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SEDIMENTOLOGY OF THE MIDDLE ORDOVICIAN PLATTEVILLE FORMATION SOUTHEASTERN MINNESOTA

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SEDIMENTOLOGY OF THE MIDDLE ORDOVOCIAN PLATTEVILLE FORMATION, SOUTHEASTERN MINNESOTA

by

John H. Mossler

ABSTRACT

The Platteville Formation, a thin Middle Ordovician unit, is subdivided into several members in Minnesota. The basal Pecatonica and upper Carimona Members are present throughout all the Minnesota/western Wisconsin outcrop belt. The medial McGregor, which is recognized in the southern part of the Minnesota outcrop, is replaced by the Mifflin, Hidden Falls, and Magnolia Members in the Twin Cities area. Distribution of the Mifflin is restricted to the Twin Cities structural basin; the other two units extend slightly beyond the Twin Cities basin. Their distribution may have been influenced by proximity to a paleoshoreline north of the present outcrop.

The Platteville Formation was deposited in a transgressing sea as part of the Middle Ordovician-Silurian Tippecanoe sequence. It is interpreted to have been deposited on a shallow marine shelf in deeper water than the shoreward facies represented by the underlying St. Peter Sandstone and Glenwood Formation. Fossils of stenohaline organisms are present throughout the formation. The formation has no exposure indicators, stromatolites, or intraclasts. Features indicative of shallower water, such as ferruginous ooids and coquina layers, are present in the Twin Cities/western Wisconsin area.

Hardgrounds--surfaces of submarine nondeposition indicative of low rates of sedimentation--characterize the Pecatonica and lower McGregor Members, but are less common in the upper part of the formation. The Carimona Member is characterized by limestone beds separated by shale beds and partings that thicken toward the west and north. This increased detrital sedimentation during deposition of the Carimona Member and the succeeding Decorah Shale may indicate uplift along the Transcontinental Arch.

The proportion of dolomite to calcite in the carbonate rocks of the Platteville increases toward the north and northeast. In southern Minnesota the formation is principally limestone; in the Twin Cities Metropolitan Area and western Wisconsin, it has a high proportion of dolomite.

The formation does not have any diagenetic fabrics indicative of subaerial exposure, and deposition of the overlying Decorah Shale appears to have followed deposition of the Platteville without interruption. The pervasive dolomitization is probably a result of burial diagenesis.

INTRODUCTION

The Platteville Formation is a thin Middle Ordovician (Champlainian) carbonate unit that crops out in southeastern Minnesota from the Twin Cities to the Iowa border. The general purpose of this report is to document major lithofacies within the formation and to present chemical and carbonate mineralogical data.

The Middle and Upper Ordovician formations (Fig. 1) of southeastern Minnesota are the lower part of a succession (the Tippecanoe Sequence) of sedimentologically mature sandstone, siltstone, shale, and carbonate rocks that were deposited in a transgressing sea. In the northern Midcontinent area, this marine incursion moved out over the craton from the Oklahoma basin (Ross, 1976) (Fig. 2). In Minnesota and northern Iowa, these sedimentary rocks were deposited in the Hollandale embayment, a lowland along the southeastern margin of the Transcontinental Arch. Rocks of similar lithology and equivalent age also were deposited on the northwestern side of the Transcontinental Arch in the Williston basin, where they are assigned to the Winnipeg and Red River Formations (Webers, 1972).

The transgressive sequence begins with the St. Peter Sandstone (Fig. 1) and equivalents. The St. Peter was deposited in regimes associated with the transgressing marine waters, including beaches (Fraser, 1976), large submarine waves (Pryor and Amaral, 1971), and coastal eolian dunes (Dott and Byers, 1980).

The overlying Glenwood Formation (Fig. 1) is interpreted to be a shallow marine shelf deposit (Ostrom, 1970; Schutter, 1978). Alternatively, the shale and sandstone of the Glenwood may have been laid down in a broad coastal lagoon occupying the area between the Transcontinental Arch and a barrier bar, the Starved Rock Member (Fig. 2) of the St. Peter Sandstone, that extended across north-central Illinois and southeastern Iowa (Willman and Templeton, 1963; Fraser, 1976). In southern Illinois, south of the Starved Rock bar, rocks equivalent to the Glenwood are carbonates that contain anhydrite which probably formed in a shallow closed basin. North of this basin, in northeastern Illinois, carbonates in the Glenwood are interpreted to have formed in a shallow supratidal to intertidal setting over the Starved Rock sandstone bar (Fraser, 1976).

In contrast to the Glenwood carbonate rocks, the carbonates of the overlying Platteville and lower Galena (Cummingsville and Prosser Members) Formations (Fig. 1) are generally open marine subtidal deposits that interfinger with shale where they are close to the Transcontinental Arch (Weiss and Bell, 1956; Witzke, 1980).

Upper Galena carbonates coincide with maximum transgression. Stewartville dolostones have some sedimentological features and faunas indicative of restricted marine circulation and hypersaline conditions (Webers, 1972; Ross, 1976), but normal marine conditions returned briefly during deposition of the Upper Ordovician Maquoketa Formation (Ross, 1976).

FIELD AND LABORATORY METHODS

The twelve exposures selected at even spacings along the Minnesota outcrop belt for intensive study (Fig. 3) were comparatively recent and unweathered. Samples were analyzed by means of thin sections, polished and stained rock slabs, and x-ray and chemical analyses. Intermediate outcrops were less thoroughly studied, but were used in tying the principal outcrops together.

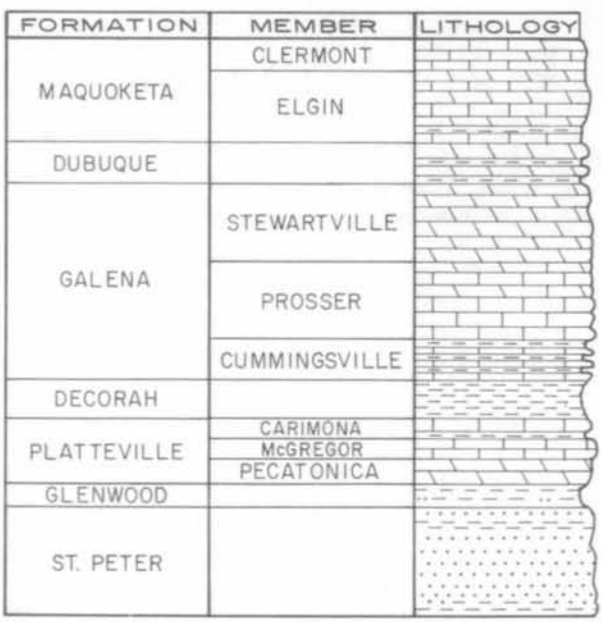

Figure 1. Champlainian and Cincinnatian Series in Minnesota (modified from Webers, 1972).

Figure 2. Map of Midcontinental United States showing some geological features discussed in text (adapted from Witzke, 1980).

Rock slabs and a few thin sections were stained with alizarin red-s and potassium ferricyanide using the methods of Dickson (1966). These stains reveal distribution of dolomite and calcite in the rock and the presence of ferrous iron in carbonates. X-ray analyses were used to determine relative proportions of calcite and dolomite in the rock using procedures described by Royce and others (1971). A few slides of oriented clay minerals were prepared and x-rayed to identify clay mineralogy. Chemical analyses were done by the Mineral Resources Research Center. The rock classification used in this report is that proposed by Folk (1959).

NOMENCLATURE

The nomenclature currently accepted for subdivisions of the Platteville in Minnesota (Austin, 1969, 1972) was originally proposed by Weiss and Bell (1956). It was derived from theses by students of W.C. Bell and R.E. Sloan on the stratigraphy of the Platteville. For most of Minnesota the classification divides the Platteville into three members (Fig. 1): (1) The basal Pecatonica Member (Hershey, 1897), a sandy, phosphatic, thick-bedded dolostone and dolomitic limestone. (2) The medial McGregor Member (Trowbridge, 1935), a dense limestone or dolomitic limestone that is characterized by thin, crinkly bedding. (3) The Carimona Member, a medium-bedded limestone with interbedded gray-green shale (Weiss, 1955).

Within the Twin Cities Metropolitan Area, the medial McGregor Member is replaced by three members subdivided on the basis of local lithologic changes (Majewski, 1953; Weiss and Bell, 1956; Sloan, 1956, 1972; Austin, 1969, 1972). The basal unit is the Mifflin Member, a thin, crinkly bedded dolomitic limestone. The medial unit is the Hidden Falls Member, a massive, argillaceous, slightly fossiliferous dolostone. The uppermost unit is the Magnolia Member, a thick-bedded, slightly fossiliferous dolostone.

The basal and uppermost of the units were named Mifflin and Magnolia because of their supposed resemblance to members of the Platteville of Wisconsin, which were named by Bays (1938). The medial unit does not resemble either southern Wisconsin unit and was therefore named for a locality in St. Paul (Sloan, 1956). Though most investigators (Majewski, 1953; Weiss and Bell, 1956; Sloan, 1972) referred to these units as members, they were considered to be beds within the McGregor Member by Austin (1972) because they are thin and have a localized distribution. Within the Twin Cities Metropolitan Area, it is advantageous to have names for these local units because the Platteville is commonly discussed in foundation and engineering reports for building and highway construction.

The most dramatic revision in Platteville nomenclature proposed by recent authors is that proposed by Willman and Templeton (1963) who raised the Platteville to group status and divided it into three formations and 24 members. Their nomenclature was first applied in Illinois, where Platteville carbonates are much thicker, ranging from less than 10 m (30 ft) in extreme northwestern Illinois to more than 180 m (600 ft) in extreme southern Illinois, and more subdivisions of the Platteville are needed for geologic mapping and economic geology. Many of the geologic units in Illinois thin and pinch out toward the north where they are represented only by diastems or minor unconformities. State surveys in adjoining states have retained variants of older, simpler nomenclature, which is satisfactory where the Platteville is thinner.

In Illinois, Iowa, and Wisconsin, the Carimona Member is included with the overlying Decorah Formation (Spechts Ferry Formation in Illinois). In that area the Decorah is predominantly limestone, and Carimona limestone has closer lithologic and faunal affinities with it than with underlying Platteville carbonates from which they are interpreted to be separated by a diastem. In Minnesota, however, the Decorah is principally shale, and for this reason the Carimona limestone is considered part of the Platteville despite some differences in lithology from underlying McGregor limestone.

GENERAL STRATIGRAPHY

Members of the Platteville Formation are distinguished on the basis of lithological criteria and correspond to major facies of the formation.

Pecatonica Member

The basal member of the Platteville is a sandy, phosphatic, biogenic dolostone that is moderately thick bedded to massive. It is thickest in southeastern Fillmore and western Houston Counties where it attains a thickness of >2 m (7 ft). It thins rapidly to the north and west, and is absent in parts of Fillmore County (Weiss, 1957) and parts of Goodhue County (Weiss and Bell, 1956; Ford, 1958). In Fillmore County, the Pecatonica Member is laterally equivalent to the upper Glenwood (Weiss, 1957; Sloan, 1972), and Pecatonica dolostone grades laterally into the 1-foot-thick, massive, calcite-cemented sandstone bed of the upper Glenwood (Fig. 4), which is easily confused with Pecatonica dolostone.

The Pecatonica thickens to the southeast toward northeastern Iowa, southwestern Wisconsin, and northwestern Illinois, and thicker sequences in Houston and southeastern Fillmore counties (Fig. 4) are a reflection of this thickening. In the Illinois basin it is as thick as 43 m (140 ft) and has been divided into several members (Willman and Templeton, 1963).

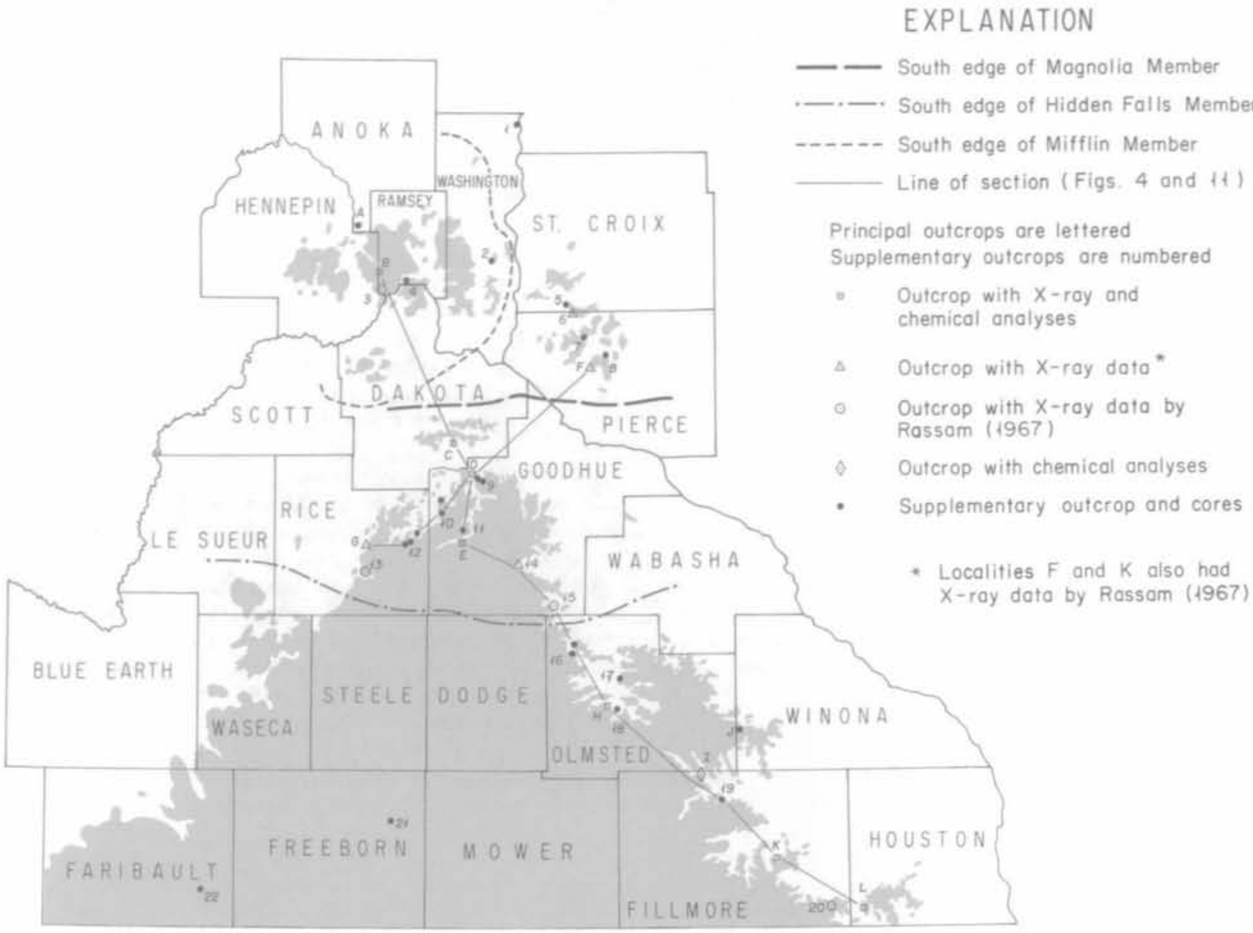

Figure 3. Locations of measured sections and cores from Platteville Formation (shaded).

A. Columbia Heights, Anoka County, NE1/4SE1/4 sec. 34, T. 30 N., R. 24 W.
B. St. Paul, Ramsey County, E1/2NE1/4SW1/4 sec. 5, T. 28 N., R. 23 W.
C. Hampton, Dakota County, SE1/4SW1/4 sec. 22, T. 113 N., R. 18 W.
D. Cannon Falls, Goodhue County, SW1/4SE1/4 sec. 18, T. 112 N., R. 17 W.
E. Sogn, Goodhue County, SW1/4SW1/4 sec. 1, T. 110 N., R. 18 W.
F. Ellsworth, Pierce County, Wisconsin, SW1/4 sec. 14, T. 26 N., R. 18 W.
G. Faribault, Rice County, SE1/2SW1/4 sec. 9, T. 110 N., R. 20 W.
H. Rochester, Olmsted County, NE1/4NE1/4 sec. 15, T. 106 N., R. 14 W.
I. Chatfield, Fillmore and Olmsted Counties, NE1/4NW1/4 sec. 5, T. 104 N., R. 11 W.
J. St. Charles, Winona County, SE1/4 sec. 31, T. 106 N., R. 10 W.
K. Preston, Fillmore County, SE1/4NE1/4 sec. 7, T. 102 N., R. 9 W.
L. Spring Grove, Houston County, SE1/4 sec. 17, T. 101 N., R. 7 W.
1. Scandia, Washington County, NE1/4NW1/4 sec. 7, T. 32 N., R. 19 W.
2. Lake Elmo, Washington County, NW1/4SW1/4 sec. 29 and NE1/4SE1/4, sec. 30, T. 29 N., R. 20 W.
3. St. Paul, Ramsey County, NE1/4SE1/4 sec. 17, T. 28 N., R. 23 W.
4. St. Paul, Ramsey County, SW1/4SE1/4 sec. 12, T. 28 N., R. 23 W.
5. Northeast of River Falls, St. Croix County, Wisconsin, NW1/4 sec. 31, T. 28 N., R. 18 W.
6. South of River Falls, Pierce County, Wisconsin, S1/2 sec. 8, T. 27 N., R. 18 W.
7. North of Beldenville, Pierce County, Wisconsin, SE1/4 sec. 27, T. 27 N., R. 18 W.
8. South of Beldenville, Pierce County, Wisconsin, SE1/4SW1/4 sec. 6, T. 26 N., R. 17 W.
9. Cannon Falls, Goodhue County, SE1/4SW1/4 sec. 20, T. 112 N., R. 17 W., south edge of SE1/4 sec. 18, T. 112 N., R. 17 W.
10. Wangs, Goodhue County, SW1/4SE1/4 sec. 16, T. 111 N., R. 18 W.; SE1/4NE1/4 sec. 5, T. 111 N., R. 18 W.
11. Sogn, Goodhue County, near center sec. 36, T. 111 N., R. 18 W.
12. Nerstrand, Rice County, SW1/4SW1/4 sec. 35, T. 111 N., R. 19 W.; SE1/4, sec. 9, T. 110 N., R. 19 W.; SE1/4SW1/4 sec. 3, T. 110 N., R. 19 W.
13. Faribault, Rice County, SW1/4 sec. 33, T. 110 N., R. 20 W.
14. Wanamingo, Goodhue County, NW1/4SE1/4 sec. 29, T. 110 N., R. 16 W.; NW1/4SW1/4 sec. 21, T. 110 N., R. 16 W.
15 Pine Island, Goodhue County, SW1/2SE1/4 sec. 29, T. 109 N., R. 15 W.
16. Douglas, Olmsted County, SE1/4NW1/4 sec. 26, T. 108 N., R. 15 W.; SW1/4SW1/4 sec. 35, T. 108 N., R. 15 W.
17. North Rochester, Olmsted County, SE1/4SW1/4 sec. 24, T. 107 N., R. 14 W.
18. South Rochester, Olmsted County, SE1/4NE1/4 sec. 14, T. 106 N., R. 14 W.
19. Fountain, Fillmore County, SE1/4NE1/4 sec. 27, T. 104 N., R. 11 W.
20. Mabel, Fillmore County, SW1/4SE1/4 and SE1/4SE1/4 sec. 15, T. 101 N., R. 8 W.
21. Northern Natural Gas #1 Hollandale, Freeborn County (core), SE1/4SW1/4 sec. 7, T. 103 N., R. 19 W.
22. Minnegasco #4 John Kingstrom, Faribault County (partial core), NW1/4NW1/4 sec. 6, T. 101 N., R. 24 W.

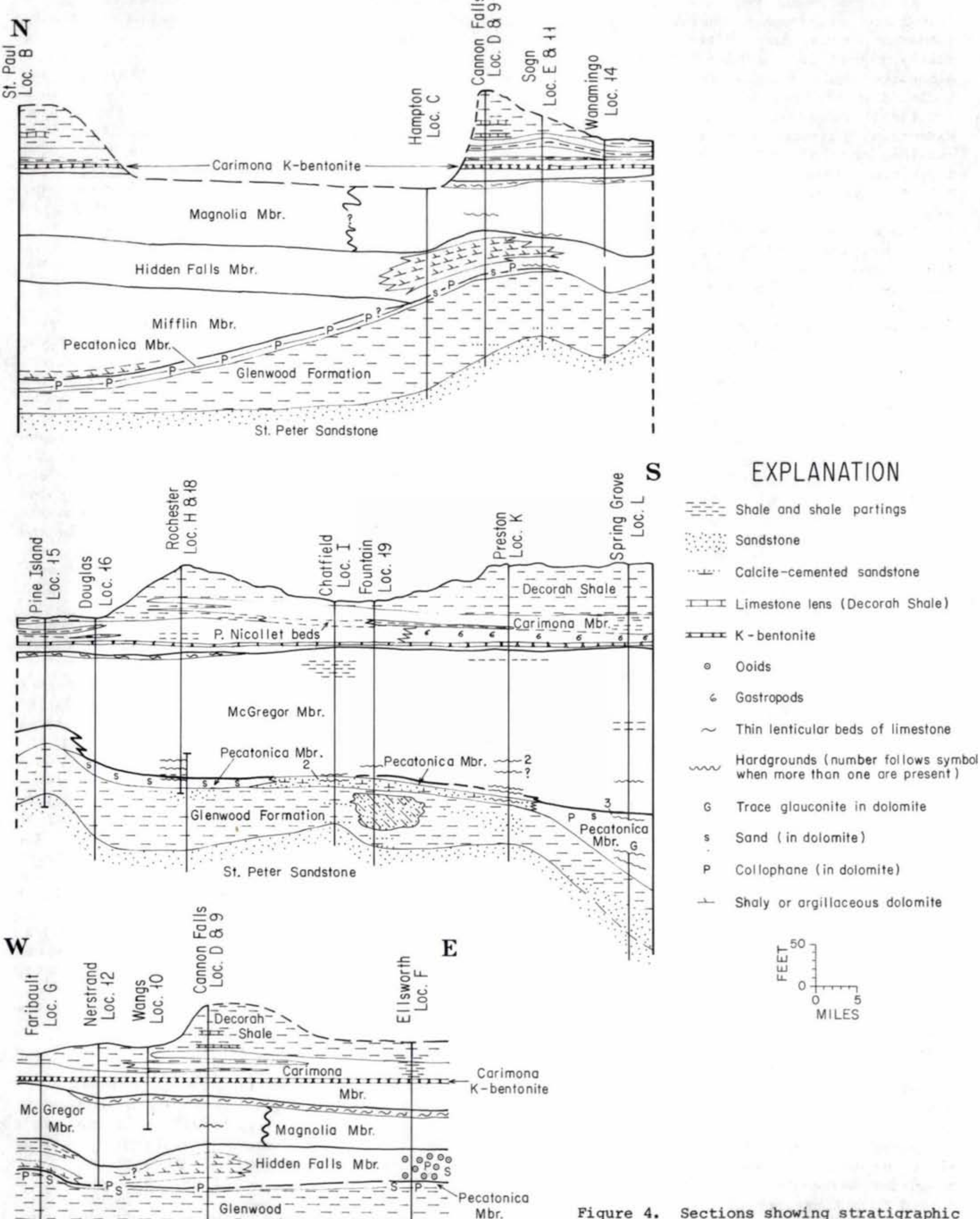

Figure 4. Sections showing stratigraphic relationships of members of the Platteville Formation and distribution of some distinctive sedimentologic features. Section restored between outliers for clarity.

A discontinuous 1-m interval (2 to 4 ft) of dolomitic siltstone, shale, and calcareous sandstone at the base of the Platteville, customarily placed in the Glenwood Formation by the Minnesota and Wisconsin Geological Surveys, is included in the Pecatonica by Willman and Templeton (1963) who named it the Hennepin Member. The Wisconsin (Ostrom, 1969) and Minnesota surveys consider the interval to be affiliated with the underlying Glenwood because of its predominantly detrital nature.

The Pecatonica can generally be distinguished from overlying units by its relatively high content of quartz sand and collophane grains, higher dolomite content, and thicker bedding except in the northern part of the study area, where it is directly overlain by the Hidden Falls which is itself massive and dolomitic.

Smooth to slightly irregular, pitted, mineralized (pyrite, hematite, and limonite) bedding planes, like those in the McGregor Member (Fig. 5), which apparently are diastemic surfaces, also are present in the Pecatonica. These surfaces typically are intensively bored and are covered by trails and by encrusting bryozoans, crinoids, and other organisms. They are interpreted to be submarine hardgrounds by many investigators (Prokopovich, 1955; Delgado, 1983).

Hardgrounds are common in the Pecatonica Member and are especially prevalent near the top of the unit in the thicker sequences in southeastern Fillmore County (Fig. 4). The convergence of individual surfaces toward the north and west from Rochester is consistent with a decrease in thickness of the Pecatonica in those directions, and more common interruptions in carbonate sedimentation toward the west and the Transcontinental Arch. These diastemic surfaces at the top of the Pecatonica south of Rochester indicate that the top of the member is isochronous in that area (Sloan, 1972).

The marked lithologic change from Glenwood shale into overlying Platteville carbonate, as well as the abundance of phosphate grains in both formations near the contact, has been interpreted by some to indicate an unconformity (Elder, 1936; Willman and Templeton, 1963) or at least a widespread diastem at the formation contact. Willman and Templeton (1963) indicate that there also is a regional diastem at the top of the Pecatonica. However, as noted by Hoeft (1959), the abundant phosphate grains and ubiquitous hardgrounds probably indicate many relatively short interruptions in sedimentation rather than widespread unconformity.

Except for thin (<2.5 cm) intervals directly above hardgrounds, which appear to be grain-supported carbonates, the rock appears to have formed from fine-grained "muddy" carbonate sediments that lacked a grain-supported framework. The grain-supported zones above the hardgrounds contain interstitial fine-grained matrix, probably introduced by infiltration and infaunal burrowing.

The Pecatonica has a high insoluble residue content, although not significantly higher than other Platteville members, despite the fact that it is transitional from the detrital St. Peter and Glenwood formations. Majewski (1953) found 17 percent insolubles in the Twin Cities basin; Ford (1958), 31 percent in Rice, Goodhue, and southern Dakota Counties; and Weiss (1953), 15 percent in Fillmore County. Most insolubles are phosphate grains (collophane) and quartz sand grains; the remainder are chiefly pyrite and detrital silt and clay.

Besides detrital sand grains, the Pecatonica contains many sand-size and larger fossil fragments; fragments from bryozoans, brachiopods, and pelmatozoans predominate. Though some of the comminution of these fossils might have been by mechanical processes, such as waves and currents, most comminution is probably the result of scavenging organisms. The micritic nature of the Pecatonica indicates that wave and current activity was negligible. Point counting of a few thin sections indicates that fossil fragments compose less than 10 percent of the rock in the Pecatonica. However some fossil material may not be recognizable because the rock is extensively dolomitized.

Mifflin Member

The distribution of the Mifflin Member (Fig. 3) corresponds closely with the boundaries of the Twin Cities basin, a small structural basin that formed in the northern part of the Hollandale embayment during Early and Middle Ordovician time. The Mifflin, which is 2.6 m (8.5 ft) thick in the center of the Twin Cities basin, is absent at Hampton in Dakota County at the southern margin of the basin (Fig. 4). Conversely, the underlying shale of the Glenwood thickens by approximately 2.1 m (7 ft) in the same distance. Outcrops on the eastern margin of the basin in St. Croix and Pierce Counties, Wisconsin, also lack the Mifflin. Sloan (1972) interprets the Mifflin of the Twin Cities to be laterally equivalent to the Glenwood at Hampton and farther south. The observed uniformity in thickness of the Glenwood-Pectonica-Mifflin stratigraphic interval between St. Paul and Hampton results from this equivalency.

The Mifflin is distinguished from the overlying Hidden Falls and underlying Pecatonica by its thin, crinkly or wavy bedding (Fig. 6), minor dolomitization, and absence of collophane grains, detrital quartz sand, and silt-size grains.

The Mifflin is a sparse biomicrite that has a fossil content ranging between 10 and 20 percent. Pelmatozoans are most numerous. Less common are

Figure 5. Hardground, McGregor Member, near Preston in Fillmore County. Lens cover shows scale.

Figure 6. Bedding in Mifflin strata, St. Paul. Hammer on ledge shows scale.

brachiopods, bryozoans, ostracodes, trilobites, and miscellaneous other invertebrates. Ford (1958) determined that the Mifflin has an average of 19 percent insolubles.

The thin, crinkly beds of the Mifflin have generally been interpreted as short-crested ripple marks (Asquith, 1967; Sloan, 1972). However Byers and Stasko (1978) state that this feature may be diagenetically induced and may simply reflect an inhomogeneous distribution of detrital clay in the original sediment. The shaly partings between beds may be insoluble residue zones that are due to compaction-solution.

The Mifflin is composed of dense, brown micrite that has not been aggraded to microspar. Dolomite selectively replaces the calcitic micrite along shale partings and burrows. Both may have had higher initial porosities. Fossil fragments are not dolomitized.

Hidden Falls Member

The Hidden Falls Member extends throughout the Twin Cities area and persists as far south as Faribault and Pine Island--farther south than the underlying Mifflin Member. To the north and northwest it grades into the Glenwood shale just like the Mifflin (Sloan, 1972). This is best seen in the vicinity of Faribault (locality G, Fig. 4) where the Hidden Falls contains a tongue of shale. To the south, it grades into laterally equivalent McGregor limestone. The Hidden Falls is characteristically an argillaceous to silty dolomite (Fig. 7) that is blocky to massively bedded (Fig. 8). It is soft and typically forms a recessive notch in outcrop. It commonly has a conchoidal fracture, especially in the Twin Cities area (Fig. 8). It is 1.1 to 1.7 m (3.5 to 5.5 ft) thick.

The Hidden Falls is distinguished from other units by its high content of insolubles, recessive outcrops, and massive to blocky bedding. A thin (2 cm) orange-yellow clay seam at the top of the unit has been interpreted by some to be a K-bentonite (Ford, 1958, p. 33). X-ray analysis of clay minerals indicates that it resembles weathered illite rather than K-bentonite; the clay seam occupies the same position at the top of the bed as a hardground in a fresher outcrop farther south in Goodhue County (locality E, Fig. 3), and like the hardground, the clay seam may represent interrupted or diminished carbonate deposition.

The Hidden Falls Member is lithologically variable. At Faribault it has a conspicuous shale interval at the top. At Ellsworth, Wisconsin, where it contains sand-size collophane fragments, quartz sand grains and "brassy" ooids (limonite) (Fig. 9), it has been correlated with the Pecatonica (Majewski, 1953, p. 24; Ford, 1958, p. 32), because of the conspicuous quartz sand and collophane content.

The Hidden Falls is generally very sparingly fossiliferous (<1 percent), although there are some fossiliferous lenses in it in the Twin Cities area. Scarcity of fossils appears to be primary, although some may have been obliterated by dolomitization.

Ford (1958, p. 33) found that the member contains an average of 36 percent insolubles, mostly clay and silt. Silt, clay, and very fine collophane grains are conspicuous in thin section (Fig. 7). Pyrite also is conspicuous in thin microlamellae parallel to bedding. Similar laminations in the Pecatonica have been interpreted to be remnants of subtidal algal mats (Fraser, 1976).

Magnolia Member

The Magnolia Member is restricted to the northern part of the study area. It has wider distribution than the Mifflin, occurring outside the Twin Cities basin in western Wisconsin (Fig. 3), and is equivalent to the upper part of the McGregor Member of southeastern Minnesota. The Magnolia is nonargillaceous dolostone with an average insoluble residue content of 8 percent and is poorly bedded to massive. It is characterized by coquinoid layers of brachiopods and other fossils (<50 percent fossil fragments) 2 or 3 cm (an inch or less) thick (Fig. 10) in an otherwise sparingly fossiliferous (<10 percent fossils) rock. It is completely dolomitized: even echinoderm fragments have been replaced by dolomite. It contains minor small (<0.6 cm diameter) pyrite-lined borings or burrows and some pyrite-lined vugs. A well-developed bedding plane that possibly is a hardground (Majewski, 1953; Willman and Templeton, 1963) separates it from the overlying Carimona Member. The Magnolia Member is generally about 2.4 m (8 ft) thick.

McGregor Member

In Minnesota, the McGregor Member extends from Hampton in southern Dakota County to the Iowa border. It ranges in thickness from 1.7 m (5.5 ft) in the north to more than 5.5 m (18 ft) in the south (Fig. 4). Its upper part is laterally equivalent to the Magnolia Member of the Twin Cities, and its lower part grades into the Hidden Falls. It may overlie the Glenwood Formation or either the Pecatonica or Hidden Falls Members of the Platteville. It can be distinguished from these units by its thin, irregular, wavy bedding; low dolomite content; and comparatively low content of detrital silt, sand, clay, and collophane.

The McGregor Member can be distinguished from the overlying Carimona Member by a slight color

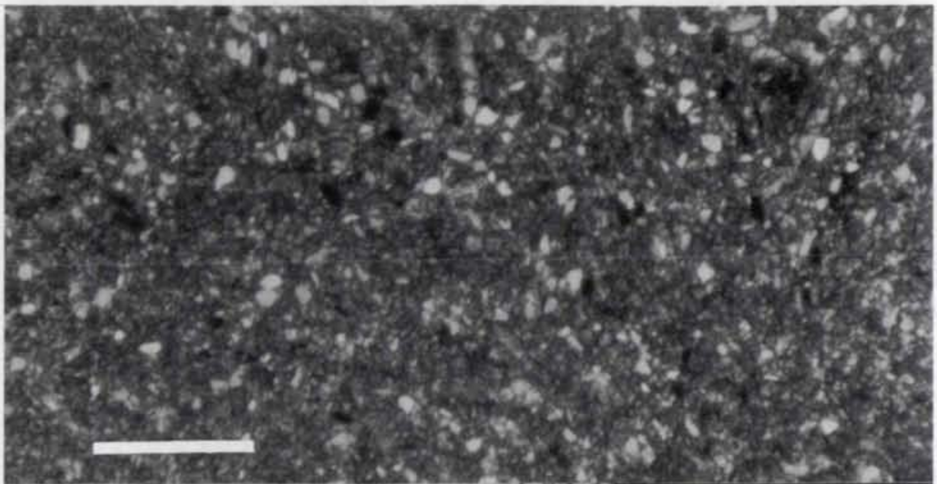

Figure 7. Detrital silt in dolostone of Hidden Falls Member, St. Paul; representative quartz grains (white) and apatite grains (black). Bar scale is 0.5 mm long.

Figure 8. Massive bedding in Hidden Falls strata, St. Paul. Note typical conchoidal fractures. Hammer shows scale.

Figure 9. "Brassy" ooids in the Hidden Falls Member at Ellsworth, Wisconsin. Bar scale is 0.5 mm long.

Figure 10. Coquina layers in Magnolia Member at St. Paul. Lens cover shows scale.

change--the McGregor is generally light olive gray to yellow gray; the Carimona is pale yellow brown. In addition, in the area north of Rochester, the top 0.15 to 0.3 m ($^1/_2$ to 1 ft) of McGregor is composed of very thin beds and lenses of limestone with numerous shale partings.

Some earlier investigators (Majewski, 1953; Weiss and Bell, 1956) placed the contact lower in the Cannon Falls area, inferring that the McGregor is absent there and that all the rock above the Hidden Falls is Carimona. However Ford (1958), Sloan (1972), and the author recognize McGregor (or Magnolia) at Cannon Falls and typical McGregor also crops out farther north near Hampton.

The McGregor Member is a sparse biomicrite that most closely resembles the Mifflin of the Twin Cities basin in overall lithology. Much of its fossil material is finely comminuted fragments that are more or less evenly distributed through the rock, but tend to be somewhat more abundant along the tops of bedding planes. Bedding is irregular, crinkly, and wavy, like bedding in the Mifflin; however the average thickness of beds is somewhat greater in the McGregor.

The McGregor is more intensively dolomitized toward the north (Fig. 11); dolomitization is pronounced in the vicinity of the Twin Cities basin. The pattern of dolomitization is similar to that in the Mifflin, with most dolomitization along shale partings and in burrowed zones.

The McGregor contains some hardground surfaces especially in the area south of Rochester. The zones that were observed are confined to the basal 1.2 m (4 ft) of the formation (Fig. 4).

Insoluble residue content is very low and averages between 5 and 10 percent. Where the McGregor directly overlies the Glenwood Formation in north-central Fillmore County, its basal 5 cm (2 inches) are sandy (Weiss, 1957).

In extreme southeastern Fillmore County and in Houston County, the top 0.3 to 0.7 m (1 to 2 ft) of McGregor is composed of sublithographic limestone that has a "glassy" appearance and conchoidal fracture, and resembles limestone from the Quimbys Mill Member of southern Wisconsin and Illinois (Weiss, 1957).

Carimona Member

This member is composed of interbedded limestone and shale, which is similar in appearance to the shale of the overlying Decorah. The upper contact of the Carimona with the Decorah Shale is customarily placed at the top of the highest prominent limestone bed. As a result, the contact does not occur at the same horizon throughout southeastern Minnesota (Fig. 4). Limestone beds bifurcate toward the north and northwest and intervening shales thicken, and so the contact picked in the Twin Cities area or near Faribault is stratigraphically lower than farther southeast (Sloan, 1972).

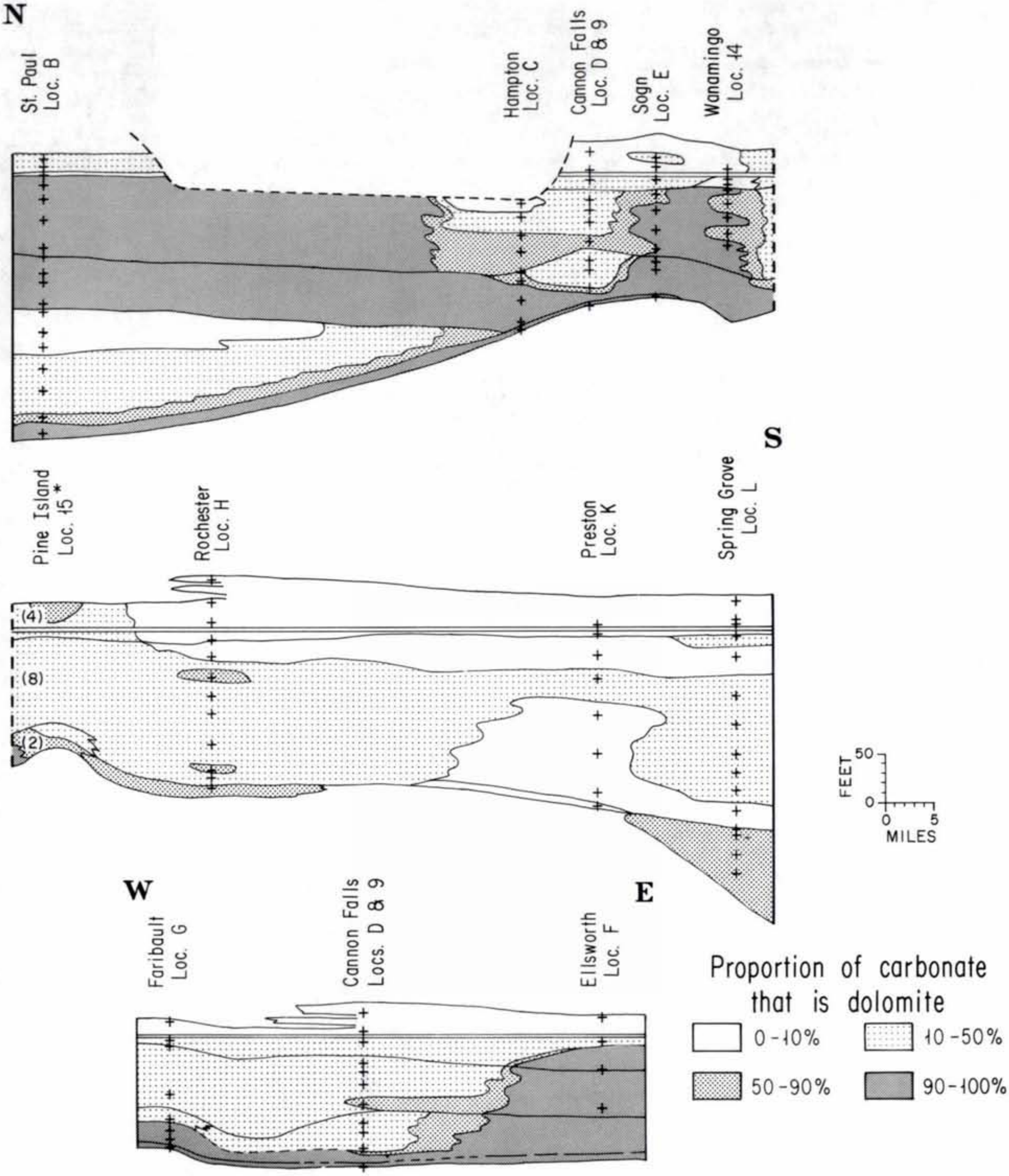

Figure 11. Sections showing the proportion of dolomite to calcite in carbonate rocks of the Platteville Formation; +, sample locations, which are shown as vertical lines on Figure 4. *Data for location 15 from Rassam (1967)--data points not plotted; numbers in brackets are number of analyses for each member. See Figure 4 for members and lithologic features.

In Wisconsin and Iowa, the Carimona or equivalent beds are considered to be the basal member of the Decorah. Assignment of the Carimona to the basal Decorah in Iowa and Wisconsin is due in large part to changes in thickness and lithology of the member at its feather edge. The basal contact with the McGregor Member (with Quimbys Mill in Wisconsin and Iowa) is a prominent bedding plane that may represent a diastem (Willman and Templeton, 1963).

The Carimona is generally sparse biomicrite. However, in the area south of Rochester, the basal bed is packed biomicrite (Fig. 12). The density of fossils may be due to widespread killing of organisms during deposition of the altered volcanic ash bed (Fig. 13) which directly overlies the basal Carimona limestone bed. In Fillmore County, zones packed with gastropods are found in the limestone bed immediately above the K-bentonite (Fig. 4); the fossils are associated with shale partings in the limestone (Weiss, 1953, p. 43). In the Rochester/Chatfield area of eastern Olmsted County, limestone full of the brachiopod *Nicolleti protozyga* occurs interbedded with the shale in the lower of two prominent shale partings within the Carimona limestone overlying the K-bentonite (Sloan, 1972) (Fig. 4). Linguloid brachiopods, some of them in life posi-

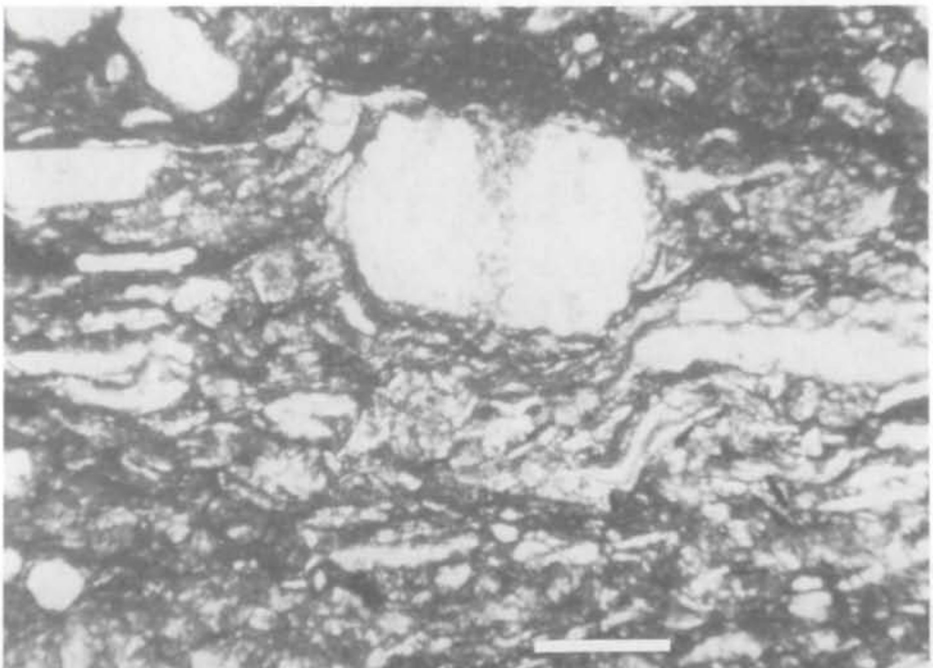

Figure 12. Packed biomicrite in the base of the Carimona Member, near St. Charles, Winona County. Note close packing of fossil fragments and compression of smaller fossil fragments around crinoid stem. Bar scale is 0.5 mm long.

Figure 13 -- Carimona K-bentonite south of Sogn in Goodhue County. Base of Carimona Member is just above the shale parting at bottom of photo. Hammer's head is in K-bentonite. Impermeability of K-bentonite is responsible for seepage of moisture visible along the base of K-bentonite.

tion, are known from the Carimona in the vicinity of Cannon Falls (Sloan and Weiss, 1956; Sloan, 1972).

In the southern part of the study area, ostracodes are the dominant fossil in the top bed of the Carimona, and other forms are scarce, although a thin Decorah-type coquina is plastered on top of this bed in Fillmore County (Weiss, 1953). Rare specimens of Endoceras proteiforme, a large cephalopod, occur in the limestone beds directly above the K-bentonite. These cephalopods generally have had the upper half of their shell destroyed by processes that probably were similar to those that formed hardgrounds in the Pecatonica and McGregor. Limestone beds of the Carimona contain 5 to 10 percent insolubles (Weiss, 1953; Ford, 1958, p. 51).

AUTHIGENIC AND DIAGENETIC MINERALS

The most prominent diagenetic change in the Platteville Formation is dolomitization. Samples of rock were ground to <325 mesh fineness and x-rayed, and the proportions of dolomite and calcite were determined using the technique outlined in Appendix A; the relative proportion of dolomite to calcite in carbonate rocks of the Platteville was determined for 117 rock samples from 11 localities (Appendix B).

The x-ray data are shown diagramatically on Figure 11 because the geographic distribution, as well as the stratigraphic distribution, is significant. The x-ray procedure allows the processing of numerous samples, which is a necessity if both geographic and stratigraphic variations are to be mapped.

Stratigraphically, the most pervasive dolomitization is in the Magnolia and Hidden Falls Members. Both units are almost everywhere 90 to 100 percent dolomite (Fig. 11; Appendix B). The Pecatonica is also generally highly dolomitic, but the distribution of dolomite is less predictable.

The geographic distribution of dolomite is closely related to its stratigraphic distribution. The most dolomitic rocks occur in the Twin Cities basin (Fig. 11) and in Pierce and St. Croix Counties, Wisconsin, which adjoin the Twin Cities area on the east. This geographic distribution corresponds roughly to the distribution of the two most dolomitic units, the Hidden Falls and Magnolia.

The dolomite is diagenetic, rather than a primary sediment, as demonstrated by the way it crosscuts stratigraphic units (Fig. 11) and replaces fossil fragments. Its selective replacement of matrix in the limestone, especially along primary sedimentary features such as shale partings and former animal burrows and borings, indicates that dolomitization probably occurred before extensive recrystallization and lithification of the calcareous matrix. The generally idiotopic (Fig. 14), rather than xenotopic fabric indicates that the dolomite crystals formed under near-surface low temperatures (>50 to 100°C) (Gregg and Sibley, 1984). The generally zoned crystals with cloudy centers and clear, euhedral rims (Fig. 15) indicate rapid early dolomitization in an environment containing abundant calcium and other contaminating ions, followed by slower precipitation in low-calcium waters. In addition, the generally blue staining of the dolomite crystals with potassium ferricyanide, both in thin section and on polished rock slabs, indicates ferrous iron in the carbonate lattice (Dickson, 1966), and therefore dolomite that formed under reducing conditions.

Several other authigenic and diagenetic minerals besides dolomite are present in the Platteville Formation. Most are trace amounts, and although volumetrically insignificant compared with dolomite, their presence is nonetheless significant. The minerals observed include pyrite, limonite, collophane, glauconite, chert, gypsum, authigenic feldspar, sphalerite, fluorite, and galena. Secondary calcite spar, like dolomite, is quite common.

Pyrite is widespread; it occurs in the micritic groundmass of the rock, encrusts hardgrounds (Fig. 16), and occurs in veins filling fractures with late ferroan calcite. Iron sulfide found in recent fine-grained sediments is interpreted to be syngenetic (Love, 1967). The pyrite that occurs along fine laminations in the Hidden Falls is probably syngenetic, and much of the pyrite in the fine-grained matrix may be syngenetic. Conversely, pyrite associated with ferroan calcite spar in veins crosscutting dolomitized limestones must be late diagenetic and postdate dolomitization.

Limonite is a common alteration product of pyrite. The pyrite along hardgrounds is particularly susceptible to weathering. Because of the strong acid from breakdown of pyrite, hardgrounds weather back in old exposures and appear similar to normal bedding planes (Delgado, 1983, p. A10). The ooids (Fig. 9) at Ellsworth, Wisconsin (locality F) are composed of limonite. This limonite may be an alteration product of the iron-rich clay mineral chamosite, if the origin of the ooids is analogous to that proposed for similar ooids in the overlying Decorah Shale (Crews, 1982).

Traces of glauconite, another iron-rich clay mineral, were found in the Pecatonica at Spring Grove (locality L). Glauconite is a syngenetic clay mineral that generally forms where sedimentation is slow or lacking.

Pellets and incrustations of collophane are present near the basal contact of the Pecatonica Member and along the hardgrounds in other mem-

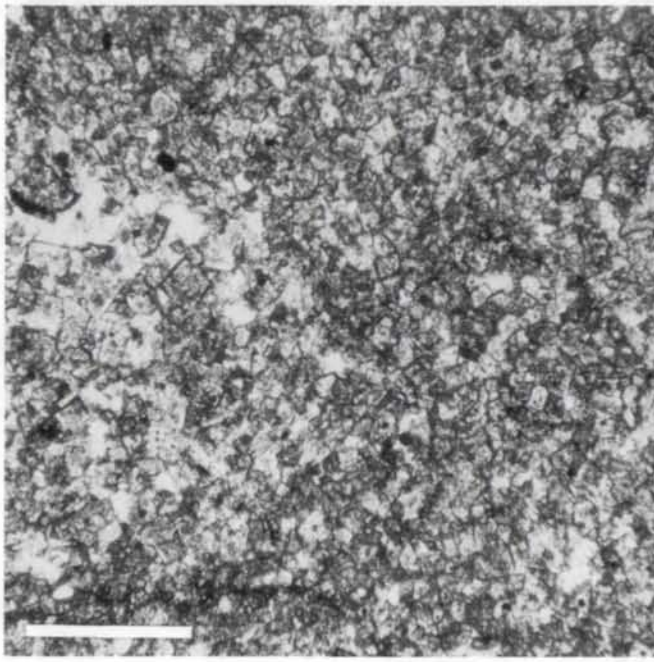

Figure 14. Idiotopic dolomite crystals. Note euhedral to subhedral crystal shapes and straight intercrystalline boundaries. Bar scale is 0.5 mm long.

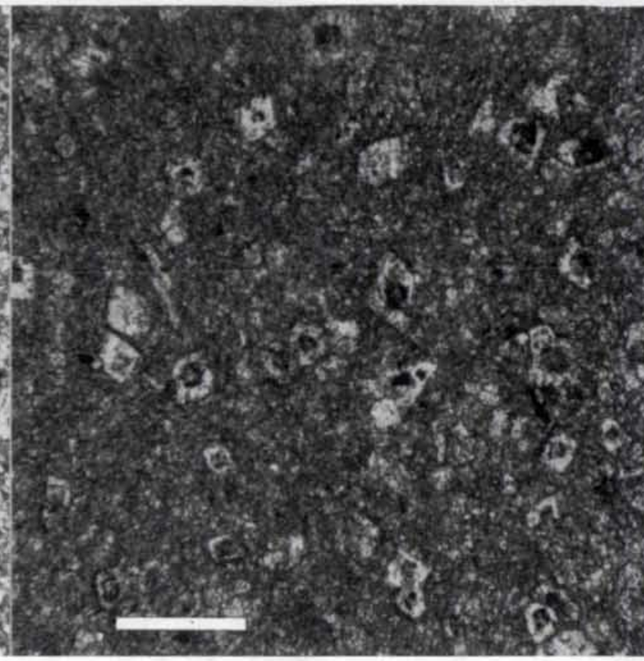

Figure 15. Zoned dolomite crystals with clear rims and cloudy centers. Bar scale is 0.1 mm long.

Figure 16. Hardground near Mabel, Fillmore County. Note abundance of pyrite (black) below hardground surface and absence of pyrite above surface. Note also truncation of bioclast at hardground surface. Bar scale is 0.5 mm long.

bers, particularly the McGregor. Silt- to sand-size collophane grains are present in the Hidden Falls. These are also interpreted to be syngenetic and to signify reduced sedimentation and disconformity.

Minor gypsum (selenite) was observed filling a few vugs (dissolved brachiopod shells) and borings in the Magnolia at locality B.

Authigenic silica (chert) appears to be quite rare in the Platteville in Minnesota, but small patches were observed in a few thin sections. It replaces some calcareous fossils such as bryozoans or brachiopods.

Overgrowths were seen on the few feldspar grains observed in the Pecatonica. Weiss (1954) found abundant diagenetic orthoclase in clay seams that he interpreted as altered volcanic ash beds. Another authigenic mineral derived from altered volcanic ash is mixed-layer mica-montmorillonite (Mossler and Hayes, 1966).

Late diagenetic sparry calcite occurs along fractures and joints, and in vugs formed by dissolution of fossils. There is also poikilotopic calcite cement, particularly in the Pecatonica Member and in underlying Glenwood sandstones. Some of the last-formed, void-filling calcite is ferroan, as is associated coarse dolomite.

Sphalerite and galena in the Platteville in Minnesota are interpreted to be outlying mineralization of the Tri-State district (Heyl and West, 1982). Lead mineralization has been observed in Fillmore County (Winchell, 1876, p. 298; 1884, p. 292; Sloan, pers. comm. cited in Heyl and West, 1982). Sphalerite was observed during the course of this study at locality 14 (Fig. 3) in Goodhue County (with fluorite) and at locality B in Ramsey County. The sphalerite was associated with slightly ferroan void-filling dolomite and calcite. Chalcopyrite has also been observed in the Twin Cities Metropolitan Area (Morey, written comm., 1984).

DIAGENETIC FABRICS

On the basis of criteria presented by Longman (1980) and Heckel (1983), it can be shown that the carbonates of the Platteville Formation have fabrics that are characteristic of transgressive, offshore marine rocks. The fabrics are similar to those of carbonate sediment that is interpreted to have gone from the marine phreatic zone into the deeper burial, connate zone without significant exposure to the subaerial or freshwater environment.

Calcarenites or biosparites, such as those directly beneath the Carimona K-bentonite (Fig. 12), are overcompacted. Grains are crushed and commonly have more than the normal number of grain-to-grain contacts. Some grain-to-grain contacts are sutured (Fig. 17), and there are minor microstylolites along shale partings. Pore space is greatly reduced, and cement is minimal.

Most vugs now are filled with blocky calcite spar composed of roughly equant crystals that increase in size from the margins toward the center of the former void (Fig. 18). Fibrous to bladed, cloudy cements are characteristic of early cementation in the marine environment (Longman, 1980; Heckel, 1983). No cloudy, fibrous cement was observed in thin section, and cloudy, blocky cement, dogtooth crystals, and bladed cement with undulatory extinction are quite rare and inconspicuous. Therefore significant cementation apparently did not occur in the marine phreatic or vadose environment, or if it did, the cement was subsequently destroyed. Limited micritic cementation probably occurred in the marine environment along hardgrounds, as suggested by Delgado (1983, p. A10). However this is hard to demonstrate, because micritic cement resembles micrite of the originally muddy sediment. Blocky equant calcite cement generally forms in either the meteoric phreatic or the deeper burial, connate environments (Heckel, 1983). The lack of evidence that meteoric leaching of carbonate grains led to the formation of vugs and solution/collapse features seems to rule out diagenetic alteration in the meteoric phreatic zone.

Overgrowths on echinoderm fragments are rare; most fossil fragments, including echinoderms, appear to have ragged edges and look slightly corroded (Fig. 19). Similarly, the upper parts of large endocerid cephalopod shells have been dissolved away (Webers, 1972). Carbonate dissolution in modern marine sediments occurs where the overlying marine waters are undersaturated with respect to calcium carbonate (Alexandersson, 1978). Corroded fossil fragments are considered characteristic of carbonate that formed offshore, in deeper, cooler water (Heckel, 1983).

Pelletal carbonate is volumetrically insignificant and is generally observed only in sheltered areas beneath fossil fragments or within body centers of such fossils as gastropods where it was not subjected to compaction (Fig. 20). Platteville carbonates contain borings and burrows, and fecal pellets presumably would be more common if sediments had not been subject to early compaction prior to lithification. By contrast, regressive marine carbonates have substantial pre-lithification interstitial cement which preserves pelletal fabrics (Heckel, 1983).

The carbonates are generally fairly dark colored and dense, and contain appreciable ferroan carbonate--features characteristic of transgressive calcilutite or biomicrite, which point to long-term compaction and maintenance of low-oxygen conditions before final cementation (Heckel, 1983).

The diverse faunas, including many filter feeders, of all members of the Platteville, as well as the overlying Decorah Shale, indicate normal marine salinity. Faunas suggestive of stressing of the normal marine environment, as might be anticipated in regressive carbonates, were not observed.

Although much of the rock is composed of micrite (microcrystalline calcite, 1-4 micron diameter) without evident grain growth, the matrix in some thin sections is coarser than micrite and probably is recrystallized to microspar. The spatial distribution of this material is irregular, and no systematic study was made of its distribution. However microspar seems to be more common in close proximity to zones that have been dolomitized. Perhaps some of the calcium displaced by dolomitization went into grain growth and microspar.

ORIGIN OF THE DOLOMITE

Various models have been proposed for dolomitization in ancient rocks. One widely applied model attributes dolomitization to evaporative pumping or capillary evaporation of saline waters through calcareous sediments in an arid tidal flat or sabkha (Illing and others, 1965). Another postulates reflux of hypersaline brines through carbonate sediments (Deffeyes and others, 1965). Rocks that formerly contained evaporitic minerals commonly have relict molds or pseudomorphs of vanished evaporitic minerals, such as gypsum, calcitized or silicified nodules, or solution-collapse breccias. However, none of these features have been identified in the Platteville of Minnesota. The small occurrence of gypsum at locality B (Fig. 3) fills fossil body cavities and borings in dolostone and apparently postdates dolomitization.

Another popular model for dolomitization involves mixing of marine water with fresh meteoric water in the phreatic zone (Land, 1973; Badiozamani, 1973). The mixing results in water with a relatively high Mg/Ca ratio and low salinity that is supersaturated with respect to dolomite and undersaturated with respect to calcite. This mechanism (dorag model) has been proposed for Platteville and Galena carbonates (Badiozamani, 1973), but it fails to account for the lack, in Minnesota as well as in Iowa (Witzke, 1983), of an emergent zone of sufficient size and duration to have caused widespread dolomitization of Middle Ordovician carbonates. The principal supporting evidence for the dorag model, as well as for the reflux (hypersaline brine) model, would seem to be the location of the most intensively dolomitized rocks near the margin of the Hollandale embayment where they could have been in close proximity to zones of reflux or freshwater intrusion. This evidence appears inconclusive because distribution of dolomite in rocks of equivalent age in Iowa evidently bears no relationship to paleoshorelines (Witzke, 1983).

If dolomitization by mixing of fresh and marine waters occurred, it must have occurred after deposition of most of the Maquoketa Formation because patterns of dolomitization in the Maquoketa and Galena largely correspond, and because there was no widespread emergence before the end of Maquoketa time (Delgado, 1983). All Platteville carbonates in Minnesota are interpreted to be subtidal and none have early diagenetic fabrics that can be unequivocally attributed to diagenesis in the meteoric zone, such as solution/collapse features in formerly metastable (aragonitic) carbonate grains (Heckel, 1983). Features indicative of emergence and desiccation (Heckel, 1983), such as birdseye fabrics and mud cracks, also are absent, as are relict caliche or residual soils. Badiozamani (1973) related three major shifts in the limestone/dolostone boundary in Wisconsin to reflux of marine water. However these boundaries (McGregor/Pecatonica, Quimbys Mill/McGregor, and Guttenberg/Quimbys Mill) appear to follow hardgrounds described by Willman and Kolata (1978, see also Byers, 1983), which are considered to be submarine.

Another argument against dolomitization by mixing of fresh and marine water is the ubiquity of authigenic K-feldspar in the Lower Paleozoic rocks of the area including the Glenwood and St. Peter formations (Odom and others, 1979). According to Friedman (1980), authigenic feldspar is an indicator of brines. The only authigenic mineral in the St. Peter indicating freshwater is kaolinite, the last to form and present only where freshwater has invaded the sandstone (Odom and others, 1979).

Data presented by Badiozamani (1973) indicate exchange of oxygen isotopes and trace elements (Sr, Na) in Mifflin carbonates, in Wisconsin, with meteoric water. However, according to a discussion by Land (1980), interpretation of such isotope and trace element data is ambiguous, because most ancient platform dolomites have been affected by massive neomorphic replacement and later cementation. Isotope values for the Mifflin appear to fall within the range of late diagenetic dolomite, as shown by Mattes and Mountjoy (1980, fig. 25), and are consistent with Land's conclusions.

The dolomite does not appear related to hydrothermal activity associated with mineralization in the Tri-State lead-zinc district, because its geographic distribution bears no relationship to the lead-zinc mineralization and most of it is idiotopic dolomite which is said to form at low, near-surface (<50°-100°C) temperatures (Gregg and Sibley, 1984). Badiozamani observed that, with minor exceptions, dolomitization of Ordovician carbonates in Wisconsin appears older than the mineralization.

Mg-rich fluids expelled by the compaction of shales (McHargue and Price, 1982) and fluids from stylolitization and solution of high-Mg calcite (Wanless, 1979) could have contributed to dolo-

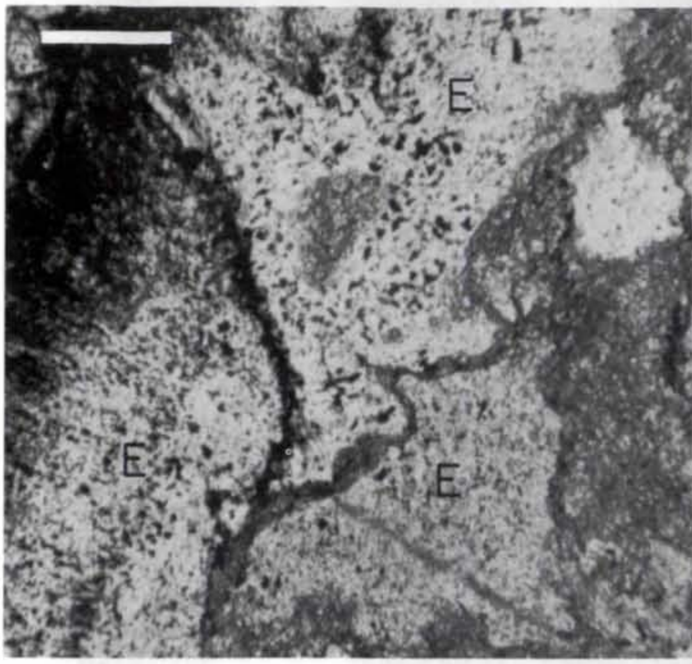

Figure 17. Sutured grains in the McGregor Member at St. Charles, Winona County. Each echinoderm fragment (E) is a single crystal. Bar scale is 0.1 mm long.

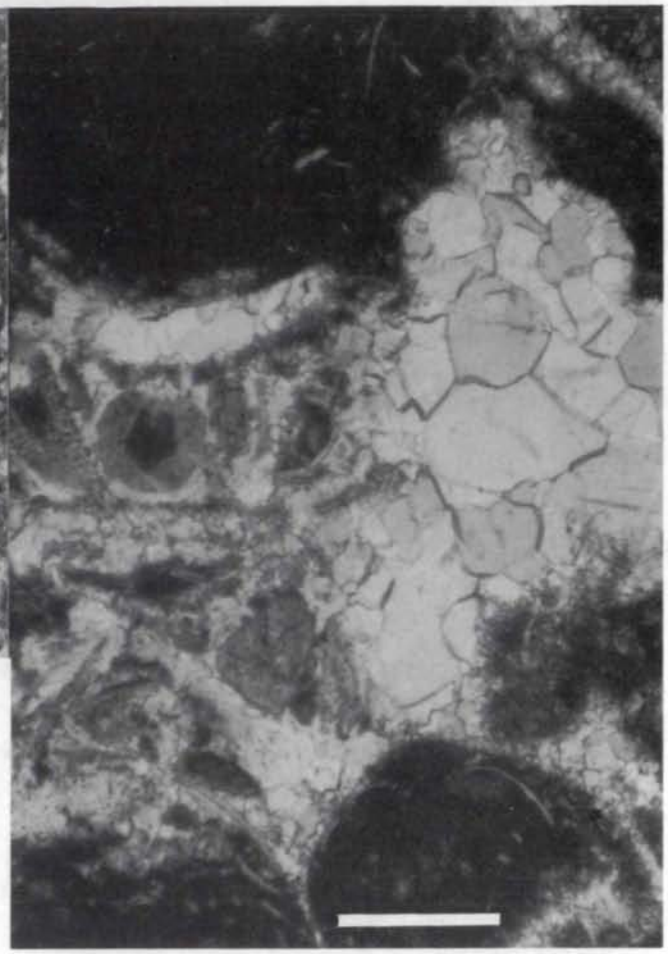

Figure 18. Drusy calcite spar in the Carimona Member at Spring Grove, Fillmore County. Note overgrowths on echinoderm grains. Overgrowths are rare in the Platteville. Bar scale is 0.5 mm long.

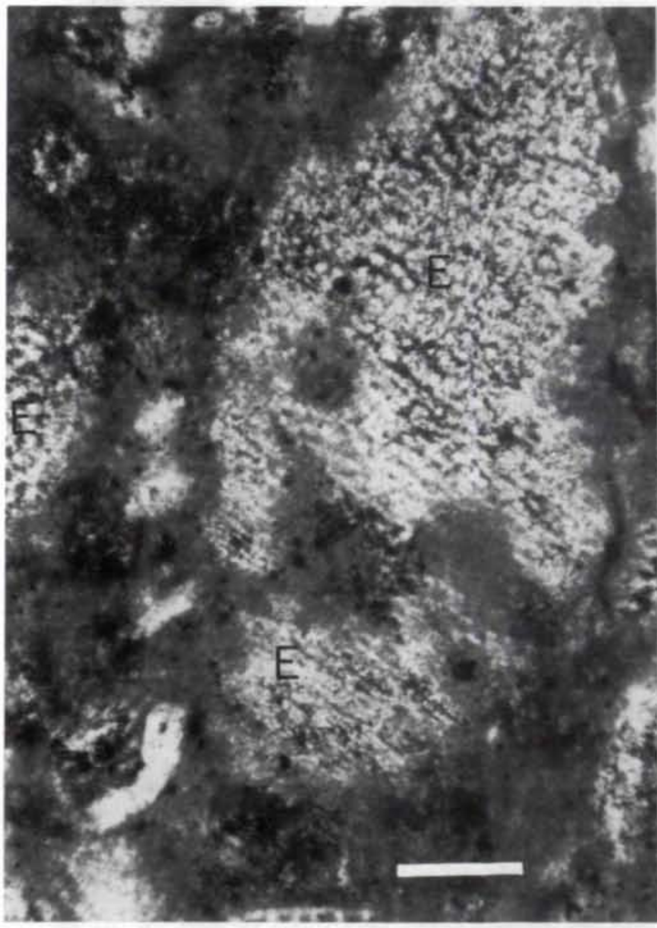

Figure 19. Corroded echinoderm fragments (E) in the Mifflin Member, St. Paul. Bar scale is 0.1 mm long.

Figure 20. Pellets in burrow in the McGregor Member, Chatfield. Bar scale is 0.5 mm long.

mitization. Pressure solution as the origin for dolomite in the Mifflin and McGregor enables the erection of a plausible, integrated diagenetic history for these units, explaining the origin of the wavy, nodular bedding, as well as the dolomite, by preferential solution along shaly zones. Close proximity of seam solution and stylolitization to dolomitization would solve the problem of fluid transport in fine-grained sediments which must have had relatively low initial permeability.

Mattes and Mountjoy (1980) mention a principal advantage of dolomitization during burial diagenesis over purely syngenetic and early diagenetic hypotheses is that pore fluids would be fairly stable in composition and would remain in contact with the sediments for a long time. One problem with the mixed-water dolomitization model (Badiozamani, 1973) is that it is difficult to envision dolomitizing fluids having a very long resident time in a given stratigraphic interval (Witzke, 1983, p. D23).

Under burial diagenesis conditions, temperatures should rise, aiding dolomitization by reducing the hydration barrier of Mg^{+2} ions (Usdowski, 1968). The alkalinity (CO_3^{-2} and OH^{-1} content) of the interstitial fluid would be increased in a reducing environment (Lippmann, 1968), whereas sulfate content (SO_4^{-3}), an inhibiting factor in dolomitization (Baker and Kastner, 1981), should be reduced. The widespread presence of ferroan dolomite in the Platteville, which is shown by potassium ferricyanide staining, indicates dolomite formed under reducing conditions.

With the exception of very minor late-stage protodolomite, Middle Ordovician dolostones outside the lead-zinc district are composed chiefly of stoichiometric dolomite (Badiozamani, 1973; Witzke, 1983). This would seem consistent with burial diagenesis, which would proceed slowly and produce well-ordered crystals. Rapid dolomitization in micritic sediments should produce generally non-stoichiometric dolomite because of depletion of the initial supply of magnesium. Lumsden and Chimahusky (1980, p. 134) found that stoichiometric dolomite is most commonly associated with evaporitic sediments, where it is syndepositional, as well as with crystalline dolostones, where it is interpreted to be middle to late diagenetic.

Most dolomite crystals in the Platteville Formation are zoned with cloudy centers and clearer rims (Fig. 15). Zoning indicates multiple episodes of dolomitization and may indicate dolomitization that occurred over an extended period of time. The more permeable parts of the Platteville were probably selectively dolomitized. For example, the Hidden Falls is siltier than other units. The silt-size quartz and collophane grains may reflect the original grain size of the carbonate. The Magnolia has numerous coquina layers which may have acted as conduits. Other units are less intensively dolomitized but have selective dolomitization along burrows and shale partings or bedding planes. According to Delgado (1983, p. A11), dolomitization in the Galena Formation follows burrow systems descending from bedding planes and is most intense at the upper bedding-plane surface. Dolomitization patterns in the Mifflin and McGregor Members of the Platteville appear similar.

DEPOSITIONAL MODEL

Most authors (Sloan, 1972; Webers, 1972; Byers, 1983) agree that the Platteville was deposited in a quiet subtidal environment. Facies changes are minimal, and the units can be traced for "scores, even hundreds of kilometers" (Willman and Templeton, 1963). Most lateral changes are due to nondeposition or submarine erosion along hardgrounds (Byers, 1983).

Stenohaline organisms are present throughout the formation (Webers, 1972). From the forms present and their distribution, there is no reason to interpret the Platteville as anything other than a normal marine environment, unlike some other Ordovician units like the Oneota and Stewartville which contain organisms apparently able to tolerate harsh, probably hypersaline, conditions. Even the Pecatonica, thought by some to be a generally unfossiliferous unit (Weiss, 1957), has fossil material that can be seen in thin section, though most fossils are dolomitized.

The biggest change in fossil content within the unit occurs between the McGregor and Carimona Members with the addition of bryozoans as a significant component of the communities (Webers, 1972). For the most part, the lower Platteville was dominated by sessile brachiopods, echinoderms, cephalopods, and gastropods. Webers (1972) and Sloan (1972) discuss the general paleontology of the formation.

The formation has no exposure indicators (Byers, 1983) and no intraclasts or stromatolites. Ooids, which are ferruginous, are restricted to one locality (F). With the exception of borings on hardgrounds (Typanites), trace fossils indicate infaunal deposit feeders (Chondrites) and a soft muddy substrate (Byers and Stasko, 1978; Byers, 1983). Fossil material is commonly comminuted, but is not abraded and does not appear transported (Webers, 1972).

Hardgrounds, which represent temporary periods of little or no deposition, may be indicative of shallowing of marine water (Bathurst, 1971, p. 406). The Platteville hardgrounds converge toward the Transcontinental Arch and may have formed in response to uplift of the arch.

The thicker shale partings in the Carimona indicate increased detrital sedimentation, probably related to uplift in the source area (Transcontinental Arch). This increase in detrital influx continued during deposition of the succeeding Decorah Shale.

Thin coquinas, which may have been formed by rare major storm waves (Byers, 1983; Delgado, 1983, p. A3-A4) occur in the Platteville. In Minnesota, they are most widely developed in the Magnolia; evidence for current and wave activity is generally lacking elsewhere in the Platteville. Thin, wavy bedding in the Mifflin and McGregor Members, long interpreted as ripples (Jacka, 1957; Asquith, 1967; Sloan, 1972), are reinterpreted as diagenetic features by Byers and Stasko (1978). The wavy bedding may be the result of inhomogeneous distribution of fine-grained detrital material within the original carbonate sediments. Upon burial the carbonate sediments would have undergone solution along the more argillaceous zones, and the purer carbonate zones would have remained as nodules in the manner described by Wanless (1979). The original inhomogeneity may have been the result of near cessation of lime mud deposition, while influx of terrigenous mud and silt and generation of skeletal mud remained unchanged (Troell, 1969; Heckel, 1972). If so, the shale partings would be crude analogs of the diastemic hardgrounds which are more abundant farther south in Minnesota. Webers (1972) interprets endocerid cephalopods, which have had the top parts of their shells planed off above bedding plane surfaces, as indicative of long periods of slow deposition that are now recorded by thin shale partings along bedding planes between adjacent limestone beds. Even if the wavy bedding originated as ripples, it is not indicative of depth, because ripples are now known to be widely distributed and are even known to occur at abyssal depths in modern oceans (Heckel, 1972, p. 242).

The Glenwood and basal part of the overlying Platteville may have formed either in a lagoonal environment behind the Starved Rock barrier bar of northwestern Illinois (Willman and Templeton, 1963; Fraser, 1976), or on a shallow, subtidal marine shelf (Ostrom, 1970; Schutter, 1978). The barrier bar model is appealing; however, if the entire Glenwood formed behind the barrier bar, then the lagoon must have been much wider (over an order of magnitude) than any modern analog, such as Laguna Madre of the Texas Gulf Coast. This interpretation may have arisen as a natural outcome of the assumption of Willman and Templeton (1963) that thin beds within Middle Ordovician units are widely traceable and therefore must be time equivalent. Schutter (1978) notes that the fauna in the Glenwood is stenohaline, which is indicative of a shelf, rather than a lagoonal environment.

The distribution of one unit in the Platteville, the Mifflin, appears to be restricted to the Twin Cities basin (Ford, 1958; Hoeft, 1959). Because the basin is structural, the distribution of the Mifflin may indicate tectonic influence on sedimentation by anticlines and faults bordering the edge of the basin. The thickness of the Mifflin Member also varies inversely with the thickness of the underlying Glenwood shale, and according to Sloan (1972) it is a lateral equivalent of the shale. The Glenwood shale is much thicker and has a higher kaolinite content (Parham and Austin, 1967) south of the Twin Cities basin in southern Dakota, Rice, and Goodhue Counties than elsewhere in Minnesota. It seems reasonable that this area may have been close to an outlet draining the emergent Transcontinental Arch (Webers, 1972), and hence the greater amount of shale.

Distribution of other units of the Platteville bears no close relationship to boundaries of the Twin Cities basin or other structural features. On the basis of sedimentologic features and faunal content, the Hidden Falls, Magnolia, and Carimona seem to have been deposited in shallower water; other factors such as detrital influx may have masked the influence of local tectonism. Most structural movement must have come after deposition of the Platteville. The Platteville is at altitudes in excess of 305 m (1,000 ft) in Rice, Goodhue, and Washington Counties and at about 244 m (800 ft) in Hennepin and Ramsey Counties, although the Hidden Falls and Magnolia are lithologically uniform throughout all these counties.

Carimona carbonate seems to have been deposited in slightly shallower waters than underlying McGregor carbonate because it contains *Lingula sp.* in life position in their burrows (locality D; Webers, 1972), the grain size of bioclastic debris is coarser (Sloan, 1972), and some beds within the unit have ripple marks of long wavelength on their upper surfaces (Sloan, 1972). However, *Lingula* in life position is not necessarily by itself an indicator of shallow water because it has been found in deep-water Ordovician carbonate rocks in eastern Canada (Pickerill and others, 1984).

The distribution and lithic characteristics of the Hidden Falls, Magnolia, and Carimona Members may be controlled by proximity of the margin of the Hollandale embayment. Near Faribault in Rice County, increase in shale content in the Hidden Falls and divergence of limestone beds in the Carimona indicate detrital influx from the west and the Transcontinental Arch. However, sedimentologic and diagenetic features seem to indicate influence from a paleoshoreline lying to the north and northeast of the Twin Cities basin, as well. Sloan (1972) mentions that the Hidden Falls grades into Glenwood shale at the Soo Drawbridge section of northern Washington County. The high sand content and ferruginous ooids in the Hidden Falls at locality F in western Wisconsin (Fig. 3) also are indicative of relatively close proximity to a shoreline. The distribution of dolomite also supports proximity of a shoreline to the north and east of the Twin City area, because dolomite is supposed to increase toward ancient shorelines. Relative abundances of conodonts, which decrease in the Twin Cities and Ellsworth outcrops (Rassam, 1967), lend support to this interpretation. This shoreline was probably related to the Wisconsin Dome and related structures. Parts of the highlands formed by Keweenawan lavas directly north of the Twin Cities basin (Taylors Falls, Minnesota, and St. Croix-Dresser, Wisconsin area, southern Pine County), which had formed islands and headlands during the Late Cambrian, may have continued to exert an influence on sedimentation during the Middle Ordovician, as well.

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APPENDIX A

CALCULATION OF PERCENTAGE OF DOLOMITE BASED ON X-RAY DIFFRACTION DATA

In the method of Royce and others (1971), the intensity of the principal calcite (3.03 Å) and dolomite (2.88 Å) reflections are measured by counting the maximum peak heights for a fixed time interval of 100 seconds (Fig. A1; Table A1). See Appendix B for results obtained. This method is reported to give accuracy in terms of weight percent dolomite of about ± 6 at the 95-percent confidence level (Royce and others, 1971).

X-ray diffraction measurements were made of mixtures prepared from ground calcite spar and dolomite spar; the x-ray results deviated by less than 3 percent dolomite from values obtained by calculating the known weights of dolomite and calcite in the mixtures (Table A2). Use of these known mixtures was made to check analytic technique.

The presence of non-stoichiometric dolomite can result in overestimation of dolomite using this technique (Lumsden, 1979). However most of the Middle Ordovician dolomitic rocks in the Upper Midwest are stoichiometric, and so compositional variations should be too small to affect any but the most exacting work (Runnels, 1970).

Iron substitution for magnesium in the dolomite lattice can have a similar effect (Runnels, 1970), but the amount of substitution (1-2%) is probably not enough to affect results significantly. Most iron in the chemical analyses (Appendix C) is probably in the form of pyrite and limonite. The chemical analyses in Appendix C are not from the same samples as the x-ray data; therefore they are not directly comparable.

Lithological features in the rock, such as concentration of dolomite in burrows in the Mifflin and McGregor Members and concentration of calcite spar in spar-filled vugs in the Pecatonica, cause sampling variations and consequently variations in compositional determinations that probably are more significant than deviations caused by laboratory technique.

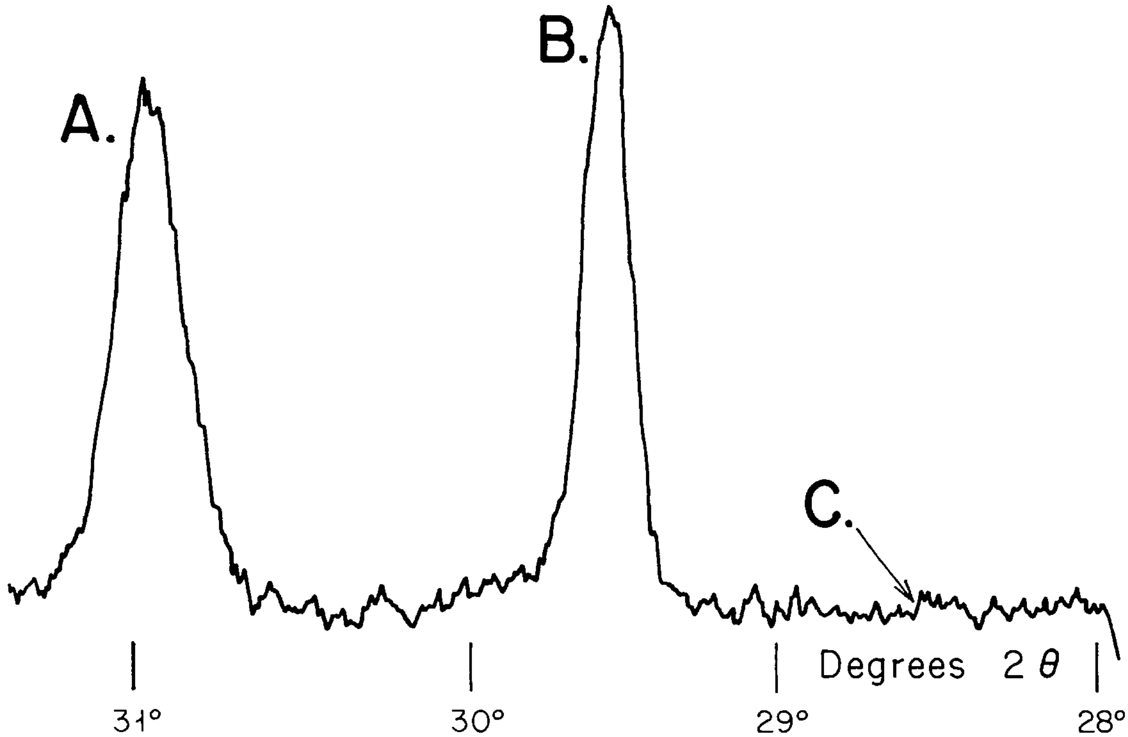

Figure A1. X-ray diffractometer recording showing principal (10.4) dolomite (2.88 Å) and calcite (3.03 Å) reflections. A, maximum peak height intensity for dolomite, counting 100 seconds = 15,827 (maximum of four readings between 30.95° and 30.98° 2θ. B, maximum peak height intensity for calcite, counting 100 seconds = 19,622 (maximum of five readings between 29.49° and 29.53° 2θ). C, background intensity, counting 100 seconds = 4,193. Nickel-filtered $Cu_{K\alpha}$ radiation, 40 Kv, 20 MA.

Table A1. Calculation of dolomite as percentage of total carbonate for sample in Figure A1

$$\frac{A-C}{(A-C) + (B-C)} = \%\ \text{dolomite}$$

Dolomite (A) max peak height = 15,827

Calcite (B) max peak height = 19,622

Background intensity (C) = 4,192

$$\frac{15{,}827 - 4{,}193}{(15{,}827-4{,}193) + (19{,}622-4{,}193)} = \frac{11{,}634}{11{,}634 + 15{,}429} = \frac{11{,}634}{27{,}063} \times 100 = 43\%\ \text{dolomite}$$

Table A2. Comparison of calcite/dolomite calculations from X-ray diffraction data with known weight percent of dolomite in samples

	Samples						
Known weight percent	15.7	24.2	39.3	49.6	61.2	76.5	84.5
Percent from XRD data	13.3	23	38.2	48.5	64.4	75, 77.6	85.6
Difference	2.4	1.2	1.1	1.1	3.2	-1.5, -1.1	-1.1

APPENDIX B

PROPORTION OF DOLOMITE IN SELECTED SAMPLES OF THE PLATTEVILLE FORMATION DETERMINED BY X-RAY DIFFRACTION ANALYSIS

Member	Height m	(feet)	Dolomite weight %
Location B (St. Paul)			
Carimona	8.84	(29.0)	36
	8.53	(28.0)	47
	8.23	(27.0)	100
Magnolia	7.92	(26.0)	100
	7.47	(24.5)	100
	6.86	(22.5)	100
	5.94	(19.5)	89
Hidden Falls	5.64	(18.5)	89
	5.18	(17.0)	95
	4.88	(16.0)	92
	4.11	(13.5)	95
Mifflin	3.90	(12.8)	8
	3.29	(10.8)	4
	2.83	(9.3)	12
	2.13	(7.0)	12
	1.46	(4.8)	29
	0.61	(2.0)	55
Pecatonica	0.03	(0.1)	95
Location C (south of Hampton)			
McGregor	3.96	(13.0)	0
	3.51	(11.5)	37
	2.90	(9.5)	71
	2.44	(8.0)	90
Hidden Falls	1.83	(6.0)	48
	1.52	(5.0)	90
	0.91	(3.0)	100
Pecatonica	0.30	(1.0)	100
	Base		100
Locations D and 9 (near Cannon Falls)			
Carimona	4.72	(15.5)	0
	4.11	(13.5)	0
	3.89	(12.7)	19
McGregor	3.20	(10.5)	33
	2.97	(9.7)	27
	2.51	(8.2)	10
	1.92	(6.3)	85
Hidden Falls	1.37	(4.5)	23
	1.07	(3.5)	37
	0.55	(1.8)	43
Pecatonica	Base		100

Member	Height m	(feet)	Dolomite weight %
Location E (south of Sogn)			
Carimona	4.34	(14.25)	8
	4.05	(13.3)	0
	3.66-3.81	(12.0-12.5)	11
McGregor	3.28	(10.75)	80
	2.79	(9.0)	95
	2.13	(7.0)	93
	1.52	(5.0)	89
Hidden Falls	1.13	(3.7)	100
	0.91	(3.0)	100
Pecatonica	Base		100
Location 14 (near Wanamingo)			
Carimona	2.68	(8.8)*	0
	2.38	(7.8)*	3
	2.13	(7.0)*	7
McGregor	2.07	(6.8)*	96
	2.62	(5.3)*	60
	1.22	(4.0)*	93
	0.70	(2.3)*	85
	0.30	(1.0)*	91

*Distance above base of quarry, which is approximately 1.68 m (5.5 ft) above base of formation

Member	Height m	(feet)	Dolomite weight %
Location H (Rochester)			
Carimona	6.77	(22.2)	0
	6.07	(19.9)	0
	5.49	(18.0)	3
	4.97	(16.3)	0
McGregor	4.42	(14.5)	0
	3.81	(12.5)	67
	3.12	(10.2)	17
	2.59	(8.5)	12
	1.68	(5.5)	24
	0.84	(2.7)	82
	0.55	(1.8)	43
Pecatonica	0.34	(1.1)	52
	0.30	(1.0)	73

Member	Height m	(feet)	Dolomite weight %
Location K (east of Preston)			
Carimona	6.00	(19.7)	0
	5.43	(17.8)	0
McGregor	4.97	(16.3)	8
	4.30	(14.1)	13
	3.14	(10.3)	9
	1.92	(6.3)	0
	0.70	(2.3)	0
	0.24	(0.8)	0
Location L (near Spring Grove)			
Carimona	8.29	(27.2)*	0
	7.62	(25.0)*	0
	7.32	(24.0)*	0
McGregor	7.16	(23.5)*	13
	6.71	(22.0)*	0
	5.49	(18.0)*	26
	4.57	(15.0)*	19
	3.66	(12.0)*	30
	3.05	(10.0)*	11
	2.53	(8.3)*	26
	1.86	(6.1)*	0
Pecatonica	1.31-1.40	(4.3-4.6)*	78
	1.13	(3.7)*	86
	0.54	(1.8)*	74
	Base		78

*Distance above base of quarry, which is estimated to be 0.91 m (3 ft) above base of formation

Member	Height m	(feet)	Dolomite weight %
Location G (north of Faribault)			
Carimona	3.96	(13.0)	0
	3.35	(11.0)	46
McGregor	3.20	(10.5)	33
	1.68	(5.5)	47
Hidden Falls	0.91	(3.0)	7 to 11
	0.53	(1.7)	100
	0.30	(1.0)	100
Pecatonica	Base		95
Location F (near Ellsworth)			
Carimona	4.79	(15.7)	0
	3.96	(13.0)	22
Magnolia	3.65	(12.0)	100
	2.90	(9.5)	100
	1.68	(5.5)	100
Location 6 (near River Falls)			
Magnolia	5.64	(18.5)	92
	4.27	(14.0)	100
	3.73	(12.25)	100
	3.35	(11.0)	100
	3.20	(10.5)	100
Hidden Falls	2.79	(9.0)	100
	2.06	(6.75)	92
and	1.90	(6.25)	95
	1.62	(5.3)	88
Pecatonica	0.73	(2.4)	100
	0.46	(1.5)	100
	Base		100

APPENDIX C

CHEMICAL ANALYSES OF SELECTED SAMPLES OF THE PLATTEVILLE FORMATION

[Analytical data provided by Mineral Resources Research Center, University of Minnesota, 1970. Results in weight percent. See Figure 3 for outcrop locations. Height, distance of sample from base of Platteville Formation.]

Member	Height m (ft)	CaO	MgO	LOI	Fe	SiO_2	Al_2O_3	P_2O_5	S	Na_2O	K_2O	Total	Insol
Location B (St. Paul)													
Carimona	8.23 (27.0)	32.28	15.55	43.44	2.74	2.04	0.29	0.14	0.44	0.069	0.14	97.13	2.86
Magnolia	7.54 (24.75)	26.99	15.96	40.07	2.09	8.72	5.16	0.087	0.23	0.142	0.73	100.18	11.43
	6.02 (19.75)	27.78	14.09	38.26	2.66	10.18	4.03	0.064	0.46	0.117	0.87	98.51	14.15
Hidden Falls	4.88 (16.0)	19.37	9.94	27.21	2.58	27.04	11.71	0.28	1.00	0.125	1.33	100.59	33.90
Mifflin	2.68 (8.8)	43.49	5.10	39.97	2.27	5.80	1.59	0.087	0.23	0.109	0.42	99.07	6.94
	1.45 (4.75)	42.71	2.95	37.00	1.45	10.24	3.65	0.071	0.54	0.108	0.80	99.52	13.15
Pecatonica	0.40 (1.3)	22.47	11.47	31.45	2.50	20.08	8.03	0.055	1.37	0.137	1.18	98.74	27.37
Location C (near Hampton)													
McGregor	3.51 (11.5)	46.36	5.05	42.23	1.53	2.96	0.76	0.046	0.056	0.098	0.189	99.28	3.45
Hidden Falls	1.83 (6.0)	22.79	11.03	31.56	3.54	20.72	5.57	0.20	0.19	0.166	1.01	96.78	25.74
Pecatonica	0.30 (1.0)	22.93	11.61	32.04	2.81	21.36	6.51	0.082	0.08	0.173	1.18	98.78	26.62
Location D (Cannon Falls)													
McGregor	3.05 (10.0)	43.84	6.14	41.53	1.45	4.16	1.19	0.044	0.21	0.231	0.143	98.94	5.39
Location E (south of Sogn)													
Carimona	4.34 (14.25)	47.70	1.28	38.83	2.01	6.64	1.21	0.117	0.49	0.073	0.41	98.76	7.36
McGregor	2.74 (9.0)	30.86	14.67	40.22	4.99	5.48	1.06	0.187	0.40	0.067	0.37	98.30	6.10
	1.52 (5.0)	30.48	14.09	39.65	3.38	7.53	1.08	0.158	0.49	0.081	0.40	97.34	9.35
Pecatonica	Base	23.75	10.94	30.21	2.50	20.97	3.69	1.49	2.18	0.109	0.89	96.73	25.46
Location H (Rochester)													
Carimona	5.49 (18.0)	45.92	0.73	37.57	1.21	10.60	2.00	0.089	0.06	0.050	0.30	98.54	12.24
McGregor	4.42 (14.5)	52.06	0.66	41.73	0.80	2.88	0.51	0.169	0.32	0.101	0.47	99.70	3.12
	2.59 (8.5)	47.10	3.32	40.47	1.27	5.00	1.42	0.071	0.49	0.085	0.88	100.11	6.16
	1.68 (5.5)	39.99	6.33	38.81	1.45	8.96	2.06	0.050	0.47	0.081	0.70	98.90	11.29
Pecatonica	0.30 (1.0)	30.40	11.60	38.52	2.09	11.56	1.10	0.028	0.25	0.084	0.41	96.04	11.57
Location I (south of Chatfield)													
Carimona	5.94 (19.5)	49.56	0.74	39.96	0.72	6.52	1.36	0.050	0.043	0.116	0.27	99.34	4.38
McGregor	4.62 (15.15)	46.16	4.23	40.89	1.13	4.76	1.53	0.046	0.27	0.114	0.29	99.42	6.14
Location K (east of Preston)													
Carimona	6.00 (19.7)	50.61	0.66	40.55	1.13	2.43	0.51	0.101	1.52	0.087	0.119	97.72	3.31
McGregor	3.84 (12.6)	49.33	1.35	40.11	1.05	5.20	1.32	0.078	0.18	0.100	0.26	98.98	6.32
	1.92 (6.3)	49.95	0.66	40.37	0.89	5.28	1.15	0.062	0.085	0.089	0.27	98.81	6.17
	0.24 (0.8)	49.67	0.52	39.45	1.20	6.52	1.47	0.094	0.054	0.084	0.31	99.37	7.39
Location L (Spring Grove)													
Carimona	8.53 (28.0)	52.31	0.50	41.67	0.89	2.79	0.61	0.076	0.06	0.058	0.30	99.27	3.09
McGregor	6.40 (21.0)	45.82	2.67	39.10	0.96	8.20	1.66	0.048	0.32	0.101	0.47	99.35	9.02
	4.57 (15.0)	41.39	2.49	36.08	0.97	13.32	2.74	0.096	0.49	0.085	0.88	98.54	15.78
	2.74 (9.0)	45.87	1.66	38.07	0.80	9.35	2.25	0.073	0.47	0.081	0.70	99.32	11.05
Pecatonica	1.46 (4.8)	35.33	13.34	42.84	1.37	4.96	1.10	0.050	0.25	0.084	0.41	99.73	5.89