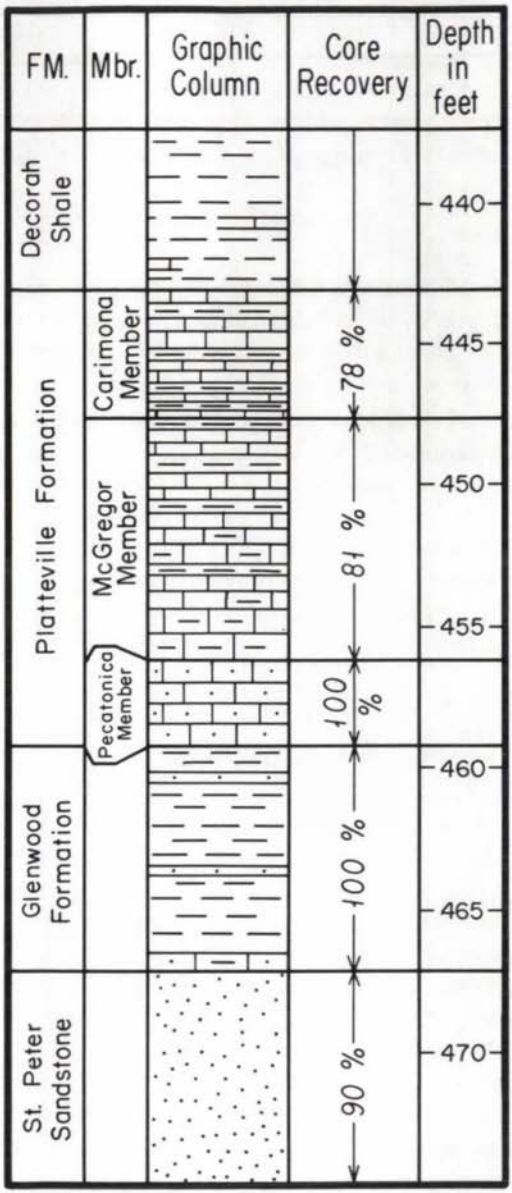

Figure 4b– Enlarged graphic column and core recovery of the thin Glenwood and Platteville Formations.

residual layer of iron oxide, ferruginous clay, and insoluble debris from Paleozoic formations (Andrews, 1958; Austin, 1963). Above the Iron Hill Member is the Ostrander Member of the Windrow Formation, which contains interbedded clays, friable sandstones, and ferruginous gravels with rounded chert and white and pink quartz pebbles that probably were deposited by anastomosing streams near the margin of the Cretaceous sea.

Devonian System

Cedar Valley Formation

The Cedar Valley Formation, composed of a light-colored, silty dolomite, was intersected at depths of between 70 and 90 feet in the Hollandale hole. The altitude of the lower contact is accurate only to ± 10 feet because of the 10-foot sample intervals in the cuttings.

The Cedar Valley Formation was deposited in a marine basin that covered the upper midwest during late Middle Devonian time (Collinson and others, 1967). The sediment was deposited in a shallow sea under slightly reducing conditions (Kohls, 1961). As the sea transgressed across the flat erosion surface, debris from the underlying Maquoketa Formation of Ordovician age was incorporated into the basal part of the unit. Because very little non-Maquoketa debris is present in the basal Cedar Valley, it is probable that the Cedar Valley sea advanced over a tectonically stable land mass with very low relief (Kohls, 1961).

Ordovician System

Maquoketa Formation

The Maquoketa Formation, at depths from 90 to 154 feet, is a gray or light gray, silty, sandy, limy dolomite that underlies the Cedar Valley Formation. The basal part was deposited in a lagoonal or basinal environment in which circulation periodically was restricted (Bayer, 1965). This restricted environment was succeeded by an open shelf carbonate environment during deposition of the middle part of the formation. The upper part of the Maquoketa in Minnesota is dolomitic, and Bayer (1965) states that dolomitization occurred shortly after deposition, probably under periodic conditions of shoaling, restricted circulation, and subsequent increase in salinity. The sandy Maquoketa dolomite in the Hollandale hole probably represents Bayer's "Lithosome IV" and is a nearshore facies. The sand probably was washed or blown into the shallow Maquoketa sea from a source to the west (Bayer, 1965).

Dubuque Formation

The Dubuque Formation lies 154 to 170 feet below the surface in H-1, and is an argillaceous dolomitic limestone. The contact between the Dubuque and

the underlying formation probably is slightly above 170 feet because cuttings from 163 to 170 feet contain some white dolomite typical of the Stewartville Member of the Galena Formation.

Judging from the intercalated limestone and shale in the outcrops of the Dubuque Formation, the muds that formed the unit originated both from within the basin and from the adjacent upland surfaces. The Dubuque is interpreted to have been deposited in an environment with cyclic alternations between intervals of low-energy and low-terrigenous influx and intervals of higher energy and higher terrigenous contributions.

Galena Formation

The Galena Formation is divisible into three members (Weiss and Bell, 1956; Weiss, 1957), which in ascending order are the Cummingsville, the Prosser, and the Stewartville. The formation is 229 feet thick in H-1 and is present at depths from about 170 to 399 feet below the surface.

The Galena Formation was deposited on a shallow marine shelf. Terrigenous components decrease upward in the formation, while at the same time the depositional environment changed from one of higher energy at the base to one of lower energy toward the top of the formation. However, there were minor reversals in these trends, as shown by the intertongued Prosser and Stewartville Members in the Hollandale No. 1 hole (fig. 5).

The *Cummingsville Member* of the Galena Formation, intersected between 325 and 399 feet in H-1, is a gray or green, fine-grained limestone that contains interbeds of grayish-green calcareous shale. The contacts between the shale and limestone beds within the member are generally sharp, but the bedding is irregular. In H-1 the base of the unit is placed below the lowest non-coquinoid limestone and above the thick shale beds of the Decorah Shale. The clay minerals in the shales both above and below this contact are composed essentially of illite, indicating little change in climates or source areas from Decorah to Galena time insofar as can be determined from the terrigenous materials. The Cummingsville is fossiliferous and contains coquinas and corrosion zones indicative of deposition in relatively shallow water. Cyclic fluctuations between shale and limestone are thought to be indicative of the fluctuation of relatively nearshore currents.

The *Prosser Member* of the Galena Formation, a light-gray, silty, dolomitic allochemical limestone, with current structures and carbonate intraclasts, is divided into two sections in H-1 by a yellowish-gray dolomitic limestone unit with Prosser lithology, typical of the lithology of the overlying Stewartville member of the Galena Formation. The upper section, from 245.4 to 260.9 feet, is identified as Prosser Tongue A, whereas the lower section, from 280.9 to 325 feet, is identified as the Prosser Member of the Galena. It is obvious from the

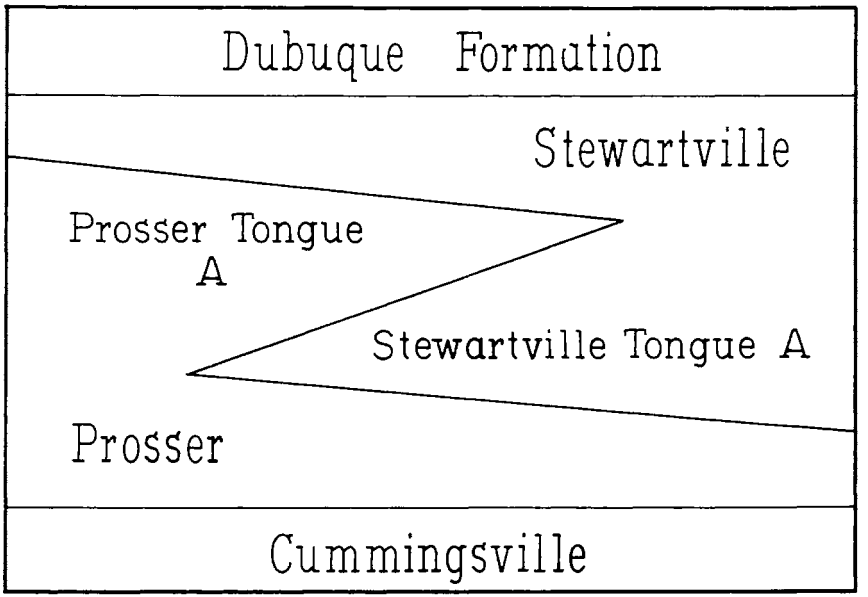

Figure 5 – Intertongued relationship between Stewartville and Prosser lithologies in H-1.

intertonguing of the Prosser and Stewartville Members of the Galena (fig. 5) that the members represent lithosomes which were forming concurrently in different parts of the Galena sea.

The *Stewartville Member* of the Galena Formation, a yellowish-gray to pale-orange dolomite or dolomitic limestone, is a vuggy, mottled, and recrystallized orthochemical carbonate rock in H-1. The upper contact is placed at approximately 170 feet and the lower at 245.4 feet. Another interval of core between 260.9 and 280.9 feet, which is lithologically indistinguishable from the Stewartville core between 212 and 245.4 feet and therefore also is considered to be Stewartville, is herein identified as Stewartville Tongue A. The intervening interval is identified as Prosser Tongue A of the Galena Formation.

Decorah Shale

The Decorah, at depths of 399 to 443 feet, is a greenish-gray,fissile shale with some interbeds of coquinoid limestone, particularly near the top. The base of the formation is in Minnesota arbitrarily placed at the contact between the last non-coquinoid carbonate bed of the underlying Platteville and the first

massive shales of the overlying Decorah. A study of the mineralogical composition of the clay-sized fraction of the shale was published previously as a part of a regional study of the Decorah Shale (Parham and Austin, 1969), and a summary of data from the H-l core is included in the Appendix.

The Decorah Shale was deposited during a transgressive phase of the Ordovician sea (Parham and Austin, 1969). Clay-mineral assemblages within the shale vary vertically from a nearer-shore facies near the base, characterized by abundant kaolinite, to a farther-from-shore facies at the top, characterized by abundant illite. Although the most northerly sections are the thickest, lateral variations of the clay-mineral assemblages indicate that the sediment source and nearest land area during Decorah time was to the southwest of the present Decorah outcrop area in southeastern Minnesota (Parham and Austin, 1969).

The Decorah-Galena succession illustrates cyclic Cambro-Ordovician sedimentation identified by Ostrom (1964) in the Upper Cambrian and Lower Ordovician rocks of the upper midwest. Admixing of sediments derived from both terrigenous and marine sources in Decorah time was gradually succeeded by carbonate sediments derived from within the embayment in Galena time, culminating with the orthochemical deposition of the Stewartville Member.

Platteville Formation

The Platteville Formation, found in H-1 from 443.0 to 459.9 feet, contains three members. In ascending order these are the Pecatonica Member, the McGregor Member, and the Carimona Member. The Platteville Formation is a sandy carbonate rock at the base, a very shaly carbonate rock above, and a relatively pure carbonate rock with interbedded shale at the top.

The source area producing quartz-sand during St. Peter and Glenwood time was submerged shortly after the beginning of Platteville time; and accordingly, the Pecatonica Member is the only sandy unit in the formation. Clay-sized material, which is essentially illite (Rassam, 1967), became the dominant terrigenous component during the deposition of the McGregor and Carimona Members. After an initial period of contemporaneous clay and limy mud depostition, as represented by the lower part of the McGregor Member, clay-sized detrital material was deposited in cyclic fashion during deposition of the upper part of the McGregor and Carimona Members. The interbeds of carbonate rock in these members represent periods during which there was a reduced and cyclic influx of terrestrial material into the basin. The Carimona Member, therefore, was deposited under cyclic conditions in a sea that achieved its maximum transgression within the St. Peter-Glenwood-Platteville sedimentary cycle. Kaolinite near the base of the Decorah Shale in southeastern Minnesota is taken to be indicative of a new depositional cycle with a closer source area than was present during deposition of the Carimona Member.

The *Pecatonica Member* of the Platteville Formation, intersected from 456.0 to 459.9 feet in H-1, is a tan, very sandy, silty, calcilutite that contains corrosion zones at several horizons.

The *McGregor Member* of the Platteville Formation, penetrated from 447.5 to 456.0 feet, is a light olive-gray argillaceous limestone which is calcarenitic at the base and calcilutitic at the top. The limestone is mottled in composition and color near the base as a result of admixed argillaceous material and carbonate rock. Interbedded shale and limestone with distinct to gradational contacts comprise the upper part of the member. The shale beds contain blebs of carbonate surrounded by dark olive-gray illitic shale, which produces the "crinkly" bedding characteristic of the McGregor Member.

The *Carimona Member* of the Platteville Formation, found from 443.0 to 447.5 feet, is a light olive-gray calcilutite with interbeds of darker olive-gray illitic shale. The "Carimona bentonite," which represents a volcanic ash fall, occurs from 447.0 to 447.3 feet in the lower part of the member. The limestone in the Carimona Member is macroscopically indistinguishable from the limestone at the top of the underlying McGregor Member. The shale beds, however, lack the carbonate blebs which produce crinkly bedding.

Glenwood Formation

In Minnesota the Glenwood Formation is predominantly a green fissile shale with some argillaceous sandstone. In H-1 it is found from 459.9 to 467.0 feet and has a thin bed of sandy, shaly limestone at the base below greenish-gray sandy shale. The clay-sized fraction of the Glenwood contains illite and some kaolinite (Parham and Austin, 1969). Vertical changes in clay mineralogy are summarized in the Appendix.

The probable source area for the Glenwood Formation was to the west (Parham and Austin, 1967) and the formation was deposited as part of the transgressive phase of the St. Peter-Glenwood-Platteville cycle. In general, a distant low-lying source area contributed illitic muds to a shallow sea in the Hollandale area during Glenwood time. However, minor reversals of the overall near-shore to far-from-shore deposition within this transgressive cycle are suggested by the presence of limestone at the base of the Glenwood and the sandy Pecatonica Member above the shaly Glenwood.

St. Peter Sandstone

The St. Peter Sandstone, intersected from 467.0 to 558.5 feet, underlies the Glenwood Formation and is a tan, medium-grained to fine-grained silty quartzarenite. Core recovery was poor in the unit and only 2.7 feet of the upper 7.1 feet were recovered. The interval from 474 to 532 feet was not cored and the analysis is based on the study of cuttings. Although the interval from 532 to

558.5 feet was cored, poor core recovery makes it difficult to identify the erosional contact that Ostrom (1965) described at the base of the formation in Wisconsin.

The St. Peter in H-1 is significantly more silty than in exposures farther to the north and east, presumably because of the absence of waves that would have winnowed out the silt-sized material as sand was accumulating. In contrast to the sandstone in the outcrop areas, which was deposited in a relatively high-energy environment at the edge of an advancing sea, in the Hollandale area the sediments in H-1 were deposited in a lower energy environment farther from shore. Silty, fine-grained sandstone at the base of the St. Peter Sandstone, deposited in a retreating sea, overlies the shaly carbonate at the top of the Willow River Member of the Shakopee Formation with little evidence of a disconformity. In addition, there is little oxidation in the hole below the fine-grained silty sandstone near the base of the formation and it seems likely that the Ordovician sea did not retreat from this area after deposition of the Prairie du Chien Group.

Prairie du Chien Group

A predominantly carbonate unit beneath the St. Peter in southeastern Minnesota, the Prairie du Chien Group, consists of the Shakopee Formation above and the Oneota Dolomite below. The New Richmond Sandstone Member of the Shakopee Formation, which separates the Willow River Dolomite Member of the Shakopee Formation from the Oneota Dolomite in extreme southeastern Minnesota, apparently is absent in H-1, but there is some uncertainty because of the mediocre quality of the cuttings at depths between 725 and 1,000 feet.

Rocks of the Prairie du Chien Group were deposited on a shallow marine shelf that existed in the Hollandale area during Early Ordovician time. The Oneota Dolomite, which is silty, was deposited in a relatively deeper water, low-energy environment, whereas the Shakopee Formation, which is sandy and locally oolitic, was deposited in a shallow water, higher energy, environment. Furthermore, it appears that the Shakopee was deposited during a different cycle of sedimentation than that of the Oneota Dolomite (Ostrom, 1964).

Most of the Willow River Dolomite Member of the Shakopee Formation was cored, but toward the bottom of the member a drill bit was lost, forcing abandonment of the initial hole. A second hole was located 20 feet from the first hole, but only the section from 1,005 to 1,905 feet was cored. Therefore, only cuttings are available for the lower part of the Willow River Dolomite, all of the Oneota Dolomite, the Jordan Sandstone, and part of the St. Lawrence Formation below.

Oneota Dolomite

The Oneota Dolomite is a silty dolomite that contains dolomite crystals in a matrix of dolomitic silt. The formation is generally darker in color than the overlying Willow River Dolomite. In H-1 quartz sand and glauconite pellets are present in cuttings only near the base of the Oneota. The quality of cuttings in H-1 decreases with depth, and cuttings from the Oneota-Jordan Sandstone contact are poor; however, the contact was placed at 920 feet, where significant amounts of free quartz sand first appeared. The upper contact was placed at 800 feet, where significant amounts of gray, silty dolomite first appeared in the cuttings.

Shakopee Formation

The *Willow River Member* of the Shakopee Formation in H-1 is a light-colored dolomite with embedded quartz sand grains, interbedded sandstones, and a few thin green shale beds. The member has moldic porosity, contains dolomite intraclasts which form flat-pebble conglomerates, and contains stromatolites; all are indicative of deposition in a shallow-water, high-energy environment (Davis, 1966b). Sulfides, mostly pyrite, are present in some of the cavities in the dolomite. The cored section of the Willow River extends from the upper contact with the St. Peter, at a depth of 561.5 feet, to 725 feet. However, across the interval from 725 to 800 feet, the Willow River Member was analyzed only from cuttings obtained at 10-foot sample intervals.

Cambrian System

Jordan Sandstone

In cuttings from H-1A, the Jordan Sandstone is composed of poorly sorted light-gray sandstone and carbonate rock; the carbonate may be inherent in the Jordan Sandstone or derived from overlying units. If the carbonate in the cuttings is an inherent part of the Jordan, it indicates deposition in deeper water than of that in outcrop, a depositional pattern similar to that for the St. Peter Sandstone. The sand is poorly sorted, which is atypical of the Jordan and indicative of deposition in a relatively deep water, low-energy environment. The base of the Jordan Sandstone was placed at 980 feet, where glauconitic dolomite occurs in the cuttings and where there is a marked break in lithology, as indicated by the neutron log.

St. Lawrence Formation

The *Black Earth Member* of the St. Lawrence Formation, penetrated from about 980 to 1,047 feet, comprises the entire formation in H-1. It is a pinkish-gray glauconitic dolomite that contains thin shale beds, numerous flat-pebble conglomerates, and trace amounts of quartz sand. Sparse scattered chalcopyrite

and pyrite occur in some cavities. The lower contact of the St. Lawrence is placed above the sandy dolomite of the upper Franconia and below dolomite of the St. Lawrence, which contains trace amounts of quartz sand.

The St. Lawrence Formation is an allochemical carbonate rock that was deposited on a shallow marine shelf far removed from land. Although clay-sized material from terrestrial sources was deposited intermittently, current activity in the sea was sufficiently strong to develop thin bedding and flow structures in the carbonate. However, flat-pebble conglomerates containing carbonate intraclasts indicate occasional high-energy periods which most likely developed during storms.

Franconia Formation

The nomenclature for the Franconia Formation used herein is the same as that used previously by Berg (1954) except for his Woodhill Member. Berg (1954) introduced the name "Woodhill" because he believed that the previously accepted name "Ironton" was tied too closely to the *Elvinia* fossil assemblage. This interpretation has been proved erroneous and "Ironton" now is the commonly accepted name for this lithic unit (Buschbach, 1964; Emrich, 1966; Ostrom, 1967; Austin, 1969). The Franconia Formation, as defined, and the Ironton Formation together comprise the Franconian biostratigraphic stage.

The Franconia occurs in H-1 from 1,047.0 to 1,200.6 feet. Two members are present, the underlying Birkmose Member, a highly glauconitic worm-bored sandstone, and the overlying Tomah, composed of interbedded sandstone and shale with some dolomite.

Berg (1954) established the nomenclature for the Franconia Formation from exposures along the St. Croix and Mississippi Rivers and in Wisconsin east of the central part of the Hollandale embayment. The lithologies in H-1 differ somewhat from those given by Berg in the type area. The Tomah Member, described by Berg, consists of interbedded fine-grained sandstones and micaceous shales, but in H-1 it also contains some dolomite beds, particularly near its top and bottom. The Tomah is non-glauconitic along the eastern border of Minnesota but it becomes moderately glauconitic to the west in the subsurface. The "Birkmose Member," which is locally worm-bored, is restricted in use herein to those glauconitic greensands, without beds of dolomite, which lie beneath the Tomah Member. Berg (1954) identified the conglomeratic dolomite above the Birkmose greensand, herein described as the lower part of the Tomah, as the upper part of the Birkmose. In H-1 this dolomite is 8.0 feet thick and contains some shale and sandstone beds. Further, dolomite is not restricted to this bed but is present in several other layers in the Tomah which are macroscopically similar. The dolomite beds within the Tomah above contain glauconite, as does the dolomite in question in H-1. Accordingly, this lower

dolomite has been designated as the lowest unit within the Tomah Member, and the Birkmose in H-1 is identified as a greensand with little or no carbonate (Austin, 1969).

The *Birkmose Member* of the Franconia Formation, present from 1,164.5 to 1,200.6 feet, is a highly glauconitic, fine-grained sandstone. The uppermost 2.3 feet are slightly dolomitic and, as a result of oxidation of some glauconite grains, have a mixed dark reddish brown and green color. Much of the member is worm-bored and lacks bedding; however, a few thin, light-green, silty shale layers are present.

The *Tomah Member* of the Franconia Formation, which is present from 1,047.0 to 1,164.5 feet, is a fine-grained to very fine-grained sandstone that contains authigenic orthoclase (Berg, 1954); some olive-green shale interbeds are also present in this interval. The sandstone is grayish yellow to very light gray and is glauconitic. The glauconite is very fine-grained and angular in the interval from 1,047 to 1,110.0 feet, whereas it is medium-grained to fine-grained and subrounded in the interval from 1,110.0 to 1,164.5 feet. Soluble carbonate averages 10 percent in the Tomah, excluding the top and bottom few feet, where sandy glauconitic dolomites occur. Thin beds with a high dolomite content are more common above 1,110.0 feet, as are thin shale beds. Flat-pebble conglomerates composed of intraclasts of sandy dolomite are restricted to the thin dolomite beds at the top and bottom of the unit.

Ironton Sandstone

The Ironton Sandstone is a moderately well-sorted to poorly-sorted, medium-grained, light-gray, quartzose sandstone that has trace amounts of glauconite, particularly at its top. The lower part of the Ironton and the upper part of the underlying Galesville Formation did not core well and the core from 1,205.0 to 1,232.0 feet was lost.

The Ironton was deposited in a relatively low-energy environment. The silty character of the top of the formation is indicative of the lack of strong currents, in contrast to the higher energy Galesville Formation below. Berg (1954) and Berg, Nelson, and Bell (1956) have suggested that the Ironton was deposited by a sea transgressing over a low sandy plain. Ostrom (1964), on the other hand, has suggested that the Ironton was formed during the Galesville-Ironton-Franconia-St. Lawrence sedimentary cycle and that it is a nearshore shelf deposit which lies above the beach-nearshore deposits of the Galesville. The change upward from well-sorted sandstone to poorly-sorted sandstone supports Ostrom's hypothesis.

Galesville Sandstone

The Galesville Sandstone, together with the other members of the former Dresbach Formation, has been changed to formational status because of its

lateral persistence and considerable thickness (Austin, 1969). The Galesville in H-1 is a light-gray, interbedded, fine-grained and medium-grained quartzose sandstone. The contact between it and the underlying Eau Claire Formation is placed just below the lowest medium-grained sandstone bed, which occurs in H-1 in the interval between 1,240.1 and 1,240.3 feet. The contact between the Galesville and the overlying Ironton Sandstone is placed just below the first silty sandstone beds of the Ironton. Because of the absence of core from 1,205.0 to 1,232.0 feet, this upper contact is placed at 1,207.0 feet on the basis of a marked break at that point in the gamma log.

The lower part of the Galesville Sandstone was deposited in a higher energy environment than that of the underlying Eau Claire Formation. The recessional relationship of the lower part of the Galesville and the Eau Claire is indicated by a progressive and gradual change upward from the fine-grained sandstone of the upper Eau Claire to the interbedded fine- and medium-grained sandstone of the lower Galesville to the well-sorted medium- and fine-grained sandstone of the upper Galesville. The upper Galesville, therefore, represents the highest energy lithosome of the Galesville-Ironton succession. In western Wisconsin, on the Wisconsin Arch, medium-grained upper Galesville Sandstone lies disconformably on fine-grained Eau Claire Sandstone (Ostrom, 1966), indicating that the sea had entirely withdrawn from the area. In the Hollandale area, however, the lower part of the Galesville is present, indicating that the sea had not withdrawn completely from this part of the Hollandale embayment during the time of lower Galesville deposition. Here, fine-grained shaly sandstone typical of the upper part of the Eau Claire Formation is interbedded with well-sorted, cross-bedded, fine-grained sandstone typical of the sandy unit of the Eau Claire Formation, and with minor medium-grained, well-sorted sandstone typical of the upper part of the Galesville. The lower part of the Galesville is, therefore, regressive, with a change upward from primarily fine-grained, occasionally shaly sandstone to primarily medium-grained, well-sorted sandstone. The upper part of the Galesville is transgressive, with a change upward from primarily medium-grained, well-sorted sandstone to the primarily medium-grained, silty, moderately well-sorted to poorly-sorted sandstone of the Ironton.

Eau Claire Formation

The Eau Claire Formation is subdivided into informal lithic units having transitional contacts because their lateral extent is largely unknown. The lowest unit contains red silty sandstone, which is commonly worm-bored, and some interbedded red-to-green shale. This so-called "red unit" has been identified along the western edge of the Hollandale embayment in well cuttings (Stauffer, 1927; Stauffer and Thiel, 1941; Berg, Nelson, and Bell, 1956). A second lithic unit consists primarily of glauconitic sandstone and is identified herein as the

"greensand unit." A third unit contains interbedded shale and fine-grained sandstone and is identified as the "shaly unit." The fourth, and highest, unit is composed of fine-grained sandstone with some interbedded grayish-green shale and is identified as the "sandy unit."

Because of the red coloration and worm-bored nature of the lowest Eau Claire, deposition is interpreted to have taken place in a shallow sea, which may have mostly withdrawn to the east at or near the beginning of Eau Claire time. The sea later transgressed over the red mud and sand that had been deposited at or near the strand line. Numerous brachiopod fragments and cross-bedding within some beds in the overlying greensand unit are indicative of deposition in a relatively high-energy environment. The sand and mud flats were continuously covered by marine water after deposition of the "red unit", as shown by the decrease upward of oxidized material. Current activity was low, as shown by the paucity of cross-bedding in the third or "shaly unit". The fourth unit, composed of interbedded fine-grained sandstone and shale, is unoxidized and undisturbed by mud-eating worms. In summary, the Eau Claire Formation was deposited in a transgressing sea with a concomitant reduction of current activity from the lowest to the third lithic unit. The vertical change from the third or "shaly unit" to the uppermost or "sandy unit" represents recessional deposition coupled with an increase in current activitv.

Mt. Simon Sandstone

The Mt. Simon Sandstone, which is penetrated between 1,437.0 and 1,619.0 feet, is dominantly a medium-grained quartzose sandstone but has some coarse-grained beds of white, gray, or purple sandstone and, particularly near its top, some thin greenish-gray or purple shale beds. The bottom 100 feet did not core well and the descriptions of this part of the core are based on about 50 percent recovery. The quartz sand is moderately well sorted but contains some siderite grains that have been altered to iron oxide, particularly near the base of the sandstone. The contact between the Mt. Simon and the underlying Precambrian sedimentary rocks is sharp and is marked by a thin quartz-pebble conglomerate. The lower 50 feet of the formation in H-1 is very silty and is poorly sorted.

The Mt. Simon is interpreted to have been deposited in a shallow-water high-energy environment. Fine-grained particles were winnowed out by strong currents. The thin grayish-green shale beds interbedded with the dominant well-sorted sandstones of the upper Mt. Simon are indicative of abrupt changes in sedimentation; possibly the shale beds represent the fine fraction that was deposited in sheltered areas, such as in irregular pockets developed on the sandy Mt. Simon bottom, or were the result of an influx of terrigenous argillaceous material after storms on the source areas. At the contacts with the sandstone the

shale is red, indicating that oxidizing waters moved through the sediment after deposition. The basal Mt. Simon contains yellow silt, which indicates a marked change from the environment in which the underlying Precambrian rocks were oxidized to hematite. Several minor erosional breaks occurred during the deposition of the basal part of the Mt. Simon, as shown by the cyclical repetition of beds with sharp upper contacts, composed of red, highly-cemented sandstone grading downward into white weakly-cemented sandstone. The sea repeatedly advanced, retreated, and re-advanced during Mr. Simon time. The siderite and grayish-green shale beds in the Mt. Simon above the basal yellow, silty sandstone are indicative of reducing conditions in a subaqueous depositional environment. Oxidation of the siderite and bounding layers of the shale beds to red hematitic clays occurred after deposition of the Mt. Simon and possibly at the time of deposition of the lower unit of the Eau Claire, which also contains red oxidized material. This is considered indicative of a change from reducing to oxidizing conditions within the sediment itself and of probable uplift of the sediments above sea level.

KEWEENAWAN SYSTEM

Rocks of the Red Clastic Series were intersected from 1,619.0 to 1,905.0 feet in the core. In contrast to the flat-lying Paleozoic rocks, the beds dip from 45° to 90° with respect to the core axis and are interpreted as having been deformed by both penecontemporaneous and post-depositional tectonic movements in the area of H-1. The "red clastics" are representative of Kirwin's (1963) "Type 3" sediments. The upper part of the sequence is composed mainly of silty shales; the lower part contains intercalated fine-grained argillaceous sandstone and shale. The rock color varies from a bright red at the top to a bluish gray at the base, indicating oxidation of the topmost beds of the "red clastics". A later reducing environment changed some of the bright-red shale at the top to a bright green along numerous slickensided surfaces and rounded spots in the core. The unit shows evidence of at least two episodes of fracturing, the first set of which is cemented by white calcite. Small-scale faults are particularly abundant toward the bottom of the hole, as are some small clastic dikes in which clayey sandstone intrudes other sediments. Several thin beds containing limestone, which has not been reported previously from the "red clastics", are present. Probably the "red clastics" were deposited in a deltaic nearshore environment.

SUMMARY OF THE PALEOZOIC DEPOSITIONAL ENVIRONMENT

Cyclic sedimentation in the Cambro-Ordovician rocks on a regional scale has been identified in the upper Mississippi valley by Ostrom (1964). The extension of this regional principle to Minnesota, and specifically to the Hollandale area, is useful in delineating the depositional environment of the rocks penetrated in H-1 (fig. 6).

Four recurrent lithotopes characterize the per-Cincinnatian sedimentary rocks of the upper Mississippi valley (Ostrom, 1964): (1) A quartzarenite lithotope consisting essentially of a monomineralic sandstone that contains rounded, sand-sized quartz grains and generally has less than five percent other constituents. The sand generally is medium-grained and fine-grained, although locally it is coarse-grained or very coarse-grained; cross-bedding is common. Clay, silt, and very fine sand as well as fossils are rare or absent. This lithotope developed from the progradation of continuous coalescing beach and near-shore sands that migrated over a shallow marine shelf. Overlying the quartzarenite lithotope is (2) a mixed poorly-sorted lithotope that is generally a coarse-grained, somewhat calcareous, distinctly bedded sandstone lithotope with silt, clay, and fine sand present as matrix material. Fossils are common, especially near the top of the lithotope, and consist of burrows, or trails, and less commonly of brachiopod shell fragments and casts and molds of trilobites. The poorly sorted lithotope is considered to have been deposited in a more seaward environment in contrast to the high-energy quartzarenite lithotope. As such, it consists of somewhat calcareous quartzarenites deposited under dominantly lower-energy conditions with only periodic intervals of high-energy conditions. (3) A shale or argillaceous sandstone lithotope overlies the poorly-sorted lithotope and is characterized by fine-grained sediments such as shale and very silty or argillaceous sandstone with abundant glauconite pellets. Various kinds of carbonate are common as cementing agents or as thin beds. Fossils, generally consisting of brachiopod shell fragments, trilobite molds and casts, as well as abundant burrows and trails, are common in the argillaceous lithotope. Modern sediments of this type occur primarily in the middle and outer shelf areas, beyond the beach and near-shore zones. (4) The carbonate lithotope is characterized by thick layers of carbonate with minor amounts of glauconitic shale, siltstone, and sandstone. Within the carbonate lithotope, the depositional environments may range from one of shallow water when stromatolites were developed, and relatively high-energy – evidenced by carbonate debris together with some quartz sandstone and shale – to one of deeper water, very low-energy where calcilutites having essentially no terrestrial clastic material were deposited.

Some modifications of Ostrom's regional cycles are necessary in interpreting the depositional history in the Hollandale embayment. On the

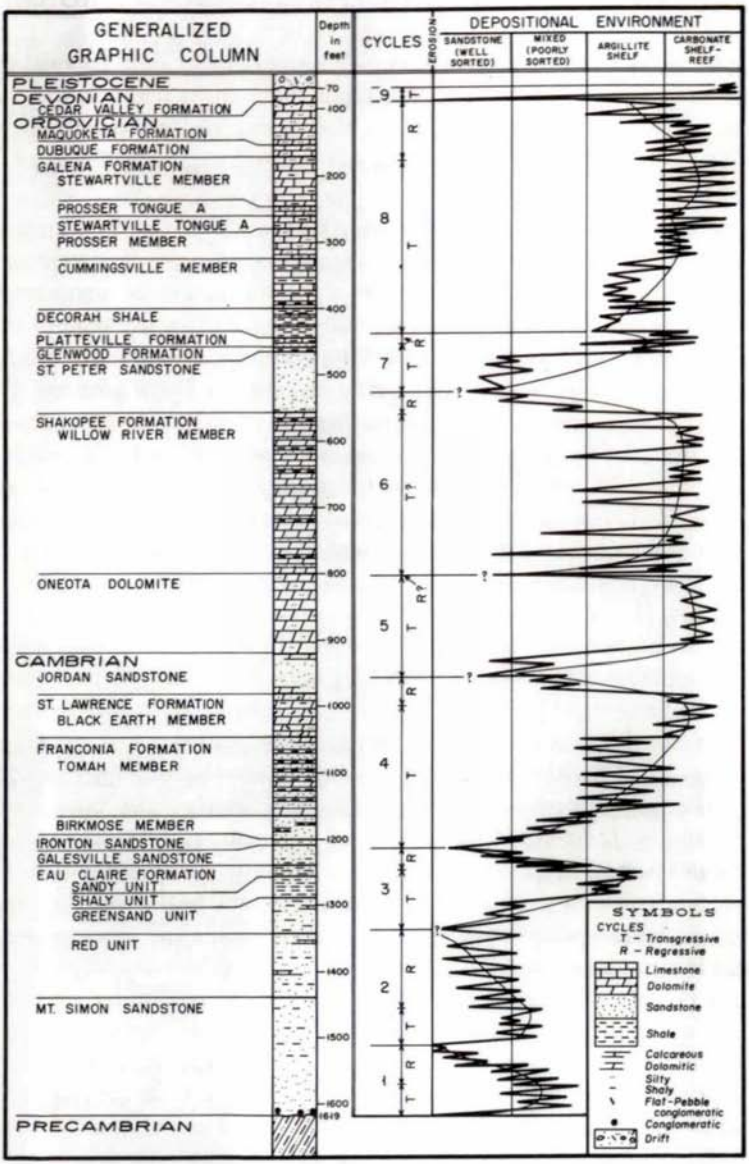

Figure 6 – Generalized graphic log and the cyclic depositional environments of the rock units in H-1. Major cycles are outlined by the light line superimposed on the irregular dark line indicating minor fluctuations in the depositional environment.

Wisconsin Arch nearly all the cycles are terminated by unconformities (Ostrom, 1965 and 1966), the recessional parts having been eroded prior to the sea's return and the beginning of a new cycle. In the Hollandale embayment, on the other hand, the sea bottom probably was submerged continually throughout most cycles. In H-1 vertical changes in lithotopes define nine distinct cycles of sedimentation in the Paleozoic rocks (fig. 6). Of the nine cycles, three – numbers 1, 8, and 9 – were terminated by subaerial erosion. Cycles 3, 4, and 5 may have ended with an unconformity, but cycles 2, 6, and 7 were not terminated by erosion. In all but cycle 9, rocks that are considered recessional, or that were deposited in a higher-energy environment in which the environmental energy increased upward, lie above rocks deposited in a low-energy environment. These recessional facies are not considered in Ostrom's (1964) Cambro-Ordovician sedimentary cycles. In basinal areas, such as the Hollandale embayment, the recessional parts of these cycles are present and are significant in the understanding of the deposition within each cycle. The general trend in the cycles from 1 to 9 shown in Figure 6 is from a large amount of sandstone and small amount of carbonate to a small amount of sandstone and large amount of carbonate. This trend reflects the wearing down of the Precambrian surface and the covering of the Precambrian and older Paleozoic source areas by younger sediments.

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REFERENCES CITED

Agnew, A. F., 1956, Facies of the Platteville, Decorah and Galena rocks of the Upper Mississippi Valley: *in* Lower Paleozoic geology of the Upper Mississippi Valley, G. M. Schwartz, ed., Geol. Soc. America Guidebook Series, Field Trip No. 2, p. 41-52.

Andrews, G. W., 1958, Windrow Formation of the Upper Mississippi Valley region, a sedimentary and stratigraphic study: Jour. Geol., v. 66, p. 597-624.

Austin, G. S., 1963, Geology of clay deposits, Red Wing area, Goodhue and Wabasha Counties, Minnesota: Minn. Geol. Survey Rept. Inv. 2, 23 p.

_____1969, Paleozoic Lithostratigraphic nomenclature for southeastern Minnesota: Minn. Geol. Survey Infor. Circ. 6, with text, 11 p.

Bayer, T. N., 1965, The Maquoketa Formation in Minnesota and an analysis of its benthonic communities: Unpublished Ph.D. thesis, University of Minnesota, 209 p.

Berg, R. R., 1954, Franconia Formation of Minnesota and Wisconsin: Geol. Soc. America Bull., v. 65, p. 856-881.

Berg, R. R., Nelson C. A., and Bell, W. C., 1956, Upper Cambrian rocks in southeastern Minnesota: *in* Lower Paleozoic geology of the Upper Mississippi Valley, G. M. Schwartz, ed., Geol. Soc. America Guidebook Series, Field Trip No. 2, p. 1-23.

Bleifuss, R. L., 1966, The origin of the iron ores of southeastern Minnesota: Unpublished Ph.D. thesis, University of Minnesota, 125 p.

Buschbach, T. C., 1964, Cambrian and Ordovician strata of northeastern Illinois: Ill. Geol. Survey Rept. Inv. 218, 90 p.

Collinson, C., James, G. W., Swann, P. H., Becker, L. E., Carlson, M. P., Dorheim, F. H., and Koenig, J. W., 1967 (1968), Devonian of the north-central region, United States: *in* Internat. Symposium on the Devonian System, Calgary (Proc.), v. 1, Calgary, Alberta, Alberta Soc. Petroleum Geologists, p. 933-971.

Davis, R. A., 1966a, Revision of Lower Ordovician nomenclature in the Upper Mississippi Valley: Jour. Geol. v. 74, p. 361-365.

_____ 1966b, Willow River Dolomite: Ordovician analogue of modern algal stromatolite environments: Jour. Geol., v. 74, p. 908-923.

Emrich, G. H., 1966, Ironton and Galesville (Cambrian) Sandstones in Illinois and adjacent areas: Ill. Geol. Survey Circ. 403, 55 p.

Heller, R. L., 1956, Status of the Prairie du Chien problem: *in* Lower Paleozoic geology of the Upper Mississippi Valley, G. M. Schwartz, ed., Geol. Soc. America Guidebook Series, Trip No. 2, p. 29-40.

Kirwin, P. H., 1963, Subsurface stratigraphy of the Upper Keweenawan red beds of southeastern Minnesota: Unpublished M. S. thesis, University of Minnesota, 74 p.

Kohls, D. W., 1961, Lithostratigraphy of the Cedar Valley Formation in Minnesota and northern Iowa: Unpublished Ph.D. thesis, University of Minnesota, 200 p.

McGannon, D. E., 1960, A study of the St. Lawrence Formation in the Upper Mississippi Valley: Unpublished Ph.D. thesis, University of Minnesota, 353 p.

Ostrom, M. E., 1964, Pre-Cincinnatian Paleozoic cyclic sediments in the Upper Mississippi Valley: A discussion: *in* Symp. on cyclic sedimentation, Kans. Geol. Survey Bull. 169, v. 2, p. 381-398.

_____ 1965, Cambro-Ordovician stratigraphy of southwest Wisconsin: Wisc. Geol. and Nat. Hist. Survey Infor. Circ. 6, 57 p.

_____ 1966, Cambrian stratigraphy in western Wisconsin: Wisc. Geol. and Nat. Hist. Survey Infor. Circ. 7, 79 p.

_____ 1967, Paleozoic stratigraphic nomenclature for Wisconsin: Wisc. Geol. and Nat. Hist. Survey Infor. Circ. 8.

Parham, W. E., and Austin, G. S., 1967, Clay mineralogy of the Glenwood Formation, southeastern Minnesota and adjacent areas: Jour. Sed. Petrology, v. 37, p. 863-869.

———————1969, Clay mineralogy, fabric, and industrial uses of the shale of the Decorah Formation, southeastern Minnesota: Minn. Geol. Survey Rept. Inv. 10, 32 p.

Rassam, G. N., 1967, Studies of the Platteville Formation of Minnesota, Iowa, and Wisconsin: Unpublished Ph.D. thesis, University of Minnesota, 124 p.

Stauffer, C. R., 1927, Age of the Red Clastic Series of Minnesota: Geol. Soc. America Bull., v. 38, p. 469-478.

Stauffer, C. R., and Thiel, G. A., 1941, The Paleozoic and related rocks of southern Minnesota: Minn. Geol. Survey Bull. 29, 261 p.

Weiss, M. P., 1957, Upper Middle Ordovician stratigraphy of Fillmore County, Minnesota: Geol. Soc. America Bull., v. 68, p. 1027-1062.

Weiss, M. P., and Bell, W. C., 1956, Middle Ordovician Rocks of Minnesota and their lateral relations: *in* Lower Paleozoic geology of the Upper Mississippi Valley, G. M. Schwartz, ed., Geol. Soc. America Guidebook Series, Field Trip No. 2, p. 55-73.

APPENDIX

Table A-1 – Summary of lithologic units in H-1: Their thicknesses, depths, and core recovery

Lithologic Unit	Footages	Interval	Core Recovered	Percentage
Soil and Pleistocene	0.0-70.0'	70.0'	-(cuttings only)-	
Windrow Formation				
Ostrander Member	70.0-70.?'	0.?'	-(cuttings only)-	
Cedar Valley Formation	70.?-90.0'	20.0'	-(cuttings only)-	
Maquoketa Formation	90.0-154.0'	64.0'	-(cuttings only)-	
Dubuque Formation	154.0-170.0'	16.0'	-(cuttings only)-	
Galena Formation	170.0-339.0'	229.0'	179.2' (of 187.0') (170-212 cuttings only)	95
Stewartville Member	170.0-245.4'	75.4'	32.6' (of 33.4')	98
and	260.9-280.9'	20.0'	20.0'	100
	total	95.4'	52.6' (of 53.4')	99
Prosser Member	245.4-260.9'	15.5'	15.5'	100
and	280.9-325.0'	44.1'	44.1'	100
	total	59.6'	59.6'	100
Cummingsville Member	325.0-399.0'	74.0'	67.0'	91
Decorah Shale	399.0-443.0'	44.0'	35.6'	81
Platteville Formation	443.0-459.0'	16.0'	13.4'	84
Carimona Member	443.0-447.5'	4.5'	3.5'	78
McGregor Member	447.5-456.0'	8.5'	6.9'	81
Pecatonica Member	456.0-459.0'	3.0'	3.0'	100
Glenwood Formation	459.0-467.0'	8.0'	8.0'	100
St. Peter Sandstone	467.0-470.0'	3.0'	2.7'	90
	470.0-532.0'	62.0'	-(cuttings only)-	
	532.0-558.5'	26.5'	18.1'	68
	total	91.5'	20.8' (of 29.5')	70
Prairie du Chien Group	558.5-920.0'	361.5'	158.2' (of 166.5')	96
Shakopee Formation	558.5-725.0'	166.5'	158.2'	96
Willow River Dolomite	725.0-800.0'	75.0'	-(cuttings only)-	
Oneota Dolomite	800.0-920.0'	125.0'	-(cuttings only)-	
Jordan Sandstone	920.0-980.0'	60.0'	-(cuttings only)-	
St. Lawrence Formation				
Black Earth Member	980.0-1000.0'	20.0'	-(cuttings only)-	
	1000.0-1005.0'	5.0'	-(no cuttings or core)-	
	1005.0-1047.0'	42.0'	42.0'	
	total	67.0'	42.0 (of 42.0')	
Franconia Formation	1047.0-1200.6'	153.6'	152.0'	99
Tomah Member	1047.0-1164.8'	117.8'	117.8'	100
Birkmose Member	1164.8-1200.6'	35.8'	34.2'	96

Lithologic Unit	Footages	Interval	Core Recovered	Percentage
Ironton Sandstone	1200.6-1207.0'	6.4'	4.4'	69
Galesville Sandstone	1207.0-1240.2'	33.7'	23.3'	37
Eau Claire Formation	1240.3-1436.0'	196.7'	188.8'	96
Sandy Unit	1240.3-1256.0'	15.7'	14.5'	92
Shaly Unit	1256.0-1288.2'	30.2'	29.2'	96
Greensand Unit	1288.2-1341.0'	52.8'	47.3'	90
Red Unit	1341.0-1437.0'	96.0'	95.8'	100
Mt. Simon Sandstone	1437.0-1619.0'	182.0'	114.6'	63
"Red Clastics"	1619.0-1905.0'	286.0'	286.0'	100

Core Recovery Totals	Cored Footage	Core Recovery	Percentage
Hole H-1	513'	415.2'	81
Hole H-1A	900'	794.8'	88
Total	1413'	1210.0'	86

Table A-2 – Sample study, Hollandale No. 1, Freeborn County, SE 1/4 SW 1/4, Sec. 7, T. 103 N., R. 19 W. Described by G. S. Austin

The combination of H-1 and H-1A is 1905 feet deep and cored sections are: 212-474, 532-725, and 1005-1905 feet. Only cuttings are available for the other sections of the holes.

Pleistocene

0-20'	Till, medium light gray (N6), silty, calcareous; with some chips of very fine-grained tan limestone.
20-60'	Till, medium light gray (N6), silty, calcareous, sandy with rounded medium- to coarse-grained quartz sand; with several sand-sized grains of igneous and metamorphic rocks.
60-70'	Gravel, medium-sized pebbles of quartz, igneous rocks, limestone and chert; silty, sandy, calcareous.

Cedar Valley Formation with a Thin Cap of Windrow Formation, Ostrander Member

70-80'	Dolomite, very pale orange (10YR8/2), fine- to very fine-grained, silty, oolitic; gravel of pink, white, and gray quartz, chert. Driller's log indicates dolomite penetrated at 70 feet.
80-90'	Dolomite, light olive-gray (5Y7/1), fine- to very fine-grained, silty; with Ostrander pebbles and pebbles of quartz, chert and feldspar from the above Pleistocene.

Maquoketa Formation

90-100'	Dolomite, light olive-gray (5Y7/1), medium-grained, slightly silty with silt surrounding carbonate crystals; with minor white dolomite and fragments of white quartz.
100-107'	Limy dolomite, light olive-gray (5Y6/1) to light yellowish-gray (5Y9/1), very fine- to fine- grained, silty matrix material, sandy; with minor gray chert, and several foreign pebbles.
107-117'	Limy dolomite, light olive-gray (5Y6/1), fine-grained, silty matrix material, crystal-lined vugs, trace of chert; a few foreign white dolomite pebbles.
117-134'	Limy dolomite, light olive-gray (5Y6/1), fine- to medium-grained, silty matrix; with minor chert, crystal-lined vugs; a few foreign pebbles.
134-154'	Limy dolomite, light olive-gray (5Y7/1), fine-grained, slightly silty; with crystal-lined cavities.

Dubuque Formation

154-163' Dolomitic limestone, light olive-gray (5Y7/1), fine- to very fine-grained, argillaceous.

163-170' Dolomitic limestone, light olive-gray (5Y6/1) and light yellowish-gray (5Y9/1), fine- to medium-grained, slightly argillaceous, with a trace of fine-grained yellow sulfides.

Galena Formation, Stewartville Member

170-212' Dolomite and limy dolomite, grayish yellow (5Y8/1), fine- to medium-grained, slightly silty; with vuggy porosity.

Next section (212 to 474 feet) is cored and descriptions are based on the core.

212-245.4' Dolomitic limestone, very pale orange (10YR8/2) to grayish yellow (5Y8/1) very fine- to fine-grained, vuggy; mottled; carbonate crystals in some cavities give a spongy appearance; section from 212 to 214.0 feet is light olive-gray (5Y7/1); very pale green (10G8/2) shale laminae with irregular bedding occur throughout section; core recovery 32.6/33.4 = 98%.

Galena Formation, Prosser Tongue A

245.4-260.9' Dolomitic limestone, light olive-gray (5Y6/1), fine- to very fine-grained; with a few vugs, very thin medium gray (N5) silt laminae, some fossils, some tarnished sulfides, and few corrosion zones. The limestone has been recrystallized. Core recovery 15.5/15.5 = 100%.

Galena Formation, Stewartville Tongue A

260.9-280.9' Dolomitic limestone, grayish yellow (5Y8/1), very fine- to fine-grained, vuggy, mottled; with some irregular, calcareous, very pale green (10G8/2) shale laminae, a few fossils – brachiopods, *Hormotoma;* the limestone is spongy looking with a few crystal-lined vugs. The core is recrystallized limestone. Core recovery 20.0/20.0 = 100%.

Galena Formation, Prosser Member

280.9-325.0' Dolomitic limestone, light olive-gray (5Y6/1), fine- to very fine-grained, slightly vuggy; with medium gray (N5) silt laminae, thin tarnished pyrite and chalcopyrite (?) zones; somewhat mottled recrystallized limestone; core recovery 44.1/44.1 = 100%.

Galena Formation, Cummingsville Member

325.0-337.0' Limy dolomite, light olive-gray (5Y6/1), very fine-grained, very sandy with very fine-grained angular quartz sand; pyrite present; mottled with many medium light gray (N6) bleb-like carbonate silt bodies; core recovery 5.3/12.0 = 44%.

337.0-338.2' Limestone, light olive-gray (5Y6/1), very fine-grained, silty, shaly with thin light gray (N7) shale separating thin-layered mottled carbonate; core recovery 1.2/1.2 = 100%.

338.2-344.9' Limestone, greenish-gray (5G7/1), very fine-grained, medium-bedded; interbedded thin light gray (N7), limy shale; core recovery 6.7/6.7 = 100%.

344.9-346.3' Limestone, greenish-gray (5G7/1), very fine-grained thin carbonate units interbedded with light gray (N7), silty shale partings; core recovery 1.4/1.4 = 100%.

346.3-349.0' Limestone, light olive-gray (5Y6/1), fine-grained, interbedded with thin greenish-gray (5GY6/1), silty shale partings; corrosion zone at 346.6 feet; core recovery 2.7/2.7 = 100%.

349.0-351.3' Limestone, light olive-gray (5Y6/1), fine-grained, mottled with thin, irregular, greenish-gray (5GY6/1) shaly partings; core recovery 2.3/2.3 = 100%.

351.3-355.2' Limestone, light olive-gray (5Y6/1), fine-grained, shale partings; greenish-gray (5GY6/1), fissile shale at 351.3 to 351.4 and 354.9 to 355.0 feet; coquina with pyrite from 352.5 to 354.9 feet; core recovery 3.9/3.9 = 100%.

355.2-363.0' Limestone, light olive-gray (5Y6/1), fine-grained, medium-bedded; with thin greenish-gray (5GY6/1) shaly partings and shaly mottling; corrosion zone at 359.0 feet; core recovery 7.8/7.8 = 100%.

363.0-399.0' Limestone, light olive-gray (5Y6/1), fine-grained, silty; fossiliferous with brachiopods and bryozoans; thin- to thick-bedded; interbedded thin- to medium-bedded limy, greenish-gray (5GY6/1), fissile, fossiliferous shale; corrosion zone at 398.9 feet; core recovery 36.0/36.0 = 100%.

Decorah Shale

399.0-428.0' Shale, greenish-gray (5GY5/1), fissile and blocky, fossiliferous; coquinas from 399.5 to 400.0, 400.5 to 401.2, 404.5 to 405.0, 406.0 to 406.2, 406.8 to 407.0, 408.0 to 408.2, 412.0 to 412.5, 412.8 to 413.0, 413.5 to 414.0, 416.7 to 417.0 feet; section from 418 to 421 feet is a shale, limy, mottled with limestone; missing sections 402.0 to 403.0, 417.0 to 418.0, 424.5 to 425.0, 426.0 to 427.2 feet. The Minn. Geol. Survey has 23.75/29.0 = 82% of the core.

428.0-443.0' Shale, greenish-gray (5GY5/1), fissile, fossiliferous; core has dark surface color due to oil staining; coquinas from 433.5 to 433.6, 435.5 to 435.6, 436.0 to 436.1 feet; core from 433.9 to 435.0 feet missing. The Minn. Geol. Survey has 11.9/15.0 = 79%.

Platteville Formation, Carimona Member

443.0-447.5' Limestone, light olive-gray (5Y6/1), very fine-grained, which is highly fossiliferous from 443 to 443.5 feet and shaly; from 443.5 to 440.0 feet olive-gray (5Y5/1), fissile, fossiliferous shale; 444.2 to 445.0 missing; from 444.8 to 447.5 feet light olive-gray (5Y6/1), very fine-grained limestone in one-foot beds interbedded with 0.1 to 0.05 foot beds of olive-gray (5Y4/1) limy shale; "Carimona bentonite" from 447.0 to 447.3 feet, a very light gray (N8) shale with blue surface coloring; thick brown limy shale from 446.0 to 447.0 feet; Minn. Geol. Survey has 3.5/4.5 = 78% of the core.

Platteville Formation, McGregor Member

447.5-450.5' Limestone, light olive-gray (5Y6/1), very fine-grained, one-foot beds separated by 0.1 to 0.5 foot beds of olive-gray (5Y4/1) shale with bleb-like bodies of carbonate; limestone indistinguishable from limestone above, but shale beds have carbonate blebs not found above; core recovery 2.9/3.0 = 97%.

450.5-456.0' Limestone, light olive-gray (5Y6/1), very fine-grained, mottled with irregular olive-gray (5Y4/1)to olive-black (5Y2/1) limy shale; black phosphate (?) pebbles and grains from 451.0 to 451.5 feet; corrosion zone at 455.5 feet; 451.5 to 452.3 feet missing; core recovery was 4.0/5.5 = 73%.

Platteville Formation, Pecatonica Member

456.0-459.9' Limestone, pale yellowish-brown (10YR6/2 to 10YR7/2), coarse-grained, very sandy with rounded medium-grained frosted quartz sand; corrosion zones at 456.8, 457.6, 458.5, 459.0, 459.1 and 459.7 (?) feet; core missing 457.8 to 458.6 feet. The Minn. Geol. Survey has 3.1/3.9 = 79% of core.

Glenwood Formation

459.9-466.8' Shale, greenish-gray (5GY6/1), fissile, easily broken; with sandy zones, *Isotelus* fragments, and pyrite; bottom 0.2 feet is sandy, shaly, light-gray (N7) limestone; core recovery 6.9/6.9 = 100%.

St. Peter Sandstone

466.8-474.0' Sandstone, pale yellowish-brown (10YR7/2), medium-grained, subrounded, moderately well-sorted, silty; section from 470 to 474 feet ground and core not available; core recovery 2.7/7.2 = 38%.

Next section – 474 to 532 feet--was not cored. Descriptions are based on cuttings.

474-489' Sandstone, very pale orange (10YR8/2), fine- and medium-grained (bimodal), each well-sorted; fine-grained sand is angular, medium-grained

sand is rounded; some iron oxide is moderate reddish-brown (10R4/6) clayey clumps with sand, some fragments of shale, carbonate from above.

489-498' Sandstone, very pale orange (10YR8/2), fine- to medium-grained, moderately well-sorted, well-rounded to subrounded; with several iron oxide clumps and a few black, shiny fine-grained particles.

498-502' As above, but with some reddish-brown (10R4/4) and very pale orange (10YR8/2) colors due to more iron oxide clumps; well-rounded to angular grains; some greenish-gray (5GY6/1) shale, carbonate, and debris from above.

502-507' Sandstone, very pale orange (10YR8/2) to pale yellowish-brown (10YR7/2), medium- to fine-grained, moderately well-sorted, well-rounded with few broken angular grains, with several pale moderate brown (5YR4/6) iron oxide clumps and iron oxide as stain; trace of greenish-gray (5GY6/1) shale from above.

507-513' Sandstone, pale yellowish-brown (10YR7/2), medium-grained, some fine and coarse grains, moderately well-sorted, slightly silty; iron oxide as cementing stain; trace of shale from above.

513-525' Sandstone, pale yellowish-brown (10YR7/2), medium-grained with some coarse grains, moderately well-sorted, subrounded-to-angular grains; minor iron oxide cement and trace of greenish-gray (5GY6/1) shale from above.

525-533' Sandstone, pale yellowish-brown (10YR7/2), medium- to fine-grained with a few coarse grains, moderately well- to poorly-sorted; with rounded-to-angular grains; minor cementing iron oxide stain and trace of shale from above.

Next section – 532 to 725 feet – is cored and descriptions are based on the core.

532-558.5' Sandstone, pale yellowish-brown (10YR7/2), medium-grained, silty, moderately well-sorted; with subrounded-to-rounded grains; core recovery 18.1/26.5 = 68%.

Prairie du Chien Group, Shakopee Formation, Willow River Member

558.5-565.0' Dolomite and sandstone. Interval from 558.5 to 559.5 feet is light gray (N6 to N7), medium-grained, very sandy dolomite with medium-grained, well-rounded quartz sand; interval from 559.5 to 560.5 feet is light gray (N7), medium-grained, thin-bedded dolomite interbedded with thin-to-medium beds of greenish-gray (5GY7/1) dolomitic shale; interval from 560.5 to 565.0 feet is pinkish-gray (5YR8/1), medium-grained, silty sandstone with rounded grains; shaly toward the base; core recovery 5.0/6.5 = 77%.

The section from 555 to 565 feet has a core recovery of 50% and the contacts and spacing on units are picked from gamma and neutron logs.

565.0-570.3' Dolomite, light brownish-gray (5YR6/1) to very light-gray (N8), medium-grained, very oolitic with empty cavities, vuggy, bedded, fragmented; minor dark dolomite which is dense; core recovery 5.3/5.3 = 100%.

570.3-571.3' Dolomite, light gray (N7), medium-grained, interbedded with greenish-gray (5GY7/1), fissile shale, thin-to-medium beds; core recovery 1.0/1.0 = 100%.

571.3-602.0' Dolomite, olive-gray (5Y4/1) to light-gray (N7), fine-to medium-grained, interbedded with locally medium-to-thick beds of tan, medium-grained sandstone; with very oolitic dolomite layers; small algal structures; dolomite is vuggy, contains some blebs of grayish-green (5G5/2) shale material (illite, malachite, or glauconite); core recovery 26.7/30.7 = 87%.

602.0-607.0' Dolomite, large porous algal structure, yellowish-gray (5Y8/1) to light-gray (N7), fine- to medium-grained; core recovery 3.0/5.0 = 60%.

607.0-614.0' Dolomite, medium gray (N5) to white (N9), fine- to medium-grained; interbedded with very pale orange (10YR8/2) sandstone and oolitic dolomitic flat-pebble conglomerates in which pebbles are not flat-lying; white (N9) siliceous alteration product fills some oolitic voids; core recovery 7.0/7.0 =100%.

614.0-623.0' Dolomite, light gray (N7), fine- to medium-grained; occasionally interbedded with medium- to thick-bedded, very fine-grained, oolitic dolomite; flat-pebble dolomite conglomerates in cross-bedded, light brownish-gray (5YR6/1), medium-grained sandstone beds; core recovery 9.0/9.0 = 100%.

623.0-625.0' Sandstone, light brownish-gray (5YR6/1), medium-grained, well-rounded, and well-sorted; thin layers of light brownish-gray (5YR6/1) dolomite near bottom; core recovery 2.0/2.0 = 100%.

625.0-631.5' Dolomite, light gray (N7), fine-grained; interbedded with light brownish-gray (5YR7/1), medium-grained, well-sorted, rounded, cross-bedded sandstone; core recovery 6.2/6.5 = 95%.

631.5-633.0' Shale, greenish-gray (5G7/1), fissile, limy, thin- to medium-bedded; interbedded with very light gray (N8), fine-grained dolomite; core recovery 1.5/1.5 = 100%.

633.0-643.0' Dolomite, olive-gray (5Y5/1) to yellowish-gray (5Y8/1), fine- to medium-grained, vuggy; with a trace of pyrite; oolitic near the top; toward the bottom thin zones of very fine-grained dolomite are interbedded with thin, pinkish-gray (5YR8/1), medium-grained sandstone; core recovery 10.0/10.0 = 100%.

643.0-645.0' Dolomite, large porous stromatolite, white (N9) to pinkish-gray (5YR8/1), fine- to medium-grained; core recovery 2.0/2.0 = 100%.

645.0-649.0' Dolomite, very light gray (N8) to light olive-gray (5Y6/1), very fine- to fine-grained, silty; with oolite voids, a few small stromatolites, and several

thin, light brownish-gray (5YR7/1) sandstone and a few greenish-gray (5GY6/1) dolomitic shale beds; core recovery 4.0/4.0 = 100%.

649.0-652.0' Sandstone, light brownish-gray (5YR7/1), medium- to fine-grained, moderately well-sorted; with subrounded grains of quartz sand; dolomite silt cement; some layers of very fine-grained, very light gray (N8) dolomite; core recovery 3.0/3.0 = 100%.

652.0-657.0' Dolomite, very light gray (N8) to light olive-gray (5Y7/1), very fine- to medium-grained; vuggy layers; with thin, very light-gray (N8) medium-grained, moderately well-sorted sandstone beds; core recovery = 100%.

657.0-676.0' Dolomite, medium light gray (N6) to light olive-gray (5Y7/1), very fine- to medium-grained; vuggy layers; a few thin very light-gray (N8) sandstone beds; a trace pyrite in the crystalline vugs; core recovery 19.0/19.0 = 100%.

676.0-679.0' Dolomite, medium light-gray (N6), fine- to medium-grained; some pyrite; interbedded with light brownish-gray (5YR6/1), medium-grained, quartzose, cross-bedded sandstone; core recovery 3.0/3.0 = 100%.

679.0-697.5' Dolomite, medium gray (N5) to light olive-gray (5Y6/1), very fine- to medium-grained; porous beds (stromatolites); pyrite; white (N9) siliceous alteration material fills brecciated zones at 683.0 - 684.2, 684.8 - 685.0, and 686.0 - 686.4 feet; some greenish-gray (5GY6/1) shale laminae; some dark greenish-gray (5GY4/1) glauconite or malachite as small spots; core recovery 18.5/18.5 = 100%.

697.5-698.2' Sandstone, light brownish-gray (5YR6/1), medium-grained, poorly-sorted, dolomitic; with light greenish-gray (5G8/1) shale laminae; core recovery 0.7/0.7 = 100%.

698.2-698.8' Shale, greenish-gray (5GY6/1), fissile, dolomitic; core recovery 0.6/0.6 = 100%.

698.8-725.0' Dolomite, very light gray (N8) to yellowish-gray (5Y8/1) to pinkish-gray (5YR8/1), very fine- to medium-grained, porous, sandy; oolitic beds; section from 699.0 to 702.0 feet has concentration of oolite voids; section from 713.0 to 714.0 feet is pinkish-gray (5YR8/1), medium-grained sandstone; light greenish-gray, (5GY8/1) dolomitic shale with interbedded pinkish-gray (5YR8/1) sandstone from 716.6 to 717.0, 718.4 to 719.0 feet; dolomite flat-pebble conglomerates from 720.5 to 721.5 feet; dark greenish-gray (5G4/1) mineral material (illite, malachite, and/or glauconite) in the form of small shaly layers and spots throughout section; core recovery 25.0/26.2 = 96%.

H-1 ended at 725 feet where the bit stuck. Hole H-1A was started 20 feet away from H-1 and rock-bitted to 1005 feet, where coring was resumed. The next section (720-1000 feet) is described from the study of cuttings only.

720.0-740.0' Dolomite, light olive-gray (5Y7/1), medium- to coarse-grained; very sandy with both free and embedded coarse- to fine-grained, angular-to-rounded quartz sand; oolitic with oolite voids filled with white siliceous alteration product; some gray, tan chert; some greenish-gray (5GY6/1) fissile shale; a trace of brachiopod shell fragments; yellow sulfides, quartz crystals from crystal-lined vugs.

740.0-770.0' Dolomite, light olive-gray (5Y6/1), medium-grained, sandy to a trace of sand; loose quartz sand; moldic porosity with a siliceous alteration product occupying the voids; a trace of chert; some rounded gray dolomite crystals in a dolomite-silt matrix typical of Oneota Dolomite; brachiopod fragments from above; vugs lined with dolomite and quartz crystals; sulfides in trace amounts.

770.0-800.0' Dolomite, light olive-gray (5Y6/1) to yellowish-gray (5Y8/1), medium- to coarse-grained, slightly sandy; traces of silt-sized dolomite, chert, oolitic dolomite, and shale; brachiopods from above; trace of moderate green (5G5/6) spots which may be illite or glauconite clay or malachite in dolomite.

Prairie du Chien Group, Oneota Dolomite

800.0-810.0' Dolomite, yellowish-gray (5Y8/1) to light olive-gray (5Y7/1), medium- to fine-grained, trace of sand both as free and embedded grains, silty with silt matrix surrounding subrounded dolomite grains; debris from higher in well.

810.0-840.0' Dolomite, light gray (N7) to yellowish-gray (5Y8/1), medium-grained, slightly silty to silty; traces of free sand, chert, shale, iron oxide, and sulfide.

840.0-885.0' Dolomite, light olive-gray (5Y7/1) to medium light gray (N6), medium- to coarse-grained; with a silty matrix around the dolomite crystals, traces of sand, shale, glauconite, iron oxide, and sulfide.

885.0-890.0' Dolomite, light olive-gray (5Y6/1) to very light gray, (N8) medium- to coarse-grained crystalline, with a silty matrix; a trace of pale red-purple (5RP6/2) dolomite; traces of free sand, shale, glauconite, and sulfide.

890.0-920.0' Dolomite, light-gray (N7) to very light-gray (N8), some medium-gray (N5), fine- to coarse-grained, slightly silty, slightly sandy to trace of sand with embedded and free sand, traces of sulfide, pale red-purple (5RP6/2) dolomite, and glauconite; trace of shale from above.

Jordan Sandstone

920.0-925.0' Sandstone and dolomite, very light gray (N8). The sandstone is medium- to coarse-grained, poorly-sorted, and quartzose, with rounded-to-subrounded grains. The dolomite is light-gray (N7), medium-grained and slightly silty, with trace of sulfides. The dolomite is from above (?).

925.0-970.0' Sandstone, very light gray (N8), medium- to coarse-grained, poorly-sorted; with rounded grains, some light-gray (N7) to pink (5R8/4), medium-grained dolomite from above (?); trace of shale.

970.0-980.0' As above, but with light gray (N7) to light olive-gray (5Y7/1) dolomite and grayish-pink (5R8/2) dolomite; fine- to medium-grained, silty, and slightly sandy.

St. Lawrence Formation, Black Earth Member

980.0-1000.0' Dolomite, light brownish-gray (5YR6/1) and moderate pink (5R7/4), fine- to medium-grained, silty, slightly glauconitic, slightly sandy to sandy with rounded medium-grained quartz sand; some cemented white (N9) quartz sandstone from above.

1000.0-1005.0' Missing - both core and cuttings.

Next section - 1005 to 1905 - cored. The descriptions are of the core.

1005.0-1044.2' Dolomite, light brownish-gray (5YR6/1), fine- to medium-grained, slightly sandy with rounded fine-grained quartz sand present in beds, silty, locally porous; with thin beds of greenish-gray (5G6/1), fissile micaceous shale; dolomite is dark greenish-gray (5G4/1) glauconite scattered and also concentrated in a few beds as rounded, medium to coarse grains with medium- to coarse-grained, light olive-gray (5Y6/1) dolomite crystals; flat-pebble conglomerates from 1009.0 to 1010.0, 1010.8 to 1011.2, 1012.8 to 1013.2, 1016.8 to 1017.2, 1021.0 to 1021.5, 1022.8 to 1023.5, 1024.5 to 1026.0, 1027.5 to 1028.0, 1035.0 to 1038.3 (with short non-conglomeratic zones), 1042.8 to 1043.1 feet; many conglomeratic zones are incipient corrosion zones; core recovery 39.2/39.2 = 100%.

1044.2-1045.2' Dolomite flat-pebble conglomerate with pebbles oriented with the long direction vertical. The dolomite is light olive-gray (5Y6/1) and medium-grained; core recovery 1.0/1.0 = 100%.

1045.2-1047.0' Dolomite, light brownish-gray (5YR7/1), medium- to fine-grained, silty; with trace of sand; dark greenish-gray (5G4/1) glauconite concentrated in layers as well as being scattered throughout the dolomite; interbedded thin, greenish-gray (5GY6/1), fissile, micaceous shale; flat-pebble conglomerate zone from 1046.4 to 1056.8 feet; core recovery 1.8/1.8 = 100%.

Franconia Formation, Tomah Member

1047.0-1110.0' Sandstone, very light gray (N8) to greenish-gray (5G6/1) to grayish-yellow (5Y8/4), fine-grained, glauconitic; upper eight feet is sandy dolomite with dolomite intraclasts and transitional with St. Lawrence; sandstone interbedded with thin-to-medium beds of greenish-gray (5GY5/1), fissile, micaceous shale up to 0.3 feet thick; core recovery 63.0/63.0 = 100%.

1110.0-1156.8' Sandstone, greenish-gray (5G6/1) to grayish-yellow (5Y8/4), medium- to fine-grained, glauconitic to slightly glauconitic with medium-grained rounded glauconite particles; some interbedded shale and dolomite; core recovery 46.8/46.8 = 100%.

1156.8-1164.8' Dolomite, very light gray (N8) to greenish-gray (5GY6/1), medium- to fine-grained, glauconitic, shaly with greenish-gray (5G6/1), fissile shale laminae; sandy dolomitic sandstone at bottom and top; core recovery 8.0/8.0 = 100%.

Franconia Formation, Birkmose Member

1164.8-1166.2' Sandstone, dark reddish-brown (10R3/4), dusky green (5G3/2), and light gray (N7), fine-grained, well-sorted, glauconitic with rounded grains, slightly dolomitic, bedded; oxidized shaly layer 0.05 feet thick at 1165.0 feet; core recovery 1.4/1.4 = 100%.

1166.2-1176.0' Sandstone, dusky green (5G3/2) and light gray (N7), fine-grained, moderately well-sorted, glauconitic; with a trace of silt and a few micaceous, slightly sandy, light olive-gray (5Y6/1) shale laminae; core recovery 9.8/9.8 = 100%.

1176.0-1200.3' Sandstone, light gray (N7) to grayish-green (10G4/2), fine-grained, well-sorted, glauconitic, silty, mottled (worm-bored and lacks bedding); bedding from 1194.5 to 1194.8, 1195.5 to 1195.8, and 1196.5 to 1198.0 feet remains; core recovery 22.7/24.3 = 93%.

1200.3-1200.6' Sandstone, dark greenish-gray (5G4/1), fine-grained, bedded, well-sorted, silty, very glauconitic; core recovery 0.3/0.3 = 100%.

Ironton Sandstone

1200.6-1201.6' Sandstone, medium light gray (N6) to very light gray (N8) to light greenish-gray (5GY8/1), fine- to medium-grained, poorly-sorted, slightly glauconitic; with rounded-to-subrounded quartz sand and numerous brachiopod fragments; top 0.5 feet is moderately well-sorted, medium-to-coarse-grained sandstone; core recovery 1.0/1.0 = 100%.

1201.6-1205.0' Sandstone, pinkish-gray (5YR9/1) to light gray (N7), medium-grained, moderately well-sorted, bedded; with rounded-to-subrounded quartz grains; brachiopod shell fragments; a trace of glauconite; thin greenish-gray (5GY6/1) shale layers interbedded with sand near top; core recovery 3.4/3.4 = 100%.

1205.0-1232.0' Core lost.

The contact between the Ironton and Galesville Sandstones was placed at 1207.0 feet from gamma and neutron logs.

1232.0-1240.3' Sandstone, pinkish-gray (5YR9/1) to light greenish-gray (5GY9/1), fine-grained, moderately well-sorted; a trace of glauconite; a few irregular silty, shaly sandstone beds interbedded with fine-grained sandstone from 1233.0 to 1233.5, 1234.5 to 1234.7, 1234.7 to 1236.2, 1237.5 to 1238.2, 1238.6 to 1238.9 feet and other units less than 0.2 feet thick; a few cross-bedded sandstone beds with brachiopod fragments and locally well-sorted medium-grained sandstone beds; core recovery 7.5/8.3 = 92%.

Eau Claire Formation, Sandy Unit

1240.3-1256.0' Sandstone, light gray (N7) to grayish-green (10G4/2), fine-grained, poorly sorted, silty, fossiliferous; interbedded with irregular laminae of greenish-gray (5GY6/1), silty-sandy shale; slightly glauconitic with highly glauconitic zones from 1251.5 to 1251.8 and 1253.4 to 1257.0 feet; pinkish-gray (5YR8/1), fine-grained, well-sorted, slightly glauconitic sandstones, cross-bedded in part, present from 1247.6 to 1248.6, 1248.8 to 1248.9, 1249.0 to 1249.2, 1255.8 to 1256.0 feet; core recovery 14.5/15.7 = 92%.

Eau Claire Formation, Shaly Unit

1256.0-1264.5' Shale, greenish-gray (5GY6/1) to greenish-black (5GY2/1), fissile, very sandy, silty; with some irregular bedding; interbedded with very light gray (N8), fine-grained, moderately well-sorted, slightly glauconitic sandstone; high-glauconite zones from 1257.0 to 1257.6, 1259.0 to 1259.6 feet with glauconite as pellets and shaly material; numerous brachiopod fragments, especially in the high-glauconite zones; core recovery 8.5/8.5 = 100%.

1264.5-1270.0' Shale, greenish-gray (5GY5/1) to dark red (5R3/6) to light greenish-gray (5G8/1), fissile; interbedded very pale orange (10YR8/2), very fine-grained sandstone; traces of glauconite, brachiopod fragments, and dolomite; contacts between shale and sandstone vary from sharp to gradational; core recovery 5.5/5.5 = 100%.

1270.0-1288.2' Sandstone, very pale orange (10YR8/2) to moderate red (5R5/4), fine-grained, well-sorted, micaceous; with a few shaly partings and some ripple bedding; interbedded with light gray (N7) to dusky red (5R4/4), fissile shale and grayish-green (10GY5/2), medium-grained, medium-sorted, highly glauconitic sandstone; numerous brachiopod fragments; core recovery 16.2/18.2 = 89%.

Eau Claire Formation, Greensand Unit

1288.2-1293.5' Sandstone, very pale orange (10YR8/2) to dusky yellowish-green 10GY3/2), fine-grained, well-sorted; with subrounded grains; a few medium-grained sandstone beds; cross-bedded in part; glauconitic to very glauconitic; some interbedded, fissile, greenish-gray, (5GY6/1) shale with dusky red (5R4/4) contacts; brachiopod fragments sparse to numerous and

most common in the highly glauconitic sandstone; sandstone and shale are locally worm-bored; core recovery 5.3/5.3 = 100%.

1293.5-1304.6' Sandstone, grayish-yellow (5Y8/4) and dusky yellowish-green (10GY3/2), fine-grained, moderately well-sorted, glauconitic, bedded and locally cross-bedded; with subrounded grains; some medium-grained, highly fossiliferous, glauconitic sandstone; a few greenish-gray (5G6/1) shale layers with grayish-red-purple (5RP4/2) contacts, as above; brachiopod fragments common; some red limy dolomite in layers and as scattered grains; core recovery 10.0/11.1 = 91%.

1304.6-1315.0' Sandstone, grayish-olive (10Y4/2) to light olive-gray (5Y6/1) to moderate yellow (5Y8/6), glauconitic, fine-grained, well-sorted, bedded to cross-bedded, with subrounded grains, brachiopod fragments; a few grayish-red purple (5RP4/2) and greenish-gray (5GY6/1) shale layers; a few moderate reddish-brown (10R4/6) dolomite crystals; core recovery 6.0/10.4 = 58%.

1315.0-1341.0' Sandstone, moderate greenish-yellow (10Y7/4) to yellowish-gray (5Y7/2) with some moderate reddish-brown (10R4/6) mottling, fine-grained with subrounded grains, moderately well-sorted, glauconitic, bedded, locally cross-bedded; worm-bored sandstone lacking bedding from 1329.0 to 1331.0, 1336.0 to 1342.0 feet; brachiopod fragments; a few thin grayish-red-purple (5RP4/2) and greenish-gray (5GY6/1) shale beds; much dusky red (5R3/4), limy dolomite in crystals, especially toward the bottom of the unit; core recovery 26.0/26.0 = 100%.

Eau Claire Formation, Red Unit

1341.0-1347.0' Sandstone, very pale orange (10YR8/2) to moderate red (5R5/4) and moderate orange-pink (10R7/4), fine-grained with subrounded sand grains, moderately well-sorted, silty, slightly dolomitic; with several irregular and scattered very dark red (5R2/6) and greenish-gray (5G6/1) shale beds; minor red limy dolomite; glauconitic to slightly glauconitic but the green color is obscured by red silty dolomite; sandstone is worm-bored, mottled except from 1342.8 to 1344.6 feet where bedded; core recovery 6.0/6.0 = 100%.

1347.0-1352.6' Sandstone, pale yellowish-brown (10YR7/2) to moderate orange-pink (10R7/4) and pale reddish-brown (10R5/4), fine-grained, subrounded, well-sorted, glauconitic to slightly glauconitic, bedded; with little or no carbonate; interbedded with thin- to medium-bedded very dark red (5R2/6) and greenish-gray (5R6/1) shale; core recovery 5.6/5.6 = 100%.

1352.6-1360.2' Sandstone, very pale orange (10YR8/2) and pale yellowish-brown (10YR7/2) to dark reddish-brown (10R3/4), fine-grained, well-sorted, quartzose, bedded, some cross-bedding; a few grayish-red-purple (5RP4/2) to greenish-gray (5G6/1), fissile, slickensided shale layers; core recovery 7.6/7.6 = 100%.

1360.2-1379.5' Sandstone, pale orange-pink (10R8/4) and pale red-purple (5RP6/2) to dark reddish-brown (10R3/4), fine-grained, well-sorted, angular-to-subangular grains; traces of glauconite, brachiopod fragments in zones; reddish-brown layers contain much calcite or limy dolomite; a few grayish-red-purple (5RP4/2) to light olive-gray (5Y6/1), fissile, micaceous shale layers up to 0.1 feet thick; boundaries between sandstone and shale vary from sharp to gradational; sandstone has some disrupted bedding which appears to be due to either worm-boring or penecontemporaneous slumps; local ripple bedding and flat-pebble sandstone conglomerates; core recovery 19.3/19.3 = 100%.

1379.5-1394.0' Sandstone, pale red-purple (5RP6/2) and pale orange-pink (10R8/4), to moderate reddish-brown (10R4/6), fine-grained, well-sorted, with subangular-to-angular grains; zones of disrupted bedding; dusky red (5R4/4) carbonate commonly occurs in the sandstone; some grayish-red-purple (5RP4/2) to light olive-gray (5Y6/1) shale layers up to 0.05 feet thick alternating with sandstone above 1390 feet; core recovery 14.5/14.5 = 100%.

1394.0-1401.0' Sandstone, moderate reddish-brown (10R4/6) and dark reddish-brown (10R3/4) to grayish-pink (5R8/2) and pale red-purple (5RP7/1), fine-grained, well-sorted, with subangular-to-angular grains; bedded but with a few disrupted zones; red carbonate-rich layers are interbedded with light-colored sandstone which contains brachiopod fragments; the bottom foot has many grayish-red-purple (5RP4/2) to light olive-gray (5Y6/1) shale beds up to 0.1 feet thick interbedded with the sandstone; core recovery 7.0/7.0 = 100%.

1401.0-1413.2' Sandstone, pale red-purple (5RP6/2) and dark reddish-brown (10R3/4) to grayish-pink (5R8/2) and moderate reddish-orange (10R6/6), fine-grained, moderately well-sorted, shaly with silt- and clay-sized matrix, medium-bedded; with subangular-to-angular grains, some flat-pebble conglomerates, and interbedded with thin beds of greenish-gray (5GY6/1) and grayish-red-purple (5RP4/2) micaceous shale; a trace of glauconite; core recovery 12.2/12.2 = 100%.

1413.2-1428.8' Sandstone, pale purple (5P6/2) to grayish-pink (5R8/2) to grayish-red-purple (5RP6/2), fine-grained, moderately well-sorted; with silty and clayey matrix; subangular-to-angular sand grains and a few brachiopod fragments; red carbonate grains occur locally; bedding generally disrupted; core recovery 15.4/15.6 = 98%.

1428.8-1437.0' Sandstone, pale red-purple (5RP6/2) to dusky red (5R3/4) to grayish-pink (5R8/2), fine-grained, some medium-grained, well-bedded, moderately well-sorted; some shaly, limonitic, poorly sorted, medium- to coarse-grained sandstone beds; the light-colored sandstone is slightly glauconitic and contains very pale green (10G8/2) to pale red-purple (5RP6/2) shale laminae; basal 0.5 feet is a poorly sorted, coarse- to fine-grained, glauconitic, red sandstone, with much red carbonate, several flat sandstone pebbles and a few brachiopod fragments; core recovery 8.2/8.2 = 100%.

Mt. Simon Formation

1437.0-1457.2' Sandstone, grayish-pink (5R8/2) to pale brown (5YR6/2) to reddish-brown (10R4/4), medium-grained, subrounded-to-rounded grains, poorly sorted with both coarse- and fine-grained sand, shaly with numerous very pale green (10G8/2) to pale red-purple (5RP6/2) shale layers with sandstone pebbles; brachiopod fragments are common especially in the coarser sandstone; sandstone is finer and contains some bedding near the base of the unit; erosional or depositional breaks occur above many shale laminae; lighter colored sandstone with less than 1 percent non-quartz material; core recovery 19.2/20.2 = 95%.

1457.2-1462.6' Sandstone, grayish-pink (5R8/2) to pale-red (10R6/2) to grayish-red (5R5/2), fine- to medium-grained, moderately well sorted, with angular grains; interbedded grayish-red-purple (5RP4/2) and grayish-yellow-green (5GY7/2) silty micaceous shale beds up to 0.4 feet thick; shale and sandstone both bedded and shale has intraclasts of weathered sandstone pebbles and zones containing brachiopod fragments; the sandstone is coarse-grained near bottom; core recovery 5.2/5.4=97%.

1462.6-1476.0' Sandstone, pinkish-gray (5YR8/1) to pale brown (5YR6/2) with some grayish-red-purple (5RP4/2), mottled, medium- to coarse-grained, poorly sorted, interbedded with poorly-bedded, very pale green (10G8/2), sandy shale; the coarse, pale brown (5YR6/2) sandstone is highly fossiliferous; sandstones are bedded and commonly cross-bedded; purple shale beds up to 0.1 feet thick; core recovery 12.7/13.4 = 95%.

1476.0-1494.5' Sandstone, pale brown (5YR5/2) to grayish-orange pink (5YR7/2), coarse- to fine-grained, quartzose, poorly sorted, bedded, slightly fossiliferous; with subrounded-to-angular grains, a few small quartz pebbles, and a few red-brown hematite spots (altered siderite) in the lower 2.0 feet; core recovery 10.7/18.5 = 58%.

1494.5-1506.0' Sandstone, grayish-pink (5R8/2) to grayish-orange-pink (5YR7/2), medium- to coarse-grained, poorly-sorted, quartzose; with some irregular very pale green (10G8/2) and pale red-purple (5RP6/2) shale laminae; scattered red-brown hematite spots; much interbedded shale in top 0.5 feet; some beds up to 0.1 feet thick of very coarse sandstone; bottom 0.2 feet is very coarse sandstone and lies on an eroded surface; core recovery 10.7/11.5 = 93%.

1506.0-1508.5' Sandstone, light brownish-gray (5YR7/1) with grayish-red-purple (5RP4/2) mottling, coarse- to medium-grained, moderately well-sorted, quartzose; with subrounded-to-angular grains; siderite grains which have been oxidized to hematite are common; top 0.5 feet is a dark reddish-brown (10R3/4) to pale yellowish-brown (10YR7/2) limonitic sandstone and lies below an erosion surface; the underlying 0.5 feet is a dark yellowish-orange (10YR6/2) to very pale orange (10YR8/2), coarse-grained sandstone; core recovery 2.5/2.5 = 100%.

1508.5-1511.0' Sandstone, grayish-orange-pink (5YR7/2), coarse- to fine-grained, poorly-sorted, some siderite altered to hematite, interbedded light brownish-gray (5YR6/1) to dark reddish-brown (10R3/4) to very pale green (10G8/2), sandy shale; shale is fissile and has sharp contacts with sandstone; core recovery 2.5/2.5 = 100%.

1511.0-1550.0' Sandstone, light brownish-gray (5YR6/1) to grayish-red-purple (5RP4/2), coarse- to fine-grained, poorly sorted, subrounded-to-angular grains; with irregular greenish-gray (5GY6/1) shale laminae, hematite spots, and brachiopod fragments; some rounded black grains in sandstone; false oolites of crystalline calcite in sandy silty matrix from 1522.8 to 1523.5 feet; erosional contacts with sharp upper boundaries and gradational lower ones at 1514.0 to 1517.2 feet and incipient ones elsewhere; core recovery is poor, especially near the bottom; core recovery 28.5/39.0 =73%.

1550.0-1595.0' Sandstone, grayish-orange-pink (5YR7/2) to dusky-red (5R3/4) to dark yellowish-orange (10YR6/6), very coarse- to fine-grained, poorly-sorted, silty, micaceous; with trace of glauconite and rounded black grains; interbedded moderate red (5R5/4) to dark reddish-brown (10R3/4), very sandy shale; poor core recovery 7.2/45.0 = 16%.

1595.0-1619.0' Sandstone, dark yellowish-orange (10YR6/6) to pale red (5R6/2) to grayish-orange-pink (10R8/2), very coarse- to fine-grained, poorly sorted, silty; with a trace of black grains; interbedded with dusky red (5R4/4) micaceous silty shale, especially toward the bottom where coarse sand and small quartz pebbles in some slickensided shale beds, which are altered red clastic boulders, are common; at the base, a thin conglomerate of subrounded quartz pebbles in yellow and red clayey matrix; core recovery 15.4/24.0 = 64%.

Precambrian Red Clastics, "Type Three" Material of Kirwin (1963)

1619.0-1625.0' Shale, pale red (5R6/2) to dark reddish-brown (10R3/4), blocky; silt-sized grains predominate; many slickensided joints; unit not obviously bedded; pale yellowish-green (10GY7/2) coloration along joints and as spherical discolorations in the red shale is due to reducing conditions after oxidation of shale; some slickensided joint surfaces have raised or heaved lumps due to mineral growth after slickensided joints formed; core recovery 6.0/6.0 = 100%.

1625.0-1672.0' Shale, dusky red (5R4/4) to pale red (5R6/2); silt-sized grains predominate; composed of very fine micaceous material interbedded with thin laminae of pale red (5R6/2) and grayish-red (5R4/2) siltstone; bedding varies from 45° to 90° from horizontal; slickensided joints are greenish-gray (5G7/1), no change in clay mineral assemblage between green joint material and red shale; joints are healed with white (N9) calcite; the whole core highly fractured and slickensided; core recovery 47.0/47.0 = 100%.

1672.0-1684.5' Shale, dusky red (5R4/4); silt-sized grains predominate; interbedded with grayish-red (5R5/2), fine-grained argillaceous sandstone bedding planes up to 90° from horizontal; some fractures filled with reddish-brown (10R4/4) or white (N9) calcite; some greenish-gray (5G7/1) to dark yellowish-green (10GY4/4) joints and spherical zones; some bedding planes distorted also with penecontemporaneous disruptions; core recovery 12.5/12.5 = 100%.

1684.5-1688.0' Shale, pale red (5R6/2) to grayish-red (5R4/2) and dark yellowish-green (10GY4/4) to grayish-green (5GY6/1), silty; interbedded with fine-grained argillaceous sandstones; bedding planes up to 90° from horizontal; unit badly fractured with many green slickensided joints; core recovery 3.5/3.5 = 100%.

1688.0-1692.5' Shale, grayish-red (5R4/2); with silt- and clay-sized material about equal; minor amount of argillaceous sandstone; the unit is one massive bed with little bedding apparent; a few greenish-gray (5G7/1) reduced areas; core recovery 4.5/4.5 = 100%.

1692.5-1746.0' Interbedded siltstone and argillaceous sandstone, grayish-red (5R4/2) to pinkish-gray (5R8/2) to medium light gray (N6); with slickensided joints and pre-slickensided minor faulting; bedding nearly vertical, some fractures healed with pinkish-gray (5YR8/1) calcite; the sandstones are calcareous; minor grayish and greenish areas but also irregular red mottling; argillaceous sandstone areas from 1699.0 to 1702.5, 1704.0 to 1705.5, 1707.0 to 1798.0, 1711.0 to 1733.5 feet; unit from 1710.0 to 1746.0 feet is highly sheared with many fractures healed with calcite; core recovery 53.5/53.5 = 100%.

1746.0-1755.0' Sandstone, mottled grayish-pink (5R8/2) and medium light gray (N6), argillaceous, fine-grained, calcareous; with fractures healed by calcite and also bedded calcite in the pink sandstone; bedding is approximately 60° to the horizontal; core recovery 9.0/9.0 = 100%.

1755.0-1755.8' Siltstone, grayish-red-purple (5RP4/2) and some medium gray (N5), fine-grained; interbedded with fine-grained argillaceous sandstone; with highly sheared areas; bedding generally about 75° to horizontal; some calcite-filled fractures; core recovery 0.8/0.8 = 100%.

1755.8-1778.0' Sandstone, mottled grayish-pink (5R8/2) and medium-gray (N5), argillaceous, fine-grained, thick-bedded; with calcite; some crossbedding present but mostly normal bedding with minor disruptions; bedding nearly vertical; one layer of medium dark gray (N4) shale 0.05 feet thick with interbedded gray shale and siltstone; some calcite-filled fractures present; core recovery 22.2/22.2 = 100%.

1778.0-1782.2' Interbedded siltstone and argillaceous sandstone, grayish-red (5R4/2) and light brownish-gray (5YR6/1); bedding 75° to horizontal; minor faulting; bottom is highly sheared; core recovery 4.2/4.2 = 100%.

1782.2-1803.5' Sandstone, light brownish-gray (5YR6/1), argillaceous; thick-bedded with some medium-bedded zones; calcite-healed fractures; bedded grayish-red (5R3/2) and medium gray (N5) siltstone and argillaceous sandstone in the zone from 1796.0 to 1798.0 feet; locally faulted in zone of dark red silt; the bedding is at 45° to horizontal; core recovery 21.3/21.3 = 100%.

1803.5-1809.2' Siltstone, grayish-red (5R3/2) and medium-gray (N5); fine-grained micaceous material present; bedding indistinct; some sandstone "dikes" up to 0.01 feet thick; some slickensides and sheared areas; core recovery 5.7/5.7 = 100%.

1809.2-1811.0' Sandstone, mottled medium gray (N5) and grayish-pink (5R8/2), fine-grained, argillaceous, with bedding indistinct; white (N9) calcite-healed fractures; core recovery 1.8/1.8 = 100%.

1811.0-1815.0' Siltstone, grayish-red (5R3/2); a few irregular medium bluish-gray (5B4/1) shale interbeds; bedding at about 50° to horizontal, slickensided fractures parallel the bedding; core recovery 4.0/4.0 = 100%.

1815.0-1832.0' Interbedded argillaceous sandstone and siltstone; sandstone mottled pinkish-gray (5YR8/1) and medium gray (N5), fine-grained; siltstone is grayish-red (5R3/2) to medium bluish-gray (5B5/1); the bedding is at 50° to the horizontal; graded bedding present; many fractures healed with white (N9) coarse-grained calcite; core recovery 17.0/17.0=100%.

1832.0-1880.0' Siltstone, dusky brown (5YR2/2) to blackish-red (5R2/2) and medium bluish-gray (5B4/1), pinkish-gray (5YR8/1) and medium gray (N5); thinly laminated zones from 1849.0 to 1852.0, 1859.0 to 1862.0, 1866.0 to 1868.0 feet; white (N9) calcite-filled fractures common; bedding, where present, varies from 75° to vertical with respect to the horizontal; special features present: graded bedding, sandstone dikes (1864.8), highly sheared zones (1835.0 to 1838.0, 1840.0 to 1840.8, 1878.0 to 1880.0 feet), black fissile argillite from 1840.0 to 1841.6 feet, folded and faulted bedded strata with bedded calcite from 1866.0 to 1868.0 feet; bottom 10 feet (1870.0 to 1880.0 feet) have alternating dark red and blue colors; core recovery 48.0/48.0 = 100%.

1880.0-1889.0' Siltstone, blackish-red (5R3/2); with some interbedded graywacke, highly faulted and sheared; white (N9) calcite-healed fractures; core recovery 9.0/9.0 = 100%.

1889.0-1901.6' Siltstone, blackish-red (5R3/2) and grayish-red (5R4/2), massive except near the top and bottom where highly sheared; core recovery 100%.

1901.6-1905.0' Sandstone, medium light gray (N6), some pinkish-gray (5YR8/1), bedded, fine-grained, argillaceous; bedding at about 50° to horizontal; some calcite-healed fractures present but where the fractures are slickensided there is no calcite; core recovery 3.4/3.4 = 100%.

Table A - 3 – Mineralogy of the clay-sized fractions of the Decorah[1] and Glenwood[2] Formations of Hole H-1

Decorah Formation

Sample Number	Sample position in feet above Platteville Fm.	Type X-Ray Curve[3]
345-A (Galena Fm)	45	F
345-B	43	F
345-C	41	F
345-D	39	C
345-E	37	C
345-F	35	C
345-G	33	C
345-H	31	C
345-I	29.5	F
345-J	28	C
345-K	26	F
345-L	24.5	F
345-M	22.5	F
345-N	21	B
345-O	19.5	B
345-P	17	B
345-Q	15	F
345-R	13	B-C
345-S	11.5	B
345-T	10	B
345-U	8	B
345-V	6	B
345-W	3	B
345-X	1	B

[1] Parham, Walter, E., and Austin, George S., 1969, Clay Mineralogy, Fabric, and Industrial Uses of the Shale of the Decorah Formation, Southeastern Minnesota: Minn. Geol. Survey Rept. Inv. 10, 30 p.

[2] Op. Cit. p. 8.

[3] X-Ray Curves illustrating the range in composition of the clay-sized fraction. Curve B, 1/3 kaolinite and 2/3 illite; Curve C, 1/4 kaolinite and 3/4 illite; and Curve F, illite only. The general vertical variation in clay mineralogy is a decrease in kaolinite upward in the section.

Glenwood Formation

Three samples were taken of the Glenwood Formation from H-1: 459 to 461, 461 to 463, and 463 to 467 feet.

Interval in feet Below Surface	Type X-Ray Curve[4]
459 - 461	C
461 - 463	C - D
463 - 467	B

[4] X-ray curves illustrate the range in composition of the clay-sized fraction: Curve B 1/3 kaolinite and 2/3 illite, Curve C 1/4 kaolinite and 3/4 illite, and Curve D is illite only.

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