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FIELD TRIP GUIDEBOOK FOR PALEOZOIC AND MESOZOIC ROCKS OF SOUTHEASTERN MINNESOTA

PREPARED FOR THE ANNUAL MEETING OF
THE GEOLOGICAL SOCIETY OF AMERICA
AND ASSOCIATED SOCIETIES
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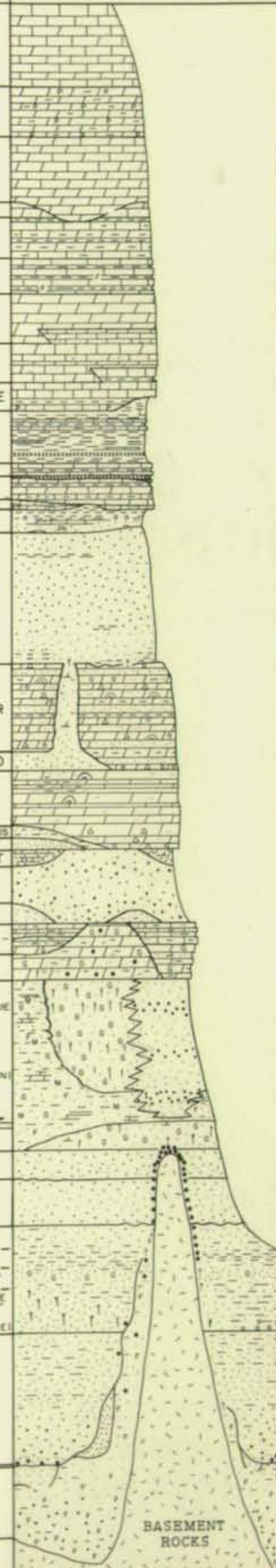
GEOCHRONOLOGIC			CHRONOSTRATIGRAPHIC			LITHOSTRATIGRAPHIC			DOMINANT LITHOLOGY	APPROXIMATE MAXIMUM THICKNESS IN FEET	
ERA	PERIOD	EPOCH	SYSTEM	SERIES	STAGE	GROUP	FORMATION	MEMBER			
PALEOZOIC	DEVONIAN	MIDDLE	DEVONIAN	MIDDLE	TIOUGHNIOGAN – TAGHANICIAN		CEDAR VALLEY	CORALVILLE		305	115+
								RAPID			55+
								SOLON			70+
	ORDOVICIAN	LATE	ORDOVICIAN	CINCINNATIAN ?– ?–?	Undifferentiated CINCINNATIAN ?– ?–?		MAQUOKETA	CLERMONT		70	20+
								ELGIN			
							DUBUQUE			35	
		MIDDLE		CHAMPLAINIAN	TRENTONIAN ?– – –		GALENA	STEWARTVILLE		230	95
								PROSSER			75
								CUMMINGSVILLE			75
							DECORAH			95	
					BLACK RIVERIAN ?– – ?		PLATTEVILLE	CARIMONA		35	11
								McGREGOR			22
								PECATONICA			?
							GLENWOOD			18	
							ST. PETER			155	
					CHAZYAN ?						
		EARLY		CANADIAN		PRAIRIE du CHIEN	SHAKOPEE	WILLOW RIVER		360 / 240	240
								NEW RICHMOND			65
							ONEOTA	BLUE EARTH BEDS		170	4
								KASOTA BEDS			6
	CAMBRIAN	LATE	CAMBRIAN	ST. CROIXAN	TREMPEALEAUAN (=TREMADOCIAN ?)		JORDAN	SUNSET POINT		115	20
								VAN OSER			90
								NORWALK			55
							ST. LAWRENCE	LODI (upper / lower)		65	65 (35 / 30)
								BLACK EARTH			65
					FRANCONIAN		FRANCONIA	MAZOMANIE		190	(Mz) 115
								RENO			(Rn) 115
								S ← → N			
								TOMAH			(Tt) 140
								BIRKMOSE			(Bk) 65
							IRONTON			45	
					DRESBACHIAN		GALESVILLE			95	
							EAU CLAIRE	"SANDY UNIT"		195	70
								"SHALY UNIT"			45
								"GREENSAND UNIT"			45
								"RED UNIT" – "SAND-SHALE UNIT" (W ← → E)			70 / 70
							MT. SIMON			315	
PRE-CAMBRIAN						"RED CLASTICS SERIES"	HINCKLEY FOND du LAC OLDER SEDIMENTARY UNITS				
						OLDER IGNEOUS AND METAMORPHIC ROCKS					

MINNESOTA GEOLOGICAL SURVEY
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P. K. Sims, Director

FIELD TRIP GUIDE BOOK FOR

PALEOZOIC AND MESOZOIC ROCKS OF SOUTHEASTERN MINNESOTA

Leaders

G. F. Webers and G. S. Austin

Special Papers

PALEOZOIC LITHOSTRATIGRAPHY OF SOUTHEASTERN MINNESOTA, G. S. Austin

PALEOECOLOGY OF THE ORDOVICIAN STRATA OF SOUTH-EASTERN MINNESOTA, G. F. Webers

NOTES ON THE PLATTEVILLE FORMATION, SOUTH-EASTERN MINNESOTA, Robert E. Sloan

PRECAMBRIAN QUARTZITE AND CRETACEOUS ROCKS OF SOUTHERN MINNESOTA, G. S. Austin

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PALEOZOIC LITHOSTRATIGRAPHY OF SOUTHEASTERN MINNESOTA

George S. Austin[1]

INTRODUCTION

The Paleozoic rocks of southeastern Minnesota (fig. 1) were deposited from a marine sea which occupied the Hollandale Embayment (fig. 2), a shallow depression that extended northward from the Ancestral Forest City Basin (Iowa Basin) onto the cratonic shelf and into Minnesota and Wisconsin in Early and Middle Paleozoic time. The rocks that now remain within the embayment in Minnesota are bordered to the east by nearshore-facies Paleozoic rocks on the Wisconsin Arch, to the northeast by Precambrian rocks that constitute the Wisconsin Dome, and to the north and west by nearshore-facies Paleozoic rocks lying near the margins of the Hollandale Embayment and the Precambrian rocks of the Transcontinental Arch. The embayment overlies older basins and horsts that are bounded by large-scale Precambrian faults (Sims and Zietz, 1967). Many smaller Paleozoic basins, depositional barriers, and faults within the embayment probably have resulted from relatively minor recurrent movements along Precambrian faults during Paleozoic time (Craddock and others, 1963).

PRE-MT. SIMON ROCKS

Several types of older rocks, mainly Keweenawan in age, lie directly beneath the Cambrian Mt. Simon Sandstone in southeastern Minnesota. These are principally the Hinckley Sandstone and arkosic sandstones and shales of the Red Clastic Series, considered to be Late Keweenawan in age, and basalt and rhyolite flows of Middle Keweenawan age. Near the margins of the embayment and on the Wisconsin Arch older granitic rocks directly underlie the Mt. Simon.

PALEOZOIC FORMATIONS

The Paleozoic lithostratigraphic nomenclature for southeastern Minnesota (fig. 3) has developed primarily from a study of outcrops near the St. Croix and Mississippi Rivers along the eastern border of Minnesota. Recently, deep cores within the Hollandale Embayment have become available and the stratigraphy has been revised (Austin, 1969; 1970).

[1]Indiana Geological Survey, Bloomington, Indiana

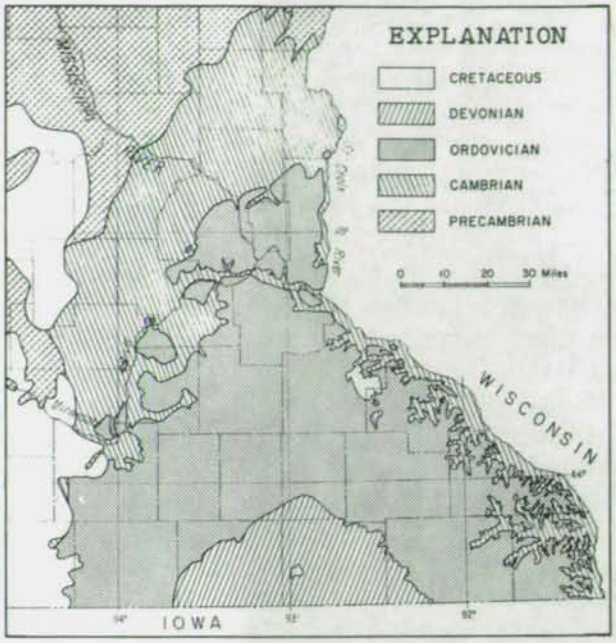

Figure 1. Generalized bedrock geologic map of southeastern Minnesota.

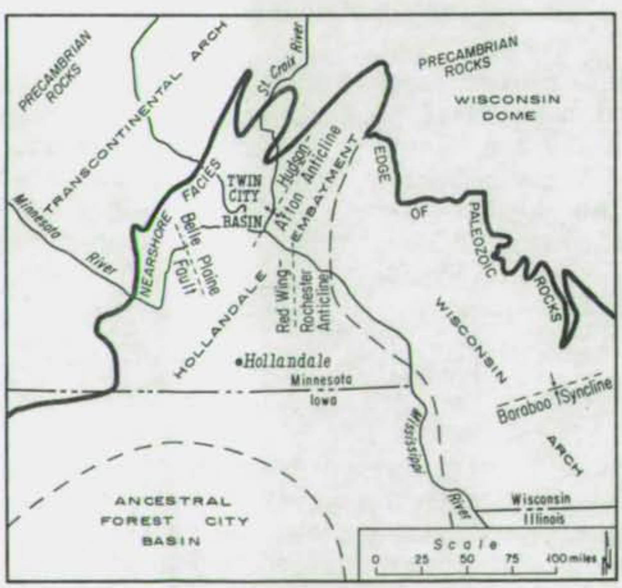

Figure 2. Map showing the location of large structural elements in southeastern Minnesota and adjacent states.

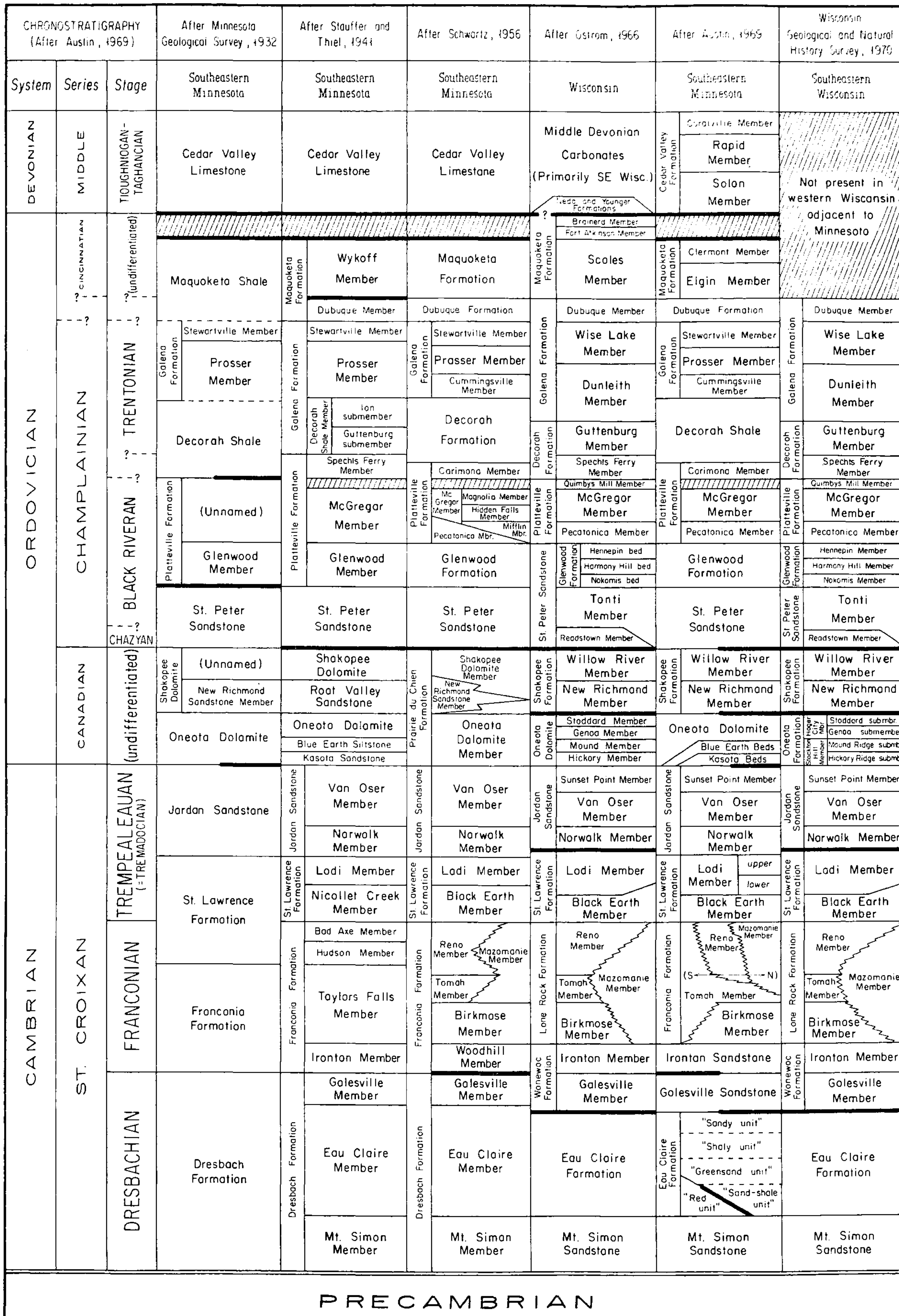

Figure 3. Development of the classification of Paleozoic rock units in southeastern Minnesota and western Wisconsin from 1932 to present.

Cambrian

The Mt. Simon Sandstone is composed of white, gray, pink, or yellow medium-grained quartzose sandstone and some thin shale beds. Fine-grained sandstone near the top of the unit and coarse to very coarse-grained sandstone toward the bottom are interbedded with medium-grained sandstone. Although the Mt. Simon is a quartzose sandstone, it may contain siderite, particularly near the base. Many cross-bedded zones and numerous fragments of inarticulate brachiopods, indicating a high-energy depositional environment, are present in the Mt. Simon. However, the thin grayish-green and red shale beds, which are especially common in the upper part of the formation and are interstratified with these high-energy deposits, indicate periodic lower energy environments of deposition or influx of fine-grained clastic sediment.

The Eau Claire Formation in Minnesota consists of five different rock units. A "red shale phase" (Stauffer, 1927; Stauffer and Thiel, 1941) -- more properly classified as a red, silty, fine-grained quartzose sandstone and shale or red, locally worm-burrowed siltstone -- occurs along the western border of the Hollandale Embayment and below the other rock types of the formation near the center of the embayment (Austin, 1969). Fine-grained nonglauconitic quartzose sandstone and interbedded grayish-green fissile shale are found in the lowest part of the Eau Claire where the red unit is absent. Glauconitic, very fine- to medium-grained quartz sandstone with some thin grayish-green shale beds characterizes the middle unit of the formation. Interbedded grayish-green shales and fine-grained quartzose sandstones comprise the fourth rock type. The thickest shale bed noted in this unit is about 8 feet thick. The fifth and uppermost unit is a massive, light-gray, locally glauconitic, fine-grained quartzose sandstone with some interbedded shale. West of the Minnesota River and north and west of the Twin City Basin the distinctive lithologies of the Mt. Simon, Eau Claire, Galesville, and Ironton Formations blend and this sequence may be composed of white quartzose sandstone in one locality and interbedded white sandstone and varicolored shale in another.

The Galesville Sandstone in Minnesota is a white to light-gray, slightly glauconitic, well to moderately well sorted, mostly medium-grained quartzose sandstone but is interbedded with fine-grained quartzose sandstone beds toward its base. The base is placed just below the first medium-grained sandstone and just above the massive fine-grained sandstone that is typical of the upper part of the Eau Claire Formation. In western Wisconsin the Galesville lies disconformably on the Eau Claire (Ostrom, 1966) but this relationship has not yet been observed in Minnesota.

The Ironton Sandstone is a white, medium-grained, moderately well sorted to poorly sorted quartzarenite that has a significant amount of admixed silt-size material. The top few feet contain some glauconite and are typically stained yellowish-brown in contrast to the dominant white or light-gray color of the bulk of the formation. The base of the Ironton is placed just above the nonsilty, better sorted, medium- and fine-grained sandstones of the Galesville and just below the silty, less well sorted, medium-grained sandstones of the Ironton.

Berg (1954) and Berg and others (1956) identified an unconformity at the base of the Ironton which separates the regressive Galesville from the transgressive Ironton. However, the Ironton Sandstone is more properly classified as a lower energy sandstone that lies above the higher energy Galesville. Where both entire Galesville and Ironton Formations are present, as is perhaps the case near the center of the Hollandale Embayment, the bottom part of the Galesville is regressive and the upper part is transgressive. Away from the center of the embayment, as on the Wisconsin Arch, only the upper transgressive Galesville is present and an unconformity is found between the underlying Eau Claire Formation and the overlying Galesville Sandstone (Ostrom, 1966).

The Ironton Sandstone was deposited in quieter and deeper water than the lower part of the Galesville Sandstone. Sand reworked from the Galesville or from the same source as the Galesville, and therefore of about the same grain size, was deposited during Ironton time. The sandstone of the Ironton, however, is less well sorted than the Galesville and commonly contains silt. Bottom currents of low energy could not sort grains as efficiently as those of Galesville time.

The sharp contact between Ironton and Galesville Sandstones in the St. Croix Valley area is due to a rapid change in current activity and may have resulted from recurrent movement along Precambrian faults in Cambrian time (G. B. Morey, oral comm., 1969); this movement also produced the angular unconformity between the Galesville and Ironton noted by Berg (1954) and Berg and others (1956). The proof of the presence or absence of a widespread unconformity in Minnesota, however, awaits a detailed study of the fauna, not at the margins, but at the center of the embayment.

An isopach map of the Ironton and the underlying Cambrian formations (fig. 4) suggests that the Hollandale Embayment itself was not defined in Ironton or earlier time; there is no obvious relationship between the isopachs and the shape of the embayment. In general, the Ironton and underlying Upper Cambrian formations increase in thickness to the southeast and decrease in thickness to the northeast. The principal source of sediment therefore may have lain to the southeast and the Transcontinental Arch contributed little if any clastic material. The structural contour map of the top of the Ironton Sandstone (fig. 5) indicates that the development of the major structural elements in southeastern Minnesota, such as the Twin City Basin and the Belle Plaine fault, occurred after the deposition of the Ironton.

The <u>Franconia Formation</u> contains four members. In ascending order they are <u>the Birkmose Member</u>, a glauconitic, worm-burrowed, fine-grained quartz sandstone containing some silt and some dolomitic layers; the

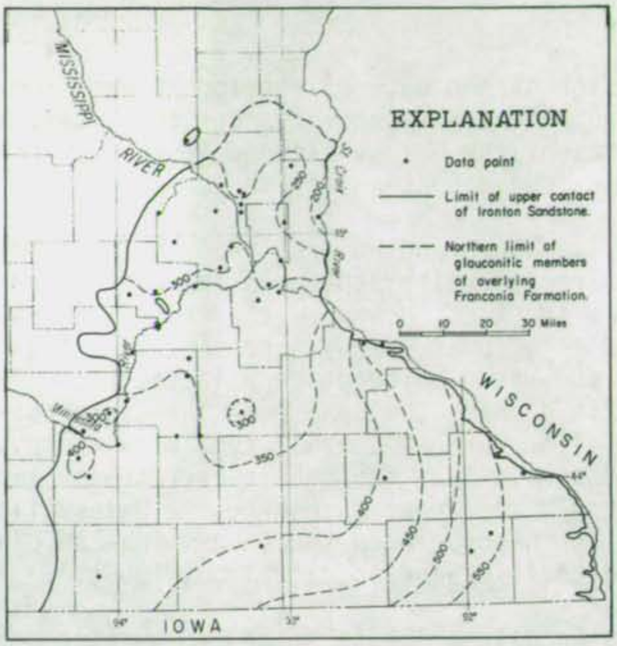

Figure 4. Isopach map of the combined Ironton, Galesville, Eau Claire, and Mt. Simon Formations of southeastern Minnesota.

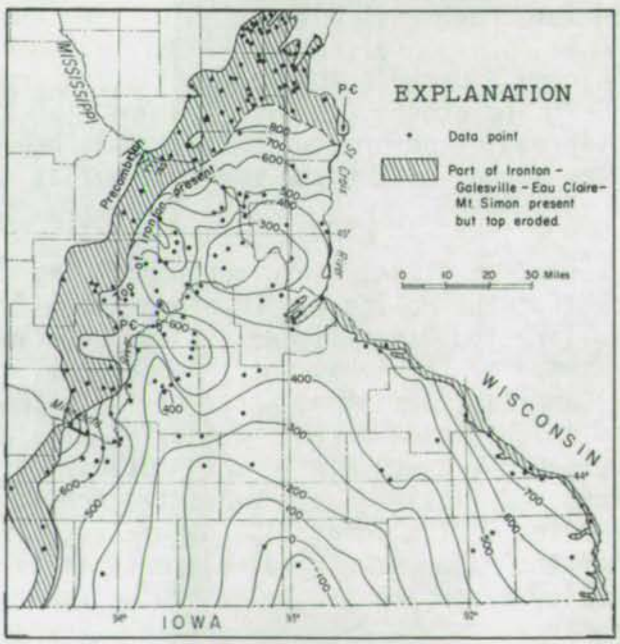

Figure 5. Contour map of the present altitude of the top of the Ironton Sandstone in southeastern Minnesota.

Tomah Member, a very fine- to fine-grained, locally glauconitic, feldspathic, silty quartz sandstone with some interbedded greenish-gray micaceous shale and minor amounts of glauconitic dolomite; the Reno Member, a glauconitic, worm-burrowed, fine-grained quartz sandstone and a glauconitic siltstone west of the Minnesota River; and the Mazomanie Member, a thin bedded or cross-bedded, essentially nonglauconitic, dolomitic, fine- to coarse-grained quartzose sandstone that interfingers with and replaces the Reno and Tomah Members in the northern part of the Hollandale Embayment.

The Mazomanie Member is present in the northern part of the Twin City Basin and to the north and east. The Reno constitutes nearly the entire Franconia section along the Mississippi River Valley and west of the Minnesota River but disappears toward the center of the Hollandale Embayment. The Birkmose is quite continuous but disappears north of the Twin City Basin and near the center of the embayment. The Tomah is the most laterally persistent member of the formation and is at places the only member present near the center of the embayment. Berg and others (1956) suggest that the regional distribution of the members of the Franconia Formation and the thickness of the unit are dependent on the position of the shoreline.

The Franconia Formation ranges from about 100 to 200 feet in thickness and is thinnest along the western border of the subdrift outcrop belt. The formation is thickest to the north, where the shoreward Mazomanie Member predominates, and thins to the south and east, where the glauconitic members are dominant. Outcrop and well data have shown that the Mazomanie predominates north of the center of the Twin City Basin and the Reno is the dominant facies along the Mississippi and Minnesota Rivers. Recent work (Austin, 1969) has suggested that the dolomitic Tomah Member is the dominant unit near the center of the Hollandale Embayment and that the glauconitic members predominate between the more shoreward and more basinward accumulations. Therefore, the embayment is roughly defined by the distribution pattern of the members of the Franconia Formation, but the absence of the Mazomanie Member to the west suggests that the sea extended much farther to the west during Franconia time and perhaps covered the Transcontinental Arch.

The St. Lawrence Formation contains a variety of silty and sandy dolomitic rocks lying between the overlying Jordan Sandstone and the underlying Franconia Formation. The lower member of the St. Lawrence Formation, the Black Earth Member, is composed of glauconitic, argillaceous, silty or sandy dolomite and commonly is highly resistant but does contain some less resistant silty beds. Flat-pebble conglomerates occur in the member and are particularly common near the base (Twenhofel and others, 1935; McGannon, 1960).

The upper or Lodi Member of the St. Lawrence Formation is composed of silty argillaceous dolomite. The lower part of the Lodi contains mottled green, slightly glauconitic, argillaceous dolomite, which is less resistant than the Black Earth Dolomite, and buff dolomitic siltstones or alterations of these types. The upper Lodi consists of unmottled buff or gray, thin to thick bedded, hard, argillaceous, silty dolomite, with some units of white or brown, friable to well cemented, sandy siltstone and a trace of glauconite.

The St. Lawrence Formation ranges from 35 to 190 feet in thickness in Minnesota but the variation is not systematic and no directional trends in thickness of the formation as a whole are observed. The Black Earth Member of the St. Lawrence Formation, however, thins eastward and northward and is absent at the most northerly exposures of the St. Lawrence in the valley of the St. Croix River, where the upper member of the St. Lawrence lies directly on the underlying Franconia Formation. Near the center of the embayment and to the west the Black Earth makes up the entire St. Lawrence succession. The Lodi generally makes up the entire thickness of the St. Lawrence Formation on the northern part of the Wisconsin Arch and in the Mississippi and St. Croix River Valleys. In southeastern Minnesota and western Wisconsin the carbonate content of the Lodi decreases and the sand content increases north, south, and east of an east-west line drawn through Winona, Minnesota (McGannon, 1960). The distribution of the Black Earth and Lodi and their lithologies indicate that the Wisconsin Arch was the principal source of clastic sediment and the Hollandale Embayment probably opened basinward toward the west, southwest and south during St. Lawrence time.

The Jordan Sandstone in Minnesota contains three members. In ascending order these are the Norwalk Member, a yellow, silty, fine-grained quartzose sandstone; the Van Oser Member, a white or yellow, coarse- to medium-grained orthoquartzite; and the Sunset Point Member, an argillaceous and dolomitic quartz sandstone with pebble-sized clasts of dolomitic sandstone and thin beds of dolomite. The Van Oser is the thickest and most laterally persistent member of the Jordan Sandstone in Minnesota and is the only member known to be present in the Twin City Basin. The Sunset Point Member occurs principally along the Mississippi Valley, and the Norwalk Member is confined to the fringes of the Hollandale Embayment in Minnesota.

The Jordan Sandstone is an average of 85 feet thick north to south across the Hollandale Embayment and thins from 100 to 120 feet in extreme southeastern Minnesota to 50 feet to the west near Mankato, Minnesota (fig. 6). This east-west trend in sedimentation is similar to the trend in the underlying Lodi Member of the St. Lawrence Formation and supports the theory that the embayment opened seaward to the west and southwest during Trempealeauan time.

Lower Ordovician

The Lower Ordovician rocks are difficult to differentiate in southeastern Minnesota (Heller, 1956). Accordingly, where the underlying Oneota Dolomite cannot be separated from the overlying Shakopee Formation, it is advisable to identify the entire succession as the Prairie du Chien Group.

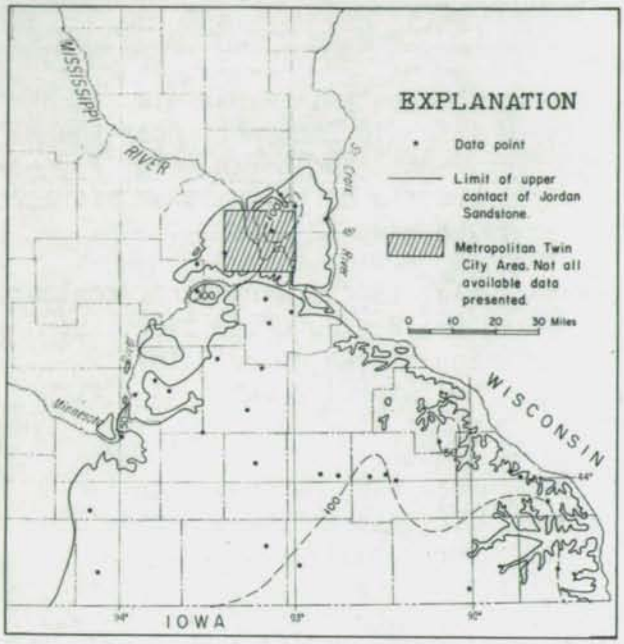

Figure 6. Isopach map of the Jordan Sandstone in southeastern Minnesota.

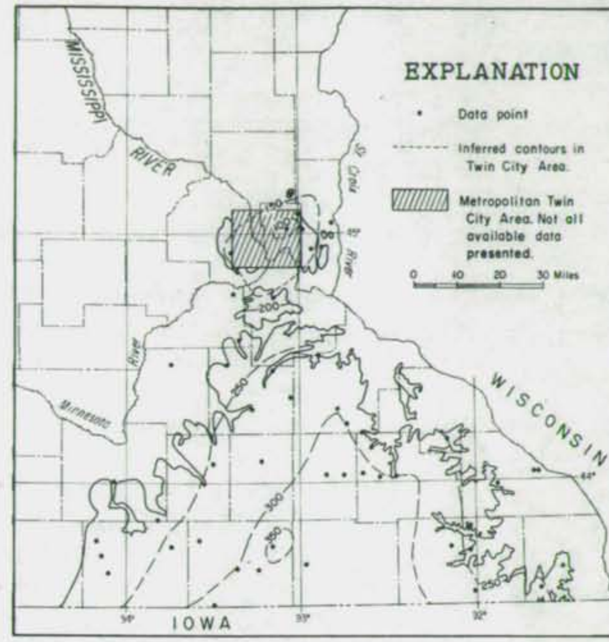

Figure 7. Isopach map of the Prairie du Chien Group in southeastern Minnesota.

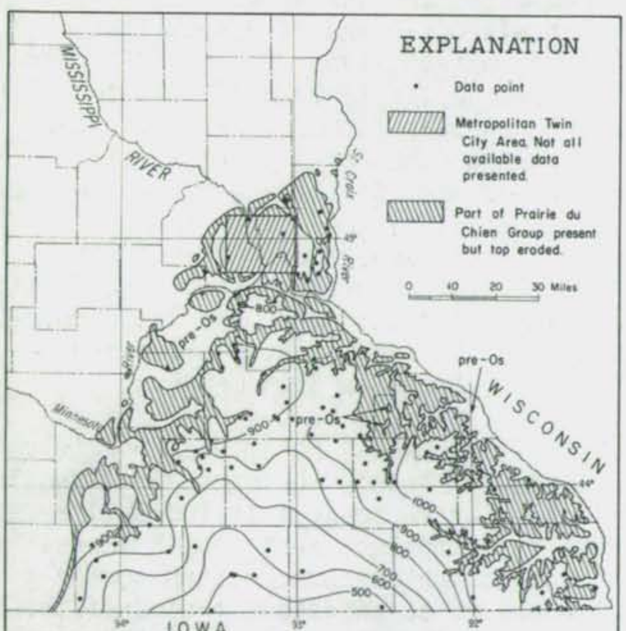

Figure 8. Contour map of the present altitude of the top of the Shakopee Formation of southeastern Minnesota.

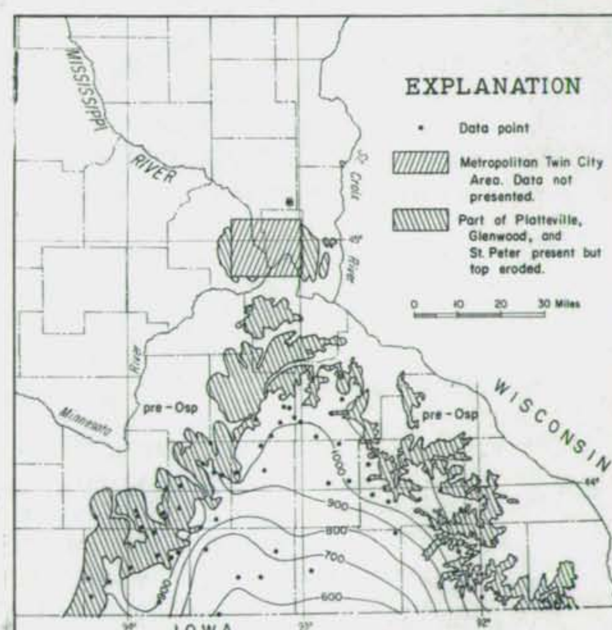

Figure 9. Contour map of the present altitude of the top of the Black Riveran Strata of southeastern Minnesota.

The Prairie du Chien Group thickens to the south in Minnesota, exceeding 350 feet toward the center of the Hollandale Embayment near the Minnesota-Iowa border, and thins to the east, west, and north (fig. 7). Near the center of the Twin City Basin, the Prairie du Chien is an average of 100 feet thick and increases away from the basin.

The isopach contours follow a trend similar to the structural contour lines (fig. 8) in the Twin City Basin during Prairie du Chien time, suggesting that the basin was affecting deposition of the group. This is the first indication of the development of the Twin City Basin as a structural feature in the geologic column.

The Oneota Dolomite is primarily a thin to thick bedded, locally stromatolitic, light brownish-gray or buff, fine- to medium-grained dolomite. Chert and some sand-sized detritus occur locally near the base of the formation. A greenish-gray shaly siltstone locally present beneath the dolomite is designated the "Blue Earth Siltstone Beds" of the Oneota Dolomite. A thin sandstone unit lithologically similar to the underlying Jordan Sandstone but containing Ordovician fossils (Powell, 1935) is present locally beneath the Blue Earth Beds and is designated the "Kasota Sandstone Beds" of the Oneota Dolomite.

The Shakopee Formation consists of two members (Davis, 1966a; Austin, 1969). The lower member, the New Richmond Member, consists of fine- to medium-grained quartzose sandstone, dolomite, and quartzitic dolomite and minor amounts of shale. The upper boundary of the member commonly is marked by a thin zone of interbedded grayish-green shale, quartzose sandstone and dolomite. The New Richmond in Wisconsin and Minnesota lies unconformably on the Oneota (Ulrich, 1924; Ostrom, 1965; Davis, 1966a and 1966b; Austin, 1969). This unconformity is particularly difficult to locate in southeastern Minnesota where an angular discordance is rarely observed and the dolomite above and below the unconformity are similar. The quartzose sandstones of the New Richmond west of the Red Wing-Rochester Anticline (fig. 2) are thin and difficult to distinguish from the thin sandstone beds within the upper member of the Shakopee Formation. The upper member of the Shakopee Formation, the Willow River Dolomite, consists of thin to thick bedded, fine- to medium-grained dolomite, quartzose dolomite, some interbedded quartzose sandstone, and some grayish-green shale. Chert and algal stromatolites commonly are present in both members.

The Shakopee Formation and the underlying Oneota Dolomite separately and together as a unit (fig. 7) thicken toward the center of the Hollandale Embayment. This accumulation of shallow-water carbonates is indicative of the more rapid deepening of the center of the embayment and indicates that perhaps the embayment opened seaward to the south more than to the west during Early Ordovician time. The quartzose sandstone facies of the New Richmond Sandstone Member of the Shakopee Formation thins to the west and north from extreme southeastern Minnesota and represents a remnant of the east-west trend in sedimentation of the underlying Trempealeauan Stage in the Early Ordovician.

Rock Stratigraphy of the Black Riveran Stage

In Minnesota the Black Riveran Stage contains, in ascending order, the St. Peter Sandstone, the Glenwood Formation, and the Platteville Formation. Black Riveran strata increase in thickness from south to north from about 100 feet thick near the Minnesota-Iowa border to 190 feet thick in the Twin City Basin. The Platteville and Glenwood Formations reach a maximum thickness from south to north from about 100 feet thick near the Minnesota-Iowa border to 190 feet thick in the Twin City Basin. The Platteville and Glenwood Formations reach a maximum thickness of 35 and 18 feet respectively (Austin, 1969) and thus the greater thickness of Black Riveran strata is due to the St. Peter Sandstone, which thickens from south to north and may be 155 feet thick in the Twin City Basin (Austin, 1969). Structural contours on top of Black Riveran strata (fig. 9) indicate that the Belle Plaine Fault has affected the Platteville Formation and older strata and thus is younger in age than these formations.

The St. Peter Sandstone is a light yellow or white, medium-grained but locally fine-grained, massive-appearing, generally well sorted orthoquartzite composed of rounded and subrounded grains. Because of its uniform grain size and low content of minerals other than quartz, cross-bedding is rarely observed in outcrop. A few thin beds of green shale are present within the formation, and the bottom few feet locally may be silty and contain some shale. The large-scale relief on the erosional unconformity at the base of the St. Peter in Wisconsin (Ostrom, 1965; 1967) does not seem to be present in Minnesota, and the contact between the St. Peter and the Shakopee Formation even may be gradational in the center of the embayment.

The lower part of the St. Peter has been described as shaly in Minneapolis (Thiel, 1944). Studies of cuttings from several wells in the western suburbs where the St. Peter is thickest indicate, however, that the supposedly shaly St. Peter is probably the sandy New Richmond Member of the Shakopee Formation (Austin, 1969). Below this shaly sandstone are thin sandy dolomites and interbedded sandstone, shales, and dolomites which are identified as shoreward equivalents of the Oneota Dolomite.

The Glenwood Formation is composed of grayish-green or yellow shale and a basal argillaceous quartz sandstone. A few local beds of limestone or dolomite also may be present. The lower contact is placed between the massive white sandstone of the underlying St. Peter and the argillaceous sandstone of the overlying Glenwood. The upper contact is placed above the uppermost thick shale bed and below the first massively bedded, commonly sandy, dolomitic limestone of the Platteville Formation.

Parham and Austin (1967), on the basis of the lateral variation in clay mineral assemblages of the shaly upper part of the formation, suggested that the Glenwood Formation in southeastern Minnesota was derived from a positive area which lay to the west or southwest during Glenwood time. Further, the Wisconsin Dome was not contributing clastics to this area during this time.

The Platteville Formation consists of three members. The lower or Pecatonica Member is a yellowish-brown, medium- to fine-grained dolomite or dolomitic limestone which may be sandy, particularly at the base, as a result of the presence of medium- to fine-grained rounded quartz sand. The Pecatonica Member commonly contains several corrosion zones in Minnesota. The middle or McGregor Member is a gray, light olive-gray, or buff, fine- to very fine-grained, thin bedded, dolomitic limestone or dolomite with interbedded brown or olive green shale. The McGregor has rippled bedding surfaces, which give it a characteristic crinkly bedding. The upper or Carimona Member is a medium bedded, fine-grained, light olive-gray or buff limestone with interbedded olive-gray shale. A 0.1 to 0.2-foot-thick metabentonite, the "Carimona bentonite," commonly is found at or just above the Carimona-McGregor contact.

Rock Stratigraphy of the Trentonian Stage

In Minnesota the Trentonian Stage, containing the Decorah Shale below and the Galena Formation above, is not separated from rocks of the underlying Black Riveran Stage by an unconformity. Parham and Austin (1969), on the basis of the vertical variation in clay mineral assemblages, have suggested that the Decorah Shale was deposited from a transgressing sea which had regressed but still covered southeastern Minnesota at the end of Platteville time.

Trentonian strata thicken to the south toward the center of the Hollandale Embayment and thin to the east, west, and north (fig. 10). The Decorah Shale, which is the basal formation of Trentonian strata in Minnesota, is 95 feet thick in the Twin City Basin and thins to the south to 55 feet thick near the Minnesota-Iowa border. The Decorah thins to 20 feet near the Mississippi River Valley in extreme southeastern Minnesota and to 40 to 45 feet in south-central Minnesota. Thus the thickening of the Galena Formation toward the center of the embayment is more pronounced than is shown by the combination of Decorah and Galena Formations.

Parham and Austin (1969) have suggested that the source of the clay minerals in the Decorah Shale was the portion of the Transcontinental Arch lying to the west or southwest of the embayment. The same source is suggested for the clay minerals in the Glenwood Formation of the underlying Black Riveran strata. Therefore, the shaly formations of Trentonian and Black Riveran strata appear to be derived from the west or southwest rather than from the part of the Transcontinental Arch to the north of the embayment or from the Wisconsin Dome to the northeast or east.

The Decorah Shale is a greenish-gray or olive-gray, fissile, fossiliferous shale containing scattered limestone beds which are commonly coquinoidal in Minnesota. For practical purposes the lower contact is

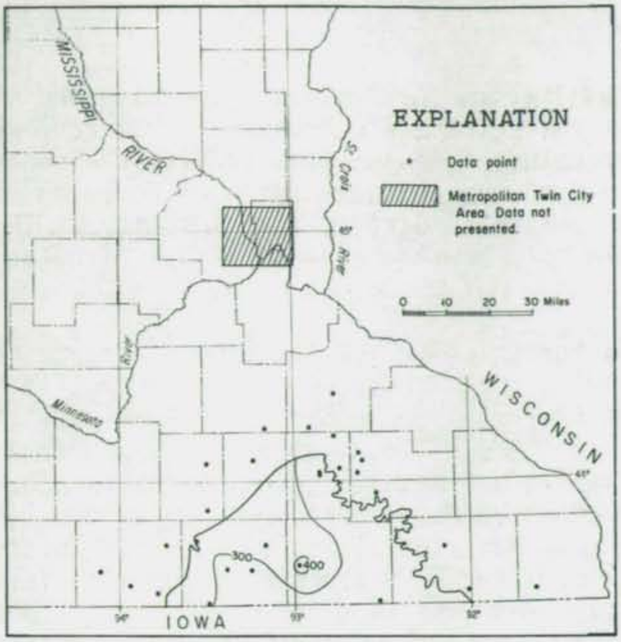

Figure 10. Isopach map of the combined Galena and Decorah Formations of southeastern Minnesota.

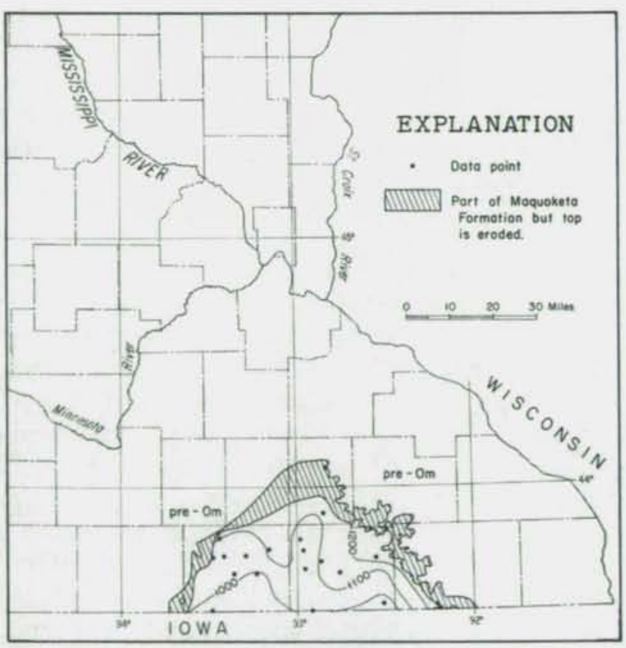

Figure 11. Contour map of the present altitude of the top of the Maquoketa Formation in southeastern Minnesota.

placed above the lowest non-coquinoid carbonate bed of the Platteville and below the first thick shale bed of the Decorah. Parham and Austin (1969) have indicated, however, that locally the contact may be a shale-on-shale type, with Decorah shale lying directly on Carimona shale. Because such a contact is difficult to identify in the field, however, it is preferable to place the contact at the lithologic break previously used.

The Galena Formation in southeastern Minnesota contains three members. In ascending order they are the Cummingsville Member, the Prosser Member, and the Stewartville Member. The Cummingsville is composed of interlayered thick beds of light olive-gray or buff limestone and thinner beds of both fissile and massive greenish-gray shale. The Prosser contains gray thin- to medium-bedded limestone or dolomitic limestone and has a small detrital component (Weiss and Bell, 1956; Weiss, 1957). The Stewartville Member is a buff-weathering, grayish-yellow, fine- to medium-grained dolomitic limestone that has a conspicuous mottled appearance. Although the units within the Galena Formation are considered members, the lithotopes are known to have alternated, producing interfingering lithologies (Austin, 1970).

Upper Ordovician

The Dubuque Formation in Minnesota is composed of interbedded light olive-gray or grayish-yellow, medium-bedded, crinoidal, fine-grained limestone and gray shale. The Dubuque is tentatively correlated with the Cincinnatian formations of Eden-Maysville age in Ohio and Kentucky on the basis of conodont assemblages (G. F. Webers, oral comm., 1969), although data from the study of ostracodes (Burr and Swain, 1965) indicate that this correlation is questionable.

Two members comprise the Maquoketa Formation in Minnesota (Bayer, 1965). The lower or Elgin Member contains flaggy limestones with nodular calcareous shales, shaly dolomite and calcareous shale beds, and coarsely crystalline dolomitized limestone. The upper or Clermont Member is a tan sandy limestone. The remainder of the Ordovician Maquoketa Formation in Minnesota was eroded prior to the deposition of the Cedar Valley Formation during Devonian time. The stratigraphy of the Maquoketa in Minnesota closely corresponds to that of the lower part of the Maquoketa in northern Iowa (Parker and others, 1959). The Maquoketa in Minnesota, however, does not contain the distinctive "depauperate beds" which are characteristic of the Maquoketa in Iowa (Glenister, 1957), and there is quite probably no break in deposition between the Dubuque and Maquoketa Formations, as is present in Iowa. In Minnesota the Maquoketa Formation (fig. 11), which ranges in thickness from 50 to 90 feet, was deposited from a sea which had occupied the area since before the underlying Dubuque Formation was deposited. Bayer (1965) indicates that the source of the detritus in the Elgin Member lay to the northeast or east, possibly as far away as the Taconic orogenic belt; however, the detritus in the sandy Clermont or upper member was derived from an uplift of the Transcontinental Arch in central Minnesota.

Devonian

The Cedar Valley Formation consists of three members in Minnesota (Kohls, 1961). In ascending order they are the Solon Member, the Rapid Member, and the Coralville Member, as defined by Stainbrook (1941). The Solon Member is transitional from a buff-gray, fine-grained, biogenic dolomite at the base to a light buff-gray, sublithographic dolomitic limestone toward the top. The Rapid Member is composed of gray, fine-grained shaly dolomite with prominent microbedding and black streaks of finely divided pyrite. The Coralville Member contains lithographic high-calcium limestone with microbedding and buff-gray, fine- to medium-grained dolomite and calcitic dolomite.

The Cedar Valley was deposited in a shallow sea under slightly reducing conditions. As the sea transgressed across the erosion surface, debris from the underlying Maquoketa was incorporated into the basal part of the unit. As 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. A thickness of 305 feet in southeastern Minnesota, more than twice that of east central Iowa, and a corresponding thickening of all three members are indicative of greater subsidence in Minnesota than in southeastern Iowa (Kohls, 1961) and suggest that the Cedar Valley extended much beyond its present outcrop area (fig. 12).

POST-CEDAR VALLEY ROCKS

Nonmarine rocks of Cretaceous (Sloan, 1964) 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. To the west these rocks interfinger with and are overlain by marine shales and sandstones of Late Cretaceous age (Sloan, 1964). Bedrock exposures of these rocks are commonly limited to the deeper stream valleys because of the thick mantle of Pleistocene materials.

SUMMATION OF THE LITHIC ENVIRONMENT DURING THE DEPOSITION OF PALEOZOIC STRATA IN SOUTHEASTERN MINNESOTA

Cyclic Sedimentation

Cyclic sedimentation in the Cambro-Ordovician rocks of the Upper

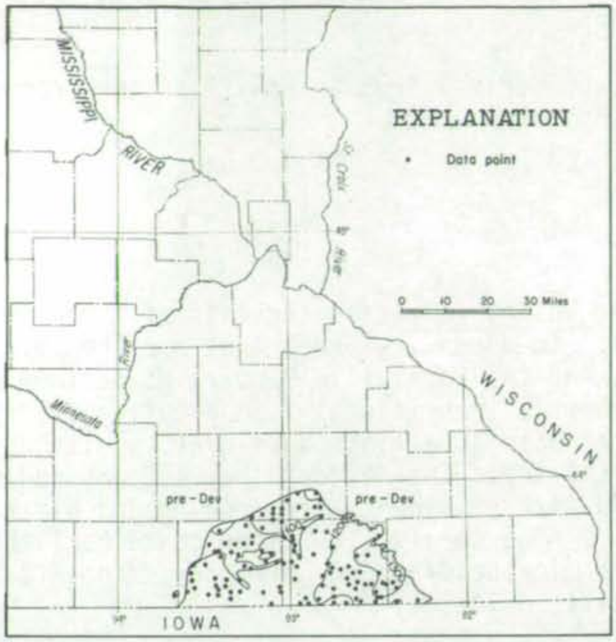

Figure 12. *Contour map of the present altitude of the eroded top of the Cedar Valley Formation in southeastern Minnesota.*

	Depositional environments			
Cycles	Beach-nearshore	Nearshore shelf	Depositional shelf	Reef
5	St. Peter Fm.	Nokomis Mbr.	Harmony Hill Mbr.	Ottawa Group
4	New Richmond Fm.	?	Present, but unnamed	Shakopee Fm.
3	Jordan Fm.	Madison Mbr.	Blue Earth Mbr.	Oneota Fm.
2	Galesville Fm.	Ironton Fm.	Franconia Fm. and Lodi Mbr.	Black Earth Mbr. (Trempealeau Fm)
1	Mt. Simon Fm.	"U. Mt. Simon"	Eau Claire Fm.	Bonneterre Fm.

Figure 13. *Strata comprising Ostrom's five pre-Cincinnatian Paleozoic sedimentary cycles in the Upper Mississippi Valley. (After Ostrom, 1964).*

Mississippi Valley has been identified by Ostrom (1964) and Ostrom and others (1970) and I have applied this concept to the Paleozoic rocks of southeastern Minnesota (Austin, 1970). Ostrom (1964) identified four recurrent lithotopes which characterize the rocks of the region, (1) well sorted quartzarenite, (2) poorly sorted unit of mixed lithologies, (3) shale or argillaceous sandstone, and (4) carbonate rock. Ostrom defined five successive episodes of submergence and emergence of the depositional shelf; these episodes developed in the continental interior during early Paleozoic time and are reflected in the lithologies of pre-Cincinnatian rocks (fig. 13). The cycles resulted from repeated marine transgression and regression, the former caused by rejuvenation of tectonically positive portions of the craton, and the latter resulting from submergence of the Appalachian geosynclinal basin far to the south and east and of the neighboring shelf area of the craton.

All Paleozoic rocks of southeastern Minnesota are shallow-water deposits and the terms "transgressive" and "regressive" denote vertical changes in the sequence of grain size, sorting, and the detrital-nondetrital ratio of the rocks. The recurrent lithotopes were caused by the cyclic variation of the amount, mineralogy, and grain size of the clastic influx into the depositional basin and reflect the cyclic depositional environments and, to a lesser degree, the environments and proximity of the source area.

In applying Ostrom's concept specifically to the Paleozoic rocks of southeastern Minnesota I defined nine cycles of recurrent lithotopes that characterize the rocks of this part of the depositional shelf during early and middle Paleozoic time (Austin, 1970). My approach to cyclic sedimentation in southeastern Minnesota resulted in (1) the identification of incomplete cycles, (2) extending the cycles into Devonian time, (3) distinguishing the Hollandale Embayment as a depositional area where both regressional and transgressional facies of the cycles were developed, and (4) identifying a gradual shift in sedimentation from predominant sandstone and subordinate carbonate near the base of the Paleozoic cycles to predominant carbonate and subordinate sandstone in the upper cycles (fig. 14).

The differences between the regional pattern and the pattern in southeastern Minnesota are small and, in general, Ostrom's concept is valid and can be used in the interpretation of the succession of strata in southeastern Minnesota. The variations in lithology and unconformities from the regional pattern are primarily due to the greater stability of the Hollandale Embayment as a subsiding depositional area and to shifting sources for clastic material during Paleozoic time. In Minnesota the paleoslope was not continuously toward the southeast during Paleozoic time, as was suggested by Ostrom. Further, the direction of sediment transport differs from the regional northeast-to-southwest pattern as identified by Ostrom during the deposition of several cycles.

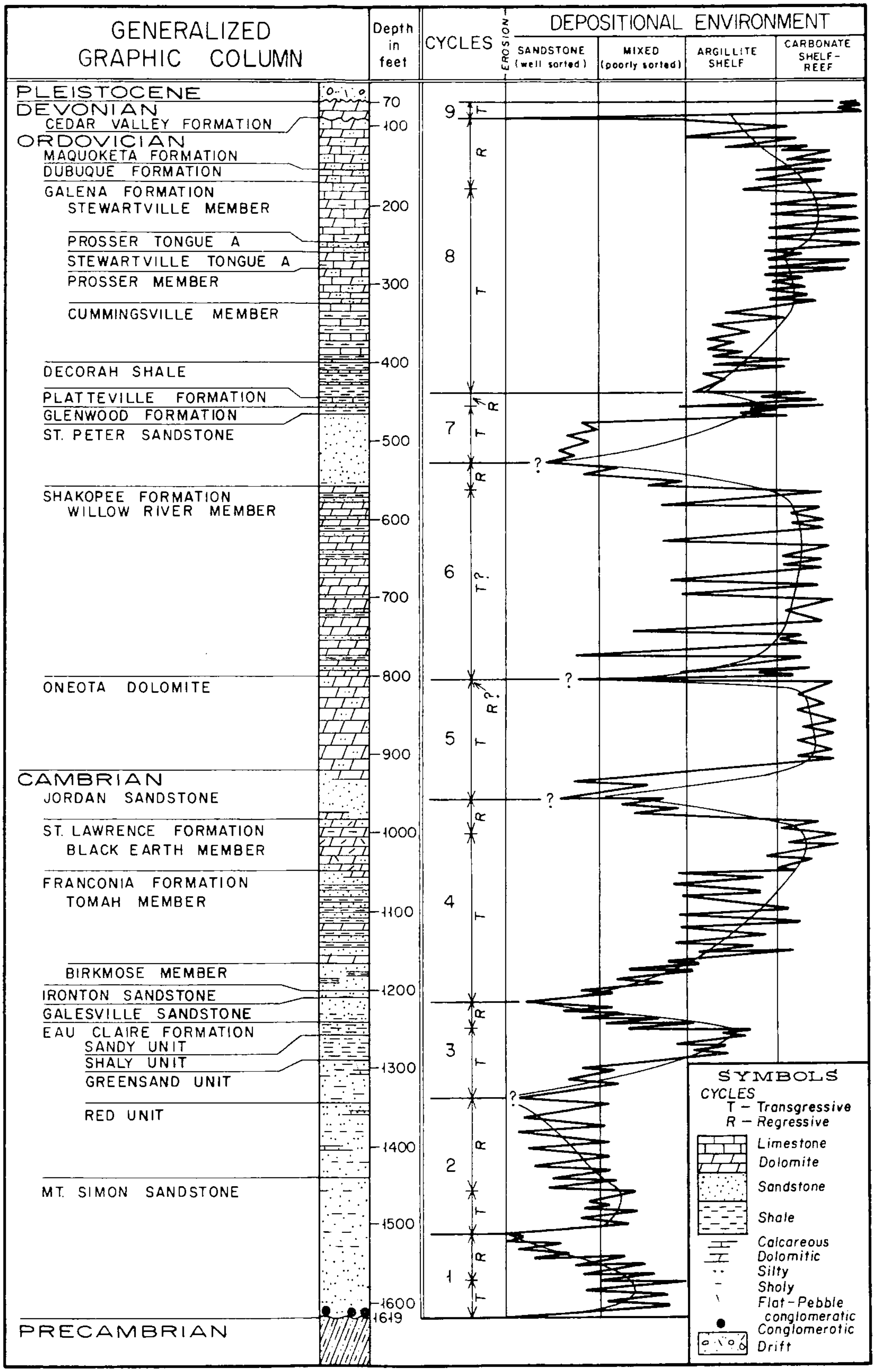

Figure 14. Generalized graphic log and cyclic depositional environments of the rock units in the deep stratigraphic test well near Hollandale, Minnesota (Austin, 1970).

Direction of Sediment Transport

Studies in southeastern Minnesota indicate that the direction of sediment transport and the paleoslope may have varied with time, with the uplift and degradation of different parts of the Transcontinental Arch-Wisconsin Dome positive area, and with the development of structures on the bottom of the Paleozoic seas which affected sedimentation. During Late Cambrian time the source of clastic material apparently was the Wisconsin Dome, which extended into northeastern Minnesota. Erosion of this positive area and the subsidence of the Wisconsin Arch at a more rapid rate than southeastern Minnesota resulted in (1) the thicker sequences of Mt. Simon, Eau Claire, Galesville and Ironton in extreme southeastern Minnesota (fig. 4), Wisconsin (Ostrom, 1967), and northern Illinois (Buschbach, 1964) than in the remainder of southeastern Minnesota, (2) the decrease of grain size in the Eau Claire and Galesville Formations from Wisconsin toward southeastern Minnesota, and (3) the reduction of labile constituents in the Mt. Simon from up to 40 percent in Wisconsin to 1 to 7 percent in Minnesota (Crowley and Thiel, 1940).

During Franconian time the source of clastic material in the embayment was northwestern Wisconsin and perhaps northeastern Minnesota. The absence of the Mazomanie Member in the western part of the Hollandale Embayment suggests that parts of the Transcontinental Arch lying in western and central Minnesota were not contributing large quantities of sediment to the basin. However, the dominance of the dolomitic Tomah Member in the center of the embayment does suggest the embayment was beginning to affect sediment patterns during this time. The dominant pattern of sediment transport during St. Lawrence time was from the east to the west as the sea widened to the west or southwest, with northwestern Wisconsin and perhaps northeastern Minnesota contributing the bulk of the clastic sediments. The Transcontinental Arch in central Minnesota was contributing sediment by Early Ordovician time to the developing Hollandale depositional area, forming a crescent of New Richmond Sandstone around the embayment. During St. Peter time the subsiding Twin City Basin filled with sand derived from sources lying to the northwest, north and northeast.

Studies of the clay mineral assemblages of the Glenwood and Decorah Formations (Parham and Austin, 1967 and 1969) suggest that northwestern Wisconsin and northeastern Minnesota were not contributing clastic material to southeastern Minnesota during Black Riveran and Trentonian time but that the Transcontinental Arch in southwestern and perhaps central Minnesota was the dominant positive area. Decorah is found in the Twin City Basin (Parham and Austin, 1969); however, this area is relatively far from the source of the clay minerals. This suggests that the Twin City Basin was subsiding more rapidly than the surrounding area and acting as a "sediment trap" during Decorah time. By the end of Middle Ordovician time little detrital material was derived from the old positive areas to the north and northeast but local uplift of central Minnesota resulted in the influx of sand into the upper or Clermont Member of the Maquoketa Formation in Late Ordovician time.

After an uplift and erosion of the Ordovician and older strata in the embayment the sea returned during Middle Devonian time and deposited the Cedar Valley Formation on an eroded surface of low relief which was subsiding more rapidly to the north than south. At some time after the deposition of the Cedar Valley Formation the continuing uplift of the Transcontinental Arch with subsequent erosion defined the limits of the present expression of the Hollandale Embayment.

Development of the Large-Scale Structural Features in Southeastern Minnesota

The Hollandale Embayment and smaller structural features on the embayment were not clearly defined until Early Ordovician time. The first indication of the embayment as a feature which affected sedimentation in the Cambrian sea is the distribution of facies in the Eau Claire Formation. The presence of the "red unit" (Austin, 1969) along the western border and as the basal unit near the center of the embayment, but its absence on the Wisconsin Arch, indicates that the Transcontinental Arch was emergent and contributing some sediment to the embayment. The color and grain size of this unit suggest that the source of the sediment was the Red Clastic Series, which now underlies the center of the embayment but which was elevated to the west during Upper Cambrian time. The decrease in the amount and grain size of the sand-size fraction of the other units within the Eau Claire from western Wisconsin toward the embayment suggests that the source of this clastic material lay to the east. The effect of the embayment on sedimentation during the deposition of the Franconia Formation is indicated by the predominance of the highly glauconitic members of the Franconia Formation in semicircular fashion around the center of the embayment. However, it is in rocks deposited during Early Ordovician time, when southeastern Minnesota was covered by the shallow Prairie du Chien sea from which principally carbonates were being deposited, that the subsiding center of the embayment is defined by isopach contours (fig. 6) and by the semicircular ring of the New Richmond Sandstone Member of the Shakopee Formation.

The Twin City Basin was outlined in Early Ordovician time. The isopach contours of the Prairie du Chien clearly show that sedimentation in the Twin City Basin was restricted during Early Ordovician time. The analysis of drill data suggests that the contact between the Shakopee Formation and the overlying St. Peter Sandstone of Middle Ordovician age may not be erosional, as is found in Wisconsin, and that isopach studies accurately define the thickness of the Prairie du Chien Group prior to the deposition of the St. Peter Sandstone. During St. Peter time the Twin City Basin was subsiding more rapidly than the rest of southeastern Minnesota and thicker sections of St. Peter Sandstone are found in the Twin City Basin than are found in the rest of Minnesota.

The Belle Plaine Fault faulted or folded the Paleozoic sedimentary units along the western margin of the Hollandale Embayment. This feature affected the altitude of units at least as far away as 30 miles southeast of the Minnesota River at Belle Plaine. The age of the movement is definitely post-Black Riveran (fig. 9) and is probably post-Ordovician (Sloan and Danes, 1962)

Isostatic adjustments in Paleozoic time along Precambrian faults east and south of the Twin City Basin produced the Hudson-Afton Anticline and the Vermillion Anticline (Morey and Rensink, 1969). The movements at least along the Vermillion Anticline appear to be recurrent and concurrent with sedimentation from Mt. Simon through Jordan time but cease before the advent of Early Ordovician time (G. B. Morey, oral comm., 1970).

The time of the initiation of the Red Wing-Rochester Anticline as a structural feature which affected sedimentation is not clear. The New Richmond Sandstone Member of the Shakopee Formation is limited in thickness to less than 10 feet west of the anticline and increases to 65 feet east of the anticline in extreme southeastern Minnesota. However, the lithologies of the underlying and overlying units apparently are not affected across the structure. Therefore, the Red Wing-Rochester Anticline is most likely a post-Ordovician feature produced by gentle warping of the Paleozoic strata during the subsidence of the Hollandale Embayment.

CONCLUSIONS

Several major concepts can be gleaned from a study of the lithostratigraphy of the Paleozoic rocks of southeastern Minnesota: (1) there are detectable lateral changes in lithology and mineralogy for most if not all of the units, which lead to conclusions about the changing directions of source areas and of deeper marine water; (2) the vertical changes in rock type are cyclic on a grand scale; and (3) most if not all of the Paleozoic structural features can be related to underlying Precambrian structural features. These concepts make the geology of southeastern Minnesota more interesting, more challenging, and more comprehensible.

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PALEOECOLOGY OF THE ORDOVICIAN STRATA OF SOUTHEASTERN MINNESOTA

Gerald F. Webers[1]

INTRODUCTION

Minnesota was the site of at least two marine transgressions during Ordovician time. Sediments in southeastern Minnesota and southwestern Wisconsin accumulated in a shallow depression which rapidly shoaled to the north, between the northeast-trending Transcontinental Arch and the northwest-trending Wisconsin Arch (fig. 1). This sedimentary basin has been called the Hollandale Embayment of the Ancestral Forest City Basin (Austin, 1970).

Probably the sea remained in Minnesota within the Hollandale Embayment continuously from Late Cambrian through Early Ordovician time and then retreated. The sea returned during the Middle and Late Ordovician, and at this time also covered extensive parts of northwestern Minnesota, and possibly the entire state, as the seas encroached on either side of the Transcontinental Arch (fig. 1).

The thicknesses and to some extent the character of the Ordovician formations were affected by growing intrabasinal flexures such as the Twin City Basin and the Red Wing-Rochester Anticline.

CANADIAN SERIES

The Lower Ordovician Series in Minnesota is composed of a thick succession of predominantly dolomitic rocks, and represents a relatively thin segment of a very extensive dolomitic sequence found in central, southern, and eastern United States (fig. 2). The strata in this series are referred to as the Prairie du Chien Group, which is divided into the Oneota Dolomite and the Shakopee Formation; these formations are further subdivided into several formal members and informal beds of restricted geographic extent (Austin, first part of this guidebook).

Although several investigators indicate an unconformity at the base of the Lower Ordovician Series (Graham, 1933; Powell, 1933; Stauffer, 1925), recent studies have shown that the systematic boundary was the site of continuous sedimentation marked only by the gradual deposition of carbonate (Sardeson, 1936; Kraft, 1952; Berg and others, 1956). Indeed, only at Stillwater and Vermillion, Minnesota, is the contact between Cambrian and Ordovician sediments considered "sharp," and even here there is some gradation. The environment during the Early Ordovician in Minne-

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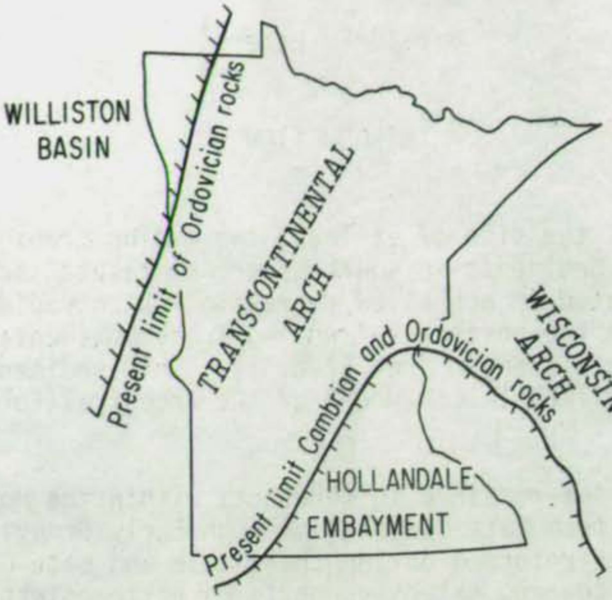

Figure 1. Regional setting of Paleozoic rocks in southeastern and northwestern Minnesota.

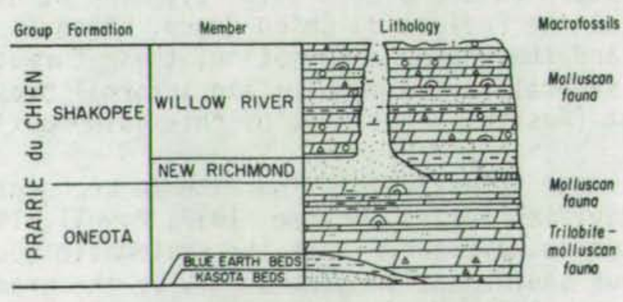

Figure 2. Lower Ordovician Series in Minnesota (modified from Austin, 1969).

sota was one of a shallow marine epicontinental sea, with extensive development of carbonate banks. Commonly, these banks were dotted with algal stromatolites, which formed biohermal structures. Shoaling is indicated by oolitic chert and dolomite, and periodic exposure is indicated by mudcracks and desiccated algal structures. Large, low-amplitude sand waves composed of cross-bedded dolo-arenites possibly represent deposits formed by tidal currents. Oscillation and current ripples and flat-pebble conglomerates are common.

Occasionally, the carbonate banks were affected on a regional scale by moderate to extreme quartz-sand sedimentation. This influx of sand resulted locally in the deposition of sandy dolomites and supermature quartz-sandstone beds as much as several feet thick. At places, the rapid influx of quartz sand inundated and killed the algal flora involved in reef building. The New Richmond Sandstone Member of the Shakopee Formation overlies an unconformity and represents a regionally important tongue of sandstone from nearby source areas to the east, west, and north.

Davis (1966) has compared the environment of the Willow River Member of the Shakopee Formation with modern algal reefs of Shark Bay, Australia, as described by Logan and others (1964). Davis considered the Willow River environment to be one of a warm epeiric sea, with both shallow marine and intertidal regimes extensively represented. The three environmental regimes he recognized are: (1) a shallow, open marine area with oolitic beds and relatively abundant fossils; (2) an intertidal or near intertidal, high-energy zone where stromatolitic algae flourished, as represented by algal bioliths; and (3) a locally intertidal and hypersaline, low-energy zone represented by algal mats and abundant desiccation features.

A predominantly molluscan fauna is associated with the algal stromatolites. Gastropods are the most abundant and cephalopods rank second. Monoplacophorans, pelecypods, and crinoids are present but not abundant. Brachiopods and trilobites are rare in the lower part of the Oneota Dolomite and are generally absent throughout the remainder of the Prairie du Chien Group. Three somewhat overlapping faunas are found in the Prairie du Chien: a lower trilobite-molluscan and an upper molluscan fauna in the Oneota, and a molluscan fauna in the Willow River Member of the Shakopee. Simple-cone conodonts occur sporadically throughout the Prairie du Chien and have been described by Furnish (1938).

The Prairie du Chien Group is sparingly fossiliferous and preservation is generally poor. Internal molds are the most common form of preservation. Chert nodules crowded with well-preserved specimens are described by Stauffer (1937 a and b) from the Shakopee Formation. The fauna contains monoplacophorans, gastropods, cephalopods, minor pelmatozoan fragments, and a trilobite. Except for rare crinoids, bottom-dwelling filter-feeders are absent. Perhaps more important, the fauna is dwarfed; larger equivalents of the same species are found elsewhere in the group. Apparently, conditions were far from optimum for normal marine life, and some environments may have been relatively barren of life. These conditions may represent hypersaline environments. Because of the predominance of gastropods, the virtual lack of filter-feeders, and occasional dwarfed faunas, I do not believe that abundant organic remains were destroyed by penecontemporaneous dolomitization. Rather, I think that the environment was too rigorous to support a diverse or abundant fauna.

CHAMPLAINIAN AND CINCINNATIAN SERIES

It is not known whether the seas retreated from the Hollandale embayment after the deposition of the Prairie du Chien Group. The presence of an unconformity between the Canadian and Champlainian Series in Wisconsin and elsewhere cannot be demonstrated at the rather poor exposures of the contact of these series in Minnesota. Rather, the contact appears to be conformable, but weathering has obscured critical evidence (fig. 3). Regardless, sedimentation in the Hollandale embayment was probably continuous from the deposition of the St. Peter Sandstone in early Middle Ordovician (Chazyan) time to the deposition of the Maquoketa Formation in early Late Ordovician time. In northwestern Minnesota, sedimentation began somewhat later, with the deposition of the Winnipeg Formation in Middle Ordovician time (Black Riveran), and ended with the deposition of the Red Rock Formation along the eastern edge of the Williston basin in Late Ordovician time. Rocks of Cambrian age are not known in this area, and the Ordovician strata lie directly on the Precambrian basement.

Southeastern Minnesota

St. Peter Sandstone

The St. Peter Sandstone is an atypical formation in many ways, including its uniformity of grain size, mineralogy, and sorting, its lack of sedimentary structures, and its wide areal extent. Dapples (1955) estimated the present areal extent of the St. Peter Sandstone to be 225,000 square miles. In Minnesota, the formation averages about 80 feet thick and, as elsewhere, consists of medium- to fine-grained sand, more than 99 percent of which is quartz. Sorting is typically very high, resulting in a general lack of sedimentary structures. The sand grains are well rounded and the larger grains show a frosted and pitted surface. Normal and cross-bedding are known but rather rare. Shale is very rare and reported only in the subsurface of the Twin City basin.

Dapples (1955) interpreted the St. Peter Sandstone as having been deposited in an extensive area of low relief by a sea that gradually inundated the area from the southeast toward the northwest. The absence of shale is attributed by him to shoreline currents moving the fine clastics far to the southern and southwestern parts of the basin. He suggested that toward the end of St. Peter deposition the transgressing shorelines covered the Wisconsin and Transcontinental Arches.

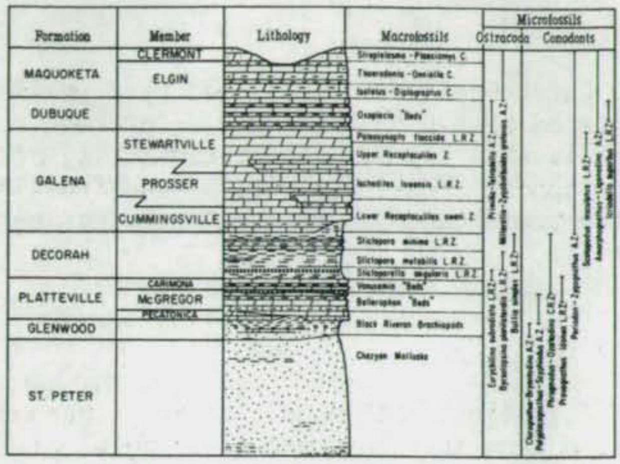

Figure 3. *Champlainian and Cincinnatian Series in Minnesota (modified from Austin, 1969).*

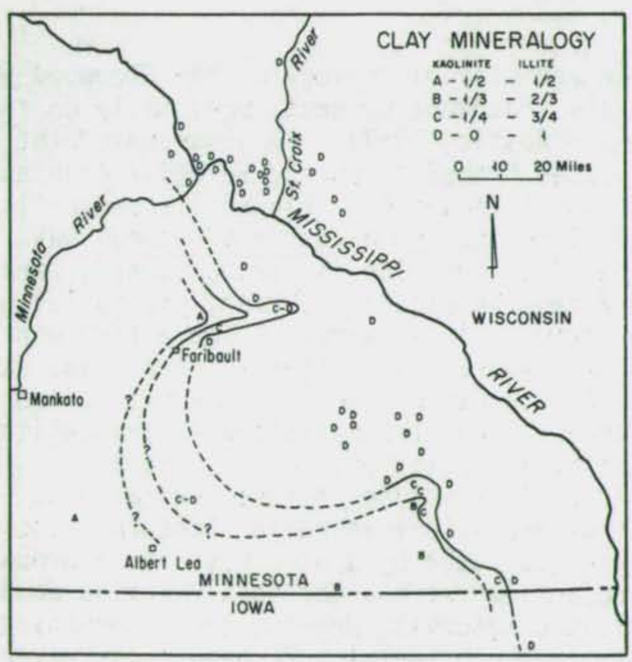

Figure 4. *Relative abundance and distribution of kaolinite and illite in the Glenwood Formation (modified by Parham from Parham and Austin, 1967).*

That the St. Peter was indeed deposited by a shallow marine environment is indicated by the sparse fauna recovered from the Twin City region. The fauna is entirely molluscan, consisting of pelecypods, gastropods, and cephalopods. Possibly, pitting and frosting of the sand grains indicate the presence of shoreline dunes that were reworked by the transgressing sea.

Glenwood Formation

The Glenwood Formation, a thin unit of argillaceous sand and shale, marks the transition from the shoreward environment of the St. Peter Sandstone to the offshore carbonate bank environment of the Platteville Formation, as the sea continued its westward transgression onto the Transcontinental Arch. In Minnesota, the unit ranges in thickness from about 2 to 16 feet and averages about 5 feet. The lower boundary of the formation is difficult to define as there is only a slight gradational change in sediment size from the St. Peter into the Glenwood. The lower part of the Glenwood is sandy and barren of fossils. The upper part is easily recognizable in that it consists of gray-green shales overlain by shaly sandstone. These shales are generally barren of macrofossils but yield abundant conodonts of the Chirognathus-Bryantodina Assemblage Zone.

Variations in the clay mineralogy of the Glenwood Formation indicate a source area to the southwest or west, presumably on the Transcontinental Arch (Parham and Austin, 1967). A geographic plot of the clay mineral variations, based primarily on the relative abundance of kaolinite and illite, is shown in Figure 4. Figure 4 shows belts of clay facies which presumably follow the shoreline in a general way. As might be expected, the general orientation is northwestward, paralleling the Transcontinental Arch. In detail, however, the facies pattern shows marked departures from a linear array. The marked northeasterly trend is modified by an east-northeast projection north and east of Faribault and by a second more subdued projection somewhat to the southeast. These two features are separated by an area characterized by a strong, broad, westerly shift in facies pattern. It is interesting to speculate on the possible significance of these variations. One might imagine that they indicate actual shoreline features, including well developed headlands separated by a wide bay. More probably, however, these eastward projections were areas that received an abnormally large supply of fine clastic material, whereas the intervening area received sparse amounts of clastic material. Perhaps major river systems of the Transcontinental Arch entered the sea to the west of the promontories. An isopach map of the Glenwood lends support to this idea; the thicker parts of the formation coincide with the eastward-trending projections. Near Cannon Falls, Minnesota, the Glenwood is more than three times as thick as the average for the formation (W. E. Parham, oral comm.).

Judged from the character of the Decorah, Galena, Dubuque, and Maquoketa formations, the western source area of the Transcontinental Arch probably continued to supply clastics to southeastern Minnesota throughout the remainder of Ordovician time.

Platteville Formation

The Platteville Formation, which overlies the Glenwood Formation and is about 30 feet thick in Minnesota, is dominantly a carbonate unit comprised mainly of limestone. Dolomite is common, however, especially in the lowermost member, and shales alternate with the limestone beds in the upper parts of the formation. In the same way as the St. Peter Sandstone, the Platteville is a thin, widespread unit throughout the midwest.

A shallow marine carbonate bank environment existed during deposition of the Platteville Formation. The first widespread bottom communities of a sessile benthonic nature developed in this environment. These communities were dominated by articulate brachiopods, but also included diverse other invertebrates, especially mollusks. Species of *Pionodema*, *Protozyga*, and *Strophomena* are the most important of the articulate brachiopods, and commonly form coquinoid layers within the limestone beds. Cephalopods reached their greatest diversity and were most abundant during this time. They range in size from the one-inch *Zitteloceras* to the large *Endoceras*, which grew to lengths of as much as 15 feet. Gastropods, especially the bellerophontids, also were quite common in the formation.

The rate of development of the sessile-dominated bottom communities was slow. The lowermost Pecatonica Member, like most other dolomites or dolomitic limestones in the Ordovician of Minnesota, records a relatively low development of bottom communities. However, these communities were well established during the deposition of the remaining members, and they persisted, with minor exceptions, in the younger Middle and Upper Ordovician strata of Minnesota, and changed only by the gradual replacement of individual species. Only in the Decorah Shale and in the Stewartville Member of the Galena Formation do we find significant differences.

Seafloor conditions were generally stable and quiet in Platteville time. Scattered coquinoid layers within beds attest to periodic intervals of gentle current activity. Although crinoids, brachiopods, and other invertebrates are commonly disarticulated, they do not show evidence of abrasion. The seafloor itself must have been carpeted by a soft calcareous ooze. The large (as much as 10 inches in diameter) endoceroid cephalopods sank in the ooze to depths of two thirds of their shell diameters. The exposed parts of the shells apparently dissolved before deposition of the next bed, inasmuch as the tops of the cephalopod shells are planed off at the upper bedding surface. Thus, long time intervals probably are recorded by the thin clay partings between carbonate beds.

In the Carimona, the uppermost member of the Platteville, limestone beds alternate with shales, and ultimately, these beds pass into strata assigned to the Decorah Shale. The widespread addition of bryozoans to the bottom communities characterizes the shale beds. The addition of abundant fine-grained clastic material to the upper part of the Platteville Formation marks an uplift of the Transcontinental Arch in western Minnesota, and is a precursor to deposition of the Decorah Shale.

Local variations in the environmental regime of the Platteville Formation can be distinguished. For example, where the formation is only 12 feet thick in the Cannon Falls area, specimens of Lingula occur upright in their burrows in the Carimona Member. However, at this locality the Glenwood Formation is as much as 16 feet thick, and may represent a large local clastic supply.

Decorah Shale

The Decorah Shale is characterized by gray-green shale and scattered, thin coquinoid limestone beds. It is as much as 80 feet thick in the Twin City region, but thins both eastward and southeastward; in southeastern Minnesota it is only about 45 feet thick. On the basis of variations in clay mineralogy, Parham and Austin (1969) have shown that the Decorah detritus was derived from a westerly or southwesterly source area, presumably the Transcontinental Arch.

The Decorah Shale was deposited in a shallow, near-shore marine environment, and the diversity of species indicates that the waters were warm and of normal marine salinity. Nearly optimum conditions for marine life must have prevailed, inasmuch as a large number of marine macro- and microorganisms, as represented by nearly all phyla of marine invertebrates found in the Ordovician of Minnesota, attain maximum abundance and diversity in the Decorah Shale.

Bottom communities are dominated by bryozoans and brachiopods, and include species of Rhynidictya, Pionodema, Batostoma, Hallopora, Strophomena, and Sowerbyella as well as many others. The fossil remains are typically broken or disarticulated but lack size sorting, and thus probably are representative of a biocoenose. Microfossils are abundantly represented by ostracodes, conodonts, scolecodonts, and chitinozoans.

The bottom itself must have been a soft muddy ooze. As in the Platteville Formation, large endoceroid cephalopods settled to two-thirds of their shell diameter, leaving the upper parts exposed. Also indicative of soft bottom conditions are species of the bryozoan Prasopora. These individuals initiated colonies on bits of debris on the bed surface, and then to obtain maximum support, developed low, flat-bottomed colonies. Although one might expect highly turbid conditions resulting from an influx of fine clastic material from nearby source areas, the high percentage of filter-feeders among the marine invertebrates indicates relatively clear water.

Except for periods of episodic high-energy conditions, the environment was relatively quiet. Layers of coquinoid limestone as much as 2 inches thick are common in the Decorah Shale, and represent winnowings of the bottom material by currents and/or waves. Weiss (1957) believes they are caused by large amplitude storm waves. These coquinoid layers can be found at some places with ripple marks as large as 2 feet in wavelength. Bryozoan colonies within the coquinas indicate high energy conditions. Twig-like colonies as much as half an inch in diameter are commonly broken into segments 2 inches or less long. Periodic storm waves should, however, not only result in a coquinoid layer but also in a relatively thick shale layer devoid of coarse fossil debris. This is not the case, however. Perhaps a periodic shoaling of the water or changes in tidal currents produced the coquinas.

Galena Formation

The lower part of the Galena Formation, the Cummingsville Member, represents a gradual change in lithology and in bottom communities. The land mass to the west which supplied the fine clastics incorporated in the Decorah Shale continued to supply detritus, but on a reduced and intermittent basis, and the alternating limestones and shales of the Cummingsville Member gave way gradually upward to limestones of the Prosser Member. As the clastic supply diminished, the bottom environment became rather quiet and a carbonate bank was established. Evidence of current activity is lacking, and the fossils in the fine-grained limestones are neither abraded nor broken.

Bryozoans, including species of Prasopora, Batostoma, and Rhynidictya, are well established in the shales and shaly limestones in the lowermost beds of the Cummingsville. Apparently adapted to the muddy substrate, they gradually disappeared from the bottom communities and were virtually absent by the beginning of Prosser sedimentation. The problematic Receptaculites is a common member of the bottom communities, which are dominated in upper Cummingsville and Prosser strata by articulate brachiopods. Some of the more common brachiopods include species of Sowerbyella, Resserella, Rafinesquina, and, to a lesser extent, species of Parastrophina and Plectorthis. Conodonts record an abrupt change in faunal composition at the Decorah-Galena contact. No less than 15 form species of conodonts which ranged throughout the Decorah Shale are absent in the lowermost limestone of the Galena. A possible climatic change is indicated by the gradual disappearance of the "midcontinent" conodont fauna and the appearance of species characteristic of the Appalachian and Scandinavian faunas. This trend continues throughout Galena time, and reaches a maximum in the alternating limestones and shales of the Dubuque Formation. The upper Dubuque and the Maquoketa Formation record the gradual return of the midcontinent fauna. Assuming that the Ordovician North Pole was to the west of North America, the relationship between the two faunas would be north-south rather than the present east-west. With this relationship, a temperature change seems a likely possibility.

The Prosser Member is predominantly limestone, which records a quiet offshore carbonate bank environment. Bottom communities continued to be dominated by filter-feeders, and indicate quiet, clear water of normal marine salinity.

Strata of the Stewartville Member record a profound environmental change. Bottom communities consisting of brachiopods and other filter-feeders are nearly absent, and they are replaced by faunas dominated by gastropods and cephalopods. The large gastropod Maclurites dominates the fauna; Receptaculites is also a common constituent. The environment may have been one of a shallow carbonate bank with restricted circulation. Hypersaline conditions in such an environment would account for the lack of filter-feeders and would limit the sparse populations to those with higher ecological valences -- the cephalopods and gastropods. The presence of Climactograptus in the highly dolomitic strata of the Stewartville tends to support this possibility. Although not poorly preserved, the conodont faunas also record adverse conditions inasmuch as the fauna is sparse in number and diversity of forms. The overall lithology, faunal diversity, and composition is similar to that of the Prairie du Chien Group.

Dubuque Formation

The Dubuque Formation, which averages about 35 feet in thickness in Minnesota, consists of intercalated, buff, medium-grained limestones and gray shales. The interlayered limestone and shale beds appear to indicate cyclical sedimentation. Two feldspathized bentonites are present, and aid in tracing individual limestone beds for many miles. The limestone beds thicken to the west as a result of increased amounts of fine clastic detritus within individual beds. The interbedded shales also thicken to the west, as they change from a dominantly calcilutite to an argillaceous shale. The cyclical nature of the limestones and shales as yet is not adquately explained. The Transcontinental Arch apparently was slightly uplifted at the beginning of deposition of the Dubuque Formation.

Bottom communities in the Dubuque Formation are dominated by filter-feeders, and differ markedly from the restricted faunas found in the Stewartville Member of the Galena Formation. However, this change was gradual. The lowermost Dubuque beds are highly dolomitic and sparsely fossiliferous. Conodonts are the most common fossils and even they are sparse. Limestones with abundant pelmatozoan remains are found slightly higher in the formation and filter-feeder bottom communities become well established in still higher beds. These filter-feeding bottom communities are dominated by brachiopods, and with some evolutionary modification are not unlike those of the Prosser Member of the Galena Formation. Common brachiopod species include Resserella corpulenta and Sowerbyella minnesotensis. Microfossils include abundant conodonts, characteristic of Appalachian and Scandinavian faunal areas, and ostracodes. These bottom communities indicate a return to normal marine conditions with open circulation.

Maquoketa Formation

The transition from the Dubuque Formation to the Maquoketa Formation is marked by a decrease in fine clastics and an increase in dolomitic strata, apparently without any break in sedimentation.

Environments represented by Maquoketa strata are complex and Bayer (1965) recognized four lithosomes in Minnesota, each of which is associated with variations in bottom communities. The phosphatic "depauperate" bed, widespread in Iowa, is absent. A possible local equivalent is found in the lower 10 to 15 feet of strata at the base of the formation near Granger, Minnesota. Filter-feeding organisms are not represented in the meager fauna consisting of abundant graptolites and trilobites, with minor amounts of conodonts and cephalopods. Bayer referred to this fauna as the Isotelus-Diplograptus Community, and considered it indicative of periodic stagnation in an offshore area with associated toxic bottom conditions. The abundant concentrations of organic material and the fetid odor of some of the strata within this interval support his conclusion.

Most of the Maquoketa Formation is composed of alternating limestone, shaly dolomite, and dolomitic limestone. The limestone is typically sublithographic and sufficiently fossiliferous to form shell beds at many intervals. Filter-feeding organisms dominate the fauna. Most common are articulate brachiopods, with less abundant pelecypods, cephalopods, and graptolites, and a few gastropods and crinoids. Bayer referred to this as the Thaerodonta-Onniella Community, after two of the most common brachiopods. The fossiliferous limestone alternates abruptly with barren shaly dolomite or dolomitic limestone. Such abrupt changes in lithology and fossil content would argue for a sudden change from a normal marine environment with open circulation to one with restricted circulation and hypersaline waters. Bayer considered the strata to be cyclic, and preferred periodic epeirogenic oscillations to account for the observed variations in fossils and lithology. With this explanation, the dolomite would represent shallow near-shore conditions. The higher percentage of argillaceous clastic material in the dolomites supports this conclusion.

A local and thin facies of the above unit contains an atypical fossil assemblage. The bottom community is almost entirely composed of a single species of rugose coral -- Streptelasma corniculum. A few brachiopods and sparse crinoids complete the fauna of the Streptelasma-Plaesiomys Community. The rugose corals are typically oriented and are surrounded by a matrix of fossil debris. Lithologies within the strata containing the corals are dominantly dolomitized limestones. Crude cross-bedding is present in some of the beds. Possibly, the deposition was in a shallow marine environment near or at wave base.

The beds in the upper part of the Maquoketa Formation are barren of fossils, with the exception of conodonts, and consist of sandy and shaly dolomitic limestone. Coarseness and abundance of clastic material in the strata increase in a westerly direction. Apparently the major source of sediments for all the Ordovician rocks in Minnesota was from the west, where gentle epeirogenic uplifts periodically increased the influx of clastic material. Apparently, the Wisconsin Arch served as a barrier to clastic deposits from the east that were associated with the Taconic orogeny.

DIVERSITY OF SPECIES IN THE ORDOVICIAN OF MINNESOTA

The Ordovician strata of Minnesota reflect a variety of environments, which are indicated by marked variations in species diversity of the major invertebrate groups. Data presented here summarizing the faunal composition of the various stratigraphic units were taken principally from the work of Stauffer and Thiel (1941). Although several faunal studies have been completed since this publication, they are either detailed studies of only a part of the Ordovician strata or are restricted to a particular fossil group. Undoubtedly, the species names used in Stauffer and Thiel are out of date, but the relative number of species recognized by them in each of the various invertebrate groups probably will not change markedly with additional work.

The major groups of invertebrates selected for this study of species diversity include trilobites, gastropods and monoplacophorans, cephalopods, pelecypods, bryozoans and brachiopods. Information on these groups is tabulated in Figures 5 - 8.

It can be seen from Figure 5 that there is considerable variation in the total number of species between given stratigraphic intervals. Nearly optimum environmental conditions must have prevailed during Platteville through Prosser deposition, inasmuch as these rocks are characterized by a maximum in the total number of species as well as a maximum in the diversity of species (figure 6). Most maxima occur in the Cummingsville and Prosser Members of the Galena Formation. The stratigraphic interval between the Platteville Formation and Prosser Member is marked by limestone and shale that probably reflect deposition in warm shallow waters that had normal marine salinity. In general, the abundance of individuals on bedding plane surfaces also closely follows their diversity. With the exception of the Dubuque Formation, which consists of limestone and shale, all the remaining stratigraphic intervals having low species diversity have dominant sandstone or dolomite lithologies. Inasmuch as the limestones within the Dubuque Formation are commonly criquinas, I believe further investigation would reveal a much greater diversity of species than shown in Figure 6. In contrast, dolomites or highly dolomitic limestones within the section are almost devoid of bottom organisms. However, the general lack of both micro- and macrofossils appears not to result from destruction of the fossils by dolomitization, but rather to reflect the rigorous nature of the environment. There is good evidence that the environment was probably hypersaline at the time of deposition of the Prairie du Chien Group, and this was probably also true at the time of deposition of the Stewartville Member of the Galena Formation. For example the conodonts show a continual decline in diversity and abundance in the Galena Formation, and this is especially marked in the Stewartville Member (Webers, 1966). However, the conodonts were not destroyed through recrystallization in the dolomites; they simply were sparse to begin with.

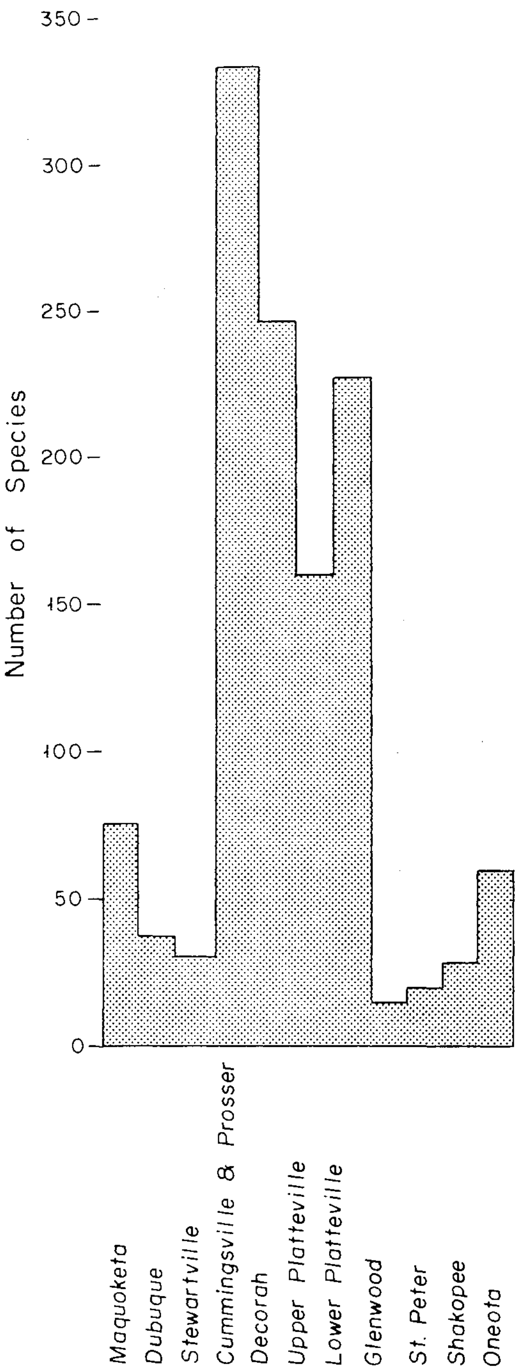

Figure 5. Total number of invertebrate macrofossil species in the Ordovician of Minnesota.

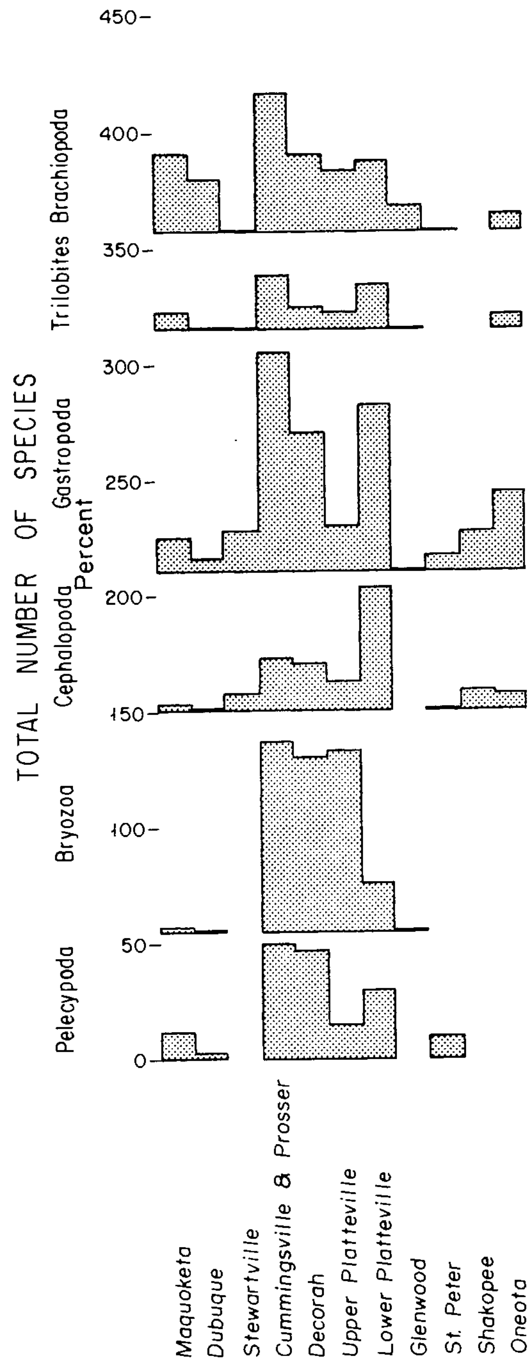

Figure 6. Number of species of major phyla in the Ordovician of Minnesota.

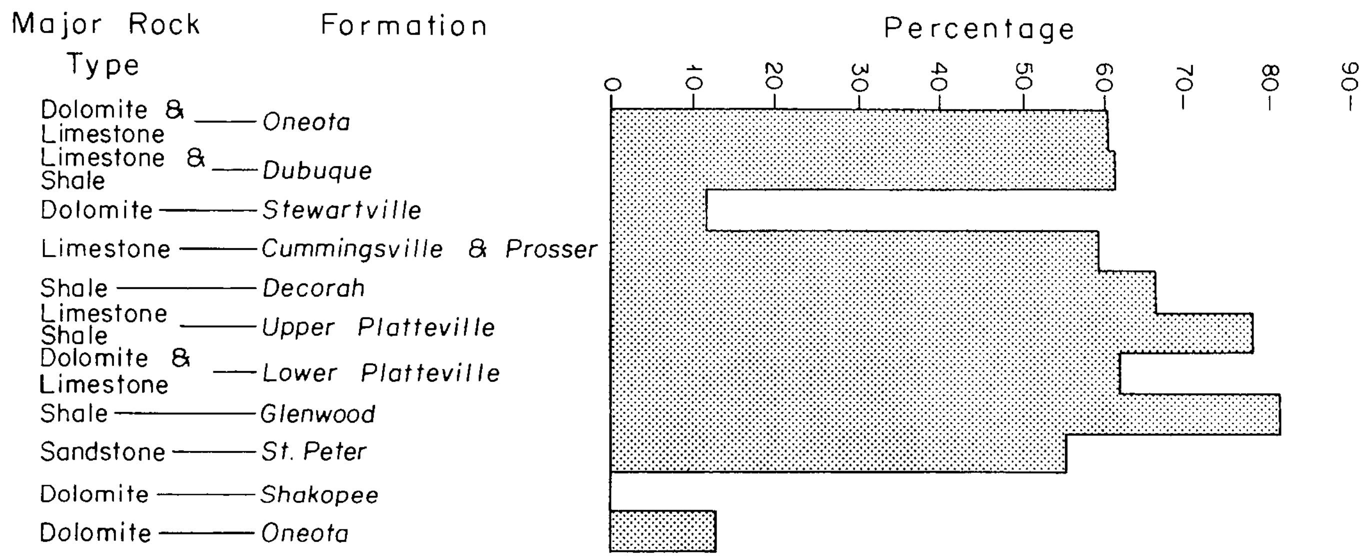

Figure 7. Percentage of major invertebrate phyla in the Ordovician of Minnesota.

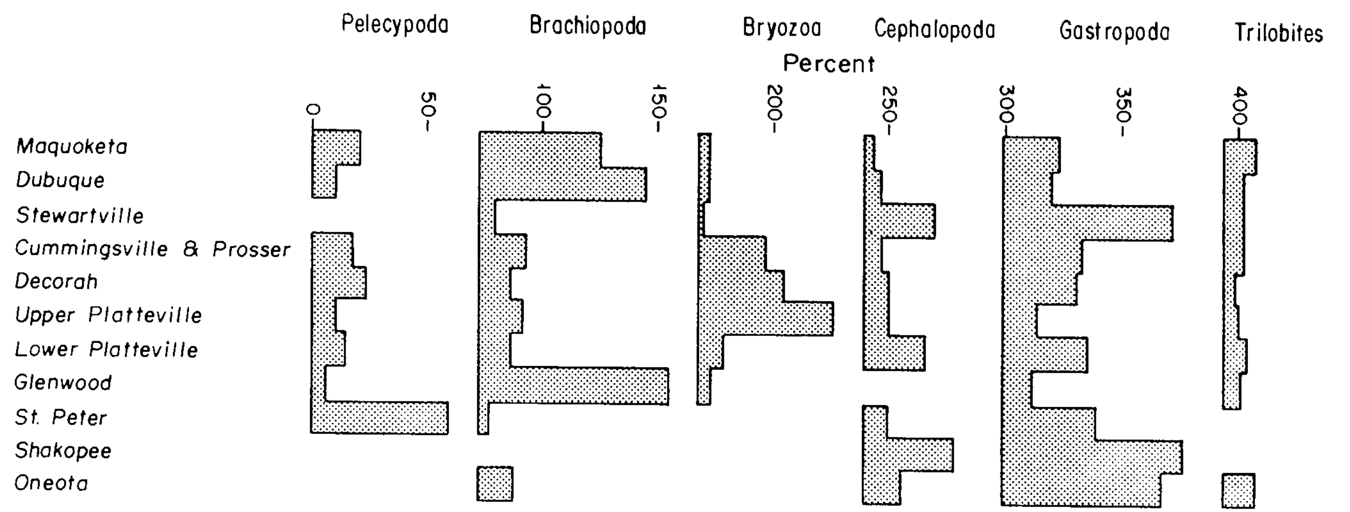

Figure 8. Percentage of filler-feeding macrofossil species in the Ordovician of Minnesota.

It appears that only those organisms with wide ecological tolerances were able to tolerate the environment represented by the dolomites. Gastropods are known for their high tolerance of diverse conditions. A study of the fauna of the Permian Reef Complex (Newell and others, 1953) indicated that the fauna of the hypersaline backreef environment was dominated by gastropods. Virtually the only other organisms in this environment were various kinds of blue-green algae. Filter-feeding organisms, especially attached forms, were practically non existent inasmuch as these tend to be stenohaline in nature. This ecological picture generally fits the faunal picture of the dolomitic environments of the Minnesota Ordovician. From Figure 7 it can be seen that filter-feeding organisms dominated the fauna at all stratigraphic intervals in the Ordovician of Minnesota except those that are marked by abundant dolomite.

Figure 8 indicates that there is a marked variation in ecological tolerance among major groups of marine invertebrates. Bryozoans appear to be most restricted and to have the narrowest tolerances. These are followed in order by the brachiopods and pelecypods. The non filter-feeders, whether bottom dwelling or not, appear to have the greatest tolerance for changes in environment. This is especially true of gastropods and cephalopods, whose patterns of diversity and abundance are similar. One might have predicted the pattern of the gastropods, but their similarity to the cephalopods is quite surprising. A possible answer to the close parallelism of the cephalopods and the gastropods might be found in the relatively simple faunal relationships found in the Prairie du Chien dolomites. Here we basically have only algae, gastropods, and cephalopods. The gastropods belong to herbivorous families and probably fed on the algae. The ratio of cephalopod to gastropod specimens in the Prairie du Chien is about 1:100. It seems likely that the cephalopods at this time were preying on the gastropods. A similar situation is present in the dolomites of the Stewartville Member of the Galena Formation. Perhaps the predator-prey relationship between these two molluscan groups was present in other Ordovician environments as well.

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NOTES ON THE PLATTEVILLE FORMATION, SOUTHEASTERN MINNESOTA

Robert E. Sloan[1]

The Platteville Formation, of Middle Ordovician age, has been the most intensively studied of all the Paleozoic rock units in southeastern Minnesota. The primary reason, of course, is the accessibility of the formation to the Minneapolis campus of the University of Minnesota. In addition, it is very fossiliferous, contains wide variations in lithofacies, interfingers with both superjacent and subjacent formations and has many key beds which permit establishment of a lithologic time-stratigraphic correlation network. The latter reason permits very detailed studies of lithofacies and biofacies variations. To add to its interest, the formation contains, in a limited stratigraphic interval, all the lithofacies and biofacies present in the balance of the middle Ordovician rocks of the upper Mississippi valley, and so provides a model for their interpretation.

The current cycle of work on the Platteville Formation began with the students of W. C. Bell (Weiss, 1953, 1955, 1957a,b; Majewske, 1953) and continued with my students (Sloan, 1956; Ford, 1958; Hoeft, 1959; Thompson, 1959; Webers, 1966 and Rassam, 1967). My own studies on the Platteville Formation extended from 1953 to 1962 and intermittently since then. The F. W. Sardeson Collection, acquired by the University in 1950, and M. P. Weiss' collections afford abundant well preserved and well documented fossil material which has been of great aid in the faunal analyses of this short note.

The original Ordovician geographic position for the southeastern Minnesota basin was tropical in latitude, between the equator and 30^{o} south latitude, with the Ordovician parallels of latitude now oriented roughly northeast-southwest. The precise latitude depends on the particular polar wandering curves adopted and the extent to which the Proto-Atlantic was closed during the Caledonian to Hercynian-Appalachian orogenies, during the late Paleozoic assembly of Pangaea.

The Platteville Formation is the carbonate wedge of the Black Riveran transgressions across the upper Mississippi valley. It and the subjacent St. Peter Sandstone and Glenwood Shale, and the superjacent Decorah Shale and Cummingsville Member of the Galena Formation are correlative with the Winnipeg Formation of the Williston basin, on the other side of the Sioux Arch of central Minnesota. The Glenwood Shale and St. Peter Sandstone represent the more inshore terrigenous clastic deposits contemporary with the Platteville Formation. The lower Platteville Formation and the upper Glenwood Shale interbed throughout southeastern Minnesota as do the basal Glenwood Shale and the upper St. Peter Sandstone.

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The principal source area for clastic sediments, contributing to the Platteville sea, was a linear belt through central Minnesota oriented northeast-southwest. The central part of this core was probably composed of Precambrian metamorphic rocks, whereas the margins were probably composed of Late Cambrian sandstones. During the deposition of the St. Peter Sandstone, much of the source area was apparently covered with the Croixan Sandstones and the total area of Precambrian metamorphic rocks was probably small since there is a great disparity between the total volume of St. Peter sand and Glenwood Shale throughout the upper Mississippi valley. The middle part of the McGregor or the Magnolia Members as recognized in Minnesota represents a time interval of maximum transgression, as well as greatest depth of deposition of the preserved sediments. The Decorah Shale which follows the Platteville interval is a wedge-shaped prism of shale which grades southeasterly into limestones. The Decorah had the same source area as the St. Peter and Glenwood clastics although the Croixan sandstones were apparently stripped away since sand is a very minor part of the Decorah. This prism has a maximum thickness of 100 feet in the Twin City area and a width to the wedge edge of about 400 miles. The maximum horizontal extent of shale deposition was reached during the first 5 to 10 percent of the entire Decorah time interval; the rate of production of the fine-grained particles of the Decorah Shale was greatest at this time. Since the rate of production of clastic sediments is a measure of the rate of erosion and the rate of erosion a function of the relief of the source area, the Decorah Shale wedge suggests a rapid uplift of the source area followed by denudation and renewed transgression. The magnitude of the uplift can be estimated from the area of the source and the volume of erosion products, the Decorah Shale wedge. Since in cross section this wedge has an area of 100 feet times 200 miles, the southeastern half of the source area must have had a similar cross section raised above sea level (the northwestern half of the source area contributed a similar wedge to the Williston basin, the upper half of the Winnipeg formation). Therefore, the uplift had an initial average elevation of at least 400 feet. This uplift also extended into the basin since there appears to be a decrease in depth of deposition from about 150 feet to about 75 feet in the upper Platteville Formation.

Six members have been recognized in the Platteville Formation of Minnesota, although five is the maximum number recognized at any one locality.

The basal member of the Platteville Formation, not recognized everywhere, is the Pecatonica sandy dolomitic limestone Member. It contains 2 to 3 percent of collophane granules dispersed through it as well as about 1 percent of frosted medium-size sand grains of St. Peter type, probably wind blown. It reaches a maximum thickness of 8 feet in the extreme southeastern corner of the state, thickening downward in Iowa and southern Wisconsin, and thins to a maximum of 2 feet northwest of Rochester. In places it is completely missing and is replaced by an expanded upper Glenwood Shale. It can be demonstrated that the Pecatonica Member interfingers with the Glenwood Shale between Rochester and Spring Grove in Houston County. The upper surface of the Pecatonica Member is, in general, a time equivalent surface through the area. The terrigenous clastic component of the Pecatonica Member ranges from 10 to 36 percent; the average content is about 27 percent in the Twin City area. In Fillmore County the insoluble residues are somewhat lower, ranging from 5 to 20 percent and averaging about 12 percent.

In the southeastern half of the basin, the McGregor limestone Member overlies the Pecatonica Member. The McGregor Member is a crinkly bedded dolomitic limestone with major parting planes about 1 foot apart, and subdivided into many smaller sedimentation units about an inch thick with crinkly minor parting planes. This crinkly bedded character is due to the widespread occurrence of interference, i.e., short-crested ripple marks of one quarter-inch amplitude and 3-inch wave length. The clay content of the member is concentrated preferentially at these parting planes. The carbonate grains in the McGregor Member are of silt size; fossils are most unevenly distributed. The insoluble residues of the McGregor Member are lower than in the Pecatonica Member, ranging from 2 to 30 percent and averaging 7 percent.

To the north, the McGregor Member is replaced by three members, particularly prominent in the Twin City Artesian Basin. The lowest of these three is the Mifflin Member, a term carried into the Twin City basin from southeastern Wisconsin by Majewske (1953) despite a lack of continuity with the type Mifflin. The Mifflin Member is a crinkly bedded calcilutite similar to the McGregor Member but with a considerably higher proportion of terrigenous clastic components. It has a thickness of from 11 to 15 feet in the Twin City basin. The insoluble residues range from 10 to 30 percent with an average value of 20 percent. The bulk of the Platteville Formation used for foundations and drywall construction in the Twin City Metropolitan area has been quarried from this member. The uneven distribution of the clay-sized clastic sediment in these rocks is responsible for decomposition of the quarry blocks over a 50-year time span to the point where foundations and bridge footings made of this material can fail. The Mifflin Member is sparsely fossiliferous. To the south of the Twin Cities, between South St. Paul and the Mendota bridge on the one hand and Hampton on the other, the Mifflin Member grades laterally into Glenwood Shale, with little change in total stratigraphic interval.

The middle member of the Platteville Formation in the Twin City Basin is the Hidden Falls shaly dolomite Member (Sloan, 1956). The Hidden Falls Member has a minimum observed insoluble residue of 11 percent near the base and near the top and reaches a maximum of 50 percent clay and silt-sized terrigenous clastics in the middle of the member. The average is about 30 percent. The member averages 5.5 feet thick and is generally restricted to the Twin City Basin. It extends to the south as far as Faribault and Cannon Falls and southeast of this line, the approximate border of the basin, the member becomes indistinguishable from the middle and lower McGregor Member. In the eastern part of Olmsted County, near the hamlet of Saratoga, there is a local rise in insoluble content of the McGregor in a stratigraphic interval appropriate for the Hidden Falls. This may be the result of a sediment trap on the east side of the asymmetric Red Wing-Rochester Anticline. To the north, both the Mifflin and Hidden Falls Members grade into the Glenwood Shale. The Hidden Falls Member is of little use except for fill. It is not richly fossiliferous, although Sardeson found a rich pocket of the pelecypods Ctendodonta, Vanuxemia, Cyrtodonta, the starfish Hudsonaster and the peculiar crinoid Cremacrinus in the Johnson Street Quarry of northeastern Minneapolis, now mined out and filled with dump material.

The fourth member of the Platteville Formation in the Twin City basin is the Magnolia dolomite Member, a buff-pink colored medium grained dolomite with fossils preserved as dolomite-lined molds, averaging about 8 feet in thickness. This type of fossil preservation is restricted to the Magnolia Member. Beds average one foot in thickness. The insoluble residues range from 2 to 15 percent with 8 percent the average value. The Magnolia Member grades into the upper part of the McGregor Member and becomes crinkly bedded at about the edge of the Twin City basin. To the north, the Magnolia Member is the principal part of the formation at the most shoreward exposure in the ravines one half mile northwest of the Soo Railroad drawbridge over the St. Croix river at the northern edge of Washington County. The Magnolia Member there rests on the Glenwood Shale, with no signs of unconformity.

The uppermost member of the Platteville Formation is the Carimona limestone Member, a medium-grained shelly limestone with shale interbeds. The thickness varies from 2 to 8 or 9 feet, with the greatest thickness near the edge of the Twin City basin. The basal Carimona Member in the Faribault-Cannon Falls area grades laterally into the Magnolia Member to the north and the upper McGregor Member to the southeast. The upper Carimona Member is interbedded with and grades northwesterly into the basal Decorah Shale. The contact between the Platteville Formation and the Decorah Shale can be demonstrated to be an arbitrary cutoff of slightly different age in different places, older to the northwest and younger to the southeast. Individual beds average 6 inches in thickness. Because individual beds of Carimona limestone thicken northwest, the contact is generally placed from 2 to 4 feet above a prominent 4 inch bentonite, the Carimona Bentonite (Weiss and Bell, in Schwartz 1956) but individual beds of Carimona limestone can be traced northwestward to the point where they are separated from the main body of the member by 2 or 3 feet of Decorah Shale. The Carimona Member is a comparatively shallow-water deposit. Such ripple marks as occur in it are megaripples with wave length of 2 feet (see figure on page 95 of G.S.A. Guidebook, Field Trip No. 2, 1956). Insoluble residue content of the Carimona Member is low, ranging from 2 to 14 percent with the average about 6 percent. Throughout southeastern Minnesota the Carimona Member was widely used as foundation stone due to the uniformity and durability of its beds. The Carimona Member includes about 2 feet of thin-bedded sublithographic limestone in the area east of Rochester. These beds, the Protozyga nicolleti beds, have a distinctive biofacies to be discussed later.

Perhaps the most striking observation during my studies of the Platteville Formation was the extreme degree of continuity of trivial sedimentation units over great distances. Most distinctive beds an inch or greater in thickness could be recognized in a series of detailed sections measured at 3 mile spacing over distances of 40 miles; a few beds were recognizable at this spacing from the Twin Cities to the extreme southeastern corner of the state and into northeastern Iowa. The first beds to be so traced were the Carimona and Decorah bentonites (Weiss and Bell, in Schwartz 1956) and beds between and close to them, but on reducing the spacing of measured sections, similar degrees of continuity were established for most of the formation. Even such minute beds as the shaly parting plane weathering to a 1/10 inch crack between two massive limestone beds could be traced for tens of miles, and represented a very brief geologic event of widespread occurrence. The shale partings, which are traceable over such long distances, can be interpreted as the material put into suspension during major storms, settling out again after the storm subsided. Wave base varies in depth, with the character (wave length, amplitude) of the sea waves; a major storm would lower wave base, putting the bottom carbonate oozes in suspension. On the decline of the storm, the coarser grained carbonate particles would settle rapidly, while the clays would take longer to subside, forming a thin lamina of enriched clay content. This lamina in the present weathering environment serves as a parting plane. This same process can be invoked to explain the megaripples of 2-foot wave length in the coarse coquinas of the Carimona Member and the Decorah Shale.

In addition to the bentonites, the shale beds and parting planes, and thin limestone beds of distinctive character, there are a series of corrosion zones (Weiss, 1957b) in the upper Pecatonica and lower McGregor Members that maintain a constant stratigraphic relationship with each other. These occur in the area from Rochester to the southeastern corner of the state. These corrosion zones appear to be brief interruptions in deposition of little more time duration than the usual bedding planes, and similarly serve as key beds for a time-stratigraphic framework.

Space in this short paper does not permit presentation of 75 measured sections of the Platteville Formation, measured to .01 foot, with average bed descriptions of .4 foot, and the details of correlation between them. Summary statements of the type of results are to be seen in Figures 1 to 3. Figure 1 is a cross section, in general perpendicular to the axis of the source area, extending from the most shoreward locality known, through the Twin Cities and Rochester to the southeastern corner of the state. Figure 2 is a cross-section from Faribault, Minnesota to Ellsworth, Wisconsin, generally along the southeastern border of the Twin City basin. Figure 3 is a series of six lithofacies maps for a set of arbitrarily chosen time intervals during the deposition of the Platteville Formation, keyed to the cross section Figure 1.

Demonstration of the continuity of individual beds of the Platteville Formation facilitates the understanding of the relationships between the various members. These distinctions are most obvious in the upper part of the formation, within 5 feet of the Carimona Bentonite. It is possible to demonstrate that a bed of upper Magnolia Member in the Twin Cities is of Carimona lithology at Faribault and Cannon Falls and is part of the

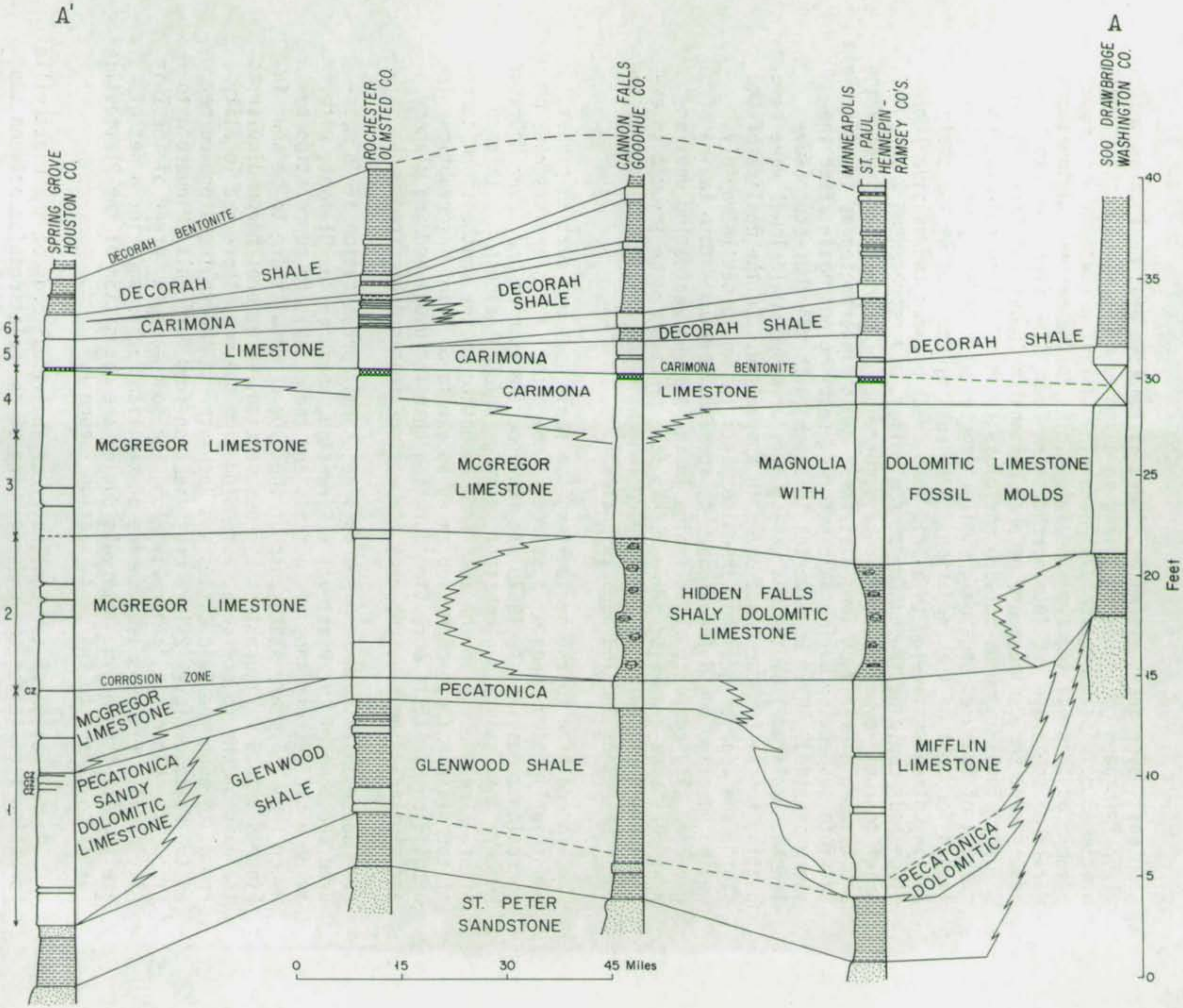

Figure 1. Cross section A-A'. See Figure 3 for location of cross section.

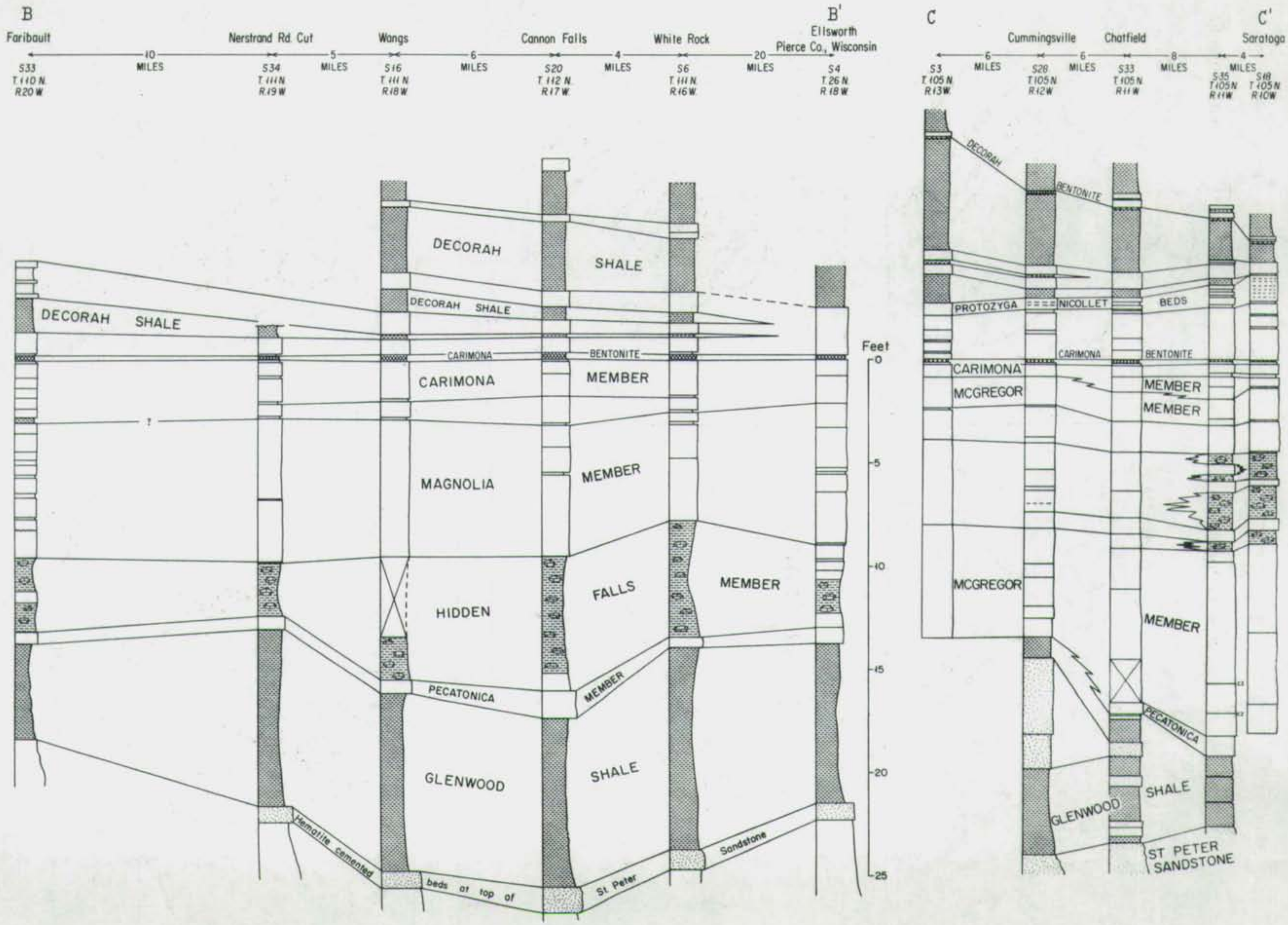

Figure 2. Cross sections B-B' and C-C'. See Figure 3 for locations of cross sections.

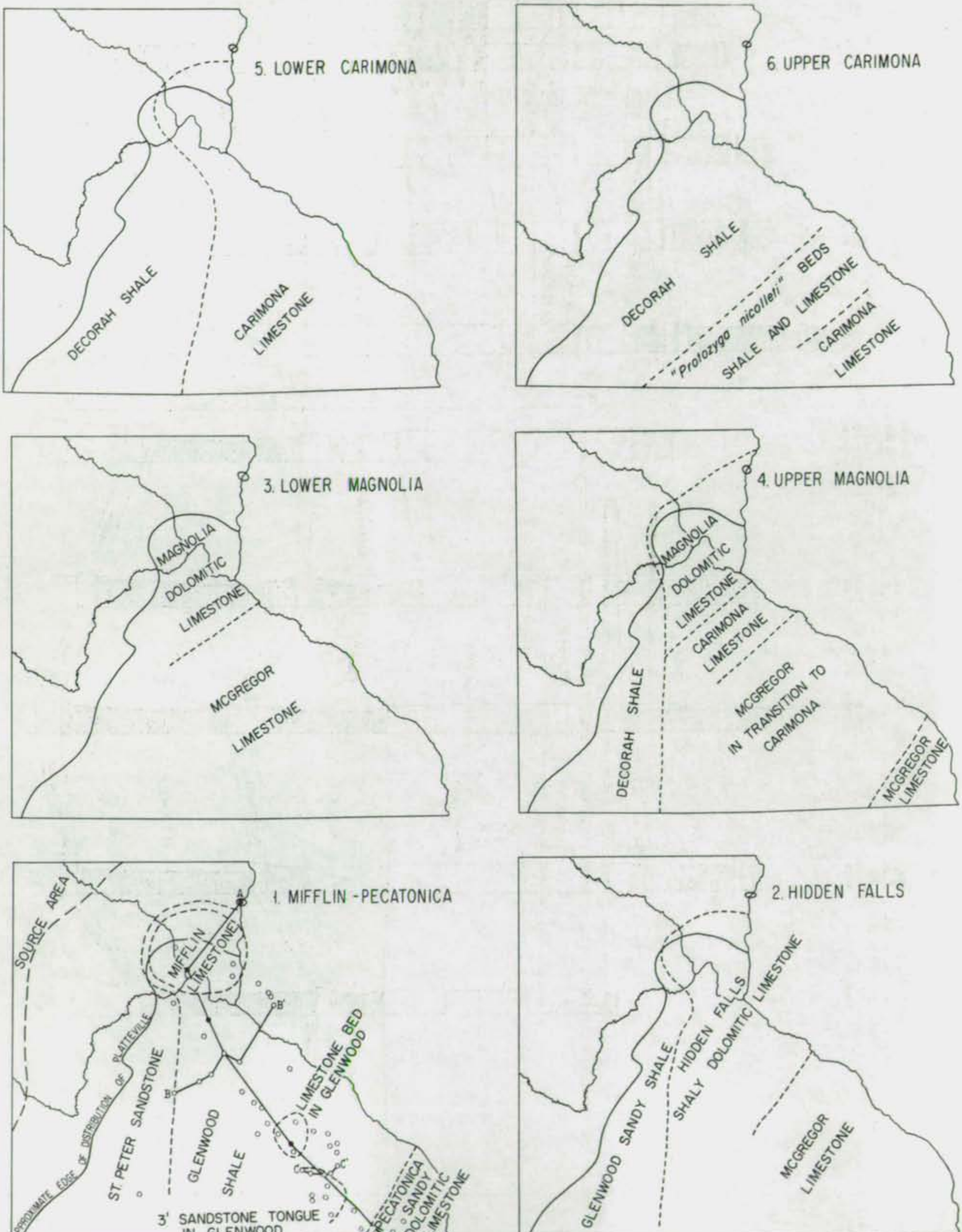

Figure 3. Paleogeologic maps of southeastern Minnesota during the time of Platteville deposition.

McGregor Member at Rochester and Spring Grove, while remaining uniform in thickness and maintaining the same relationships to adjacent beds of distinctive lithology.

The features of the depositional environment that produced the differences between the several members are principally those associated with depth. These include degree of agitation, and light intensity or food production. The Carimona Member was clearly deposited in shallower water than any of the other members. The grain size of the bioclastic carbonate is coarser, fines having been winnowed out implying greater agitation. The wave length of ripples is larger than in any other part of the formation, implying greater agitation and shallower water.

The number and variety of herbivorous gastropods and trilobites is greater than in the other members, implying greater photosynthesis and hence, shallowest depth. In addition, the only occurrences of *Lingula elderi* are in the upper Carimona Member, suggesting depths less than 75 feet for this part of the formation.

The McGregor and Mifflin facies with the short-crested interference ripple marks and a fauna consisting principally of attached orthid brachiopods such as *Hesperorthis*, *Campylorthis*, *Glyptorthis*, *Opikina* and the primitive rugose coral *Lambeophyllum* clearly suggests a quieter deeper water facies. A suggested depth of deposition for this facies is about 150 feet.

The productivity of the Platteville sea was apparently rather high. The Carimona bentonite offers us a possibility of measuring the essentially instantaneous standing crop of organic matter. The bentonite produced a wholesale extinction of many organisms, and marks an abrupt faunal change. Throughout the region, the bentonite is underlain by an organic rich shale, which locally is petroliferous. It would appear that the flocculation of this ash trapped all the organisms and organic matter and sealed them in. I sampled the complete interval of the petroliferous shale at Cannon Falls some years ago. Dr. Francis Ting, now of the University of North Dakota, was kind enough to determine total nitrogen on an aliquot, and with this figure it is then possible to calculate the equivalent amount of wet organic material (protoplasm) per square meter. The calculated figure is 2.5 kg per square meter, for a water column about 25 meters deep. This level of standing crop is close to that of modern shallow tropical seas.

A fairly complete list of the fauna of the Platteville Formation is present in Stauffer and Thiel (1941). This list suffers the usual problems with lists in that there is no indication of abundance nor is there any indication of major communities or associations of species. Each of the six members has several distinctive bottom communities preserved in it. No group of species in the Platteville Formation, save the conodonts, is really independent of the bottom sediment type and the conodonts vary greatly in abundance in different lithofacies and members, even at the same time. The zonation and distribution of conodonts in the Platteville Formation has been discussed by Thompson (1959) and Webers (1966). The principal zonal boundary is associated with the mass extinction at the Carimona Bentonite. However, the physical abundance of conodonts in the rock is closely related to lithofacies. Only in the shallow-water Carimona Member is the conodont density between 100 and 400 conodonts per 100 grams of rock. Elsewhere in the deeper water subjacent members the conodont density is on the order of 20 conodonts per 100 grams of rock. In the vicinity of the edge of the Twin City basin, even in the Carimona Member the conodont density increases by a factor of five to densities as high as 500.

The cephalopod genera in particular are associated with particular members. Large Endoceras is to be found only in the Carimona Member. Triptoceras and Gonioceras are associated with the Magnolia and McGregor Members.

The shallow-water medium-grained shelly limestone facies of the Carimona Member has as dominant members of its community the cephalopod Endoceras; the brachiopods Lingula, Sowerbyella, Doleroides and Pionodema; the herbivorous gastropods Sinuites, Hormotoma; the carnivorous gastropod Subulites, the largest and most robust of the crinoids Carabocrinus, and the herbivorous trilobites Eomonorhachis and Isotelus. This same community, in a later edition, occurs in the Dubuque Formation of late Middle Ordovician age.

A finer grained sublithographic calcilutite facies of this member present at Faribault and in the eastern part of Olmsted County contains as a principal element, the primitive spiriferid Protozyga nicolleti, the sessile but unattached brachiopods Strophomena and Rafinesquina, Rhynchotrema, and the herbivorous trilobites Isotelus and Eomonorhachis. This facies recurs in the early late Ordovician Elgin Member of the Maquoketa Formation.

A deeper water calcilutite of the Magnolia Member includes as the dominant members the brachiopods Opikina, Campylorthis, Hesperorthis, Glyptorthis, the primitive rugosan Lambeophyllum, the infaunal pelecypods Ctenodonta, Vanuxemia and Cyrtodonta, and the herbivorous gastropods Maclurites, Lophospira and Clathrospira. Isotelus and Bumastus are present but smaller and rarer than in the Carimona Member. This community continues to the south into the McGregor Member. Glass sponges are rare throughout the formation even as isolated spicules in insoluble residues. Graptolites are occasionally present in pyritic shales.

In conclusion, the Platteville Formation continues to offer more possibilities for detailed lithofacies and biofacies studies than does any other comparable unit in the upper Mississippi Valley.

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PRECAMBRIAN SIOUX QUARTZITE AND CRETACEOUS ROCKS OF SOUTHERN MINNESOTA

George S. Austin

INTRODUCTION

The exposed Precambrian Sioux Quartzite of southwestern Minnesota is part of a larger body of quartzite in Minnesota, Iowa, South Dakota, and Nebraska, which is covered by Pleistocene drift and sedimentary rocks of Paleozoic and Mesozoic age. In Minnesota it forms a large part of the Transcontinental Arch and lies to the west of the Paleozoic rocks of southeastern Minnesota. The Cretaceous rocks in southern Minnesota surround the Sioux, overlying it at lower elevations, and extend eastward dotting the Paleozoic landscape beneath the drift as outliers.

SIOUX QUARTZITE

The Sioux Quartzite in Minnesota crops out in three areas (fig. 1). The largest of the three is in northern Rock and southern Pipestone Counties in the extreme southwestern part of Minnesota. A long southerly-dipping ridge of Sioux Quartzite is exposed in northern Cottonwood, southwestern Brown and western Watonwan Counties. The smallest and most easterly exposure of Sioux Quartzite is in Nicollet County along the Minnesota River east of New Ulm.

Lithologically, the Sioux Quartzite is composed essentially of red, tightly cemented quartzite with some beds of mudstone and conglomerate. The quartzite consists of silica-cemented, well sorted, rounded, medium-grained quartz sand which is coated with hematite, and forms perhaps three-fourths of the formation. The conglomerates may be as much as 350 feet thick and contain material as much as 13 inches in diameter in a matrix of sand or fine gravel. The mudstones range in lithology from nearly pure claystone to silty mudstone to argillaceous quartzites. The larger particles in both the quartzites and the conglomerates are composed essentially of rounded siliceous fragments with vein quartz predominant. The mudstones consist of sericite, hematite, diaspore, and quartz.

The dominant structure in the outcrop areas of southwestern Minnesota is that of a gentle basin approximately 10 to 20 miles long and about half as broad. Baldwin (1951) has shown that the basin in extreme southwestern Minnesota contains a sequence of Sioux at least one mile thick but suggests that the thickness may be as much as one and one-half miles. No faulting is present in exposures but faulting may be considered to be an important aspect of the history of the formation. Some joint patterns appear to be independent of the development of the basins. Bedding is observed in the Sioux in nearly all exposures and cross-bedding, ripple marks, and locally

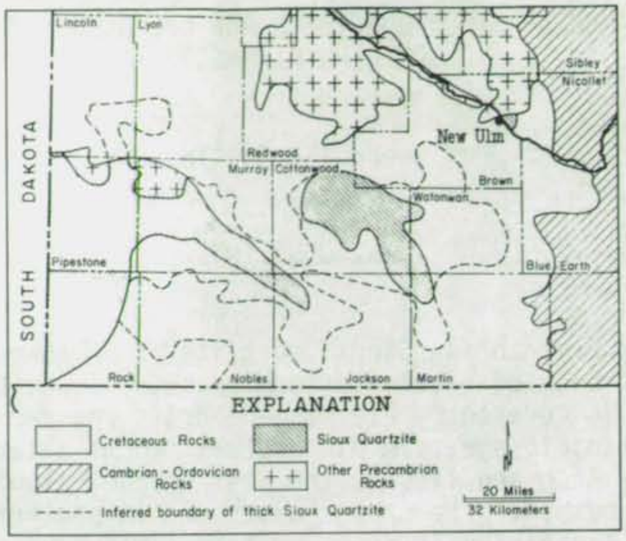

Figure 1. Generalized geologic map of southwestern Minnesota.

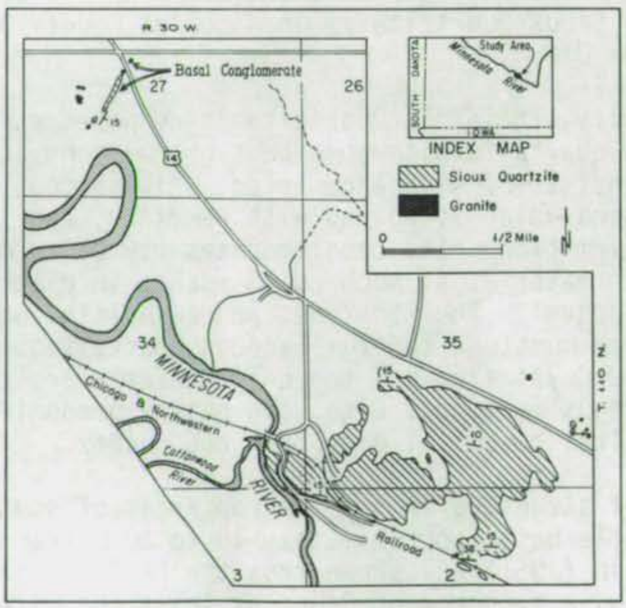

Figure 2. Sioux Quartzite outcrop areas in the New Ulm area (after Miller, 1961).

mud cracks are found.

The dominance of resistant mineral constituents and the great thickness of the Sioux Quartzite suggest that the source area was tectonically stable and rising very slowly and that only the most stable mineral could endure the existing climatic conditions. The presence of a dusty hematite coating between the original grain and the silica overgrowths and the presence of diaspore in the Sioux suggest lateritic conditions on the source area. Weathering products, principally detrital quartz, were probably shed into a slowly subsiding lowland which was occupied by a shallow body of water. The cementation by silica occurred by the action of silica-bearing ground water and, perhaps in part, in response to pressure-solution of the finer grained materials after deposition.

Goldich and others (1966) suggest that the Sioux was deposited between 1,200 - 1,700 million years ago. A rhyolite encountered in a well drilled into the Sioux in northeastern Iowa has been dated at 1,440± 50 million years ago; however, there is some question as to the quality of the sample and whether the rhyolite is actually bedded with the Sioux.

New Ulm Area

The most easterly exposures of Sioux Quartzite are in Nicollet County east of New Ulm, Minnesota, on the northeast side of the Minnesota River (fig. 2). The lowest beds are found in sec. 27, T. 110 N., R. 30 W., where 50 to 60 feet of conglomerates crop out, forming a cuesta which strikes N. 15-20° E. and dips 15-20° to the east. One and one-half miles southeast of the conglomerate exposure quartzite beds crop out which contain thin interbedded mudstone. The beds strike N. 45-85° W. and dip northeasterly at 5-38°. The outcrops in the New Ulm area define a structural basin or trough in the Sioux which plunges to the east.

The Sioux Quartzite in the New Ulm area consists of 700 feet of predominantly well cemented, purple-to-red quartzite with locally interbedded poorly cemented sandstone and red mudstone (Miller, 1961). The contact between the Sioux and the underlying rock is not exposed in the New Ulm area. However, 360 feet west of the basal conglomerate a reddish-orange, very coarse-grained to porphyritic granite is exposed. The basal conglomerate contains pebbles, cobbles, and some small boulders of only siliceous rocks in a matrix of sand and fine gravel. No granite pebbles are present to indicate that the granite was older than the quartzite; however, most writers have rejected the idea that the granite is younger than the Sioux. The possibility of a fault contact has been discussed but rejected by both Baldwin (1951) and Miller (1961) who indicate that an unconformable contact between the older granite and the younger Sioux is more likely.

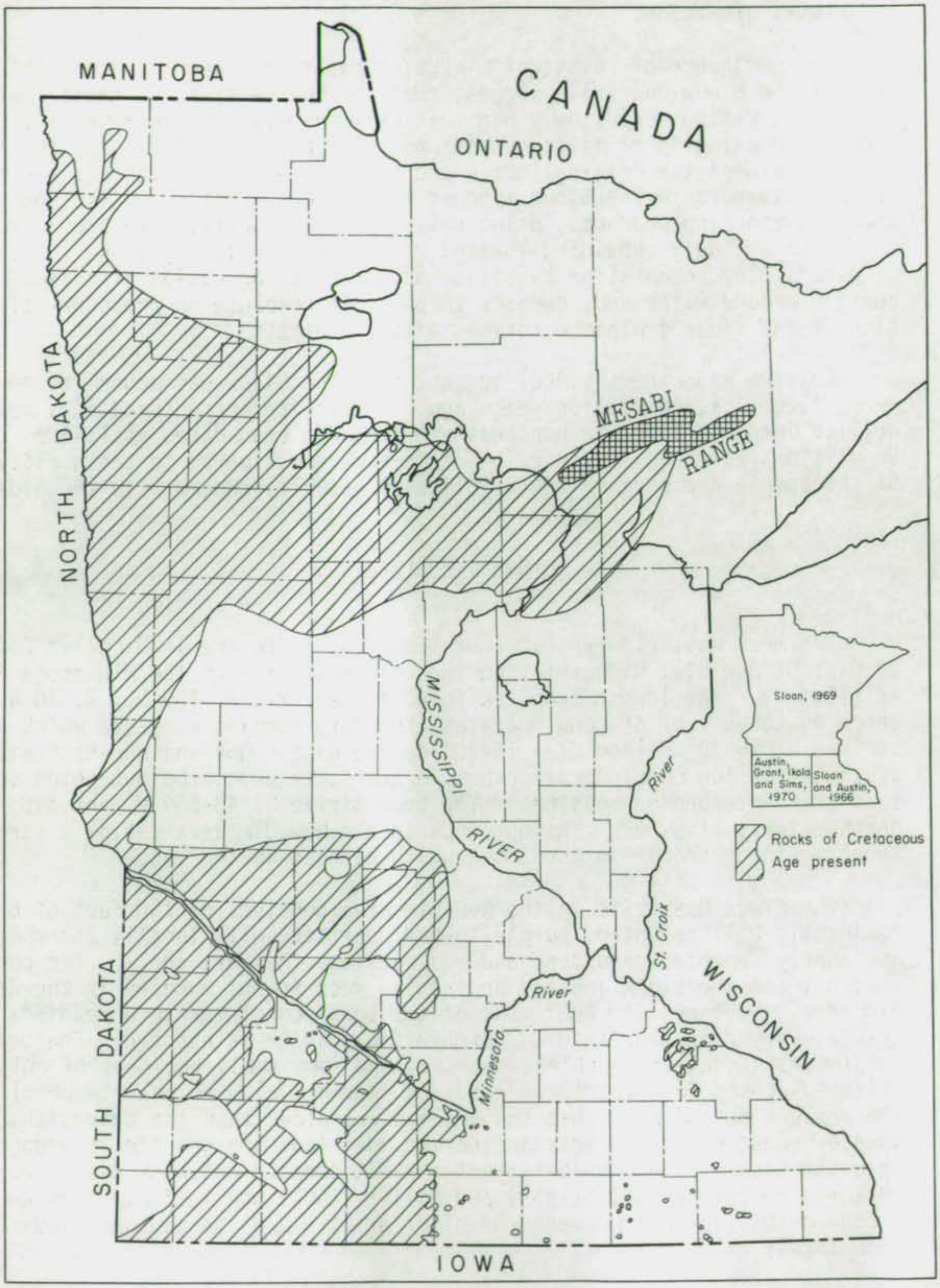

Figure 3. Generalized geologic map of Cretaceous rocks in Minnesota (modified from Sloan, 1964).

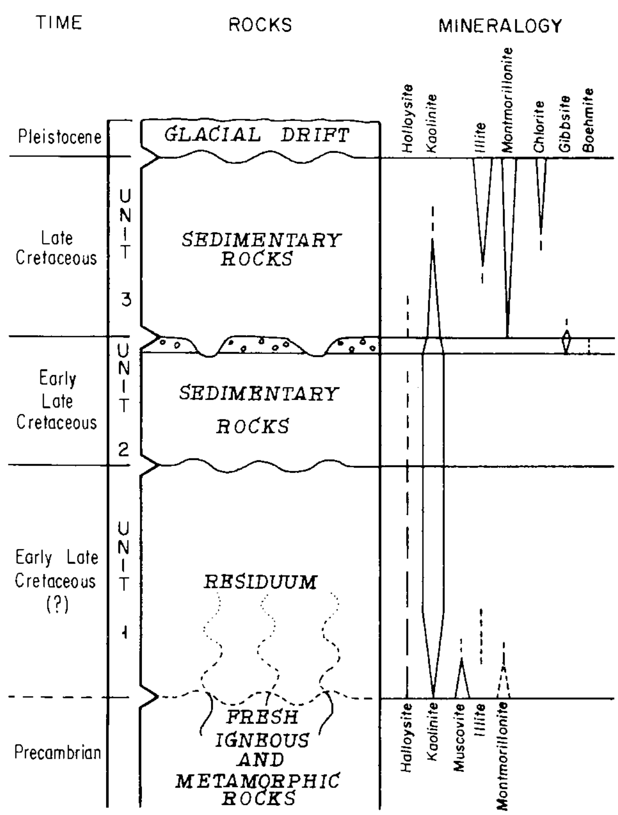

Figure 4. Vertical variations in clay mineral assemblages of weathered residuum and of Upper Cretaceous sedimentary rocks of Minnesota (after Parham, 1970).

CRETACEOUS ROCKS IN SOUTHERN MINNESOTA

Rocks of Cretaceous age are nearly continuous beneath thick Pleistocene drift throughout the western half of Minnesota and form numerous outliers in the eastern half of the state (fig. 3). These rocks, consisting of underlying residuum and overlying shale, sandstone, and minor limestone, rest unconformably on a surface with a maximum relief of 1,400 feet and on rocks ranging in age from Precambrian to Devonian. The basal residuum developed during a long interval of weathering that existed from sometime after Middle Devonian into earliest Late Cretaceous time. Upper Cretaceous marine and nonmarine sedimentary rocks overlie the residuum.

According to Sloan (1964), a widespread epicontinental sea existed in Minnesota and the states immediately to the west, probably no earlier than Late Jurassic time and definitely during Late Cretaceous time. The sea had a warming effect on the land and served as the source for precipitation necessary for the development of a thick, chemically weathered zone. Water well drillers in western Minnesota have reported penetrating "decomposed granite" is excess of 200 feet thick overlying "fresh granite." The kaolinitic residuum has been penetrated beneath Upper Cretaceous sedimentary rocks and glacial drift or both over a wide area in western Minnesota and eastern North and South Dakota and is very likely equivalent to a weathered zone in Manitoba (Parham, 1970). Although the residuum is best preserved overlying granitic rocks, it is also found overlying Precambrian Sioux Quartzite in the Minnesota River Valley (Austin, 1970) and, in south-central Minnesota, carbonate rocks, sandstones, and shale (Parham, 1970; Austin, 1971).

Paleontologic and stratigraphic data indicate that the weathering interval in Minnesota, which produced abundant kaolin clays, ended sometime later in Cenomanian time (Austin, 1970; Parham, 1970). A significant climatic change took place after the residuum was formed and prior to the advance of the Late Cretaceous seas into Minnesota. The climate became more temperate and the water table rose, resulting in stagnant alkaline waters on the nearby land areas. With the transgression of the Cretaceous seas from the west, thick shales with some sandstone and minor limestone were deposited above a basal sandstone identified as the Dakota Formation. The included clay minerals (fig. 4), rather than chiefly kaolinite, are dominantly illite and smectite (Austin, 1970; Parham, 1970).

Southeastern Minnesota

Nonmarine sedimentary rocks of Late Cretaceous age are exposed discontinuously in the southeastern part of the state from the Mississippi River westward to west of Mankato, where they are covered by marine Upper Cretaceous rocks. These nonmarine rocks lie as patches upon a post-Devonian erosion surface. Near the Mississippi River the glacial cover is relatively thin and the rocks lie at or near the surface. To the west the drift is thicker and, with few exceptions, Cretaceous rocks are known only from drill holes which penetrate bedrock.

The Cretaceous rocks of southeastern Minnesota have been identified as the Windrow Formation, a name originally proposed by Thwaites and Twenhofel (1921) to designate rocks lying above material of Paleozoic age in the Driftless Area of Wisconsin. Later Andrews (1958) applied the name to all Cretaceous and pre-Cretaceous nonmarine rocks lying above Lower and Middle Paleozoic formations in the Upper Mississippi Valley. Andrews (1958) distinguished two members, a lower Iron Hill Member, an iron-oxide-rich regolith developed on pre-Cretaceous bedrock, and an upper clastic unit subsequently identified as the Ostrander Member of the Windrow Formation (Austin, 1963; Sloan, 1964). The Iron Hill and Ostrander Members are equivalents of the kaolinitic residuum and the Dakota Formation respectively of western Minnesota. The Windrow Formation contains leaf imprints and carbonized wood. The presence of a shark's tooth in place in a clay pit in Goodhue County (fig. 1) suggests that marine sediments overlay the nonmarine sediments in southeastern Minnesota (Sloan, 1964). This theory is supported by the discovery of several specimens of the nannofossil Ophiomorpha nodosa Lundgren (W. W. Pryor, written comm., 1970) in exposures in the same county.

The Windrow Formation is important economically in Minnesota. It has been a significant source of brown iron in Fillmore and adjacent Olmsted and Mower Counties (Stauffer and Thiel, 1944 and 1949; Sloan, 1964), although Bleifuss (1966) has suggested that the brown ores are Tertiary in age rather than Cretaceous. The Ostrander Member of the Windrow Formation has served as a source of ceramic clay in Goodhue County in southeastern Minnesota (Austin, 1963).

Southwestern Minnesota

In southwestern Minnesota a thin- to-thick, white-to-pale yellow sandstone containing thin lignite beds commonly lies above the residuum and below the dominantly marine shales. This sandstone unit is identified as the Dakota Formation and was derived from the chemical weathering of the Sioux Quartzite and exposed granitic rocks of the Transcontinental Arch during Cretaceous time. The Dakota Formation represents a deltaic deposit in South Dakota (Schoon, 1965) or continental deposit in Minnesota (Sloan, 1964) which is progressively younger to the east (Schoon, 1965). As the Late Cretaceous epicontinental sea transgressed, the clastic sediments became finer grained and marine shale succeeded the Dakota Formation. Sloan (1964) indicates that more or less continuous deposition of marine shales took place in western Minnesota from Cenomanian to Santonian time with the Pierre Shale of Campanian time perhaps present beneath the glacial drift in southwestern Minnesota. The maximum known thickness of Cretaceous strata in western Minnesota is in Lincoln County along the South Dakota-Minnesota border, where Cretaceous strata are approximately 600 feet thick (Minnesota Geological Survey files).

Age of Minnesota Cretaceous Rocks

The sedimentary Cretaceous rocks in Minnesota (fig. 5) can be correlated with the Dakota Formation, the Colorado Group, and perhaps the Pierre Shale of the western interior United States (Sloan, 1964). Although the age of the underlying residuum developed on pre-Cretaceous rocks in Minnesota is not firmly fixed, its development most probably began during Jurassic or Early Cretaceous time with the encroachment of warm epicontinental seas from the west and may have begun as late as Early Cenomanian time. Later during Cenomanian time an abrupt change in climatic conditions brought a halt to the development of a kaolinitic residuum present over much of western Minnesota. As the epicontinental sea advanced across Minnesota under more temperate climatic conditions, thick beds of predominantly shaly strata were deposited on the previously formed residuum and nonmarine sedimentary rocks.

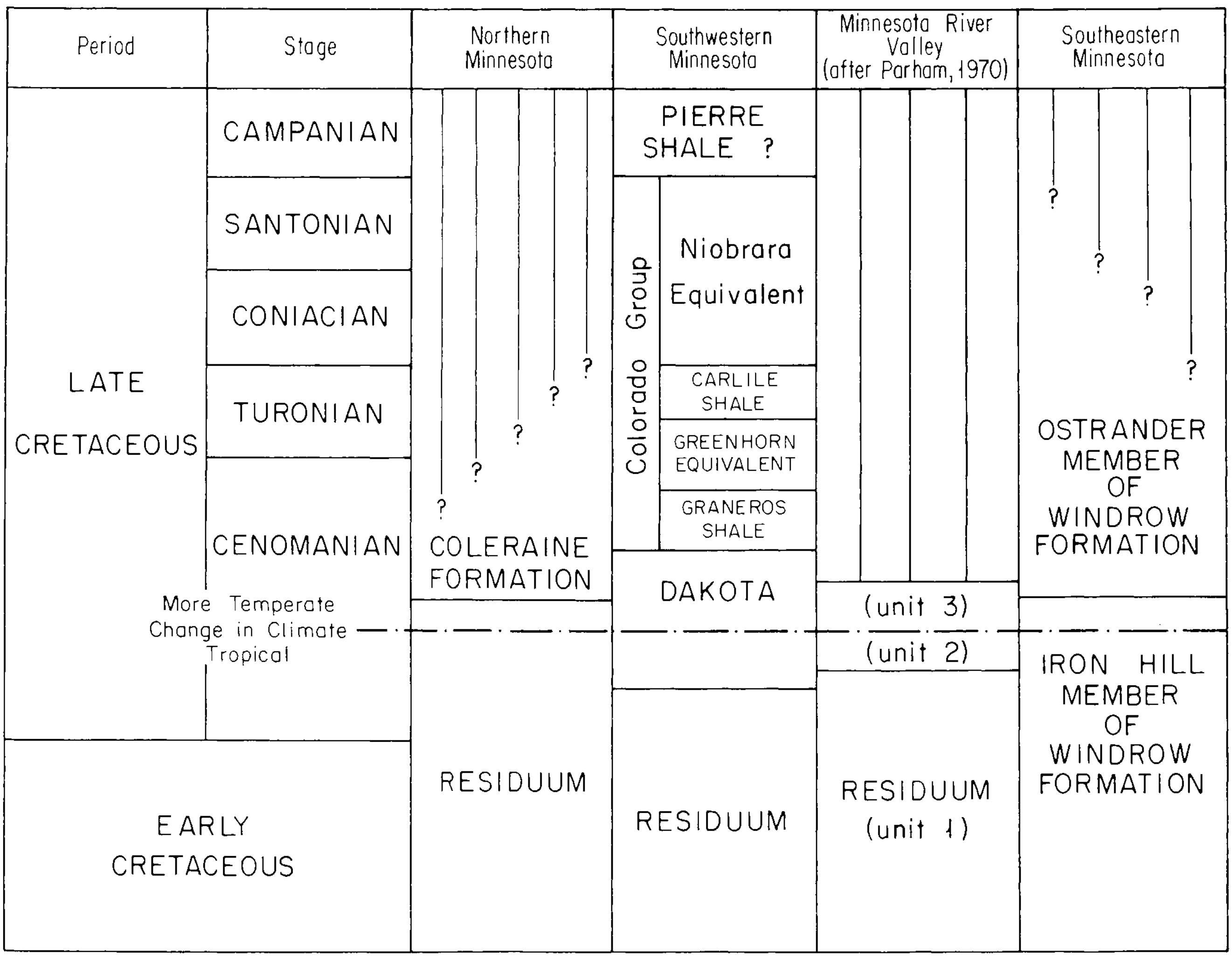

Figure 5. Correlation chart of the Cretaceous System in Minnesota (modified from Sloan, 1964).

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ROAD LOG AND STOP DESCRIPTIONS

Gerald F. Webers and George S. Austin

Assisted by Thomas Bayer, Vincent Kurtz, John Mossler and Robert Sloan

Mileage		
0.0	0.0	Board bus at Leamington Hotel (3rd Ave. and 10th St.) Proceed south on 10th St.
0.2	0.2	Turn left on 5th Ave. S.
0.3	0.5	Turn right on 6th St. S.
0.6	1.1	Freeway Entrance to I-94 East, proceed east to Minn. 280 exit.
2.9	4.0	Minn. 280 exit (on left), proceed north.
3.4	7.4	Junction Minn. 36 and Minn. 200, proceed east on Minn. 36.
0.8	8.2	Junction I-35W and Minn. 36, proceed north on I-35W.
4.1	12.3	Junction I-694.
9.7	32.7	Junction I-35W and U. S. 8, proceed east on U. S. 8 to Taylors Falls (Forest Lake).
11.1	43.8	Lindstrom City Limits (West).
5.4	49.2	Shafer City Limits (West).
2.3	51.5	Junction Minn. 95 and U. S. 8.
1.5	53.0	Franconia Formation (Mazomanie Mbr.).
1.1	54.1	Basalt exposures to park entrance.
0.8	54.9	Turn right at entrance of Glacial Gardens (Interstate Park).

STOP 1. The North Shore Volcanic Group is well exposed in Interstate State Park. The flows are part of a flood basalt series which reaches a thickness of about 25,000 feet near Duluth, Minnesota. At least ten flows are exposed at Taylors Falls. The nearly flat orientation of the flows can be observed in the horizontal vesicular flow tops. During Late Cambrian time, the flows formed bluffs much as they do today and

the sea gradually encroached from the south. For a time they formed islands with rather steep seacliffs but were gradually inundated toward the end of Cambrian time. The unconformity between the flows and the Cambrian sandstones can be seen at several localities around Taylors Falls.

Toward the end of the Wisconsin Glaciation, ice dammed the Straits of Mackinac and the meltwaters raised the level of the water in the Lake Superior basin more than 600 feet above its present level. This lake, known as Glacial Lake Duluth, overflowed to the south through the Brule River of Wisconsin and the St. Croix River, and cut a gorge through the resistant flow series at Taylors Falls. The tremendous discharge and the resultant velocity of the water resulted in extensive pothole formation. Over eighty potholes are present as large as 60 feet deep and 15 feet in diameter.

Turn around and proceed west (left) on U. S. 8.

0.7 55.6 Turn right at "Wild River Aquarium."

STOP 2. Mill Street Conglomerate. The Mill Street Conglomerate is one of the few localities in North America that shows a conglomerate at the base of the Upper Cambrian sandstones. The conglomerate here is very coarse, consisting of angular basalt blocks up to two feet in diameter surrounded by fine- to medium-grained buff quartz sandstone of Franconian age. The corners of the basalt blocks have been rounded by the surf action of the Upper Cambrian seas. Trilobites, inarticulate brachiopods, and monoplacophorans of the *Elvinia* Zone have been collected at this locality. Inarticulate brachiopods are common. Included in the monoplacophorans are high-coned septate hypseloconids which are representative of the group from which cephalopods evolved.

A veneer of conglomerate covers the unconformable contact between the flows and the Cambrian sandstones at several localities. The conglomerates range in age from Dresbachian to Franconian.

Return to U. S. 8 and proceed west (right) to entrance of Interstate Campground.

1.0 56.6 Entrance Interstate Campground

STOP 3. Franconia Sandstone (Curtain Falls Trail Area). Two stops are scheduled along the Curtain Falls Trail.

The first stop is about 350 yards from the beginning of the trail and the second is about 300 yards from the end of the trail.

The first stop begins at a small bridge about 300 yards from the beginning of the trail. Exposed under the bridge are basalts of the North Shore Volcanic Group. Working upstream from the bridge, the stream exhibits nearly continuous exposures of the flows some of which show brecciated flow tops. An unconformity can be observed approximately 50 yards upstream from the bridge at which point buff, fine- to medium-grained sandstones of Franconian age overlie the flows. Abundant trilobites of the Conaspis Zone can be found at the contact.

The second stop is approximately 300 yards from the end of the Curtain Falls trail and 1000 yards from stop 1 via an overland route. It is inefficient to follow the trail to the second exposure so a short but somewhat exerting walk over the bluff to the south is recommended. Those persons desiring a less exerting approach to the second stop may proceed back to the beginning of the trail, turn right for about 200 yards along the highway and turn right and proceed from the end of the trail about 300 yards to the site of Curtain Falls. About 110 feet of Franconian sandstone is exposed at the site of Curtain Falls. The lower 30 feet consists of buff-to-green, fine- to medium-grained glauconitic sandstone of the Birkmose Member of the Franconia Formation. Only the upper few feet of this unit are well exposed at the falls. This is overlain by 80 feet of the Mazomanie Member of the Franconia Formation. Trilobites of the Elvinia and Conaspis Zones are present as well as inarticulate brachiopods and the problematic Pelagella. Sandstone at this stop represents a nearshore sub-littoral accumulation and completes the picture of land, beach, and offshore areas of the Upper Cambrian seas.

Return to U. S. 8 and proceed west (left).

1.8	58.4	Junction U. S. 8 and Minn. 95, proceed south (left on Minn. 95).
5.0	63.4	Junction Minn. 243.
5.7	69.1	Junction Minn. 97.
1.5	70.6	Copas City Limits (north).

1.0 71.6 William O'Brien State Park.

1.8 73.4 Marine on the St. Croix.

0.7 74.1 Junction Minn. 7.

7.7 81.8 Cambrian sandstone exposure.

1.5 83.3 Stillwater City Limits (north).

0.7 84.0 Cambrian sandstone exposure.

STOP 4. Contact between the Cambrian Jordan Sandstone and the Ordovician Oneota Dolomite (Prairie du Chien Group). The nature of the systemic contact between the Jordan Sandstone and the Prairie du Chien Group has long been a topic of debate (see Kraft, 1956). Early workers tended to regard it as an unconformity, while later workers tended to regard it as conformable; there has not been complete agreement at any one time. The change from a quartz sandstone to a dominantly dolomite rock unit is gradational at many exposures in Minnesota over a considerable stratigraphic interval. In some sections this interval is as large as 30 feet. The change at Stillwater is unusually sharp and the only gradation is found in the abundance of quartz sand in the lower 2 feet of the Oneota and minor shale lenses just below the contact. One possible explanation for the sharp contact is that Stillwater lies near the crest of the Hudson-Afton Anticline. This structure overlies a prominent Precambrian horst. Reactivation of this structure during the Late Cambrian produced the anticline and could have resulted in the non-deposition or even erosion of the upper Jordan Sandstone beds. A generalized section is found below.

			Covered
Oneota Dolomite		6'	Massive, buff dolomite, lower 2 feet sandy, contact sharp
Jordan Sandstone	Van Oser Member	52'	Buff- to-white, medium-grained, cross-bedded, friable quartz sandstone
	Norwalk Member	20'	Buff, fine-grained, thinly laminated, well indurated quartz sandstone, prominent worm burrows
		16'	Buff- to-yellow, medium-grained quartz sandstone, some cross-bedding
			Covered

Continue south on Minn. 95.

0.6 84.6 Cambrian sandstone exposures.

2.0 86.6 Bayport City Limits (north).

3.6	90.2	Lakeland City Limits (north).
1.4	91.6	Intersection Minn. 95 and U. S. 12.
3.1	94.7	Afton City Limits (north).
6.4	101.1	Cottage Grove City Limits (north).
5.9	107.0	Junction Minn. 95 and U. S. 61, turn south on U. S. 61.
1.1	108.1	Junction U. S. 61 and U. S. 10.
1.1	109.2	Hastings Bridge.
1.5	110.7	Junction U. S. 61 and Minn. 291.
0.5	111.2	Junction U. S. 61 and Minn. 316.
8.3	119.5	Junction U. S. 61 and Minn. 20, proceed south on Minn. 20.
6.7	126.2	Cannon Falls City Limits (east).
0.7	126.9	Continue straight ahead to Minn. 24 (South 4th St.) and continue south.
1.0	127.9	Junction Minn. 24 and Minn. 25, proceed left on Minn. 25.
0.2	128.1	Quarry on left in Platteville Formation.
0.9	129.0	Exposure of Decorah Shale on right.

<u>STOP 5</u>. This stop exhibits about 15 feet of relatively unoxidized Decorah Shale. The material consists of green-to-gray highly fossiliferous shale. Brassy oolites are common. Thin limestone coquinas are present. The shale is exposed on both sides of the road, although the most productive collecting will be found on the south side. Rains have washed out much of the finer material, leaving a lag concentration of fossils on the surface. The Decorah Shale is about 60 feet thick at Cannon Falls, Minnesota and thins to the south and southeast. The clastic material of this unit is thought to have been derived from a nearby source area to the west associated with an uplift of the Transcontinental Arch.

Bottom communities dominated by filter-feeders flourished in the warm, shallow, marine seas. The abundant macrofauna of the Decorah Shale is dominated by bryozoans and articulate brachiopods. Tabulate and horn corals, cephalopods, gastropods, pelecypods, and trilobites are also common. Microfauna includes abundant ostracodes and conodonts with scolecodonts and chitinozoans also represented.

Return to Cannon Falls by previous route.

1.9	130.9	Cannon Falls City Limits (west).
1.9	132.8	Cannon Falls City Limits (east) along Minn. 20.
6.6	139.4	Junction Minn. 20 and U. S. 61, proceed south on U. S. 61.
1.3	140.7	Miesville City Limits (north).
1.0	141.7	Junction U. S. 61 and Minn. 91.
2.0	143.7	Junction U. S. 61 and Minn. 316.
2.1	145.8	Junction U. S. 61 and CTH 7.
1.5	147.3	Junction U. S. 61 and CTH 18, left (east on CTH 18).
0.7	148.0	Exposures of Prairie du Chien.
0.3	148.3	STOP 6. Quarry and roadcuts in the Prairie du Chien Group. About 68 feet of the Prairie du Chien Group is here exposed in a quarry and a series of road cuts west of the quarry along County Road 18.

The lowest unit exposed is about 4 feet of the Oneota Dolomite. This material is exposed in the quarry and consists of yellow-to-brown, thin bedded, dolomitized algal-mat biolithite. Overlying this is 21 feet of the New Richmond Member of the Shakopee Formation. The lower 8 feet of this Member consists of brown-to-orange dolomite breccia with intraclasts of underlying Prairie du Chien units surrounded by sand and shale matrix. The remaining 13 feet of the New Richmond Member consists of yellow oosparite, dolarenite, dololutite, sandy dolomite, and quartz sandstone. The overlying 47 feet is the lower portion of the Willow River Member of the Shakopee Formation and consists of algal-mat and algal-mound biolithite, pelletoidal dolomite, dolarenite, dololutite, and minor quartz sandstone. The algal-mat and algal-mound biolithites in this unit are among the best preserved in Minnesota.

The contact of the Oneota Dolomite with the New Richmond Member of the Shakopee Formation is an unconformity. The lower 8 feet of the New Richmond Member represents the rubble accumulated on the Oneota erosion surface surrounded by sand and shale matrix. The environment which existed during the deposition of the Oneota was that of a shallow-to-sublittoral, warm, marine-to hypersaline sea. Deposition of carbonate was periodically interrupted by the deposition of quartz sandstone from low-lying landmasses early during Oneota time. However, quartz sand decreases upward in the formation. Algae both in mound and in mat form flourished and supported a relatively small population of gastropods and a few cephalopods and conodonts. Normal marine bottom-dwelling filter-feeding organisms are virtually absent. At the end of Oneota deposition retreat of the seas temporally resulted in the breccia at the base of the Shakopee. With a return of the seas, conditions returned to those of the Oneota.

1.0	149.3	Junction U. S. 61 and CTH 18, south on U. S. 61.
4.5	153.8	Junction U. S. 61 and CTH 19.
4.2	158.0	Red Wing City Limits.
1.3	159.3	Junction U. S. 61 and Minn. 63, south on 61-63.
0.3	159.6	Pull off in right shoulder just past underpass.

STOP 7. Franconia and St. Lawrence Formations - Barn Bluff, Red Wing.

The Franconia and St. Lawrence Formations are here in fault contact. About 90 feet of the Reno Member of the Franconia Formation can be seen along the highway. The Reno is a green, mottled, medium-grained, highly glauconitic member of the Franconia Formation. Cross-bedding and worm burrows are common in some beds. The fault plane is nearly vertical and highway excavation has reduced the Reno to a thin slice veneering the St. Lawrence Formation. The eastern fault contact on this slice of Reno is irregular because the plane of the fault nearly parallels the outcrop orientation. The western fault contact is very sharp. Slickensides can be found on some of the St. Lawrence surfaces at the fault as well as a gouge zone of predominantly Reno material. About 30 feet of the St. Lawrence Formation is exposed on the western part of Barn Bluff. The material is predominantly a buff dolosiltite with minor dolarenites. Unweathered beds maintain a blue color. Displacement on the fault is about 175 feet.

Trilobites of the Elvinia zone can be collected from the Reno Member of the Franconia Formation and trilobites of the Dikelocephalus zone can be collected from the lower part of the St. Lawrence Formation.

Overlying the St. Lawrence Formation at Barn Bluff is about 115 feet of Jordan Sandstone and about 75 feet of the Oneota Formation of the Prairie du Chien Group.

Continue south on U. S. 61-63.

1.1	160.7	Sandstone exposures, bluffs in this area capped by Prairie du Chien dolomites.
8.9	169.6	Frontenac City Limits (north).
6.5	176.1	Lake City City Limits (north).
0.6	176.7	Junction U. S. 61 and U. S. 63, proceed south (right) on U. S. 63. Bluffs in area are Prairie du Chien capping Upper Cambrian sandstone.
3.6	180.3	Exposure of Jordan Sandstone on right.
0.5	180.8	Exposures of Jordan Sandstone on left.
0.5	181.3	Exposures of the Prairie du Chien Group for approximately one mile.
3.7	185.0	Junction with County 16, continue south on U. S. 63.
0.1	185.1	Oak Center City Limits (north).
6.1	191.2	Zumbrota Falls City Limits (north).
0.2	191.4	Weathered exposures of Prairie du Chien on left.
0.1	191.5	Junction County 60.
0.9	192.4	Exposures of Prairie du Chien along Zumbrota River and for 0.3 mile along U.S. 63.
7.2	199.6	Exposures of Prairie du Chien for 0.2 mile.
0.5	200.5	Junction County 247, continue on U.S. 63.
2.3	202.4	Exposures of St. Peter Sandstone and Platteville Formation.
1.1	203.5	Exposures of St. Peter Sandstone, Glenwood and Platteville Formations on left.

1.2	204.7	Exposure of St. Peter Sandstone on left.
0.2	204.9	Exposure of Prairie du Chien Group on left.
0.7	205.6	Exposure of St. Peter Sandstone and Platteville Formation for the next 3 1/2 miles.
2.4	208.0	Junction County 22, continue on U. S. 63.
0.1	208.1	Rochester City Limits (north).
1.5	209.6	Zumbro River.
1.0	210.6	Junction U. S. 63 (South Broadway) and First St. SW, proceed west (right) on First St. SW.
0.1	210.7	Entrance Kahler Hotel.

SECOND DAY

0.0	0.0	Board bus in front of Kahler Hotel at 8:00, proceed east on First St. SW to junction with South Broadway (U. S. 63).
0.1	0.1	Junction First St. SW with South Broadway, turn left (north).
1.3	1.4	Junction U. S. 63 (N. Broadway) with Elton Hills. Drive, turn left (west) on Elton Hills Drive.

0.3 1.7 STOP 1. Contact St. Peter Sandstone and Shakopee Formation. This outcrop is one of the very few which exposes the contact between the St. Peter Sandstone and the Shakopee Formation of the Prairie du Chien Group. The nature of the contact is controversial. An unconformable relationship can be demonstrated in Wisconsin with up to 250 feet of relief on the unconformity. In Minnesota the beds are parallel on both sides of the contact and an unconformable relationship is suspected but cannot be proved. The problem is compounded by the lack of surface exposure of the contact and the tendency of the St. Peter Sandstone to slump.

About 20 feet of the Willow River Member of the Shakopee Formation is exposed. The material is a yellow-to-brown dolomite and includes doloarenites, dololutites, oosparite, pelletoidal dolomite, algal-mound biolithite, and minor quartz sandstones. Oolites are common and glauconite can be found in some beds. Algal mounds are large but not well preserved. The Willow River represents a sublittoral saline or hypersaline environment where bottom dwelling filter-feeders could not exist. Algae are the most common fossil in the Willow River. Gastropods which probably fed on the algae are present but not common. An occasional straight-shelled cephalopod virtually completes the faunal picture.

The Willow River is here overlain by about two feet of yellow-to-white, fine-grained, well-sorted sandstone of the St. Peter Sandstone. Another 40 feet of St. Peter Sandstone is exposed on a bluff just south of the exposure.

Continue west on Elton Hills Drive.

1.6 3.3 Junction Elton Hills Drive with U. S. 52; cross over and turn south on U. S. 52.

0.9	4.2	Junction U. S. 52 and U. S. 14, turn right (west) on U. S. 14.
2.0	6.2	Stop 2 visible across median on left.
1.4	7.6	Cross median on small dirt road, turn, and proceed east (right) on U. S. 14.
0.3	7.9	Exposures of St. Peter Sandstone, Glenwood and Platteville Formations.
0.7	8.6	STOP 2. Road cuts west of Rochester along U. S. 14.

About 35 feet of yellow-to-white, friable quartz sandstone of the St. Peter Formation is exposed in a series of road cuts south of U. S. 14. The St. Peter is a unique formation in many ways including its uniformity of grain size, mineralogy, and sorting, its lack of sedimentary structures, and its wide areal extent. The St. Peter Sandstone was deposited in a shallow marine shoreline environment and marks the beginning of a Middle Ordovician transgressive sequence. The St. Peter Sandstone is overlain by about seven feet of greenish shale and sandstone of the Glenwood Formation. A prominent iron-stained sandstone is present at the base of the Glenwood. The Glenwood carries a rich conodont fauna but lacks the well developed bottom communities found in the Platteville Formation. Completing the onlap sequence at this locality is three feet of dolomitic limestone of the lower Platteville Formation.

Continue east on U. S. 14.

2.2	10.8	Junction U. S. 14 and U. S. 52, turn right (south) on U. S. 14-52.
1.9	12.7	Junction U. S. 14-52 with freeway segment to U. S. 63, continue straight ahead (south) toward U. S. 63.
0.8	13.5	Zumbro River.
0.4	13.9	STOP 3. Golden Hill, Rochester, Minnesota.

A generalized section of the rock exposures at Golden Hill is as follows:

Galena Formation
  Cummingsville Member

About 35 feet of alternating beds of buff fossiliferous limestones and gray-to-buff limy fossiliferous shales. A corrosion zone is found in the first thick limestone above the base of the member. The bottom bed of the Cummingsville is a two-foot layer of shale with thin limestone lenses.

Decorah Shale

About 47 feet of gray-green fossiliferous shale with thin coquinoid limestone layers. The Decorah interfingers with both the Cummingsville and the Platteville. The top of the Decorah is marked by a coquinoid limestone with brassy oolites. The base is marked by the first thick limestone of the Platteville Formation. The diverse fauna at this locality is generally the same as at Cannon Falls (First Day, Stop 5).

Platteville Formation

Carimona Member

About seven feet of gray-to-tan limestone with interbedded shales. The bottom is placed at the top of a thick gray indistinct corrosion zone about 0.4 feet thick. The white to bright yellow Carimona Bentonite is found 1.3 feet above the base of the member. Immediately below the bentonite is the "Oil Shale," a thin, dark brown fissile shale.

McGregor Member

About 12 feet of gray, somewhat mottled limestone with thin crinkly beds grouped into thicker units. Black fossil hash and phosphatic pellets are present.

Pecatonica Member

About 3 feet of tan dolomitic limestone. The bottom foot is very sandy. There are three corrosion zones present, the highest of which marks the top of the member.

Glenwood Formation

About 1.5 feet of green and yellow sand and shale.

The Glenwood Formation, and the Pecatonica and McGregor Members of the Platteville Formation mark a continuance of the onlap sequence initiated by the St. Peter Sandstone in Middle Ordovician time. The alternating limestones and shales of the Carimona Member of the Platteville Formation mark the beginning of an uplift of the Transcontinental Arch resulting in the clastic material of the shales. The slightly fluctuating environment shifts to dominantly clastic deposition in the Decorah Shale. The environment at this time was that of a warm, shallow marine sea not far from the low source area which lay directly to the west and was of the Transcontinental Arch. The thin coquinoid limestones within the Decorah reflect periodic winnowing of the soft bottom sediments by waves and/or bottom currents. Toward the end of the time represented by the Decorah Shale the Transcontinental Arch stopped supplying large quantities of clastics due to either subsidence or to erosion to a very low surface. With this, the offlap sequence is reversed and the alternating limestones of the Cummingsville Member of the Galena Formation reflect a return to the conditions which resulted in the deposition of the lower Platteville Formation.

Continue south toward U. S. 63.

0.5	14.4	Junction with U. S. 63, continue south on U. S. 63.
2 8	17.2	Cummingsville Member of Galena Formation exposed on left.
0.4	17.6	Cummingsville Member of Galena Formation exposed on right.
0.4	18.0	Turn left across median into Quave-Anderson Quarry.

STOP 4. About 90 feet of the Galena Formation is exposed in a quarry and road cuts along U. S. 63. A generalized section is as follows:

Galena Formation
  Stewartville Member

About 14 feet of buff, dolomitic limestone is exposed in road cuts along the highway. The material exhibits a mottled and pitted appearance typical of this unit. Receptaculites common. Corals, gastropods and brachiopods common near the contact with the Prosser. The bedding is medium-to-thick. A three foot transition is present here between the Stewartville and Prosser Members.

Prosser Member

About 75 feet of yellowish to light olive gray limestone is exposed in the quarry. Bedding is thick. The beds are highly fossiliferous but collecting is difficult because of the massive fine-grained limestone beds. Brachiopods dominate the fauna and gastropods, corals, and crinoids are common.

The Prosser Member is predominantly limestone and records a quiet offshore carbonate bank environment. Bottom cummunities are dominated by brachiopods and other filter-feeders and indicate quiet clear waters of normal marine salinity. These bottom communities disappear in the restricted perhaps hypersaline environment of the Stewartville. Receptaculites is common in the Stewartville and forms the basis of the Upper Receptaculites Zone. Some of the quarry joints have been enlarged and filled with clay during Cretaceous and early Tertiary weathering.

0.9	18.9	Return to U. S. 63, cross median and turn right (south) on U. S. 63.
0.1	19.0	Exposure of Prosser and Stewartville Members of the Galena Formation for 0.3 mile.
3.6	22.6	Junction U. S. 63 and I-90, continue south on U. S. 63.
0.9	23.5	Stewartville City Limits (north).
0.4	23.9	Junction U. S. 63 and Minn. 30. Turn left (east) on Minn. 30.
4.9	28.8	Junction Minn. 30 and Fillmore County 1. Turn right (south) on CTH 1.
4.7	33.5	The Galena Formation and the overlying Dubuque Formation crop out for the next few miles.
2.5	36.0	STOP 5. Kapper Quarry Area.

Two quarries and a series of road cuts expose about 50 feet of the Stewartville Member of the Galena Formation and about 35 feet of the Dubuque Formation. The massive dolomites of the Stewartville contrast sharply with the alternating limestones and shales of the Dubuque Formation. Neither of the above units contain an abundance of macrofossils. The buff dolomites of the Stewartville Member were deposited in an offshore saline to hypersaline environment. Similar in many ways to the Prairie du Chien Group, bottom-dwelling, filter-feeding animals are virtually absent. *Receptaculites*, a problematic form possibly an alga, is common at some levels as is *Maclurites*, a large hyperstrophic gastropod. Except for these two forms and a relatively small number of conodont species, the environment during the deposition of the Stewartville was relatively barren of life.

Deposition of the Dubuque beds mark a return to the normal marine environment. Pelmatozoan fragments are very common and many of the limestones in the sequence are criquinas. Conodonts are very abundant in the Dubuque and represent both the "midcontinent" fauna as well as the "Appalachian-Scandinavian" fauna. A mild uplift of the Transcontinental Arch probably took place early in Dubuque time.

Continue south on CTH 1.

4.2	40.2	Spring Valley City Limits (north)
0.5	40.7	Intersection of U. S. 63, U. S. 16, and Minn. 74 (and 1), proceed south on U. S. 63. Several abandoned iron ore pits can be seen along the road as we go south and east.
10.3	51.0	Intersection of U. S. 63 and Minn. 44. Turn left (east) on Minn. 44 toward Harmony, Minn.
8.5	59.5	Junction Minn. 44 and gravel road. To north of intersection is a sign on the site of the former Bristol Welch Church. Turn right (south) on gravel road.
2.2	61.7	Turn left (east) on gravel road.
1.1	62.8	Turn into farmyard on the right (south).

STOP 6. Granger Area.

One of the thickest exposures of the Maquoketa Formation in southeastern Minnesota occurs along the Upper Iowa River from one to three miles west of Granger. Here flaggy limestones and nodular shales of the basal Maquoketa are presumed to rest on the Dubuque Formation. However, the Dubuque is not visible at any point along the river.

The Maquoketa is exposed both in a vertical cliff face along the Upper Iowa River and in a ravine which joins the river valley. The ravine exposure is somewhat overgrown and weathered and the best collecting can be obtained in the blocks at the base of the cliff face.

Bayer (1965) has indicated that there are three distinct macrofaunal bottom communities in the Maquoketa Formation of Minnesota. These are in descending order:

1. The Streptelasma-Plaesiomys community contained in the coarsely crystalline dolomitized limestones of Lithosome III.

2. The Thaerodonta-Onniella community contained in the shell beds of Lithosome II. These shell beds alternate with barren shaly dolomites and dolomitic limestones.

3. The Isotelus-Diplograptus community found in the alternating limestones and nodular shales of Lithosome I.

The section (Bayer, 1965) is as follows:

Maquoketa Formation - Elgin Member

62-66' Limestone, tan, very sandy, calcite filled vugs.

Lithosome III

55-62' Dolomitic limestone and sucrosic dolomite, light brown in 1-3" flaggy beds, Streptelasma abundant, Plaesiomys rare.

Lithosome II

42-48' Limestone, tan, cherty, in irregular discontinuous beds, Ctenodonta, _Thaerodonta_.

30-42'	Predominantly light gray-tan calcareous dolomite in wavy, irregular beds. Fossiliferous limestone beds uncommon. Gray chert nodules common. Upper 3 feet fossiliferous as above.
20-30'	Alternating fossiliferous limestones and shaly dolomites as above, _Thaerodonta_, _Onniella_.
10-20'	Thin-bedded, shaly limestones, some interbedded dolomitic limestones and thin shale beds. Fossils not abundant, include _Thaerodonta_ and _Isotelus_. Prominent 2 inch yellow clay bed 5 feet above base.
	Lithosome I
0-10'	Gray, fine-grained limestones in 2 to 3 inch beds which alternate with chocolate brown nodular shales. _Diplograptus_ and _Isotelus_ fragments abundant.

Turn left (west) onto gravel road from farmyard.

1.1	63.9	Junction (T) of gravel roads, turn right (north) on gravel road.
2.2	66.1	Junction (T) of gravel road and Minn. 44, turn left (west) on Minn. 44.
2.5	68.6	Junct. Minn. 44 and gravel road; stop 7 is in area just SW of intersection.

STOP 7. Residual Iron Ore, Windrow Formation, Iron Hill Member.

Extensive lateritic weathering on the Cedar Valley Limestone and other carbonates during Cretaceous times has resulted in pockets of residual iron ore. These pockets formed the basis of small scale iron mining from the forties to the late sixties. Most of these pockets are now mined-out and mining has ceased. The deposit at this stop represents one of the few remaining in SE Minnesota. Elongate trenches give a cross-section of the deposit. The owner estimates a reserve of 100,000 tons.

Continue west on Minn. 44.

4.0	72.6	Junction Minn. 44 and CTH 114, turn right (north) on CTH 114.
4.0	76.6	Junction CTH 114 and CTH 14, turn left (west) on CTH 14.
2.0	78.6	Junction CTH 14 and gravel road, turn right (north) on gravel road.
1.0	79.6	STOP 8 is in limestone quarry to right of road just before bridge.

STOP 8. Quarry in the Cedar Valley Formation (Devonian) near Etna, Minnesota.

The Cedar Valley Formation occurs in southeastern Minnesota, in northern Iowa, and in western Illinois. It unconformably overlies the Ordovician Maquoketa Formation. No Silurian strata are present in Minnesota. The Cedar Valley Formation marks a return of the sea to the Hollandale Embayment of the Ancestral Forest City Basin in Devonian time. The Formation is divided into the Solon Member, the Rapid Member, and the Coralville Member.

The quarry exposed about 22 feet of the Solon Member. The material consists of a buff-gray, fine-grained dolomite containing abundant brachiopod, coral and crinoid molds. Liesegang-type banding, and black flecks of finely divided pyrite are common in the thick beds. The buff, mottled, and pitted surfaces in the quarry are typical of weathered Cedar Valley. This quarry represents one of the few localities in Minnesota in which fossils of Cedar Valley age are common. Residual iron ore deposits developed on the Cedar Valley Formation are confined to the Solon Member.

Turn around and return on gravel road to CTH 14.

1.0	80.6	Junction gravel road and CTH 14, turn right (west) on CTH 14.
1.0	81.6	Junction CTH 14 and U. S. 63, continue on CTH 14.
2.0	83.6	Junction CTH 14 and CTH 1, turn right (north) on CTH 1.
0.5	84.1	Junction CTH 1 and small road on right on south edge of Ostrander, turn right and follow road 1/4 mile to gravel pit.

STOP 9. Gravel pit at south end of Ostrander, Minnesota.

This gravel pit exposed 21.5 feet of Cretaceous sediments. The section (after Sloan, 1964) is given below:

Quaternary

2.0 feet	Loess and soil
2.0 feet	Drift, with a few boulders

Cretaceous
Windrow Formation
Ostrander Member

2.5 feet	Sandstone, brown, coarse, pebbly, iron-stained and iron-cemented, very hard.
10.0 feet	Sand, coarse, and sandy yellow gravel, pebbles are smooth, rounded to ellipsoidal, pink and white quartz, together with subangular flint and chert pebbles.
1.5 feet	Sandstone, brown, pebbly, hard; in part conglomerate.
1.5 feet	Gravel, yellow, medium-to fine-grained sands, pebbles of flint and chert.
1.0 feet	Sandstone, brown, coarse, pebbly, poorly cemented.
5.0 feet	Gravel, yellow-stained, poorly sorted, medium- to coarse-grained sand, some pebbles greater than one inch in diameter, the pebbles are flint and quartz, some residual siliceous fossils of large size.

The material at Ostrander represents non-marine sediments. Streams transported weathered materials from eastern source areas toward the Cretaceous seas which were present in western Minnesota at that time. Fossiliferous cherts in the gravels range in age from Silurian to Late Devonian (Sloan, personal communication) so some of the material must have been derived from distant sources. Sedimentary rocks of Silurian age are unknown in Minnesota.

0.5	84.6	Return 1/4 mile to CTH 1 and turn right (north).
5.3	89.9	Junction CTH 1 and gravel road. As CTH 1 curves to the east, turn left onto gravel road and continue north.
1.2	91.1	Junction gravel road with U. S. 16-63, turn left (west) on U. S. 16-63.
2.5	93.6	U. S. 16-63 divides; turn right (north) on U. S. 63 and continue north to Rochester.
19.7	113.3	Junction U. S. 63 and U. S. 14-52 in Rochester, continue north on U. S. 63 (South Broadway).
1.2	114.5	Junction South Broadway and First St. SW, turn left (west) on First St. SW.
0.1	114.6	Arrive at Kahler Hotel.

End of Second Day

THIRD DAY

0.0	0.0	Board bus at 8:00 a.m. in front of Kahler Hotel. Proceed west on First St. SW.
0.2	0.2	Junction First St. SW and Sixth Ave. SW, turn right (north) on Sixth Ave. SW.
0.4	0.6	Junction Sixth Ave. SW and Fifth St. NW, turn left (west) on Fifth St. NW (turns into U. S. 14).
0.9	1.5	Junction U. S. 14 and U. S. 52, continue west on U. S. 14.
1.9	3.4	Exposures on St. Peter Sandstone, Glenwood and Platteville Formations on left for about 1 mile.
5.9	9.3	Byron City Limits (east).
5.0	14.3	Kasson City Limits (east).
0.6	14.9	Junction U. S. 57 and 14.
4.7	19.6	Dodge City City Limits (east).
16.0	35.6	Havana City Limits (east).
2.9	38.5	Owatonna City Limits (east).
15.7	54.2	Waseca City Limits (east).
11.0	65.2	Janesville City Limits (east).
7.7	72.9	Junction U. S. 14 and Minn. 60. Stay on U. S. 14-Minn. 60.
2.4	75.3	Eagle Lake City Limits (east).
4.3	79.6	Mankato City Limits (east). Follow U. S. 14 through Mankato toward Courtland.
2.9	82.5	Junction U. S. 169 and U. S. 14.
1.4	83.9	Prairie du Chien exposures on right.
1.5	85.4	NW City Limits of North Mankato.
9.7	95.1	Junction U. S. 14 and Minn. 111.
0.6	95.7	Junction U. S. 14 and Minn. 99.

6.9 102.6 Courtland City Limits (east).

4.4 107.0 STOP 1. Exposure of conglomerates of the Sioux Quartzite and granite.

A coarse basal conglomerate of the Sioux Quartzite is exposed as a south-trending ridge for about 1,000 feet. About 55 feet of section is present which ranges from coarse conglomerate to conglomeratic quartzite. The pebbles, cobbles and small boulders consist of a variety of siliceous rocks including translucent quartz, granular hematitic chert and fine- to medium-grained quartzite. The matrix around the clasts consists of strongly interlocked quartz grains with little cement.

About 360 feet west of the conglomerate ridge are three low knobs of strongly weathered coarse-grained porphyritic granite. The relationship of the granite to the conglomerate is problematic and unconformable, intrusive, and fault-contact relationships are possible interpretations.

The Sioux Quartzite of Late Precambrian age is exposed over an area of about 6,000 square miles in Minnesota, Iowa and South Dakota. Deep weathering during the Mesozoic resulted in the development of a thick regolith. Reworking of this material was the source of much of the Cretaceous marine sediments of Minnesota.

Turn around and head east on U. S. 14.

1.1 108.1 Junction Quarry Road and U. S. 14, turn right (south).

0.6 108.7 STOP 2. Quarry in Sioux Quartzite. This quarry is in a glaciated knob of Sioux Quartzite. The unweathered material is a dark pink-to-maroon quartzite with a glassy texture. Interlocking quartz grains are chiefly cemented by silica although sericite and diaspore are also present. Where protected from glacial erosion, the quartzite has a weathered zone where the material has been leached and the cement matrix reduced to kaolinite. The resulting regolith is composed of loose pink sand with a kaolin clay matrix and is as much as 20 feet thick. The regolith is no younger than Early Cenomanian and may be as old as Albian (Austin, 1970). This regolith can be observed in several places in the quarry.

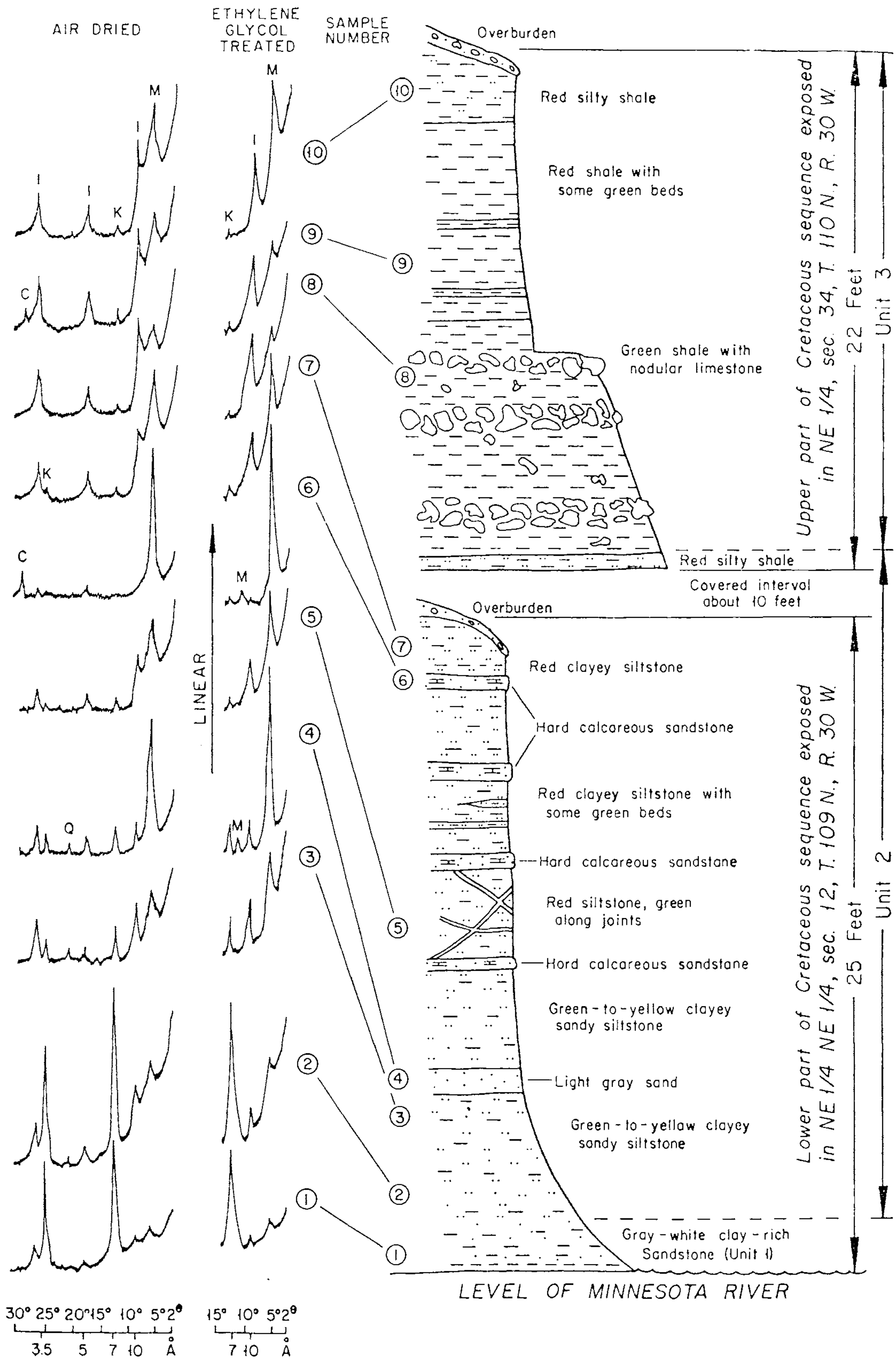
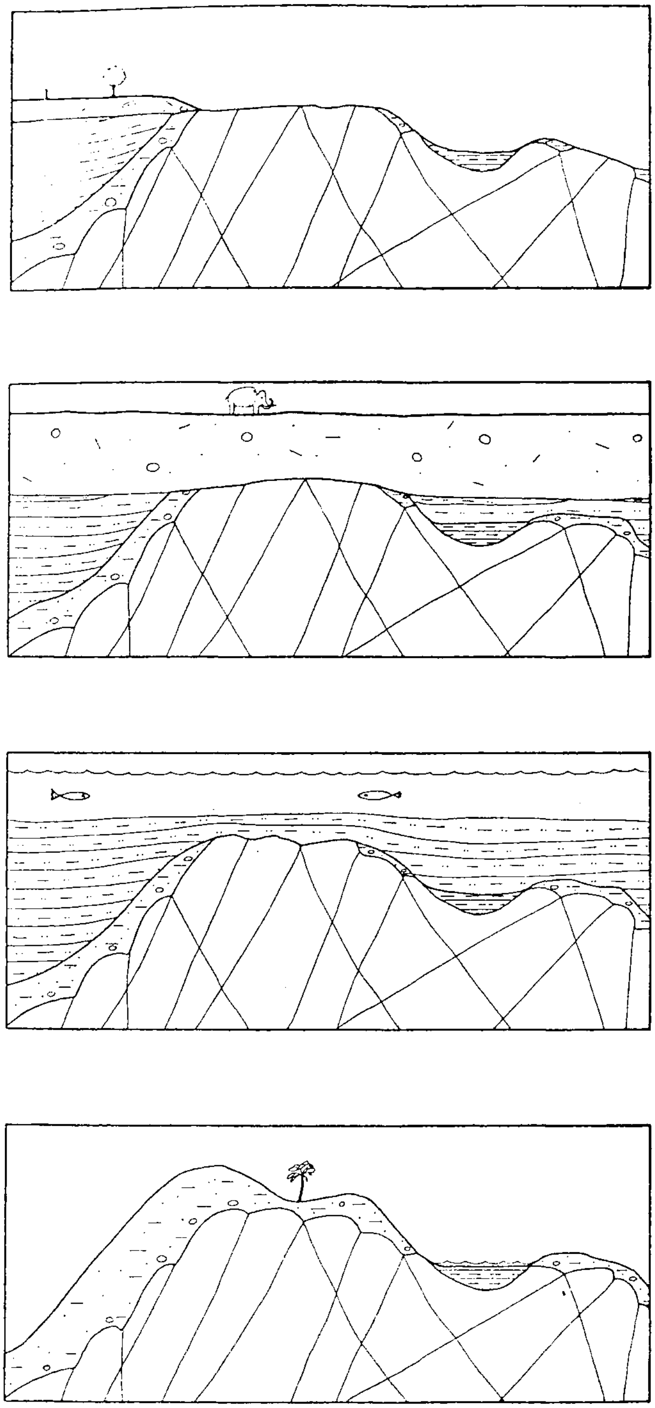


Figure 1. Generalized geologic column of the Cretaceous sedimentary rocks near New Ulm, Minnesota. Sample locations and corresponding X-ray curves are numbered. M=montmorillonite, I=illite, K=kaolinite, Q=quartz, and C=calcite. Nickel-filtered copper radiation was used.



D

HOLOCENE

The Sioux Quartzite, regolith, and sediments exhumed by streams cutting through glacial drift.

C

PLEISTOCENE

Ice covers and scours the Sioux Quartzite, the regolith, and the Upper Cretaceous sediments.

B

MIDDLE UPPER CRETACEOUS

(Coniacian)

Niobrara Sea covers the Sioux Quartzite and regolith. Clayey and silty sediments deposited as the sea transgressed.

A

EARLY UPPER CRETACEOUS

(Early Cenomanian)

Well-developed regolith over the Sioux Quartzite. Entry into quartzite along joints. Poorly-drained areas collect bedded clays.

Figure 2. Diagrammatic sections illustrating four stages in the evolution of the post-Sioux units near New Ulm, Minnesota.

Return to U. S. 14.

0.6	109.3	Junction Quarry Road and U. S. 14, turn right (east) on U. S. 14.
0.9	110.3	Flat exposures of Sioux Quartzite on right.
1.6	111.8	Junction small gravel road and U.S. 14, turn right (south).
0.8	112.6	End of road at Stoering Farm.

STOP 3. Cretaceous Shales.

At this stop about 25 feet of Upper Cretaceous shales are exposed along the Minnesota River. These sedimentary rocks consist primarily of red and green shale, siltstone, and sandstone. Illite and montmorillonite are the principal clay minerals in these rocks with kaolinite present in minor amounts. A significant change in clay mineralogy, coupled with paleontological evidence, indicates a pronounced climatic change during Cenomanian time. Kaolinite decreases rapidly upward from the grayish-white sandstone at the base of this exposure. Above the basal sandstone illite is the principal clay mineral except for montmorillonite in sandstones near the base. The humid tropical climate with good drainage conditions conducive to kaolinite formation was replaced by a temperate climate with poor drainage. The principal clay minerals incorporated in the sedimentary rocks formed after the climatic change are illite and montmorillonite. Figure 1 shows the section at this stop in the lower right. Above this is a section exposed about 2 3/4 miles to the northwest. X-ray diffraction curves on the left show the change in clay mineralogy. Figure 2 diagrammatically shows the post-Sioux history of this region. (Description of STOP 3 and Figures 1 and 2 are from Austin, 1970.)

Return to U. S. 14.

0.8	113.4	Junction gravel road and U. S. 14, turn right (east) on U. S. 14.
1.3	114.7	Courtland City Limits (west).
7.5	122.2	Junction U. S. 14 and Minn. 99. Follow Minn. 99 to St. Peter.

12.6	134.8	St. Peter City Limits (west).
0.1	134.9	Junction Minn. 99 and U. S. 169, turn left (north) on 169.
2.1	137.0	St. Peter City Limits (north).
4.7	141.7	Exposures on west side of U. S. 169.

STOP 4. Jordan-Prairie du Chien Contact.

The Cambro-Ordovician systemic contact is present in this exposure. The buff, coarse-grained, quartz sandstone of the Cambrian Jordan Sandstone is here overlain by the Ordovician Blue Earth Siltstone. The green color of the Blue Earth is due to fine-grained glauconite thought to have been derived from reworking of the Franconia Formation. Clay samples from the Blue Earth are identified as the potash feldspar adularia. The Blue Earth Siltstone appears to be "intrusive" into the basal beds of the Oneota Formation. Solution of the basal Oneota Formation along joints has resulted in the squeezing of the Blue Earth into at least 6 feet of the lower Oneota Formation. The Blue Earth Siltstone carries a rich conodont fauna of simple cone elements.

Cross median at first opportunity, turn around and proceed NE on U. S. 169.

4.7	146.4	Junction U. S. 169 and Minn. 93.
7.7	154.1	Junction U. S. 169 and Minn. 19.
6.4	160.5	Belle Plaine City Limits (southwest).
7.9	168.4	Jordan City Limits.
4.6	173.0	Quarry in Jordan Sandstone on left.
2.7	175.7	STOP 5. Bryan Rock Products Quarry (Turn left into quarry area).

About 45 feet of the Prairie du Chien Group is exposed in this quarry near Merrian Junction, Minnesota. It is not far from the poorly exposed type-section of the Shakopee Formation at Shakopee, Minnesota. Both the Oneota and the Shakopee Formations are present. The quarry exposes about 22 feet of Oneota. The lower 12 feet consist of brown-to-yellow cross-bedded doloarenites. The top of this unit forms a prominent bench in the quarry and its surface is exposed for a considerable area. Dune-like mounds of cross-bedded doloarenites can be seen on this surface. This material is overlain by about 10 feet of algal-mat biolithic dolomite.

The Shakopee Formation unconformably overlies the Oneota and is exposed for about 23 feet in this quarry. The Oneota consists of a variety of dolomitic beds including doloarenites, dololutites, intrasparite, and algal-mound biolithite.

A large number of sedimentary structures are present including mudcracks, cross-beds, oolites and chert nodules.

Return to U. S. 169 and proceed north.

0.9	176.6	Junction 169 and Minn. 41.
2.0	178.6	Shakopee City Limits (southwest).
0.4	179.0	Exposures of Shakopee Dolomite.
1.1	180.1	Junction U. S. 169 and Minn. 101, proceed on Minn. 101.
0.8	180.9	Junction Minn. 101 and Minn. 17.
0.8	181.7	Shakopee City Limits (west).
5.3	187.0	Savage City Limits (west).
1.0	188.0	End Minn. 101 at junction with Minn. 13, proceed east on Minn. 13.
2.5	190.5	Burnsville City Limits (west).
2.1	192.6	Junction Minn. 13 and I-35W, proceed north on I-35W.
6.4	199.0	Junction I-35W and I-494.
8.8	207.8	End of I-35W at junction with I-94.
0.8	208.6	Leamington Hotel.

END OF THIRD DAY