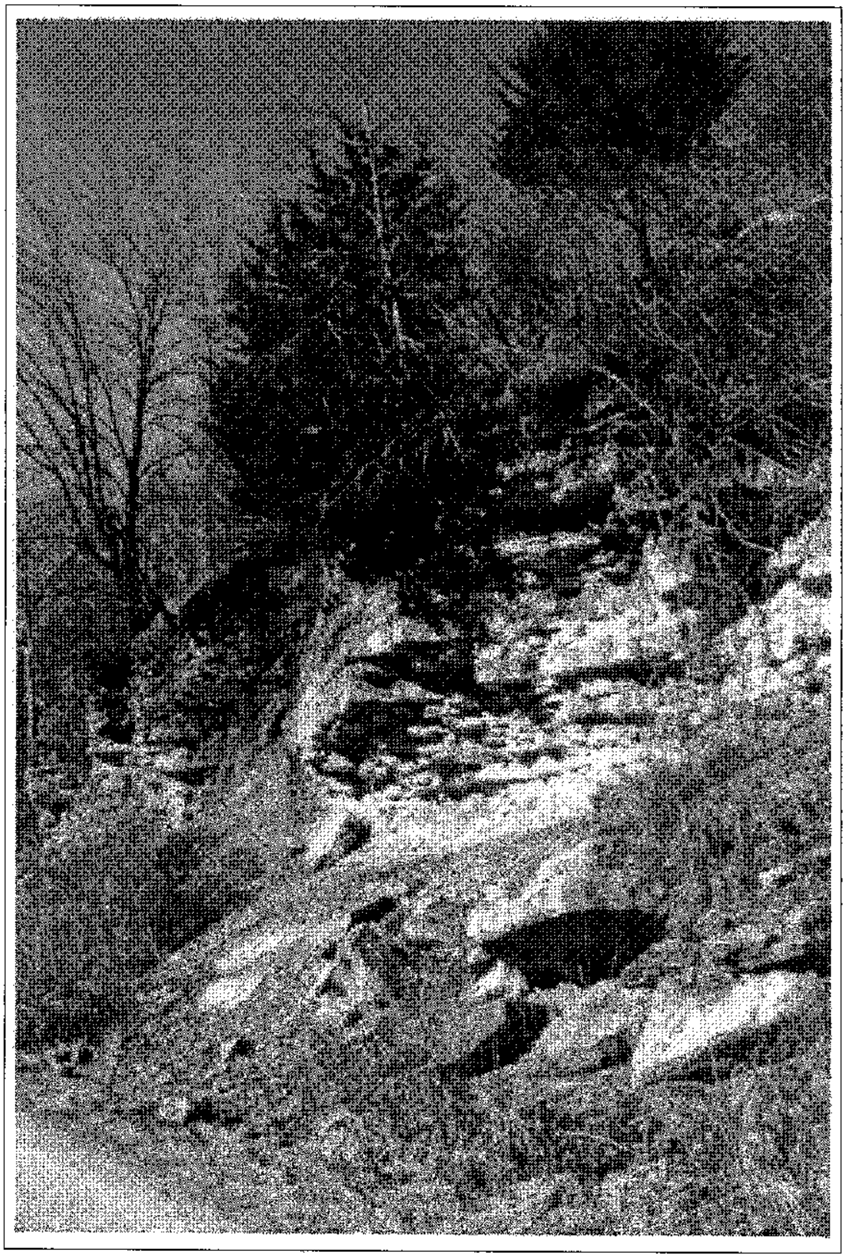
GEOLOGY IN THE DUBUQUE AREA

Brian J. Witzke, E. Arthur Bettis,
Raymond R. Anderson, and Richard J. Heathcote



LOWER MAQUOKETA FORMATION NEAR GRAF

Geological Society of Iowa

April 27, 1997 Guidebook 63

Couler Valley

"Among the many interesting topographic features of the driftless area, there is none more striking than the Couler valley, a deserted river channel some five miles long, connecting the Little Maquoketa valley at Sageville with the Mississippi at Dubuque. This valley is a sharp walled canyon nearly 200 feet deep and about a half mile wide, with flat alluvial bottom. The northern portion is used by a small branch flowing into the Maquoketa, while Couler creek flows down the valley and through Dubuque to the Mississippi. There is no col and no divide proper. In time of very high water the Maquoketa still uses it for a portion of its flood. For example, in 1853 water passed through the valley, and at present its proper drainage forms a considerable problem. Couler valley connects with the Maquoketa valley a little more than a mile above the point where the latter opens out on the Mississippi bottom lands. The waters of the Maquoketa find their way into the Mississippi by traveling about two miles northeast from Sageville. By following the Couler valley they might, in five miles, find their way into the Mississippi some seven miles below the point at which they actually join in. They travel by a route which is, roughly, four miles longer than the one which has been deserted. The change has thus resulted in lengthening the course of the stream, and also in so diverting the tributary as to cause it to join the main stream higher rather than lower. Such a change requires especial explaination."

"So far as can be learned there is no obstruction in Couler valley to account for the diversion of the stream. Such wells as are on record show a deep filling of the valley here, the same as along the Mississippi. As the locality is far outside the limits of the glacial action, the change cannot be referred to the agency of ice. Though the valley is crossed nearly at right angles by the Eagle Point anticline, there is no evidence connecting the rise of the latter with the diversion of the stream. In short, the explanation seems to be in the ordinary process of stream capture."

Samuel Calvin and H.F. Bain, 1900
Geology of Dubuque County, p. 391-392

Cover Photograph: Lower Maquoketa Formation dolomites and shales exposed at the Graf Section located along the road, about 0.5 miles south west of the town of Graf, 6 miles west of Dubuque.

GEOLOGY IN THE DUBUQUE AREA

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April 27, 1997

Geological Society of Iowa
Guidebook 63

TABLE OF CONTENTS

GEOLOGY IN THE DUBUQUE AREA

Introduction

This year's Geological Society of Iowa Spring Field Trip will provide a look at ***Geology in the Dubuque Area***, one of the most interesting and historic geologic regions in Iowa. Pioneering work by James Hall and Charles White in the mid 1800s, followed by Joseph James, Sam Calvin, and H.F. Bain in the late 1800s established the geologic foundation that has been built on by many subsequent geologists. Calvin and Bain (1990) noted that "*The geologic formations of Dubuque county are of unusual interest* "... Regarding the primary subject of this field trip, the Maquoketa Formation, they wrote; "*Scarcely any formation in this geological province has been written about more persistently; scarcely any has been more misunderstood; with respect to no other has there been greater diversity of judgement and interpretation*".

Two previous GSI field trips have visited this area. In the Spring of 1972 two of Iowa's most renowned amateur geologists, Arthur Gerk and Calvin Levorson, led GSI members and guests through a review of their ***Revision of Galena Stratigraphy*** (GSI Guidebook 25). Then, in the Spring of 1991, Jean Prior, Shirley Shermer, John Pearson, and Martha Maxon led an examination of the ***Natural and cultural history of the Mines of Spain Dubuque County Iowa*** (GSI Guidebook 53). This year's trip will feature six field trip stops to examine Pleistocene and Quaternary fluvial stratigraphy (with a little archaeology thrown in for good measure) and the stratigraphy, paleontology, and depositional environments of Ordovician Galena and Maquoketa strata.

We will begin the field trip with an overview and discussion of Quaternary and Recent geomorphology, specifically outwash terraces and subsequent modification of these features, including one of the most dramatic examples of stream capture in Iowa, at the Little Maquoketa River Mounds county archaeological preserve, located just west of U.S. Highway 52 about 2 miles north of Dubuque and just south of the Little Maquoketa River. Art Bettis will lead a hike to the mound group (100 feet above the parking area) where he will discuss the geology and geomorphology of the region and the capture of the Little Maquoketa River. During the Pleistocene the river abandoned its earlier channel through the Couler Valley (Highway 52 follows the valley to Dubuque) and took the shorter route through Peru Bottoms to the Mississippi River. He will also briefly discuss the 32 burial mounds along the top of the promontory.

From Stop 1 we will proceed into Dubuque, to the parking lot of the Tollbridge Restaurant at the north end of Rhomberg Street just below Eagle Point Park. From the lot we will have an overview of an abandoned quarry that exposes a 100 foot-thick sequence of Ordovician Galena Group strata. Brian Witzke and Rich Heathcote will lead a discussion of the geology and history of these rocks, and point out some of their more interesting features in the highwall that borders the parking area. Of particular note will be the fossil receptaculids (a calcified green algae) which can be seen at this location.

Stop 3 will be a lunch stop in Eagle Point Park, which will afford a scenic overview of the Mississippi River as well as restroom facilities. Art Bettis will continue his discussion of Quaternary and Recent geology, with emphasis on the history of the Mississippi River. The panoramic view from the park provides an exceptional vantage to see the general geomorphology of the Dubuque area.

The fourth stop of the day will be at an exposure of the Brainard Shale Member of the Maquoketa Formation (Ordovician) along U.S.Highway 20 west of Dubuque. The Brainard Shale at this stop provides an exceptional opportunity to collect a wealth of invertebrate fossils and some spectacularly fossiliferous slabs. Brian Witzke will discuss this interesting and informative rock unit and the significance of its unusual fauna.

From there we will continue west on Highway 20, then bear south to the famous Graf section, featured in Trip 23 of the Geological Society of America's ***Centennial Field Guide-North-Central Section***. This stop exposes the famous basal Maquoketa Elgin Member "brown shaly unit" with interbedded nautiloid-rich strata. The brown shaly unit contains scattered to abundant graptolite fragments and thin, phosphatic beds with a diminutive molluscan fauna. The overlying beds consist of finely crystalline dolomite and interbedded shales. Some dolomite beds contain exceptional accumulations of orthoconic nautiloids, some telescoped into other shells. A wealth of tiny fossils includes scaphopods, snails, clams, hyolithids, polyplacophoran plates, trilobites, starfish plates, sponges, and other fossils. Again, Brian Witzke will lead the discussion of the geology, history, and significance of this unique unit.

The final stop of the day will be along county road D17, where we will stop at the "D17 road cut", another stop featured in trip 23 of the GSA ***Centennial Field Guide***. Rich Heathcote and Brian Witzke will lead a discussion and examination of uppermost Maquoketa Formation strata (Brainard and Neda members) and the overlying dolomites of the Silurian Tete des Morts and Blanding formations. Of particular interest at this stop is the Neda Member, which features scattered to abundant ironstone ooids, about 1 mm in diameter, in a red-gray claystone to mudstone matrix.

References

Calvin, S., and Bain, H.F., 1900, Geology of Dubuque County: Iowa Geological Survey, Annual Report, v. 10, p. 381-622.

STOP 1: LITTLE MAQUOKETA RIVER MOUNDS STATE PRESERVE – MISSISSIPPI RIVER HISTORY AND DRAINAGE DIVERSION

E. Arthur Bettis III

The Little Maquoketa River Mound group consists of 32 prehistoric earthen mounds located atop a 200 foot long promontory overlooking the Little Maquoketa River valley. The mounds range from six inches to four feet in height and 12 to forty feet in diameter, and were presumably built by Woodland people between A.D. 700 and 1300. The mounds have not been professionally investigated and little is known about the details of their construction, relative ages, and artifact associations.

The promontory consists of Galena Group carbonate rocks overlain by late Wisconsin-age Peoria Loess. Loess from the surrounding ridge was used to construct the mounds. This mound group overlooks the lower reaches of the Little Maquoketa River valley, which contains a detailed record of late glacial Mississippi River history and one of the most spectacular examples of drainage diversion in Iowa. The Little Maquoketa River enters the Mississippi Valley behind a late glacial terrace complex on which the John Deere plant is built (Fig. 1). Two distinct terraces are present; the upper level (approximately 650 feet elevation) is the Savanna Terrace and the lower level (approximately 630 feet elevation) is the Kingston Terrace. Both terraces are underlain by sand and gravel deposited as valley train outwash by a braided stream. Deposits beneath the Savanna Terrace accumulated between 20,000 and 13,000 B.P., while those beneath the Kingston are younger, having accumulated between 12,600 and 10,200 B.P.

Savanna Terrace remnants are also found farther up the Little Maquoketa Valley around the base of Little Maquoketa Mounds State Preserve and to the north where the town of West Sageville is located (Fig. 1). In this part of the valley deposits underlying the Savanna Terrace consist of several meters of planar bedded to laminated silt, silty clay, and fine sand with abundant thin beds of reddish brown silty clay in the upper two meters. These distinctive "red clays" were derived from the Lake Superior Basin and entered the Mississippi Valley during several periods when Glacial Lake Superior drained into the Upper Mississippi Valley. The Savanna Terrace has a flat gradient in tributaries to the Mississippi and merges with the level of the modern floodplain a few miles up the tributaries. The level gradient, the fining up tributary nature of the sediment package, and the low energy depositional environment indicated by both the sedimentary structures and sediment texture all suggest that deposits underlying the Savanna Terrace in tributaries accumulated in standing water areas behind sediment dams that blocked the tributary mouths. These sediment dams formed during periods of rapid Mississippi River aggradation

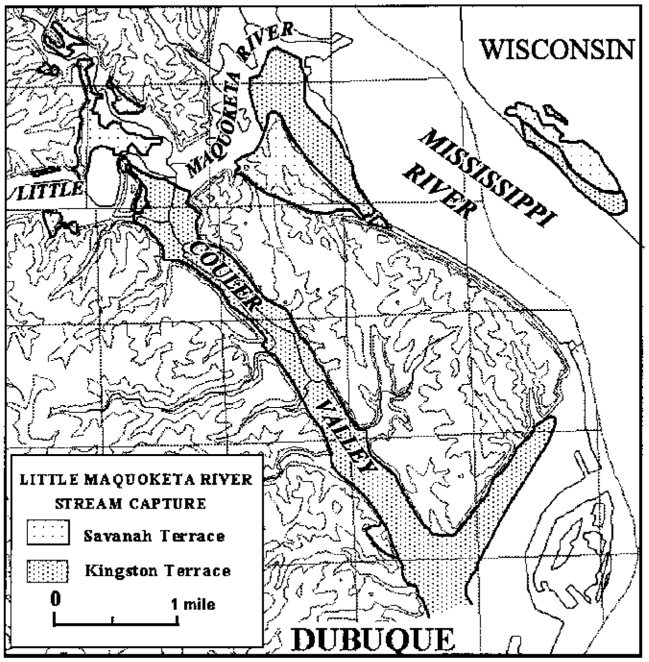


Figure 1. Quaternary terraces in the Couler Valley and nearby regions of the Little Maquoketa and Mississippi River valleys.

when large amounts of glacial outwash were entering the upper portions of the basin in Minnesota and Wisconsin.

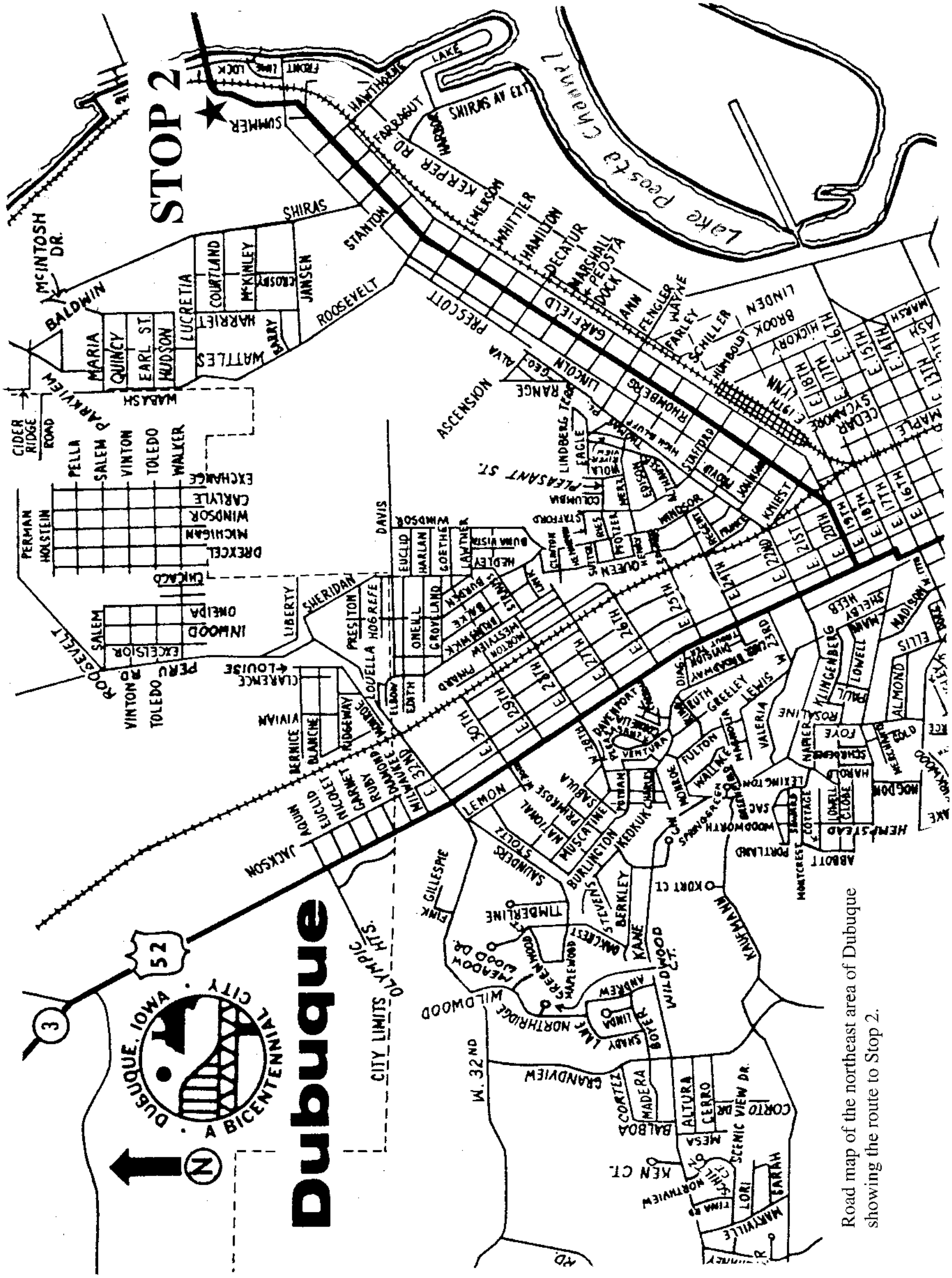
Deposits underlying the Kingston Terrace are younger than those underlying the Savanna Terrace and represent sediments that accumulated on the latest glacial floodplain. In the Mississippi Valley deposits beneath the Kingston Terrace are sand and gravel, while in tributaries like the Little Maquoketa the deposits are sand that fines upward to silt and silty clay. These sediments lie beneath a low terrace in the lower part of the tributary valleys. Radiocarbon ages on wood from sediments beneath the Kingston Terrace in Catfish Creek on the south side of Dubuque indicate that these sediments accumulated from 12,600 to 11,200 B.P. in this area.

Just south of Stop 1 lies Couler Valley, a relatively straight, uniform width abandoned valley that intersects the Little Maquoketa Valley on the north and the Mississippi Valley on the south (Fig. 1) Today flow from small tributary valleys drains both northward and southward down Couler valley from a watershed just north of Fair Ground. The width of Couler Valley is similar to that of the Little Maquoketa Valley and I (and every geologist who cared to do so before me) interpret Couler Valley as a now-abandoned lower reach of the Little Maquoketa River valley. Though no subsurface investigations have been conducted here and radiocarbon age determinations are not available from Couler Valley's deposits, topographic relationships among valley surfaces in the Little Maquoketa and Couler valleys suggest that Couler Valley was last occupied by a river during aggradation to the Kingston Terrace level.

Topographic relationships also indicate that though last occupied during aggradation to the Kingston level, Couler Valley has a longer history as part of the Little Maquoketa system. The area around West Sageville contains Savanna Terrace remnants and was therefore influenced by sediment damming between 20,000 and 13,000 years ago. Regional Savanna Terrace studies indicate the such influences do not extend more than a few miles up other large tributary valleys. If the Little Maquoketa River flowed through Couler Valley rather than its present eastward course during accumulation of the Savanna Terrace fill then the West Sageville area would have been abut 6 miles above the mouth of the Little Maquoketa Valley – too far for sediment damming to have much of an influence. It seems most probable that the eastward Little Maquoketa Valley route into the Peru Bottoms of the Mississippi Valley was in existence by 20,000 B.P. in order for the backflood facies of the Savanna Terrace fill to have been deposited in and upvalley of the West Sageville area. This would require diversion out of Couler Valley at an earlier date.

If Couler valley was already abandoned by the time the Savanna Terrace fill began to accumulate why is there no Savanna Terrace in Couler Valley? One possibility is that when large Mississippi River flow events occurred during the period between 12,600 and 10,000 B.P. some of the Mississippi and all of the Little Maquoketa River's flow was diverted through Couler Valley and removed Savanna terraces originally present.

Another curious aspect of Couler Valley is the fact that the divide between it and the Mississippi Valley is offset far toward the Mississippi. The straight course of Couler Valley is also enigmatic. Many unanswered geomorphic and landscape evolution questions remain in this area. Explanations for some of these features may provide important information for unraveling the history of the Mississippi Valley.



Road map of the northeast area of Dubuque showing the route to Stop 2.

ORDOVICIAN GALENA GROUP STRATA IN THE DUBUQUE AREA; *STOP 2*: TOLLBRIDGE INN, EAGLE POINT QUARRY

Brian J. Witzke, Richard C. Heathcote, and Raymond R. Anderson

Introduction

The Galena Group derives its name from the city of Galena in Jo Daviess County, Illinois, about 13 miles (21 km) southeast of Dubuque, Iowa. These strata were included within the "upper magnesian or cliff limestone" in Owen's (1840) early survey of the region. Galena Group strata are displayed in picturesque bold cliffs along the valley walls of the Mississippi Valley in Dubuque and Clayton counties, as dramatically shown on both sides of the river in the Dubuque area. Strata of the Galena Group are dominated by resistant carbonate rocks, primarily dolomite in the Dubuque area. Galena Group strata are comprised of progressively more limestone and less dolomite as one proceeds northward in northeast Iowa; at Decorah it is entirely a limestone facies. The dolomitization of Galena Group strata in the Dubuque area is a secondary diagenetic feature, possibly related to the progression of mixed marine-freshwater groundwater systems through the sediments when seaways withdrew from the region near the end of the Ordovician (Witzke, 1983).

Galena Group strata are of great historical significance to the Dubuque area, as the city's namesake, Julien Dubuque, first settled the area near the mouth of Catfish Creek (now known as the Mines of Spain) in 1788 in order to mine the lead mineralization hosted by these strata (Prior et al., 1991). In fact, Galena Group strata form the primary host-rock throughout the region of the classic Upper Mississippi Valley zinc-lead district in southwest Wisconsin, northwest Illinois, and northeast Iowa. Dubuque was the site of numerous lead mines, which "until 1900 was a main source of lead in the country" (Heyl et al., 1959, p. 288). "Very large quantities of galena [lead sulfide ore] have been mined from the gash-vein deposits in the vicinity of Dubuque, and some of these deposits were notable for their large size and richness. In addition, large tonnages of smithsonite [zinc carbonate] and sphalerite [zinc sulfide] were mined from several of these deposits" in Dubuque (ibid). The lead mineralization of Galena Group strata provided a major economic basis for the city of Dubuque throughout much of the 19th century.

In the 20th century, Galena Group strata have been an important source of aggregate and cut stone resources in the Dubuque area, and numerous quarries have been developed to extract the durable rocks of the Galena Dolomite. In addition, natural exposures and roadcuts of Galena strata are abundantly displayed in the Dubuque area, most recently in a series of expanded exposures created by the restructuring of Highway 20 through town. The durable rock cuts and picturesque exposures of Galena Group strata are a lasting fixture and visually pleasing aspect of the unique and attractive setting that makes up the greater Dubuque environment.

Galena Stratigraphy

Galena strata were first defined by James Hall in 1851 -- previously labeled the Galena Formation or Galena Dolomite, these strata were elevated to group status by Templeton and Willman (1963). They subdivided the group into four formations, in ascending order: Decorah, Dunleith, Wise Lake, and Dubuque (Fig. 1). Much of the stratigraphic nomenclature of Galena Group rocks derives from type localities within a short distance of Dubuque. Although the Decorah Formation was first named for exposures at Decorah in northeast Iowa, the basal shale-rich member, the Spechts Ferry, is named for a small community in Dubuque County a few miles upstream from Dubuque. A regionally prominent K-bentonite (altered volcanic ash), the Millbrig, is found near its base. The overlying Guttenberg Member is locally exposed just above river level in the Dubuque area; it is characterized by fossiliferous wavy-bedded limestone interstratified by organic-rich brown shales (Ludvigson et al., 1996), the so-called "oil rock" of

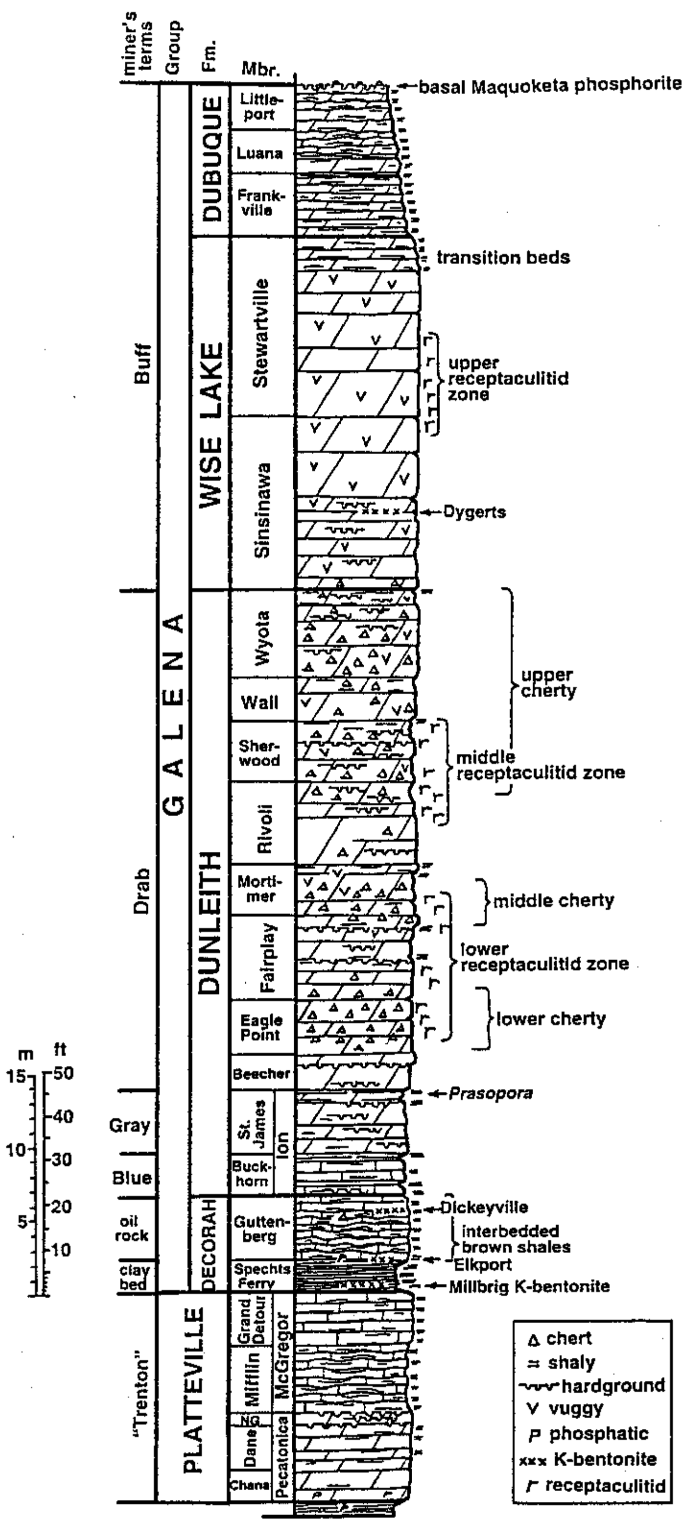


Figure 1. Composite stratigraphic section showing the subdivisions, lithologies, and key zones within the Galena Group and underlying Platteville Formation in the Dubuque area. See Stop 5 for additional lithologic symbols.

the miner's terminology. It serves as host for much of the mineralization in the lead-zinc district (Agnew et al., 1956). Two K-bentonites are locally seen in the Guttenberg in the Dubuque area (Willman and Kolata, 1978; Fig. 1).

The Dunleith Formation is named for Dunleith Township, Illinois, and the type section is in the Mississippi River bluffs immediately across from Dubuque (Templeton and Willman, 1963; Willman and Kolata, 1978). In the type area, the formation is characterized by bedded dolomites, variably cherty and vuggy, and typically about 125 feet (38 m) thick. Two zones with comon receptaculitid algae (the so-called "sunflower corals") are found within the formation; these distinctive algae were previously identified as *Receptaculites*, but are now assigned to *Fisherites* (Delgado, 1983). The constituent members of the Dunleith are characterized by variations in chert content, and each is marked by an argillaceous to shaly zone near the top. Most of the members derive their names from streets or bluff localities in the Dubuque area (Beecher, Eagle Point [this stop], Mortimer, Rivoli, Sherwood, Wall, Wyota). The Dunleith Formation contains numerous hardground surfaces, sometimes termed "corrosion zones"; these are characterized by irregular sculpted surfaces, sometimes darkly stained by pyrite and apatite encrustation.

The Wise Lake Formation, unlike the underlying Dunleith, is primarily chert-free, and is, in general, a purer, less argillaceous vuggy dolomite interval. The upper receptaculitid zone is recognized within the Wise Lake (Fig. 1). The top-most formation of the Galena Group, the Dubuque, obviously derives its name from the city of Dubuque, and its type locality is found in the quarry and athletic field exposures on the campus of Loras College

(Delgado, 1983). The Dubuque Formation is a distinctive interval of thin to medium-bedded dolomite, each bed separated by a thin shale. The constituent members of the Dubuque are widely recognizable in the region (Levorson et al., 1979). The base of the Dubuque was previously drawn at the first shale interbed in the upper Galena sequence, but is now delineated at a widespread "marker bed" (ibid.). As such, uppermost Wise Lake strata in the area appear transitional with typical Dubuque lithologies.

The composite section of the Galena Group is based on a series of measured sections in the Dubuque area, including sections in Dubuque (Delgado, 1983), East Dubuque (Templeton and Willman, 1963; Willman and Kolata, 1978), and nearby Dickeyville, Wisconsin (Willman and Kolata, 1978). The Galena Group overlies strata of the Platteville Formation (Fig. 1), which are locally exposed near river level in northern part of the Dubuque area and points further north in the county. The top of the Galena Group is marked at the base of a regionally prominent phosphorite (basal Maquoketa Fm.) developed above a hardground at the top of the Dubuque Formation (see Stop 4 for more discussion).

The age of the Galena Group sequence is not precisely clarified, although the Decorah and Dunleith formations clearly belong within the late Champlainian Mohawkian Series (late Middle Ordovician), encompassing the Rocklandian, Kirkfieldian, and Shermanian stages. The upper Galena Group is an Upper Ordovician interval (Cincinnatian Series), although the exact position of the Middle-Upper Ordovician boundary is not known with certainty; it likely falls somewhere at or near the Dunleith-Wise Lake contact. The Wise Lake Formation includes strata at least in part of Edenian age (early Cincinnatian), and the Dubuque Formation is of Maysvillian age (middle Cincinnatian). Although the overlying Maquoketa Formation has commonly been correlated with a Maysvillian-Richmondian age, it now seems established that the Maquoketa is entirely of Richmondian age (late Cincinnatian), characerized by early Richmondian conodonts (*Amorphognathus ordovicicus*) at the base (see note in Witzke and Bunker, 1996). As such, it seems likely that the Wise Lake-Dubuque interval spans most if not all of the Edenian-Maysvillian stages, ranging considerably younger than previously thought.

Fossils and Sedimentary Features

Although many primary sedimentary fabrics have been diagenetically compromised by dolomitization, the Galena Group nevertheless displays a number of sedimentary features that serve to characterize these strata. Fossils are generally poorly preserved in the dolomite facies, but a number or marine invertebrate taxa have been recognized, generally preserved as porous molds. These include crinoid debris, brachiopods, rare trilobites, bryozoans, and molluscs. Parts of the Wise Lake Formation include horizons with common large gastropods (especially *Hormotoma, Maclurites*). Distinctive hemispherical colonies of trepostome bryozoans (*Prasopora*) are widely recognized in the upper St. James Member (Fig. 1). Likewise, three intervals within the Galena Group sequence are marked by distinctive occurrences of receptaculitid algae (the lower through upper receptaculitid zones shown on Fig. 1). These disc-shaped fossils, commonly 5-25 cm in diameter, are typified by *Fisherites*, whose geometry grossly resembles the seedhead of a sunflower (hence the misnomer, "sunflower coral" for these fossils). *Fisherites* is the dominant calcareous alga of the Galena, but *Ischadites* is also noted (a smaller algal form), especially in the middle receptaculitid zone.

Trace fossils are a noteworthy part of the Galena sequence, especially large complex networks of dwelling tunnels commonly assigned to the ichnogenus *Thalassinoides*. Commonly 1-4 cm in diameter, these tubes are often expressed in the dolomite exposures as branching networks that are slightly more porous than the surrounding rock. In limestone facies, these networks are commonly preferentially dolomitized. A distinctive vertical burrow, *Palaeosynapta*, is restricted to parts of the upper Stewartville and lower Dubuque formations. The numerous hardground surfaces in the Galena, and their associated hardground clasts (intraclasts), display small borings (*Trypanites*) to varying degrees, indicating that these surfaces were lithified while on the seafloor.

The origin of the common hardground surfaces in the Galena Group have been the subject of much debate, but all workers seem to agree that these formed in lithified sediment on the seafloor and represent a hiatus (interruption) in deposition. These oddly sculpted surfaces truncate the underlying bed, commonly 1 to 10 cm in depth. The surfaces are commonly bored, and are locally encrusted with bryozoa or crinoid holdfasts. Truncation along the hardground surfaces has been interpreted by some to relate to physical scour (generated by storm or wave currents), but the irregular surface form and overhanging edges seem difficult to generate by such physical processes. Other workers have suggested chemical corrosion on the sea bottom, with partial dissolution of the lithified carbonate sediments. The deposition of primary iron sulfides and apatite encrustations along some hardground surfaces (especially the so-called "blackened hardgrounds") provides evidence of varying bottom water chemistry during Galena deposition. A significant amount of time may be represented by the development of these hardground surfaces, marking episodes of nondeposition on the seafloor, possibly coincident with episodic sea-level rises.

Regional dolomitization of Galena Group carbonate strata occurred prior to the initiation of Silurian sedimentation in the region, and may have been associated with the migration of groundwater systems accompanying seaway withdrawal near the end of the Ordovician (Witzke, 1983). The development of secondary porosity likely accompanied regional dolomitization, which is marked by moldic and intercrystalline porosity as well as abundant vugs of varying size. Chert nodules are especially abundant in parts of the Dunleith Formation, and their development generally preceded dolomitization in the paragenetic sequence. Chertification of the carbonate sediments is regionally extensive, both in limestone and dolomite facies, and likely relates to the mobilization and reprecipitation of biogenic silica in the sediment (possibly derived from siliceous sponges).

The emplacement of zinc-lead mineralization in Galena Group strata of the region occurred later in the Paleozoic, possibly derived from hydrothermal fluids originating from basinal brines in the Illinois Basin or orogenic sources further to the south. It remains unclear why the Galena Group served as primary host for this economically-significant mineralization, as similar sulfide mineralization is also known in the region from Cambrian, Lower Ordovician, Silurian, and Devonian strata.

Galena Group Deposition

The presence of marine invertebrate fossils of stenohaline marine organisms throughout the Galena sequence indicates that deposition occurred when a seaway of normal-marine salinity flooded the continental interior. The Galena Group in the Iowa area is dominated by open-marine carbonate facies, but the lower portion, the Decorah Formation, is shale-dominated northwestward, toward siliciclastic sources on the Transcontinental Arch (Witzke, 1980). Minor influx of clay during later Galena deposition is marked by argillaceous horizons in the Dunleith, Wise Lake, and Dubuque formations. Galena Group sedimentation was entirely within subtidal marine settings, with no direct evidence of subaerial exposure recognized in the sequence.

Cyclic patterns of sedimentation are recognized within the Galena Group, as evidenced by the vertical stacking of carbonate and shale facies, punctuated at prominent carbonate hardground surfaces or thin condensed intervals. These patterns are summarized by Witzke and Bunker (1996) and Witzke and Kolata (1988). The initial transgressive-regressive (T-R) sedimentary cycle of the Galena Group encompasses the Decorah Formation, which overlies a regional disconformity at the top of the Platteville. The deepest-water facies of this cycle occur in the lower to mid Guttenberg Member, which includes organic-rich brown shale beds deposited in a stratified seaway (Ludvigson et al., 1996).

The remainder of Galena Group deposition below the mid Dubuque forms another broad-scale T-R cycle, the "Dunleith-Wise Lake subcycle" of Witzke and Kolata (1988), which can be further subdivided into a series of smaller-scale T-R cycles. Witzke and Bunker (1988) proposed three smaller cycles as follows: A) St. James through Mortimer members, B) Rivoli through Wyota members, and C) Sinsinawa through lower Frankville members. In general, these cycles display the deepest depositional facies in the lower part, with a general upward increase in calcareous algae and storm-generated grainstone layers recording broad-scale shallowing. Clay influx is associated with regional regression.

The abundance of hardground surfaces in the Dunleith-lower Wise Lake interval is of special note, with up to 55 individual hardgrounds noted in northeast Iowa (Levorson and Gerk, 1972). These mark episodes of sediment starvation associated with bottom erosion, corrosion, or dissolution, and many hardgrounds apparently formed coincident with minor transgressive pulses and/or widespread changes in bottom circulation. Some hardgrounds bound abrupt carbonate facies changes that record signficant deepening events, including several regionally prominent blackened pyritic and/or phosphatic hardgrounds.

The regularly bedded and broadly correlatable couplets of crinoidal carbonate and thin shale distinguishes the Dubuque Formation from all other units of the Galena Group. Unlike underlying Galena carbonates, middle and upper Dubuque strata lack calcareous algae and display a general increase in matrix mud consistent with overall depositional deepening (Bakush, 1985). The preservation of abundant organic-walled microfossils in the Dubuque indicates lower levels of bottom oxygenation during deposition than for underlying Wise Lake strata. These differences suggest a fundamental change in depositional style coincident with Dubuque deposition, recording a new cycle of deposition that presaged the onset of Maquoketa sedimentation. As such, the Dubuque is included with the first phase of the larger-scale "Maquoketa Cycle" of Witzke and Kolata (1988). The basal Maquoketa phosphorite caps the Dubuque, and marks a dramatically condensed section associated with regional transgressive deepening that terminated carbonate sedimentation over much of eastern Iowa and northern Illinois (see Stop 5).

Stop Description

Our field trip stop will examine Galena Group strata along the old approach to the former Eagle Point Toll Bridge (NE NE SE sec. 7, T89N, R3E), which now forms the parking lot for the Tollbridge Inn restaurant. We thank the Tollbridge Inn and General Manager Marianne Yount for access to this site. The toll bridge operated into the 1980s, but was removed when the new Highway 151 bridge bypassed this area. The adjoining Eagle Point (Duccini) Quarry provides an impressive view of nearly the entire sequence of Galena Group strata that forms the walls of the Mississippi River Valley in the Dubuque area. This stop lies just downstream from Lock and Dam No. 11, and immediately below Eagle Point Park (Stop 3). Eagle Point is well named, and is a favorite area for spotting bald eagles, particularly in the winter months.

There is little point in entering the Eagle Point Quarry, as the extreme shear face of the quarry affords little opportunity to directly inspect the Galena strata. Nevertheless, the displayed face of Galena strata provides a dramatic visual impression of the bedding characteristics of the dolomite layers. Calvin and Bain (1900, p. 423-424) described the geologic section from this quarry (the old "Eagle Point Lime Works"), noting 187 feet (57 m) of strata here. The face includes strata spanning from the basal Dunleith into the upper Wise Lake (mid Stewartville Member) formations, displaying all of the Galena Group except its lowermost (Decorah) and uppermost (Dubuque) units (see Fig. 1).

The old highway access to the toll bridge, now the parking lot for the Tollbridge Inn, provides a relatively safe place to inspect charateristic dolomite strata of the Galena Group. The accessible strata here belong to the lower Dunleith Formation, primarily (and appropriately) the Eagle Point Member. Trip participants are encouraged to examine these rocks for the following features: (1) Look at the dolomite beds, and identify its vuggy and porous character. (2) Networks of thalassinoid burrows are displayed in the strata, recognizable by their more porous aspect with respect to the surrounding rock. (3) Find some of the characteristic fossils in these beds, including scattered (and sometimes hard to recognize) crinoid debris and brachiopod molds. More evident are common receptaculitid algae, which here form part of the lower receptaculitid zone. (4) These are cherty strata, and nodular cherts are a characteristic feature of the Dunleith Formation.

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STOP 3: EAGLE POINT PARK – LANDSCAPE OVERVIEW

E. Arthur Bettis III

Eagle Point Park affords a panoramic view of the Mississippi River valley and upland surfaces to the east in the Driftless Area of southwestern Wisconsin and northwestern Illinois. The Mississippi Valley marks the eastern extent of glaciation in this part of the Paleozoic Plateau. Pre-Illinoian glacial till is present as eroded remnants on the Iowa side of the valley, but has not been documented between the Wisconsin River Valley of Wisconsin and the Plum River Valley in Illinois. East of the Mississippi Valley residuum formed from Paleozoic rocks and colluvium derived from residuum lie beneath a mantle of loess. Geologist A.C. Trowbridge observed that two distinct levels of concordant upland summits were present across the Driftless Area (Trowbridge, 1921). He concluded that these surfaces were old upland erosion surfaces (penneplains) that had developed in pre-glacial times. He named the upper surface the Dodgeville Penneplain and the lower and younger surface the Lancaster Penneplain after towns in Iowa County, Wisconsin where each level was well expressed. Later Trowbridge concluded that the Dodgeville was not an erosion surface but rather an expression of differential erosional resistance in the Paleozoic rock sequence (Trowbridge, 1954). Excellent examples of differential resistance are evident from Eagle Point Park. To the east Sisinawa Mound, an outlier of Silurian dolostone rises above the surrounding upland developed on Galena Group rocks. On very clear days other Silurian outliers can be seen to the northeast. Today the general consensus is that the concept of penneplaination probably doesn't apply to the dynamic landscapes of temperate regions. Nonetheless, studies by Knox and Attig (1988) suggest that much of the upland relief of today's Driftless Area was present before a million years ago.

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UPPER ORDOVICIAN BRAINARD SHALE (MAQUOKETA FORMATION); *STOP 4:* HIGHWAY 20, DUBUQUE COUNTY

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Introduction and Stratigraphic Nomenclature

The Brainard Shale, named after a locality near Brainard in northeast Iowa (Fayette Co.), is defined to be the shale-dominated interval above the Fort Atkinson Limestone and below the Neda Member in the upper Maquoketa Formation. This interval is readily definable in areas where the Fort Atkinson Member is developed, but the Fort Atkinson carbonate unit is absent over large areas of northwest Illinois and east-central Iowa, including Dubuque County. The entire Maquoketa Formation in Dubuque County is dominated by shale, without the characteristic carbonate (dolomite and limestone) intervals which conveniently subdivide the formation in the northeast Iowa outcrop into shale and carbonate members. In ascending order, these members are the Elgin Member (carbonate), Clermont Shale, Fort Atkinson Member (carbonate), and Brainard Shale. Because of this, the standard member subdivisions of the Maquoketa Formation are not directly applicable in Dubuque County.

Brown and Whitlow (1960) recognized this problem in the Dubuque area, and proposed an informal subdivision of the Maquoketa: a lower "Brown Shaly Unit," the Brainard Member, and topmost Neda Member. This subdivision apparently equated the sub-Brainard members of northeast Iowa, that is the Elgin, Clermont, and Fort Atkinson, with the "Brown Shaly Unit" of the Dubuque area. However, this correlation is probably incorrect, and the "Brown Shaly" more likely only correlates with the Elgin Member to the north (Witzke and Glenister, 1987). As such, the "Brainard" interval of Brown and Whitlow (1960) likely correlates with the Clermont, Fort Atkinson, and Brainard members to the north. This interval above the "Brown Shaly" in Dubuque County, dominated throughout by green-gray dolomitic shales, was informally referred to as "Clermont-Brainard shales undifferentiated" by Witzke and Glenister (1987). Although this term is clearly an awkward one, it recognizes the difficulty in correlating the base of the type Brainard Member into this largely indistinguishable thick shale package in Dubuque County.

With this caveat aside, the upper part of this green-gray shale package in Dubuque County is directly comparable to the type Brainard sequence exposed in Fayette County, and the term Brainard may be realistically applied to the upper half to two-thirds of this undifferentiated shale package in Dubuque County. The only real problem in such an application is delineating the basal contact of Brainard, but this remains a moot point, as only the upper part of the Brainard Shale interval is actually exposed in Dubuque County. The actual correlation of the basal contact of the Brainard Shale remains a problem presently confined to the subsurface. Examination of Maquoketa cores in Jackson County, which reveals a closely similar sequence to that seen in Dubuque County, suggests that the base of the Brainard likely correlates to a position in the green-gray shale sequence marked by (1) change from lighter to darker colored hues of green-gray, (2) shift from dolomitic to slightly dolomitic shale, and (3) phosphatic enrichment (apatite pellets) at the base. Kolata and Graese (1983) noted similar phosphatic enrichment in the basal Brainard of Illinois.

General Characteristic of Brainard Shale

The outcrop of Maquoketa Formation is geomorphically expressed in Dubuque County as broad sloping surfaces that separate steeper slopes above (Silurian) and below (Galena Group). Because the formation is shale-dominated in the area, the Maquoketa forms a relatively uniformly sloping surface. In the northern counties, prominent carbonate units in the formation interrupt the shale slopes, marked by breaks in slope.

The Brainard Shale Member is dominated by green-gray dolomitic shale. These shales are dolomitic to varying degrees, which is reflected by the slope and consistency of the contained shale units. Those shales that are only slightly dolomitic are typically soft and squishy (when wet) or platy to crumbly (when dry) on exposure. By contrast, the more dolomitic shales are more coherent on exposure, commonly breaking into irregular chunks; these are not particularly squishy when wet. The dolomitic shales grade into unfossiliferous argillaceous dolomites which interbed in the shale sequence as nodular units or thin shaly dolomite beds. Chunky to blocky dolomitic shales with argillaceous dolomite interbeds (some with scattered burrow mottles) become noteworthy in the upper part of the middle Brainard (e.g. units 3-5, Stop 4) in Dubuque County.

The Brainard shales typically appear with light to medium hues of green-gray to grayish blue-green. These shales are compositionally dominated by the clay mineral illite, with a significant secondary component of chlorite (Kolata and Graese, 1983), which likely imparts the greenish hues. The shales also contain scattered quartz silt. Small pyrite nodules are noteworthy in portions of the shale sequence, sometimes oxidized to secondary iron oxide minerals on weathered slopes. Concentrations of small phosphatic pellets (apatite grains and small fossil molds) are found at several positions within the shale interval, probably marking condensed horizons.

The Brainard Shale sequence contains interbeds of fossiliferous dolomite in the upper 3 to 10 m (10-35 ft) of the member in Dubuque County. The preservation of the fossils is generally extremely good, with the shell and skeletal material exquisitely replaced by microcrystalline dolomite (sometimes partially silicified). In fact, the skeletal preservation is so good, that it seems surprising that these fossiliferous carbonate beds are not actually limestone. However, these beds are indeed dolomite, with only minor amounts of calcite present. The carbonate fabrics displayed by these fossiliferous dolomites commonly vary vertically in the upper Brainard sequence (see Stop 6), ranging from sparsely fossiliferous mudstones in the lower part, skeletal mudstones in the middle part, and abundantly fossiliferous skeletal packstones to grainstones in the upper part. The Highway 20 exposure (Stop 4) does not follow this general pattern, however, with the most fossiliferous beds noted near the base.

The skeletal dolomite interbeds in the upper Brainard in Dubuque County commonly contain an abundance of macrocrystalline siderite (iron carbonate mineral, individual crystals commonly about a mm in diameter). The siderite usually fills or lines voids or interskeletal pores in the carbonate beds. The abundance of siderite commonly imparts a red color to the freshly broken surfaces of the dolomite interbeds, but the siderite commonly oxidizes to iron oxide minerals on weathered exposures. The diagenesis of these interesting carbonate beds has not yet been studied in detail, although it seems possible that the siderite infilling may be related to reduced nonmarine groundwaters that moved through these rocks following the withdrawal of the seas at the end of the Ordovician.

Fossils of the Upper Brainard Shale

The upper Brainard is an exceptional interval in which to collect a wealth of invertebrate fossils, and the preservation is commony excellent considering that they are dolomitized to silicified to varying degrees. The surfaces of the carbonate interbeds commony reveal an abundance of fossils, especially brachiopods, bryozoans, and crinoid debris. In addition, loose fossils can be collected along the shale slopes, weathering out of the shaly carbonates and intervening fossiliferous shales. Additionally, a unique pyritized to phosphatized fauna is present below the interval containing fossiliferous carbonate interbeds (e.g., see unit 2 description). Finally, phosphatized diminutive faunas (most fossils < 2 mm) occur in abundance in some horizons (e.g., see unit 6 description).

Fossils of the upper Brainard in the Dubuque area have received little systematic study, although Ladd (1929) and Frest et al. (1997) have provided listings of some upper Brainard faunas. A listing of the fauna recovered from fossiliferous carbonate interbeds in the upper Brainard of Dubuque County is provided in the accompanying table; these are contrasted with fossiliferous units in the upper Brainard of nearby Carroll County, Illinois (see Ludvigson and Witzke, 1988). As recognized in the area of Dubuque-Carroll counties, the upper Brainard faunas are far from uniform in their faunal composition, but are known to vary both vertically in the stratigraphic column as well as geographically. Several recurring associations of fossils, commonly termed fossil communities or paleocommunities (analogous to benthic

MACROFAUNAL LIST, UPPER BRAINARD MEMBER

A. Hwy. 20 roadcut, SW NE sec. 6, T88N, R2E, Dubuque Co., Iowa.
B. Hwy. 151 roadcut, SW NW sec. 23, T88N, R2E, Dubuque Co., Iowa
C. Wacker railroad cut, NW NW sec. 27, T24N, R4E, Carroll Co., Illinois
[**a** - abundant; **ca** - common to abundant; **c** - common; **r** - rare; **rc** - rare to common]

TAXON	A	B	C
BRACHIOPODA			
Inarticulata			
lingulid sp.	r	r	r
craniid sp.			r
Articulata			
Orthida			
Austinella sp.		r	
Diceromyonia subrotundata	r	rc	r
Glyptorthis sp.			c
Hebertella sp.	c	r	
Hesperorthis sp.		r	r
Onniella quadrata		r	rc
Plaesiomys spp.		rc	ca
Platystrophia sp.	r	r	c
Skenidioides sp.	r		
indet. fine-ribbed orthid			r
Strophomenida			
Holtedahlina sp.	r	r	r
Megamyonia unicostata		c	r
Oepikina sp.			r
Strophomena spp.	rc	r	c
Tetraphalerella planodorsata	r	r	r
Thaerodonta recedens	r	a	rc
Spiriferida			
Zygospira resupinata		a	
Rhynchonellida			
Hypsiptycha hybrida	rc	rc	c
Hypsiptycha neenah	rc	r	c
Lepidocyclus erectus	rc	r	a
Lepidocyclus gigas	c		ca
Rhynchotrema iowense	r	r	
BRYOZOA			
Trepostomata			
Atactoporella sp.	r	r	
Batostoma sp.	c	c	c
Bythopora sp.	ca	ca	ca
Eridotrypa sp.	ca	c	c
Hallopora sp.	r	r	c
Hemiphragma sp.	ca	ca	ca
Homotrypa sp.	ca	ca	ca
Prasopora sp.			c
Trematopora sp.	r	r	
indet. trepostome spp.	a	a	a
Cryptostomata			
Arthropora sp.	rc	c	c
Helopora sp.	rc	ca	ca
indet. cryptostome spp.	c	ca	ca
Cyclostomata			
indet. encrusting cyclostomes		r	

TAXON	A	B	C
Ctenostomata			
indet. encrusting ctenostomes		r	r
MOLLUSCA			
Gastropoda			
Bucania sp.		rc	
Bucanopsis sp.		r	
Cyclonema sp.		r	
Cyrtolites sp.		r	
Donaldiella sp.		rc	
Holopea sp.		r	
Hormotoma sp.		rc	
Liospira sp.		rc	
Lophospira sp.		rc	
Loxoplocus sp.		r	
indet. gastropod spp.		c	r
Bivalvia			
Ambonychia sp.		r	r
Byssonychia sp.		rc	
Cyrtodonta sp.		r	
Modiolopsis sp.		r	
Palaeoneilo sp.		r	
Pterinea sp.		rc	
Cephalopoda			
indet. nautiloid spp.		rc	r
ECHINODERMATA			
Crinoidea			
Carabocrinus sp.	r	r	r
Cupulocrinus angustatus		r	
Cupulocrinus spp.	c	r	r
Dendrocrinus casei		c	
Dendrocrinus spp.	c	c	c
Porocrinus crassus	r	r	r
indet. crinoid material	a	c	c
Rhombifera			
indet. cystoid spp.		r	r
PORIFERA			
indet. sponge spp.		r	
CNIDARIA			
Rugosa			
Helicelasma sp.		r	
TRILOBITA			
Calliops sp.	r	r	
Ceraurus sp.		r	r
Flexicalymene sp.	r	r	r
Gravicalymene sp.		r	
Isotelus sp.		r	r
indet. asaphid sp.		r	
indet. calymenid spp.	r	r	r
MISCELLANEA			
Cornulites sp.	r	c	r

communities in the modern world), can be recognized.

The first such association is here termed the *Hypsiptycha-Plaesiomys*-trepostome-crinoid (HPTC) community, after several dominant fossils. This association is typified by unit 6 at this field stop (Stop 4). It is dominated by abundant crinoid debris, including common barrel-shaped columnals of *Cupulocrinus*, in association with common to abundant branching trepostome bryozoans. Brachiopods occur in this association, but are clearly subordinate to the crinoids and bryozoans. A variety of brachiopods are recognized (see table), dominantly *Hypsiptycha* and *Plaesiomys*, but with common *Platystrophia* and *Strophomena*, and a few rarer forms. A variety of large and unusual burrow forms are recognized in this association, including tapered, fluted, and crenulate burrows up to 4 cm in diameter not seen in any other association. Trilobite debris is present. This association differs significantly from the more characteristic upper Brainard *Thaerodonta-Cupulocrinus-Cornulites* (TCC) community (discussed subsequently) in several important ways: (1) the sowerbyellid brachiopod *Thaerodonta* and primitive spiriferid *Zygospira*, which are remarkably abundant in TCC, are absent in HPTC; (2) the enigmatic ribbed and tapered "worm" tube usually termed *Cornulites* (which characterizes the upper Brainard "*Cornulites* zone" of Ladd, 1929), is a consistent and common component of the TCC, but is virtually absent from the HPTC; (3) a molluscan component, including a variety of gastropods and epifauna bivalves, is characteristic of the TCC, but is primarily absent in the HPTC.

A second association is recognized in the upper portions of the Stop 4 roadcut (units 7, 8) which is here termed the *Lepidocyclus-Hebertella* community. It is dominated by relatively large brachiopods, primarily the name-bearers as well and *Hypsiptycha*, with lesser numbers of the brachiopods *Platystrophia*, *Strophomena*, and rare *Thaerodonta*. Echinoderm debris is variably present, as are trepostome bryozoans. This association has also been observed in upper Brainard strata of Fayette and Winneshiek counties in northeast Iowa.

The dominant association of the upper Brainard in the area, although not displayed at this field trip stop, is the previously mentioned *Thaerodonta-Cupulocrinus-Cornulites* (TCC) community, which is described and typified by Frest et al. (1997). This recurring faunal grouping is known to occur in Fayette, Dubuque, Jackson, and Carroll counties, as well as parts of eastern Wisconsin. A remarkable abundance of the flat-shelled sowerbyellid brachiopod *Thaerodonta recedens* is overwhelmingly characteristic, along with common to abundant small spiriferids *Zygospira resupinata*. In addition, the "worm" tube *Cornulites* is ubiquitous. A variety of echinoderms, including the distinctive *Cupulocrinus* columnals, are present, but crinoid debris is not as abundant as seen in the HPTC. Bryozoans, primarily trepostomes, are common. Molds of gastropods and epifaunal bivalves are relatively common in the TCC, along with scattered trilobites and sponges. An excellent exposure of the TCC community occurs south of Dubuque along Highway 151, approximately one half mile west oof the U.S. Highway 61 interchange.

The lowest fossiliferous dolomite interbeds in the upper Brainard sequence are often typified by sparsely skeletal argillaceous mudstones to wackestones at many localities, and the contained faunas are usually dominated by brachiopods encompassing a variety of strophomenids (including *Megamyonia*, *Holtedahlina*, *Tetraphalerella*, *Strophomena*, *Thaerodonta*) and some orthids. Large specimens of trilobites are locally noted (*Isotelus*). This assemblage is interpreted to represent a slightly deeper water and more dysoxic benthic association than the TCC.

Additional benthic associations are present in the upper Brainard, typified by faunas at the Wacker railroad cut in Carroll County (see Table), and are briefly noted here. In particular, brachiopod associations are unlike faunas seen in nearby Dubuque County, dominated by *Lepidocyclus* and *Plaesiomys* and co-occurring with lesser numbers of *Platystrophia, Hypsiptycha, Strophomena, Glyptorthis, Onniella, Oepikina*, and others. Echinoderm debris (including *Cupulocrinus*) and bryozoans are commonly associated in these faunas, and large hemispherical colonies of the trepostome *Prasopora* are prominent in some beds.

The faunal variations seen within equivalent upper Brainard strata in the area is of particular note, as relative faunal homogeneity characterizes many Middle Ordovician and Silurian stratigraphic units over large geographic areas. Why the local variations in faunal content over relatively short distances seen in the upper Brainard? The answer to this question is not readily apparent, but it can be assumed that variations in benthic environmental parameters were undoubtedly at play. These likely included varying water depth, intensity of storm current activity, available substrate, degree of bottom oxygenation, and other indeterminate factors.

Two additional benthic invertebrate faunas, quite unlike any described above, also occur within the upper Brainard interval, typified by occurrences at this field trip stop (Stop 4). These faunas are pyritized or phoshatized, with replacement of skeletal material by pyrite or infilling of internal molds by phosphate minerals (apatite). Unit 2 at this stop contains a remarkable pyritized and phosphatized fauna, which Frest et al. (1997) termed the *Diamphidiocystis-Bucanopsis* Association. Although fossils are not particularly abundant in this shale unit, a variety of loose fossils locally weather out of this interval, most ranging between 3 and 20 mm in size, apparently patchy in their occurrence (especially the echinoderms). This association is numerically dominated by a variety of gastropod taxa (chiefly *Bucania, Hormotoma, Liospira*), with a variety of other molluscs (nautiloids *Isorthoceras*; bivalves *Palaeoneilo, Nuculites*). This molluscan grouping is taxonomically similar to associations seen in the phosphatized diminutive faunas (see subsequent discussion and Stop 5), and it appears that it may represent the same general faunal association, only deposited under benthic environmental conditions that allowed individuals to survive longer and grow larger.

A remarkable component of this pyritized-phosphatized fauna includes an assemblage of articulated echinoderms, displaying fine-scale preservation of cups (theca), arms (brachioles), and stems. The strange extinct echinoderm group, the stylophoran carpoids, dominate the echinoderm assemblage, but a number of articulated crinoids also occur (see unit descriptions for listing).

Finally, some horizons within the upper Brainard (as well as parts of the lower Brainard) contain an abundance of phosphatized dimunitive fossils. "Diminutive" refers to the small size of these fossils, which rarely exceed 1 to 2 mm in size. The phosphatized diminutive faunas recur at several stratigraphic positions within the Maquoketa sequence, especially the basal part, and are more thoroughly considered in the discussion under Stop 5. These faunas are typically dominated by a number of tiny gastropod taxa, with additional bivalves, brachiopods, hyoliths, and others. An abundant diminutive fauna occurs in the basal parts of unit 6 at this stop, and can be recovered by acid disaggregation of the dolomite. The fauna resembles those seen in the lower Maquoketa (see listing under unit 6 desciption), but differs in containing an abundance of phosphatized molds of tiny bryozoans.

Brainard Deposition

The Brainard Member forms a discrete transgressive-regressive (T-R) sedimentary cycle of deposition, as discussed by Witzke and Kolata (1988) and Witzke and Bunker (1996). In general, the Brainard sequence is marked by the deepest depositional facies in its lower part, with progressive upward-shallowing through the interval, culminating in the expansion of mixed fossiliferous carbonate deposition at the top. A vast influx of siliciclastic material marked Brainard deposition regionally, with a broad uniformity of sedimentation over its extensive expanse (which covers Iowa, Illinois, Wisconsin, and Indiana). The Brainard shales are physically continuous with siliciclastic units of the eastern United States (Queenston Fm. and related units) which derived from the rising Taconic orogen (Appalachian area). As such, the Brainard shales were apparently sourced from distant Taconic sources (Witzke, 1980), some 1400 km to the east. The westward facies change to carbonate-dominated upper Maquoketa strata across Iowa indicates that the geographically closer Transcontinental Arch was not the primary source of the Brainard clay influx.

The unfossiliferous character of most of the Brainard sequence strongly suggests that benthic conditions were unsuitable for the proliferation of benthic faunas through much of the deposition of the member. The environmental factor which served to exclude skeletal benthos through most of Brainard deposition is interpreted to be oxygen availability, and benthic conditions were likely dysoxic to anoxic for extended times (see depositional model discussed under Stop 5). As bottom oxygenation increased slightly, probably associated with general shallowing, a few taxa of burrowing organisms were able to inhabit the bottom environments. The upper Brainard is marked by a general increase in burrowing, and an increase in the proliferation of normal-marine invertebrate taxa. This is interpreted to result from increasing availability of well-oxygenated environments associated with general depositional shallowing. In addition, carbonate fabrics reflect increasing bottom current activity upward through the sequence, with packstone-grainstone beds most abundant near the top of the sequence. This is interpreted to reflect increasing impingement of storm currents on the bottom associated with depositional shallowing. Succeeding deposition of the Neda Member likely marked a shift in this general trend, as discussed under Stop 6.

Stop Description

This stop is along the busy right-of-way of Highway 20 (Fig. 1), and trip participants are strongly discouraged from crossing the highway. Essentially the same stratigraphic section is exposed on both sides of the highway (see Figure 2 and unit descriptions). The lowest units are exposed along the ditch at the north end of the exposure. A close examination of material weathering out of unit 2 may yield articulated pyritized crinoids and carpoids and other fossils. However, most the lower half of the shale outcrop is unfossiliferous. Unfossiliferous nodular carbonates appear upward in the interval, as the shale becomes more blocky and dolomitic. Some burrows are evident.

Figure 1. Photograph of exposures of the Brainard Shale Member, Maquoketa Formation, at Stop 4, on the north side of U.S. Highway 20 about 2 miles southwest of Dubuque.

A ledge of dolomite (unit 6) is prominent across the exposure, and this interval will be of particular interest to trip participants. It is richly fossiliferous, with an abundance of well-preserved echinoderm material, bryozoans, and brachiopods, contained as skeletal packstones to grainstones. Close examination will reveal additional fossils, including several trilobite taxa (usually disarticulated). The distinctive barrel-shaped crinoid columnals are diagnostic for the crinoid *Cupulocrinus*. Additional crinoid plates are identifiable as *Carabocrinus*, *Porocrinus*, and probably some other taxa.

The dolomite ledge (unit 6) is also notably rich in siderite, evident as red-colored cements and void fills. The siderite is especially notable on freshly broken surfaces, so take a rock hammer and crack open a few pieces. The identification of this red mineral as siderite was confirmed by x-ray diffraction. A rich phosphatic diminutive fauna can also be recovered from the basal part of this ledge, easily recovered by acid disaggredation.

The upper slopes are partially covered and overgrown, but the general lithologies are clearly evident (units 7, 8). Interbedded shale and thin fossiliferous dolomite beds are intermittently exposed. Large brachiopods weather out of this interval, and can be collected along the slopes, especially *Hebertella*, *Lepiodocyclus*, and *Hypsiptycha*. These brachiopods are not as well preserved as seen in unit 6. The uppermost unit of the Brainard (unit 9) is highly oxidized and weathered, and no fossils were observed.

A ledge of dolomite is exposed in the uppermost portions of the outcrop, which, based on general lithology, is assigned to the Silurian Tete des Morts Formation (see Stop 6). As Highway 20 climbs up the escarpment a short distance to the south, a more complete section of Lower Silurian strata is exposed (Tete des Morts and Blanding formations).

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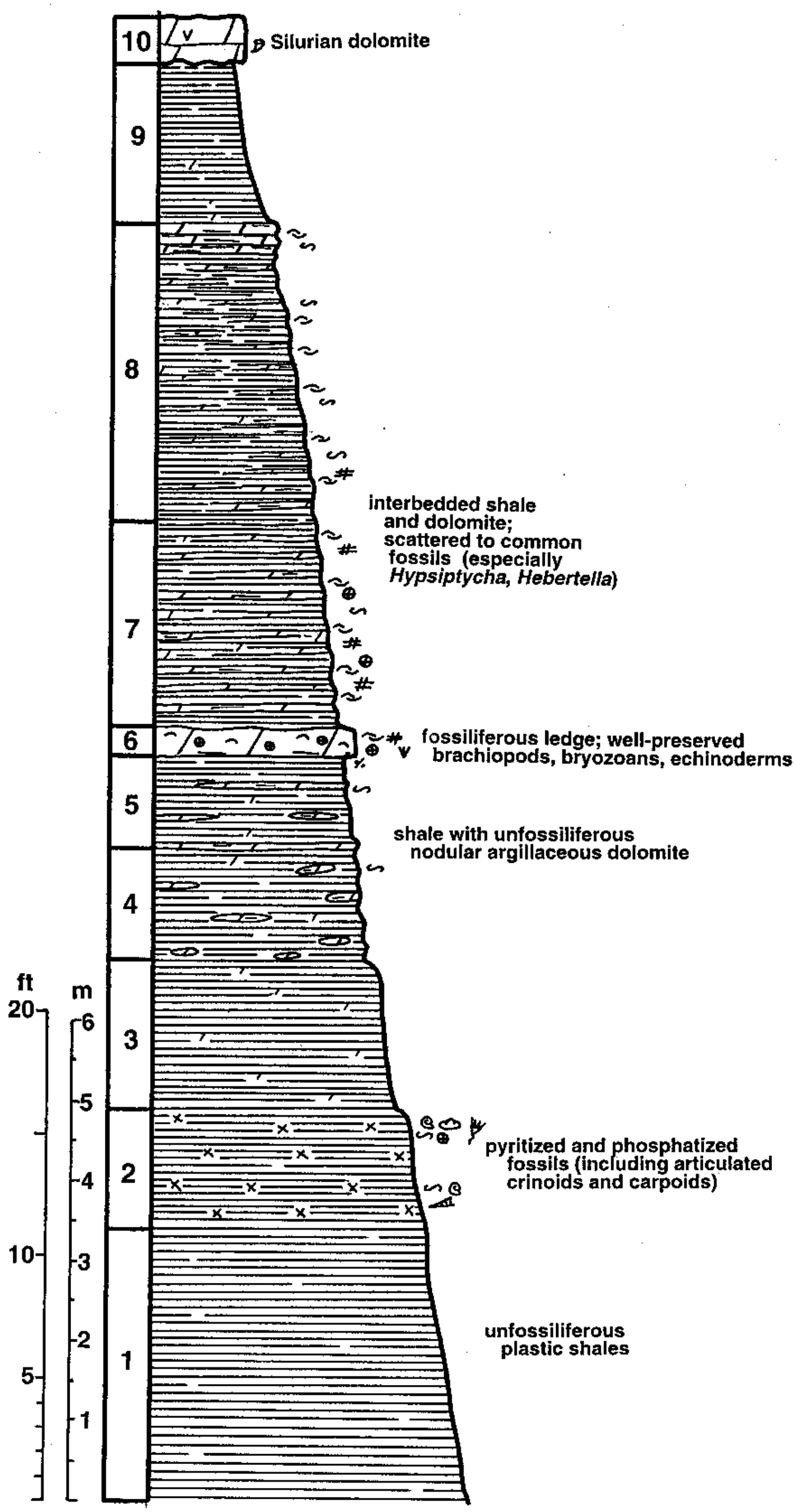

Figure 2. Graphic section of the Brainard Shale and overlying Silurian rocks exposed at Stop 4 along U.S. Highway 20 southwest of Dubuque (location: SW SW sec. 6, T88N, R.7E.). See Stop 5 for lithologic and paleontologic symbols.

HIGHWAY 20 ROADCUT

SW NE sec. 6, T88N, R2E, Dubuque Co., Iowa
measured B.J. Witzke and R.R. Anderson, 3/6/1997

SILURIAN

Tete des Morts Fm.

UNIT 10. Dolomite ledge, poorly exposed at top of section in southwest area; vf-f crystalline, scattered small vugs, microporous mottles; scattered chalcedony-filled voids and silicified corals; maximum thickness to 55 cm.

UPPER ORDOVICIAN

Maquoketa Fm.

Brainard Member

UNIT 9. Shale, green-gray (oxidized to yellow-gray where weathered); mostly covered; contains small nodular dolomites; no fossils noted; 2.05 m.

UNIT 8. Shale, green-gray, dolomitic; interbedded with thin beds (mostly 1-3 cm) and nodules of sparsely fossiliferous dolomite (with skeletal mudstone to wackestone fabrics); scattered horizontal burrows preserved as dolomite networks; scattered large brachiopods, mostly *Hebertella, Lepidocyclus, Hypsiptycha,* with rarer *Strophomena, Platystrophia, Thaerodonta*; rare trepostome bryozoans in lower part of unit; top 30 to 40 cm of unit marked by ledges of thin-bedded (2-10 cm) dolomite, skeletal mudstone with packstone-filled burrow networks; unit is partially covered to overgrown, base of unit is gradational; differs from unit 7 in being slightly less fossiliferous and in the general scarcity to absence of echinoderm and bryozoan material; 3.7 m.

UNIT 7. Shale, green-gray, dolomitic; interbedded with nodular to bedded dolomite, similar to unit 8, but thicker dolomite beds (1-10 cm) in lower part, thinner (1-3 cm) above; dolomite beds with skeletal mudstone to wackestone fabrics, scattered packstone, slightly more fossiliferous than unit 8; scattered dolomitic burrow networks; fossils not as well preserved as in unit 6; scattered to common large brachiopods, mostly *Hebertella, Lepidocyclus, Hypsiptycha*, with rarer *Strophomena, Thaerodonta*; scattered crinoid debris (articulated crinoid material noted rarely) and trepostome bryozoans, primarily in lower half; 2.5 m.

UNIT 6. Dolomite, prominent hard ledge-former, slumped blocks common on slope below; displays skeletal packstone to grainstone fabrics, some grain abrasion; very fossiliferous, abundant well-preserved echinoderm debris, common bryozoans and brachiopods, rare trilobites (see accompanying faunal list for more complete inventory); scattered small to large horizontal burrows along upper bedding surface, some to 4 cm diameter; common to abundant crystalline siderite cements and void fills, unoxidized siderite imparts a red color along freshly-broken surfaces, commonly oxidized to red-brown iron-oxide on exposure; scattered pyrite nodules and void fills; basal part of unit is argillaceous and phosphatic, with an abundant phosphatized diminutive fauna, dominantly molluscan, including gastropods (*Cyclora, Liospira Cyrtolites, Tropidodiscus, Cyclonema, Loxoplocus, Hormotoma*), bivalves (*Palaeoneilo, Ctenodonta*), bryozoa (2 spp. trepostomes, 3 spp. cyclostomes), brachiopods (*Diceromyonia, Zygospira*), echinoderms (crinoid columnals, brachials, cup plates; cyclocystoid and starfish plates), and a few others (*Hyolithes, Plagioglypta*, trilobite spines); scattered phosphatic material through unit; in one to two beds, 20-35 cm thick.

UNIT 5. Shale, green-gray, dolomitic, chunky, with interbedded discontinuous nodular argillaceous dolomites 2-5 cm thick, nonskeletal; base of unit marked by more-or-less continuous thin dolomite bed; scattered horizontal burrows; similar to unit 4; 1.15 m.

UNIT 4. Shale, green-gray, dolomitic, chunky; interbedded discontinuous nodular dolomites 2-5 cm thick (up to 1 m wide), nonskeletal; base of unit marked by minor break in slope; 1.4 m.

UNIT 3. Shale, green-gray to blue-gray, chunky; less plastic and more dolomitic than shales below, scattered small pyritic nodules (less common than unit 2); 1.8 m.

UNIT 2. Shale, green-gray, plastic when wet, less dolomitic than above; scattered to common small pyrite and phosphate nodules; scattered burrows, some pyritized; scattered pyritized and/or phosphatized fauna, most 5-15 mm, mollusc-dominated, including gastropods (*Liospira, Hormotoma, Cyrtolites, Bucania, Loxoplocus*), bivalves (*Palaeoneilo, Nuculites, Palaeoconcha, Ctenodonta, Arisaigia*), nautiloids (*Isorthoceras, Beloitoceras*), brachiopods (*Zygospira, Glyptorthis, Orbicuoidea*), sponges (*Hindia*), trilobites (including ceraurids), and indet. small bryozoa; pyritized echinoderm fauna found in patches (mostly in upper part of unit), isolated stems and plates, also includes well-preserved fully articulated forms (with arms and stems), stylophoran carpoids (*Diamphidiocystis* n. sp., *Enopleura wetherbyi*), crinoids (*Cupulocrinus, Dendrocrinus* spp., *Compsocrinus, Trichinocrinus*, indet. camerate), rhombiferan cystoid (*Antartiocystis*), edrioasteroid (*Pyrgocystis*); 1.5 m.

UNIT 1. Shale, medium green-gray, plastic when wet, dolomitic (less so than overlying units); generally featureless, no carbonate beds noted; no burrows noted; base of exposure in ditch at northern end of roadcut; 3.4 m.

LOWER MAQUOKETA PHOSPHATIC AND ORGANIC-RICH FACIES, UPPER ORDOVICIAN, DUBUQUE COUNTY;
STOP 5: GRAF

Brian J. Witzke and Richard C. Heathcote

Introduction

James Hall (1858) was the first to recognize that a shale-dominated interval, the "Hudson River Group," separates the Galena Dolomite from the overlying "Niagara" (Silurian) in eastern Iowa. Hall's primary exposure of these rocks was located in the Little Maquoketa River Valley near present-day Graf. There he observed "orthoceratite beds" (i.e., nautiloid-rich beds), graptolitic shales, and abundance of "extremely small" fossils (phosphatized diminutive fauna). Charles White (1870) named this sequence of Ordovician shales the "Maquoketa Shales" after "typical localities on the Little Maquoketa River about twelve miles westward from Dubuque" (i.e., near Graf). Joseph James (1890) described a railroad cut exposed in 1886 near the "Graf station," which he termed the "typical locality of the shales in Iowa." This same general section is accessible today, but has been expanded to the northwest by subsequent county road construction. Additional descriptions of the Graf section are given by Calvin and Bain (1900), Thomas (1914), Tasch (1955), Witzke and Glenister (1987), and Raatz (1992).

The Graf exposure (S ½ NW SW sec. 29, T89N, R1E; Fig. 1) is recognized as the type locality of the Upper Maquoketa Formation (Witzke and Glenister, 1987), although the bulk of the Maquoketa Shale sequence is represented by covered slopes above the roadcut. In some respects, however, the Graf exposure provides a rather untypical impression of the Maquoketa Formation, as it is represented at Graf by a series of rather unusual phosphatic facies and brown organic shales that do not necessarily reflect the regional characteristics of the formation. In fact, the lower Maquoketa is represented by a unique and fascinating group of rocks that is largely restricted to Dubuque County, including phosphatic dolomites and nautiloid-rich beds.

Figure 1. Photograph of Stop 5, exposure of lower Maquoketa Formation strata on the northwest side of the county road near the southwest edge of Graf.

Upland well penetrations indicate that the total Maquoketa sequence near Graf approximates 235 feet (72 m) in thickness 9 (Fig. 2). As noted for Stop 4, the formation in the area is subdivided into three basic units (Brown and Whitlow, 1960; Witzke and Glenister, 1987), in ascending order: (1) the "brown shaly unit," (2) a green-gray shale-dominated interval informally termed the "Clermont-Brainard undifferentiated" (see Stop 4), and (3) the Neda Member (see Stop 6). The "brown shaly unit" of Brown and Whitlow (1960) most likely correlates with the Elgin Member to the north, which is well exposed in Clayton, Fayette, and Winneshiek counties in northeast Iowa. The Elgin Member is dominantly a limestone and dolomite interval, cherty in part, with lesser amounts of shale interbeds; it contains characteristic trilobite-dominated faunas, which grade northward near the Minnesota border to include Brainard-like faunas of brachiopods and bryozoans. To the south and east, the "brown shaly unit" grades into a shale-dominated interval of brown organic graptolitic shales and green-gray dolomitic shales that are termed the Scales Shale in northwestern Illinois (Kolata and Graese, 1983). Dubuque County, and the Graf exposure specifically,

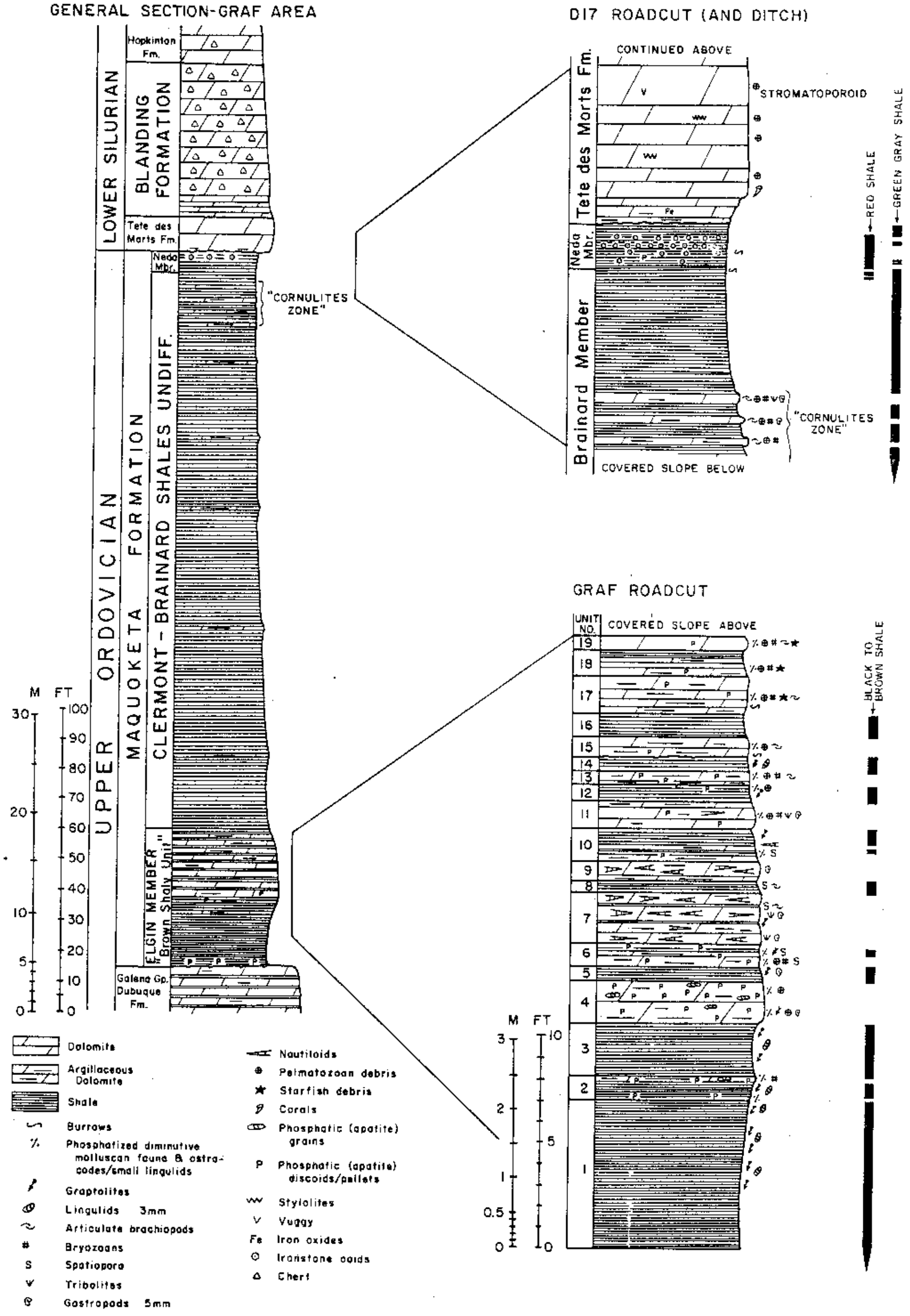

Figure 2. Stratigraphy in the Graf area. General section at left is a composite of outcrop sections and well penetrations in the area. Enlarged sections at right from measured descriptions in the Graf area (Stops 5 and 6). From Witzke and Glenister (1987).

occupies an intermediate position, where the distal carbonate facies of the Elgin carbonates interbed and interface with the Scales Shale.

Lower Maquoketa Stratigraphy, Dubuque Area

Lower Maquoketa strata of the "brown shaly unit" in the Dubuque area show complex lateral facies changes over short distances (Fig. 3). Throughout the area, basal Maquoketa strata are marked by a granular phosphorite above a sculpted hardground surface on top the Dubuque Formation. The basal phosphorite ranges from about 10 to 100 cm in thickness. The phosphorite also displays numerous hardground surfaces and apatite crusts internally, supporting the idea that it represents a considerably condensed section. The phosphorite is overlain by, and interbedded with, chocolate brown organic shales, commonly with graptolite fragments and scattered to common small lingulid brachiopods. The phosphorite and overlying brown shale interval is widespread in the basal Maquoketa, and is known to occur as far north as southern Allamakee County, Iowa, and as far east as Indiana (Witzke, 1980). The upper part of the "brown shaly unit" includes an interesting series of phosphatic dolomite beds, interbedded with brown shales, that are primarily restricted to Dubuque County. These include dolomites with abundant phosphatized diminutive fossils as well as beds with common to abundant nautiloids (Fig. 2). Brown (1966) observed that in the Dubuque area, "the phosphatic zone is thicker and appears to be richer there than elsewhere in the region."

The nautiloid-rich beds are best developed at Graf (units 7, 9). Nautiloid-bearing units eastward into the Dubuque metropolitan area (Tschiggfrie Weber Quarry; Center Grove) occupy the same relative stratigraphic position in the lower Maquoketa sequence and are likely correlative (Fig. 3). These more distal nautiloid-bearing units contain notably lower densities of nautiloids than seen at Graf. The interbedded dark organic shales in the upper part of the "brown shaly unit" show prominent phosphatic laminations, in part, and are graptolitic to varying degrees. Farther to south and east in eastern Iowa and northern Illinois, the lower Maquoketa sequence becomes less dolomitic and phosphatic, and is dominated by brown to gray shales (see Fig. 3). This interval is termed the Scales Shale of Maquoketa Group in Illinois (Kolata and Graese, 1983). The brown shales are particularly organic rich in the basal part, which includes the chocolate-brown "Argo Fay Bed" of Kolata and Graese (1983).

In general, lower Maquoketa strata in the Dubuque area can be interpreted to represent the distal margin of the Elgin Member carbonates which grade into shale-dominated strata of the Scales Shale. Unique phosphatic and organic-rich facies characterize the Dubuque County area. The interval appears to thin notably to the south and east, based on correlation of dolomite beds in Dubuque County (Fig. 3). This thinning marks the transition from inner-shelf carbonate platforms environments of the Elgin Member, into basinward middle-shelf shales of Scales Shale (Witzke and Bunker, 1996).

Lower Maquoketa Lithologies

The rock types identified in lower Maquoketa strata include some of the most unusual sedimentary rocks to be found anywhere in the Paleozoic of the North American interior. The shales are composed primarily illite with lesser chlorite (Kolata and Graese, 1983). Most shales occur in varying shades of brown, ranging from light brown-gray to deep chocolate brown. The color differences are a reflection of organic content, with the deepest shades of brown containing the highest organic values. The dark brown shales have measured total organic carbon contents ranging from about 7 to 16% (ibid.; Guthrie, 1994). The shales range from fissile to chunky, and, where unweathered, are pyritic to varying degrees. Most shales are unburrowed, but some include *Chondrites* and other burrows. Graptolite debris as well as whole graptolite rhabdosomes occur in many of the shales, and some bedding surfaces locally display abundant graptolites. Other fossils are generally scarce, but small lingulid brachiopods occur in great profusion on some bedding surfaces in the lower part (e.g. units 1, 3 Graf; lower Tschiggfrie, Fig. 3).

The basal Maquoketa phosphorite is a fascinating and unusual lithology. It is a true phosphorite, primarily composed of small discoidal pellets of apatite (most <2 mm) and a wealth of tiny phosphatic fossil

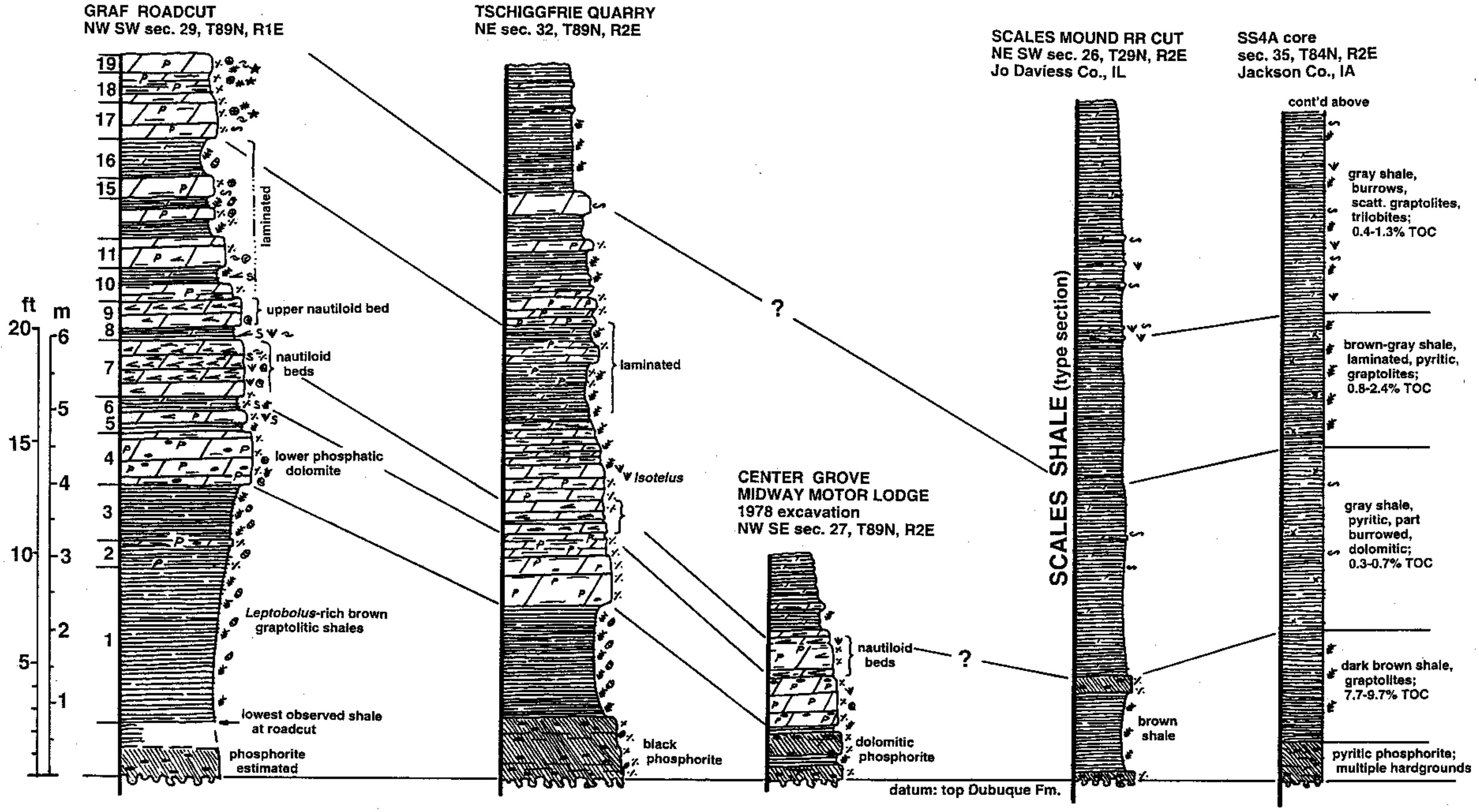

Figure 3. Stratigraphic cross-section of lower Maquoketa strata in the Dubuque area. Graf section at left (Stop 5); Tschiggfrie's Weber Quarry and Center Grove sections are from exposures immediately south of Highway 20 in the western part of the Dubuque metropolitan area; Scales Mound and Jackson County core section included for comparison. Total organic carbon values (TOC) from Guthrie (1994). Correlation lines queried where uncertain. Symbols as in Figure 1; phosphorite is cross-ruled.

molds (most <4 mm). The small pellets are flattened like flax seed, and are concentrically laminated around a phosphatic nucleus (commonly a fossil fragment). In addition, thick 1-to-2-cm crusts of apatite and large irregular apatite clasts (1-5 cm) occur within the phosphorite. The crusts commonly include both pyrite and apatite encrustations, sometimes with borings or pits. The phosphorite is poorly sorted, including silt, sand, and gravel-sized clasts in a fine clayey to dolomitic matrix. The phosphorite is typically black and pyrite cemented where fresh and unweathered, but it typically dissaggregates into loose phosphatic grains in a poorly consolidated red ferruginous matrix on weathered exposures. It is locally dolomite cemented. Fresh exposures and rock cores of the phosphorite commonly show it to contain a complex stacking of hardground surfaces and apatite encrustations. Thin phosphatic brown shales interbed with the phosphorite, and additional phosphorite layers locally interbed stratigraphically higher in the brown shale sequence.

The phosphorite contains varying quantities of organic carbon, commonly 2 or 3%, but ranging from about 0.6 to 12% (Brown, 1966; Guthrie, 1994). The phosphorite contains a number of minor elements in trace amounts, most notably Ba, Ce, La, Sr, and Y (Brown, 1966, 1974). Void spaces in the phosphorite are locally lined with fluorite or calcite.

Carbonate beds in the lower Maquoketa sequence are entirely dolomitic, and most are phosphatic to varying degrees. Some dolomites are extremely phosphatic (e.g., unit 4 Graf, 60% apatite by weight, Bromberger, 1965), containing an abundance of apatite pellets and fossil molds. Most of the dolomites are argillaceous to varying degrees, and have a petroliferous odor when freshly broken. Some of the higher dolomites in the Graf sequence include dolomitized skeletal debris (crinoids, bryozoans, brachiopods), and occasional trilobites and normal-sized gastropods and bivalves are seen in the lower dolomites. *Isotelus* trilobites are scattered to common in a thin interval in Dubuque (Tschiggfrie).

The Graf exposure is renowned for the exceptional accumulations of orthoconic nautiloids, especially in units 7 and 9 (Fig. 2). These nautiloid beds are slighly argillaceous to argillaceous, microcrystalline to finely crystalline dolomites that are slightly to highly phosphatic. The nautiloids average about 2 cm in diameter and occur in packed concentrations variably displaying parallel or random orientations. The shells are typically unbroken, but some individuals are telescoped into other shells penetrating fractured septa. Many specimens of *Isorthoceras* display a lustrous sheen that resembles pearly aragonite. However, the original shell material, including the nacreous layer, was "secondarily phosphatized at an early diagenetic stage" preserving the "original ultrastructure" (Mutvei, 1983) Co-occurring trilobite molts also preserve a phosphatized skeletal ultrastructure (Mutvei, 1981).

Lower Maquoketa Paleontology

Lower Maquoketa strata contain fascinating assemblages of fossils, primarily recovered from the phosphatic intervals. These are the famous diminutive faunas, which are characterized by vast numbers of tiny phosphatic fossils (most <2 mm). The basal Maquoketa zone of tiny fossils was recognized as early as 1854 by Daniels (1854) in southwest Wisconsin, who called it the "*Nucula* shale" after the common nuculid bivalves found in it; he described it as a "fossil Lilliput" zone. The basal phosphorite has been termed the "depauperate zone" (Ladd, 1929), a misnomer referring to the diminutive nature of the contained fossils. However, the fauna is far from "depauperate," and contains an abundance and diversity of fossils. The Maquoketa diminutive faunas have been studied by a number of workers, most notably Ladd (1929), Ojakangas (1959), Harrison and Harrison (1975), Bretsky and Birmingham (1970), and Snyder and Bretsky (1971), and Frest et al. (1997).

The faunal list of lower Maquoketa fossils is dominated by diminutive forms (see Table 1 and Fig. 4), primarily molluscan in composition. A great abundance of tiny gastropods, bivalves, chitins, and scaphopods characterizes most diminutive faunas (see Table 1), but additional fossils also occur in varying abundance. Small inarticulate brachiopods are common (*Leptobolus*), with some scattered articulate brachiopods. Echinoderm debris, hyoliths, conularids (*Climaconus* and tube-like phosphatic forms of *Sphenothallus*), sponges, and bryozoans are present in lesser numbers. Three-dimensionally preserved molds of graptolites (*Orthograptus, Climacograptus*) are noteworthy, and ostracodes are scattered to abundant (see

Table I. A list of lower Maquoketa Formation diminutive and associated faunas, reported from the basal Maquoketa phosphorites and overlying organic shales and phosphatic dolomites.

PORIFERA
- **Hindia parva*
- tetraxon sponge spicules

CNIDARIA
- Class uncertain (conulariids)
  - **Sphenothallus* sp.
  - *Climaconus pumilus*
  - *Conularia trentonensis*
  - *Conularia splendida*
  - *Glyptoconularia gracilis*

BRYOZOA
- Cyclostomata
  - *Berenicea minnesotensis*
  - *Spatiopora iowensis*
- Trepostomata
  - "*Diplotrypa*" sp.
  - *Dittopora* sp.
  - *Homotrypella* sp.
- Cryptostomata
  - *Arthroclema* sp.
  - *Arthrostyloecia* sp.
  - *Graptodictya* sp.
  - *Paleschara incrustans*
  - *Stictopora* sp.
  - indet. "acanthocladiid" sp.

BRACHIOPODA
- Inarticulata
  - *Conotreta obliqua*
  - **Leptobolus occidentalis*
  - "*Lingula*" *changi*
  - *Lingulops*? sp.
  - *Orbiculoidea* sp.
  - *Scaphelasma* sp.
  - n. gen. discinacean
- Articulata
  - **Diceromyonia* sp.
  - *Zygospira* sp.

MOLLUSCA
- Amphineura
  - **Septemchiton iowensis*
- Scaphopoda
  - **Plagioglytpa iowaensis*
- Bivalvia
  - *Ctenodonta anatina*
  - *Ctenodonta pulchella*
  - *Deceptrix scofieldi*
  - **Nuculites neglectus*
  - *Palaeoconcha? hamburgensis*
  - *Palaeoconcha obliqua*
  - **Palaeoneilo fecunda*
  - *Praenucula albertina*
- Gastropoda
  - *Bucanella conradi*
  - *Bucania lirata*
  - *Bucanopsis patersoni*
  - *Cyclonema bilex*
  - *Cyclonema humorosum*
  - **Cyclora depauperata*
  - *Cyclora minuta*
  - *Cyclora pulchella*
  - **Cyrtolites carinatus*
  - *Cyrtolites retrorsus*
  - *Holopea symmetrica*
  - **Liospira micula*
  - *Loxoplocus (Lophospira) tropidophora*
  - *Murchisonia (Hormotoma) spp.*
  - *Rhaphistomina rugata*
  - *Tropidodiscus subacutus*
- Cephalopoda
  - *Beloitoceras grafense*
  - *Cyclendoceras atkinsonense*
  - *Endoceras* sp.
  - *Ephippiorthoceras laddi*
  - *Ephippiorthoceras tenuistriatum*
  - **Isorthoceras sociale*
  - *Kionoceras tenuitectum*
  - *Kionoceras thomasi*
  - *Spyroceras calvini*
- Calyptoptomatida (hyoliths)
  - **Hyolithes parviusculus*

ECHINODERMATA
- Stelleroidea
  - indet. starfish plates
- Cyclocystoidea
  - *Apcynodiscus* sp.
  - indet. cyclocystoid plates
- Crinoidea
  - indet. crinoid debris
  - circular columnals
  - star-shaped columnals
  - pentagonal columnals
  - disc-shaped columnals
  - square columnals
  - nodose columnals
  - arm brachials
  - indet. cup plates
- Rhombifera
  - indet. cystoid plates

ARTHROPODA
- Crustacea – Ostracoda
  - *Aparchites minutissimus*
  - *Beyrichia irregularis*
  - **Bollia regularis*
  - *Bollia ruthae*
  - *Bythocypris batesi*
  - *Ctenobolbina maquoketensis*
  - *Ellesmeria scobeyi*
  - *Eridoconcha marginata*
  - *Eukloedenella richmondensis*
  - *Krausella inaequalis*
  - *Leperditella fryei*
  - *Leperditia? dubuquensis*
  - *Macrocypris kayi*
  - **Milleratia cincinnatiensis*
  - *Primitia bellevuensis*
  - *Primitia gibbera*
  - **Primitia tumidula*
  - *Primitiella carli*
  - *Primitiella milleri*
  - *Primitiella paucisulcata*
  - **Primitiella unicornis*
  - *Punctaparchites splendens*
  - **Schmidtella incompta*
  - *Schmidtella lacunosa*
  - *Ulrichia saccula*
  - *Warthinia nodosa*
  - *Zygobolboides calvini*
  - **Zygobolboides grafensis*
  - *Zygobolboides iowensis*
  - *Zygobolboides thomasi*
- Indeterminate
  - indet. spiny appendage and carapace fragments
- Trilobitomorpha -- Trilobita
  - *Anataphrus* sp.
  - *Flexicalymene* sp.
  - *Gravicalymene* sp.
  - *Homotelus* sp.
  - *Isotelus iowensis*
  - *Primaspis cf. crosotus*
  - *Thelecalymene mammillata*
  - indet. asaphid spp.

ANNELIDA
- Polychaeta
  - unstudied scolecodont spp.

HEMICHORDATA
- Graptolithina
  - *Climacograptus pumilus*
  - **Climacograptus typicalis putillus*
  - *Orthograptus quadrimucronatus*
  - *Orthograptus truncatus abbreviatus*
  - **Orthograptus truncatus peosta*

CONODONTA
- **Amorphognathus ordovicicus*
- **Drepanoistodus suberectus*
- *Panderodus gracilis*
- *Panderodus panderi*
- *Phragmodus undatus*
- *Plectodina tenuis*
- *Pseudobelodina inclinata*

CHITINOZOA
- *Ancyrochitina ancyrea*
- *Ancyrochitina* sp.
- *Ancyrochitina?* sp. 2
- *Calpichitina scabiosa*
- *Conochitina micracantha*
- *Cyathochitina campanulaeformis*
- *Cyathochitina kukersiana*
- *Cyathochitina* sp. *1*
- *Cyathochitina* sp. *3*
- *Desmochitina minor*
- *Hoegisphaera utricula*
- *Rhabdochitina hedlundi*

ACRITARCHA
- unident. acritarchs, algal spores, palynomorphs (Wicander, under study)

[asterisk (*) denotes the most common forms found in the phosphatic diminutive faunas]

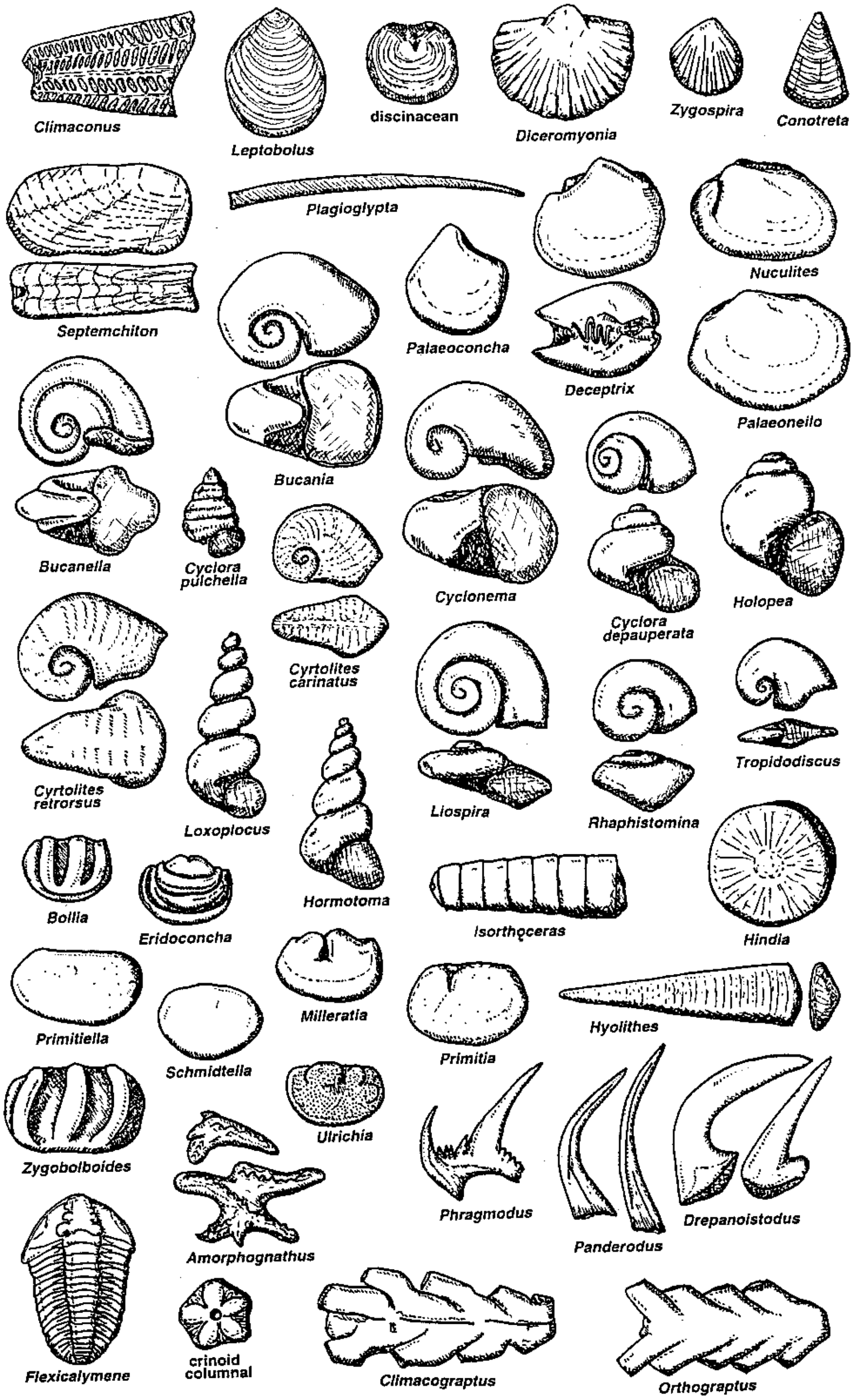

Figure 4. Sketches of representative fossils found in the phosphatic diminutive faunas, lower Maquoketa of Iowa. Most are phosphatic internal molds, although *Leptobolus, Conotreta, Climaconus,* and the conodonts preserve their original phosphatic skeletal material. Most fossils are drawn to approximate relative scale, with the bulk of specimens ranging between 1 and 2 mm in diameter (the long tapered tubes of *Plagioglypta* are commonly 3-10 mm). The illustrated trilobite (*Flexicalymene*) is not drawn to scale, with specimens in the phosphatic dolomites usually 2-4 cm.

Spivey, 1939; Burr and Swain, 1965). Conodonts are moderately abundant in the basal phosphorite, especially the distinctive elements of *Amorphognathus* (Glenister, 1957). The conodonts commonly show apatite encrustations.

Graptolites are scattered to abundant along certain bedding surfaces in the shales and argillaceous dolomites, and graptolite debris is scattered throughout many beds in the lower Maquoketa sequence. The shales preserve flattened rhabdosomes of *Orthograptus*, with *Climacograptus* noted in some horizons. Some of the phosphatic dolomites and phosphorites yield exceptional three-dimensionally preserved graptolites rhabdosomes. These 3-D specimens are commonly infilled with apatite, and preserve the organic exoskeleton externally.

The shales and phosphatic dolomites contain additional more normal-sized fossils. The lower brown shales (Graf units 1, 3) contain some very attractive large specimens of the phosphatic lingulid brachiopod *"Lingula" changi*. The shales and dolomites have also yielded occasional specimens of large conularids (Van Iten et al., 1996). Trilobites are scattered in the dolomites and associated shales, and include *Thelecalymene mammillata* (Whittington, 1971), large *Homotelus*, and others (see Table). A host of organic microfossils are known from the Graf exposure, including a number of illustrated chitinozoa (Taugourdeau, 1965).

Normal-sized molluscs occur within the nautiloid beds at Graf, primarily a great abundance of nautiloids. A few larger specimens (1-2 cm) of gastropods (*Hormotoma, Liospira*) and bivalves (*Nuculites*) are occasionally noted. The nautiloids are overwhelmingly dominated by a single orthoconic species, *Isorthoceras sociale*. However, a few additional nautiloid taxa occur, most commonly species of *Ephippiorthoceras*, *Beloitoceras*, and *Kionoceras* (see Table; Miller and Youngquist, 1949; Foerste, 1935). Huge endocerid nautiloids are rarely noted in the phosphatic dolomites at Graf. The nautiloid shells are commonly encrusted with delicate lace-like growths of the encrusting bryozoan, *Spatiopora*.

Lower Maquoketa Depositional Model

The occurrence of dark organic shales and phosphatic sediments in the lower Maquoketa Formation of Dubuque County and across much of the Midwest is of special note, as such facies are untypical of most other Paleozoic marine strata in the region. The Graf exposure is unique within the Maquoketa sequence, and at no other locality is the development of nautiloid beds and phosphatic dolomites so pronounced. Phosphate deposition is of special note in considering the overall sedimentary environment of the lower Maquoketa, as its precipitation requires some specific geochemical and oceanographic conditions. Because phosphate is a limiting nutrient in most marine environments, its precipitation typically indicates that some environmental factor served to limit the biologic uptake of phosphate from the water column and bottom sediments. Oxygen stresses, varying at times between dysoxic (weakly oxygenated) and anoxic (no oxygen), have been interpreted for the Maquoketa bottom environments (Witzke, 1980, 1987; Kolata and Graese, 1983). The limited availability of oxygen served to severely restrict the benthic faunas, and further accounts for the accumulation of organic matter on the bottom.

Phosphate and nutrient-rich waters derived from basinal bottom waters are interpreted to have impinged or upwelled along the carbonate shelf edge (Fig. 5), as first suggested by Brown (1974). The surface waters in such a setting may have been highly productive, permitting an abundance of graptolites and nautiloids to flourish. The influx of organic matter to the bottom environments tended to deplete available oxygen via bacterial oxidation, leading to dysoxia and anoxia. A zone of increasing density and decreasing oxygenation, or pycnocline, is interpreted to have existed within the Maquoketa seaway (Fig. 5); quasiestuarine circulation patterns were developed in the stratified seaway (Witzke, 1987). Sediments along the inner-shelf slope and in basinal settings were deposited under conditions of varying oxygenation. Phosphatic carbonates and phosphorites of the lower Maquoketa were apparently deposited under oxygen-stressed conditions, possibly near the interface between dysoxic and anoxic waters in a stratified seaway (Witzke, 1980, 1987; Black, 1985; see Fig. 5).

The common co-occurrence of diminutive faunas and phosphate deposition is well displayed in the lower Maquoketa facies. These faunas were previously interpreted to be composed of true paedomorphic

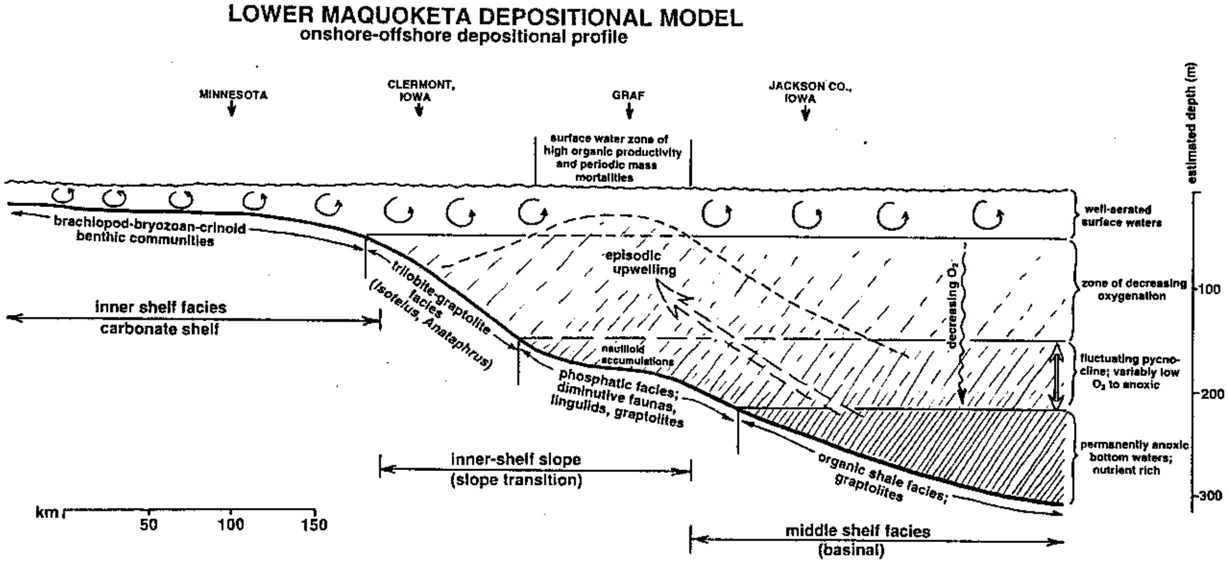

Figure 5. Lower Maquoketa depositional model. Onshore-offshore depositional profile shows relatively shallow carbonate shelf environments to the north progressing southward into a deeper-water stratified seaway with anoxic bottom waters (see Witzke, 1987). Phosphatic deposition in the Graf area is interpreted to reflect episodic upwelling along the carbonate shelf margin.

individuals specially adapted to periods of benthic environmental stress (Snyder and Bretsky, 1971). Paedomorphism is an evolutionary response whereby sexual maturity is achieved at a very early stage of development, enabling reproduction to occur in fluctuating or unstable environments. The Maquoketa diminutive faunas were likely adapted to life in environments exposed to recurrent oxygen stresses. Severe oxygen stresses and periodic oxygen depletion enabled only paedomorphically adapted faunas, primarily diminutive forms, to successfully reproduce under transitory oxygenation (Witzke, 1980, 1987). Extensive and frequent (daily to monthly) vertical fluctuations in the position of the pycnocline are known from the modern stratified Black Sea, which variably place benthic environments under recurring oxygen stress (Tim Lyons, 1997, pers. comm.). Similar fluctuations likely occurred in the Maquoketa seaway, producing a strong selective pressures for a paedomorphic evolutionary response of the benthic faunas.

The nautiloid-rich units contained in the lower Maquoketa interval in Dubuque County have stimulated much speculation regarding their deposition. Previous workers (Ladd, 1929; Miller and Youngquist, 1949; Taasch, 1955) suggested that the nautiloid beds at Graf were deposited in shallow, nearshore environments by violent wave action. The unabraded character and overall poor sorting of the contained grains as well as general facies position of the associated oxygen-stressed strata would tend to preclude such an interpretation, as the area would have been far removed from shallow nearshore wave activity. The deposition of concentrated nautiloid shells may have related to either (1) down-slope transport of nautiloid shells, perhaps triggered by storm-induced gravity flows, or (2) mass mortality events that episodically produced a rain of nautiloids from surface-water regions of high organic productivity. The orientation of shells in some of the concentrated nautiloid beds indicates that gentle current activity played a role in deposition. The gas-filled chambers of the individual nautiloids produced shells that were likely neutrally buoyant, and these could have been transported by relatively gentle density currents. The absence of orientation in some of the nautiloid beds and the enclosing muddy carbonate matrix indicate that currents could not have been particularly vigorous.

A particularly important feature of the nautiloid beds is the telescopic nesting of nautiloid shells, whereby the septa are broken and intruded by other shells. In fact, about 60% of the nautiloids are telescopically nested in the concentrated layers (Raatz, 1992). As suggested by Witzke and Glenister (1987, p. 107), "periodic failures of gas-filled phragmocones of newly-settled *Isorthoceras* shells may have resulted in implosion under depth-dependent hydrodynamic pressure . . . entry of water into the voids resulting from such failures may have caused chain reactions that nested or telescoped up to six shells, each in close proximity and oriented by gentle bottom currents." The settling or transportation of the nautiloid shells introduced them into environments of higher ambient hydrostatic pressure, which, at a particular depth threshold, resulted in mechanical failure of the septa. A physical relation exists between the strength of individual septa (a function of thickness, size, and curvature) and the water depth at which hydrostatic pressure exceeds that strength. As pointed out by Raatz (1992, p. 115), "a partially imploded nautiloid, therefore, can reveal absolute maximum water depth by determining the strength of the largest unimploded septum." Criteria for absolute depth are hard to come by in most ancient environments, and the Graf nautiloid beds provide an exceptional opportunity to constrain water depths at the time of deposition. Raatz's (1992) measurements and calculations, based on previously-published experimentally calibrated septal strength-pressure relations, yielded depths ranging between about 180 and 270 m. While some sedimentary geologists have been reticent to think that the Paleozoic cratonic seas ever exceeded a few tens of meters in depth, the Maquoketa example apparently demonstrates that depths of a few hundred meters cannot be precluded. The nautiloid beds at Graf do not represent the deepest facies of the lower Maquoketa sequence, and even deeper-water environments are envisioned for the chocolate brown shales deposited within the anoxic lower water mass (Fig. 5).

The lower Maquoketa interval has been interpreted to represent an overall transgressive-regressive depositional sequence (Witzke, 1987; Witzke and Kolata, 1988; Witzke and Bunker, 1996; Raatz and Ludvigson, 1996). A large-scale transgressive deepening event is recorded by the basal Maquoketa phosphorite. This unit is interpreted to be a greatly condensed sediment-starved transgressive interval. The phosphatic sediments and abundant diminutive faunas are interpreted to reflect oxygen-stressed sedimentation under a fluctuating pycnocline in a stratified seaway. Maximum transgressive deepening is marked by succeeding deposition of brown graptolitic shales. Deposition of the basal phosphorite and associated brown shales extended well up onto the area of Maquoketa inner-shelf sedimentation (as far north as Allamakee County, Iowa), recording maximum extent of the dysoxic-anoxic water masses during transgression and seaway highstand.

The remainder of the lower Maquoketa interval is characterized by a general shallowing-upward sequence, marking the regressive phase of the lower Maquoketa T-R cycle. This shallowing is most evident in the Elgin carbonate sequence of northeast Iowa and southern Minnesota (Raatz and Ludvigson, 1996), but is also reflected by the deeper-water sequence in Dubuque County. At Graf, the upward increase in carbonate content and overall decrease in phosphate content probably reflect shallowing sedimentation, with less influence of bottom dysoxia reflecting upward shallowing through the pycnocline. The echinoderm and bryozoan-rich skeletal packstones at the top of Graf section (unit 19) are the shallowest depositional facies in the sequence, marking shallowing into more fully oxygenated normal-marine benthic environments (although the incorporation of phosphatic diminutive faunas in this bed still suggests episodic bottom dysoxia). The shallowing patterns of lower Maquoketa deposition are also displayed in the shale-dominated facies of the Scales Shale, apparently shown by the upward shift from unburrowed organic-rich chocolate brown shale deposition (anoxic environments), into lighter colored gray shales that are variably burrowed (dysoxic environments; see Fig. 3 sequence). Subsequent depositional deepening is marked by a return to unburrowed brown shale sedimentation, possibly the beginning of the Clermont-Fort Atkinson depositional cycle (of Witzke and Kolata, 1988).

Stop Description

Trip participants will need to assemble in the parking lot of the park adjacent to the bicycle trail opposite the tavern in the small burg of Graf. We will walk back along the bike path to the roadcut along the county road. The extensive exposures of lower Maquoketa strata are easily accessed. The exposure itself lies along the county road right-of-way, but it immediately adjoins private property on the back side of the cut. Please do not climb the exposure, and stay off the private land above the rocks. In addition, there is little need to extract samples from the exposed beds, as an abundance of talus litters the base of the slope. These talus blocks are good places to collect specimens of phosphatic dolomite and nautiloid-rich rocks.

The basal chocolate brown shales at the base of the exposure are organic-rich and contain scattered to common lingulid brachiopods and graptolites. The overlying phosphatic dolomites contain an abundant phosphatized diminutive fauna, which can be extracted by acid dissaggredation of the enclosing matrix. Telescoping of shells can be observed in the nautiloid beds. Trilobites and other molluscan fossils occur in lesser numbers within the nautiloid-bearing interval. The upper phosphatic dolomites interbed with laminated phosphatic brown shales. Exceptional three-dimensionally preserved graptolites are seen in some of these units.

The slope above Graf (Fig. 6) exposure encompasses the remainder of the Maquoketa sequence, but this shale-dominated interval is covered up to the capping and more resistant Silurian dolomite strata at the top of the hill. We will examine the very top of the Maquoketa sequence at the next stop, and have already examined upper Maquoketa strata at Stop 4.

Figure 6. Photograph showing broad slope development on the Maquoketa shales above Stop 4, the Graf exposure. Photograph taken from Dubuque County road Y-21 looking to the northeast.

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UPPER ORDOVICIAN OOLITIC IRONSTONE STRATA OF THE NEDA MEMBER, AND THE ORDOVICIAN-SILURIAN UNCONFORMITY IN DUBUQUE COUNTY;
STOP 6: COUNTY ROAD D-17 ROADCUT

Brian J. Witzke and Richard C. Heathcote

Introduction and Neda Stratigraphy

The distinctive red ferruginous strata in the uppermost part of the Maquoketa sequence in Iowa are included in the Neda Member. These strata are red in color and contain scattered to abundant ironstone "ooids," which are concentrically laminated flax-seed shaped pellets composed of one or more iron minerals. The interval ranges in thickness from less than 1 to about 10 m in thickness in Iowa, but it is usually 0.5 to 1.5 m in the Dubuque County outcrop area (Fig. 1; see also Fig. 2 for Stop 5). The Neda derives its name from exposures in eastern Wisconsin near the hamlet of Neda, where the unit was extracted as an iron ore. Neda strata are widespread at the top of the Maquoketa sequence over a vast area, including Wisconsin, Illinois, Indiana, western Michigan, Iowa, northern Missouri, northeast Kansas, and eastern Nebraska. However, the Neda is not consistently recognized at the top of the Maquoketa sequence, but is erosionally absent over most of this area due to an extensive episode of pre-Silurian erosion that truncated upper Maquoketa strata. As such, the Neda Member is preserved only where the Maquoketa is thickest.

The Neda was first identified in Iowa by Howell (1916), who recognized a "peculiar reddish clay from one to two feet in thickness" that contained "great numbers of small rounded concretions of oolites" in road gradings around Lore Hill in Dubuque County (NE NE SE SE sec. 14, T89N, R1E). Neda strata can still be recognized at this locality. Agnew (1955) studied subsurface Ordovician strata across Iowa and identified a number of occurrences of the Neda, which consisted of "hematitic discoidal concretions and red shale." Parker (1971) also identifed Neda strata in the Iowa subsurface.

Brown and Whitlow (1960, 1963) noted a number of additional outcrops of the Neda Member in Dubuque County. In fact, all known surface exposures of Neda strata are restricted exclusively to Dubuque County, with scattered exposures noted in the steep-walled drainages of Swiss Valley, Granger Creek, South Fork Catfish Creek, and the Little Maquoketa River. They described the Neda as "interlayered grayish-red soft shale, dolomitic dark reddish-brown limonitic oolite, and grayish-green shale" (Brown and Whitlow, 1960, p. 28). Petrographic observations revealed flattened 1 mm "limonite concretions" enclosed in a hematite-cemented matrix of clay, dolomite, and silt. They recognized phosphatic nodules up to 5 cm long within the Neda, commonly with "limonite concretions embedded in them." Additional studies of Neda strata in Iowa have been undertaken by Synowiec (1981), Kean (1981), and Witzke and Heathcote (1983).

Neda Lithologies and Composition

The Neda Member in Dubuque County includes three basic lithologies: (1) red-gray, maroon, or red-brown silty shale and mudstone; (2) red-brown to maroon mudstone with scattered to abundant ferruginous ooids and apatite clasts, and (3) interbedded green-gray silty shale, similar to those seen in the underlying Brainard Member. The matrix of the ooid-bearing mudstones is compositionally varied, including clay and silt grains, carbonate, and hematite cement. X-ray diffraction patterns of the clay-sized component reveals the following clay minerals: (1) illite (dominant), (2) "chamosite," an iron-bearing clay mineral of the chlorite group with a 14Å spacing (this should probably be identified as berthierine), and (3) an unidentifed regular mixed-layer clay, possibly illite-chlorite mixed layering.

Subrounded to subangular silt grains, dominantly quartz, comprise up to 30% of the red Ned mudstones, and grains of glauconite, feldspar, biotite, and opaque minerals have also been identified in the

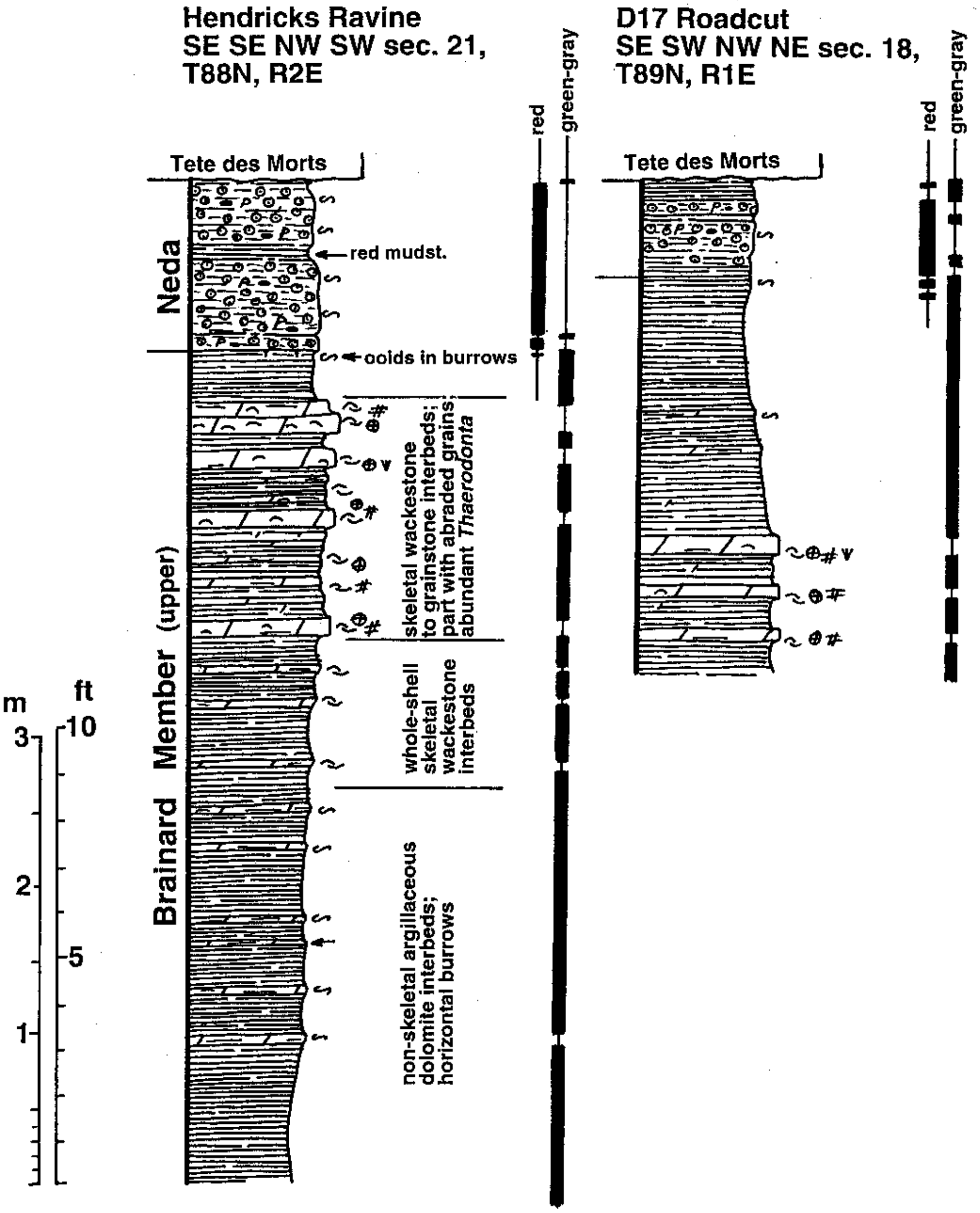

Figure 1. Exposures of Neda Member and underlying Brainard strata in Dubuque County. The Neda is characterized by red mudstones containing scattered to abundant ferruginous ooids; minor greeen-gray shale occurs in the member. The Brainard interval is now largely covered at the D17 site (Stop 6). Symbols as illustrated for Stop 5; ferruginous ooids are represented by small circles with central dot.

Iowa Neda (Synowiec, 1981). The carbonate content of the Neda is variable, consisting primarily of dolomite crystals floating in the matrix. Dolomite content ranges up to 40%. Hematite and goethite cements are apparently responsible for the reddish hue of the Neda mudstones.

Ferruginous ooids are present in the Neda mudstones in varying proportions, and entirely absent at some localities. Synowiec (1981, p. 55) noted in the Iowa Neda that "oblate, disc-shaped, spheroidal and ellipsoidal oolites are concentrated into stringers, pockets, and lenses, [and are] sporadically distributed in the sequence." The individual ooids range in size from 0.1 to 2.0 mm, with 95% having diameters of 0.25 to 1.0 mm. The majority of ooids display flatted ellipsoidal or disc shapes, resembling flax seeds. The

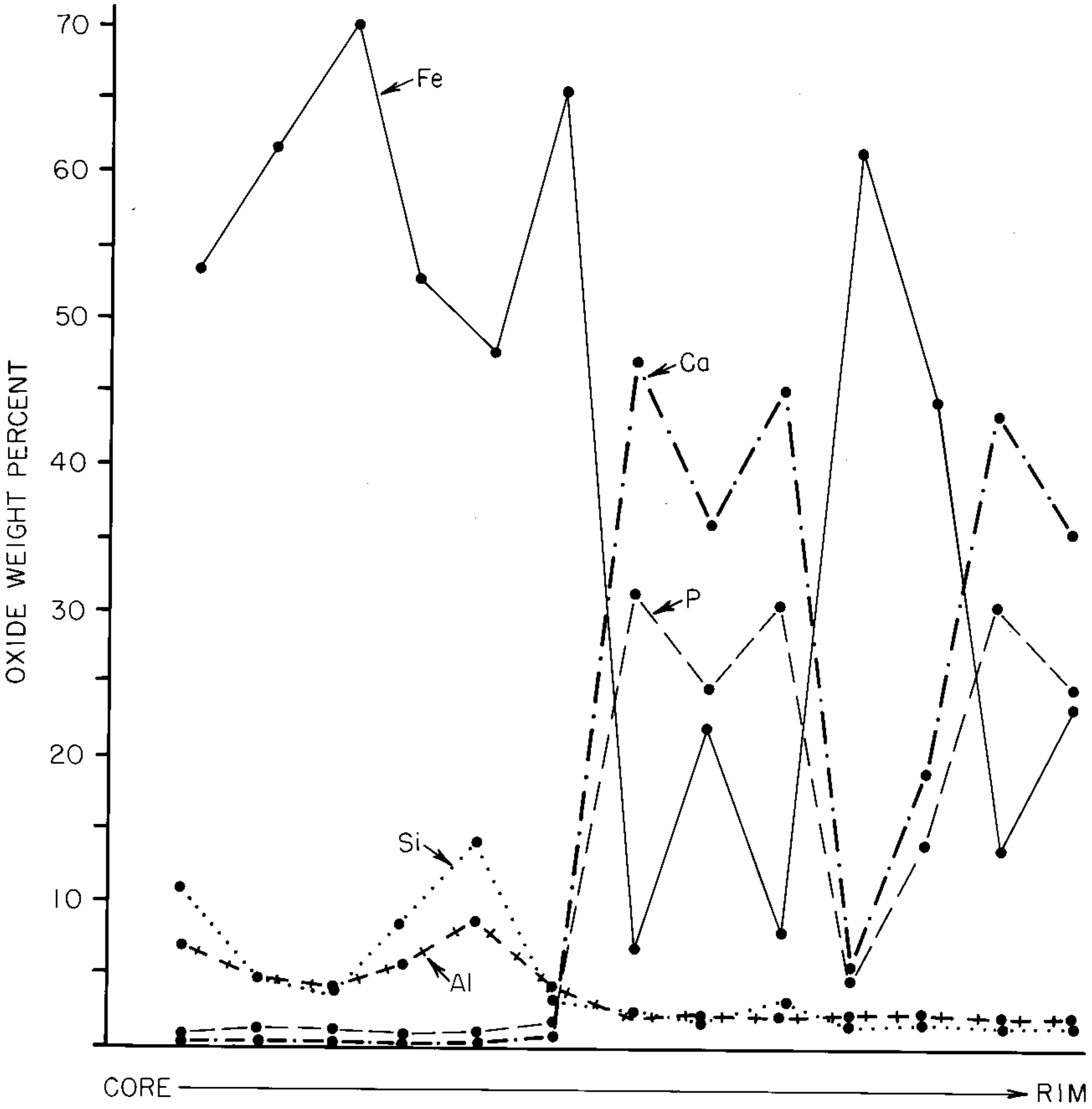

Figure 2. Electron microprobe transect across a single ferruginous Neda ooid, Dubuque County (Hendricks Ravine). Oxide weight percents are qualitative. Varying composition reflects changes in laminae mineralogy within the ooid. High Ca-P composition corresponds to apatite-rich laminae; increased Si-Al content corresponds to clay-rich laminae; highest Fe values correspond to goethite-rich laminae.

irregular and patchy distribution of the ferruginous ooids in the Iowa Neda cannot be adequately explained in terms of current-formed sedimentary structures. However, many of the ooid-rich mottlings appear to occur in burrow-mottled structures. These burrow structures are oriented subhorizontal to vertical and range from 1 to 5 cm in length by 3 to 15 mm in diameter. Clearly defined vertical burrows 1.5 to 4 cm in length, which are infilled with ferruginous ooids, extend down from the base of the Neda into the underlying green-gray shales of the Brainard in Dubuque County (Fig. 1). The long axes of the flattened discoidal ooids commonly are oriented preferentially parallel to burrowing within the Neda mudstones.

The ferruginous ooids of the Iowa Neda are typically matrix supported. In ooid-rich beds, the ooids are locally in grain-to-grain contact. Where in grain contact, the ooids may display microfracturing. Some ooids are plastically deformed around other adjacent grains, indicating that some remained unlithified during compaction. The Iowa Neda ferruginous ooids internally display concentric laminae of varied composition. Ooid nuclei are divided into four general categories: (1) quartz silt grains, (2) apatite grains, (3) broken ooid fragments, and (4) phosphatized or ferruginized skeletal grains. X-ray diffraction patterns of crushed separated ooids from Dubuque County showed the presence of goethite, hematite, quartz, apatite, and chamosite (berthierine). Hematite is also observed in some ooids, possibly formed from later-stage dehydration of original goethite. Quartz silt not only forms the nuclei of some ooids, but also occurs dispersed within the laminae of some ooids; concentric laminae are not deformed around the dispersed silt grains. The ooids consist of a series of concentric laminae accreted around a nucleus. Scanning electron micrographs of goethitic laminae reveal an aggregate of crystal platelets 0.4 to 5 microns in diameter arranged parallel to laminae.

Electron microprobe investigations revealed significant compositional variations within individual ooids. A microprobe transect across a single ooid (Fig. 2), from inner to outer laminae, shows wide variations in iron, calcium, phosphorus, silicon, and aluminum, qualitatively calculated as oxide weight percents. Points with high Fe-oxide content (62-70%) correspond to goethite-rich laminae. Other points with high Ca and P values correspond to apatite-rich laminae (apparently with various admixtures of goethite or hematite). Points with increased Si and Al content (7 to 15% oxide weight percent) presumably correspond to laminae containing clay minerals; high iron oxide content at the same points (47 to 53%) suggests the presence of an iron-rich clay, like berthierine, possibly admixed with other iron minerals.

Apatite and clay-rich laminae can occur at any position within the Neda ooids, but petrographic and microprobe investigations indicate some general relationships within most ooids examined. Although not all ooids contain apatite laminae, where present, they are characteristically best developed in the outer laminae. This is similar to the apatite-bearing outer laminae of Neda ooids from Wisconsin, where Hawley and Beavan (1934) observed that "at least 50% ofthe total phosphorus in the oolites is contained in their outer shells." In Iowa, microprobe line scans across ooids indicate that phosphorus peaks are most common in the outer one-third to one-half of the ooids, and petrographic observations also indicate the greater abundance of apatite in the outer laminae. By contrast, the iron-bearing clay minerals are best developed in the inner laminae of the ooids.

In addition to the abundance of apatite within the Neda ferruginous ooids, apatite clasts also occur within the red Neda mudstones in varying proportions. The rounded to irregularly shaped apatite nodules and grains range in size from less than 1 mm to 5 cm in diameter. As with the apatite-rich outer laminae of the ooids, the apatite nodules also have a glazed, polished-looking exterior surface. Many of the larger apatite clasts are multi-generational, and apatite clasts are commonly enclosed within the larger nodules. Brown and Whitlow (1960, p. 29) noted that "some of the larger nodules seem to be an aggregate of smaller nodules." These observations indicate that reworking of apatite nodules occurred contemporaneous with apatite deposition. In addition, many of the apatite nodules enclose scattered to abundant flattened ferruginous ooids. This further indicates that ferruginous ooids were present in the Neda sediments at the time of nodule formation, and are not the result of later diagenetic processes. Because the nodules were apparently syndepositionally reworked within the Neda sediments, deposition of apatite and iron minerals must have been, at least in part, contemporaneous with Neda sedimentation and reworking. Sediment reworking may have been accomplished by burrowing organisms. The absence of current-formed sedimentary structures in the Iowa Neda suggests that sediment reworking by wave or current activity was insignificant.

The Iowa Neda contains interbeds of green-gray mudstone and claystone similar to lithologies in the Brainard Member. Brown and Whitlow (1960, p. 29) recognzied a green-gray, silty, pyritic, dolomitic shale at Hendricks Ravine in Dubuque County (Fig. 1) that contains scattered goethitic ooids as well as collapsed ooids that have been "leached of iron oxide, leaving a small black residue of clay." The clay residue of the collapsed ooids probably represents the remains of former clay-rich laminae within the ooids. A similar green-gray shale unit, 1 to 12 cm thick, occurs at the top of the Neda at Stop 6; dark maroon nodules up to 3 cm in diameter occur within this unit. The nodules are glassy in appearance and gave an amorphous x-ray diffraction pattern; the composition remains unknown. A laterally discontinuous bed of hard cemented oolitic ironstone and mudstone occurs beneath this unit. This hard but crumbly bed differs significantly from underlying soft Neda strata, and contains, in addition to the ironstone ooids, scattered green-gray and yellow-brown mudstone clasts to 3 cm diameter. This poorly sorted unit probably represents a reworked or weathered upper Neda bed.

Neda Paleontology

The Iowa Neda is poorly fossiliferous. Nevertheless, polished sections of some apatite nodules reveal an abundance of sponge spicule molds, primarily monaxons. Some of these nodules also display borings along their surfaces. In addition, internal molds of phosphatized and ferruginized diminutive molluscan fossils are recovered from the Neda mudstones, resembling other diminutive faunas of the Maquoketa. Identified forms from the Neda of Dubuque County include gastropods (*Hormotoma, Cyclora, Liospira*), nuculid bivalves (*Deceptrix*), indeterminate bryozoan fragments, echinoderm debris, worm tubes (*Cornulites*), lingulid brachiopod fragments, and conodonts (primarily *Panderodus*).

Formation of the Neda Ferruginous Ooids

Three general explanations have been considered by various sedimentologists for the origin of ferruginous ooids: (1) pedogenic origin of ferruginous ooids during lateritic weathering, (2) diagenetic replacement of calcium carbonate ooids by ferriferous leachate, and (3) syndepositional precipitation of iron minerals in benthic marine environments. A full discussion of these various depositional models is not presented here. Suffice it to say that the lithologic and compositonal information presented above does not support a pedogenic or carbonate-replacement model. The ooids were clearly reworked by burrowers and locally incorporated within apatite nodules during Neda deposition and are not a later diagenetic or weathering product. In addition, the incorporation of marine fossils within the Neda further supports a marine origin for these unusual sediments. The flattened forms, reworking by burrowers, and varied composition of the ooids indicate that the ooids probably resided within the sediment during at least part of their accretion. Because the ooids were apparently bioturbated and reworked through the sediment, the possibility that individual ooids were exposed to a variety of geochemical conditions during their formation becomes a consideration.

A depositional model that attempts to explain the sedimentary characteristics of the Neda Member and the varied composition of the ferruginous ooids is outlined here. A redox boundary is present in virtually all sediment profiles beneath an oxygenic seafloor. Oxic geochemical conditions prevail above the redox boundary, with various anoxic and dysoxic geochemical environments developed within the sediment profile below (Berner, 1981). The three-part mineralogy of the ferruginous ooids is critical in understanding their formation. Goethite, a ferric oxide mineral, is dominant in the ooids, which must have formed under oxic depositional conditions. Apatite precipitation most commonly occurs in anoxic or dysoxic environments, suggesting that individual ooids encountered highly contrasting geochemical conditions during their formation. The additional presence of iron clay minerals like berthierine within the ooids are consistent with formation in a "post-oxic" environment (Berner, 1981), which can include weakly reducing environments or environments that experience fluctuating oxic-anoxic conditions.

Individual ooids could variably encounter oxic, post-oxic, dysoxic, and anoxic geochemical conditions in a number of ways, but physical movement within the sedment by burrowing activity is considered a likely possibility. Such movement would provide varying redox conditions during ooid growth, enabling varying mineralogies to grow as individual laminae. In addition, periodic or season fluctuation of the redox boundary may also have played a role, resulting from variations in rates of sediment/organic influx and associated bacterial activity. The co-occurrence of diminutive molluscan faunas in the Neda may further suggest that benthic conditions encompassed a spectrum of fluctuating redox conditions (see Stop 5 discussion).

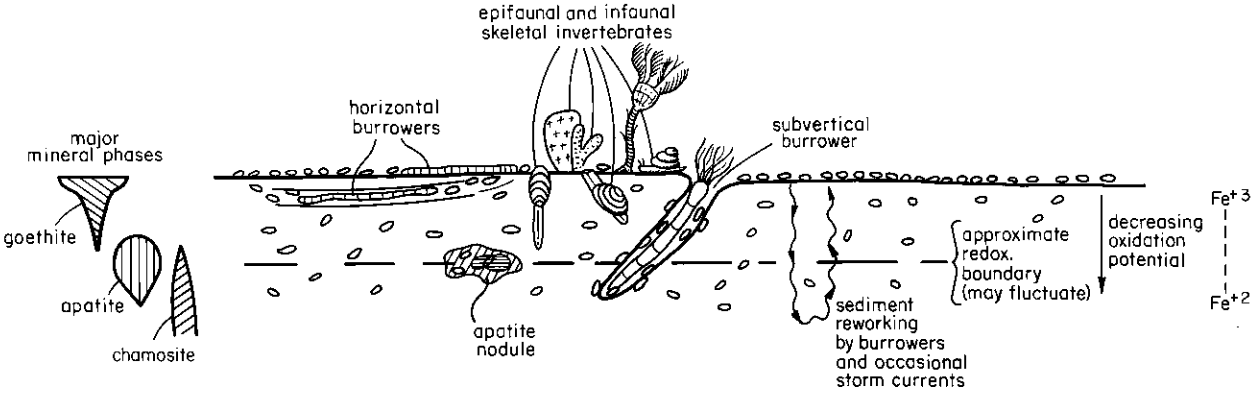

Figure 3. Interpretive sediment profile proposed for Neda deposition. Major mineral phases coincide with different geochemical environments encountered on the seafloor and within the sediment. Goethite ooids formed in oxygenic environments, whereas apatite and chamosite (berthierine) formed within the sediment in post-oxic environments. Sediment reworking by burrowers and currents enabled individual ooids to successively encounter different geochemical conditions and varying oxidation potential within the sediments.

Based on the analogy with modern oolitic ironstone deposition in Lake Chad, Africa (Lemoalle and Dupont, 1973), a sedimentary model for the formation of the Iowa Neda ooids is summarized as follows (see Fig. 3): (1) Iron was supplied to the Neda environments from fluvial sources, transported in the ferric state as colloidal particles or adsorbed to clays. (2) Upon entering the Neda marine environments, the iron was separated from the associated clays and accreted into goethitic ooids or deposited directly within the sediment. (3) As the ooids were buried and reworked within the muddy sediments, they encountered various redox conditions, resulting in precipitation of apatite and iron-bearing clay minerals.

Although the goethite in the Iowa Neda is considered to be of primary origin, the common occurrence of hematite in the matrix material is probably of diagenetic origin. Dehydration of goethite particles in the matrix material, as well as some of the goethitic ooids, likely accounts for the hematite component of the Iowa Neda. Late-stage leaching-oxidation processes may have been involved in the concentration of matrix hematite in the Neda. Regardless of which processes actually produced the hematite, the paleomagnetic identification of a Late Paleozoic chemical remanence in the Neda hematite (Kean, 1981) is taken as strong evidence for its late diagenetic origin.

Neda Depositional Cycle

Neda sedimentation was previously interpreted by Witzke and Kolata (1988, p. 73) to be the "final phase of nearshore depositon of the [shallowing-upward] upper Maquoketa [Brainard]" cycle of deposition (see also Witzke and Glenister, 1987). The shallowing phase recognized for upper Brainard deposition (see Stop 4 discussion) was interpreted to continue to shallow upward to include Neda deposition as its waning phase. Problems with this interpretation prompted a subsequent re-evaluation of the sedimentary significance of oolitic ironstone deposition, and its application to an understanding of Neda sedimentation.

As noted by Witzke and Bunker (1996), other Paleozoic oolitic ironstones of the Midcontinent area (including Upper Cambrian, Middle Ordovician, Upper Devonian examples from Iowa) were primarily observed to occupy positions associated with regional transgression and relatively condensed sedimentation. The apatite enrichment seen in the Neda, both as nodules and ooid laminae, was a feature also observed to mark condensed transgressive sedimentation in other Paleozoic examples (ibid.). The general absence of current formed sedimentary structures and overall poor sorting of the Neda contrasts notably with the winnowed and abraded skeletal packstones and grainstones seen in underlying Brainard strata

(Fig. 1). The Neda must have been deposited in quieter and more oxygen-stressed depositional settings than the upper Brainard, suggesting probable depositional deepening and renewed transgression.

This modified interpretation of Neda deposition is also more consistent with current ideas of oolitic ironstone formation presented by several workers. In general, oolitic ironstones commonly formed in areas of relatively reduced siliciclastic influx forming condensed intervals deposited "during the initial stage of renewed transgressions" (Van Houten and Arthur, 1989). If these characteristic sedimentary patterns apply to the Iowa Neda, it seems likely that the Neda should be separated from the Brainard cycle of deposition and included within its own transgressive-regressive (T-R) cycle. The abrupt lithologic change at the Brainard-Neda contact may support such a separation, and the vertical penetration of burrows at the contact resembles a burrowed discontinuity surface.

The possible occurrence of an additional T-R cycle for Neda deposition at the top of the Maquoketa sequence raises some issues concerning its correlation. Because the Neda lies below the prominent sub-Silurian unconformity, it is most likely of Ordovician age, although the contained fossils are not particularly diagnostic. Conodonts (*Rhipidognathus*) and Brainard-like ferruginized brachiopods support a Late Ordovician age in Wisconsin. A separate disconformity-bounded T-R cycle above the Maquoketa shale interval is represented by oolitic and skeletal carbonate strata to the south in northeastern Missouri and western Illinois (Amsden and Barrick, 1986). This interval is correlated with the latest Ordovician Hirnantian Stage, and Amsden and Barrick (1986) suggested that the Neda likely correlates with these strata. For these reasons, the Neda is considered to represent a separate Hirnantian cycle of deposition (Witzke and Bunker, 1996).

The final cycle of Maquoketa deposition, represented in the Iowa area by the Neda Member, was succeeded by a major withdrawal of the seaway from the continental interior. The resulting erosional unconformity marks the Ordovician-Silurian boundary in the region. The lowering of sea level and the accompanying withdrawal of the latest Ordovician seas likely related to the buildup of continental ice sheets in the southern hemisphere at this time. Sub-Silurian erosion in the Iowa area was dramatic, with local erosional relief of over 30 m (100 ft) documented in eastern Iowa. This extensive erosion was responsible for the removal of uppermost Maquoketa strata in most areas of Iowa, with only local preservation of Neda strata on remnant interfluves that fortuitously preserved the full Maquoketa stratigraphic package. The Dubuque area is one such area that displays the full Maquoketa sequence, and Neda strata are unknown from elsewhere along the extent of the Maquoketa outcrop belt in eastern Iowa.

Silurian Stratigraphy

An exceptionally instructive sequence of fossiliferous Silurian dolomite and cherty dolomite strata are well exposed in Dubuque County, but these are not considered in detail in this guidebook. Silurian strata of the Mosalem, Tete des Morts, Blanding, Hopkinton, and lower Scotch Grove formations are recognized in the county (Witzke, 1992). The basal Silurian Mosalem Formation, originally defined by Brown and Whitlow (1960), is of note because the Mosalem and Maquoketa share complementary thickness relations. This relationship occurs because the Mosalem infills erosional valleys cut into the Maquoketa shale interval, which are up to 30 m (100 ft) deep in portions of eastern Iowa. Initial Silurian transgression from the east flooded these paleovalleys, resulting in deposition of argillaceous carbonate within the estuarine embayments. The highest portions of the landscape, which preserved uppermost Brainard and Neda strata, remained exposed during Mosalem deposition, and these upland areas supplied argillaceous material from the weathering of the shaly Maquoketa sediments. As Silurian transgression proceeded and the seaway expanded westward, the entire erosional surface of the Maquoketa was flooded across eastern Iowa, and cleaner subtidal carbonate deposition of the Tete des Morts Formation became established. The Tete des Morts, originally defined by Brown and Whitlow (1960), is a massive-bedded resistant dolomite. Large blocks of Tete des Morts dolomite are commonly seen dislodged along the upper Maquoketa shale slopes, sliding imperceptively on the plastic shales. The Tete des Morts overlies the Mosalem Formation at many localities, but the Tete des Morts directly overlies the Maquoketa Formation at localities where the Mosalem is absent. This latter relation is displayed at many localities in the Dubuque area, including Stop 6.

An extremely cherty dolomite interval, the Blanding Formation, overlies the Tete des Morts in eastern Iowa, and oversteps the Tete des Mort edge into central Iowa. The basal portion of the Blanding is not cherty, however, and is characterized by medium-bedded ledges of dolomite quarrystone, the "lower quarry beds" of Calvin and Bain (1900). The "lower quarry beds" and overlying cherty strata of the Blanding Formation are displayed at Stop 6. The Blanding averages about 15 m (50 ft) in thickness in Dubuque County. The reader is referred to Witzke (1992) for a more thorough discussion of Silurian stratigraphy in eastern Iowa.

Stop Description

Parking will be along the northeast margin of the roadway; this is a potentially hazardous stop, so please be cautious along the highway. The D-17 roadcut (Fig. 4) exposes strata of the Neda Member in a recessive interval immediately below the prominent face of Silurian dolomite. While the Neda is not especially well exposed here, it is the most easily accessible exposure of Neda strata in Iowa. Minor trenching may be needed to more fully reveal the characteristic Neda lithologies and their contained ferruginous ooids. The characteristic red mudstones contain scattered to abundant flattened ferruginous ooids ("flax seed"), commonly dispersed and oriented within burrow mottles. Clasts of apatite occur with the ferruginous ooids. The most instructive and best displayed section of the Neda in Iowa is found on private property at a locality we've termed Hendricks Ravine (Fig. 1), but access to this latter stop would be logistically difficult for this field trip. Many questions concerning geochemistry and regional aspects of Neda deposition remain to be addressed. It is hoped this abbreviated discussion will inspire further work on this thin, but enigmatic unit.

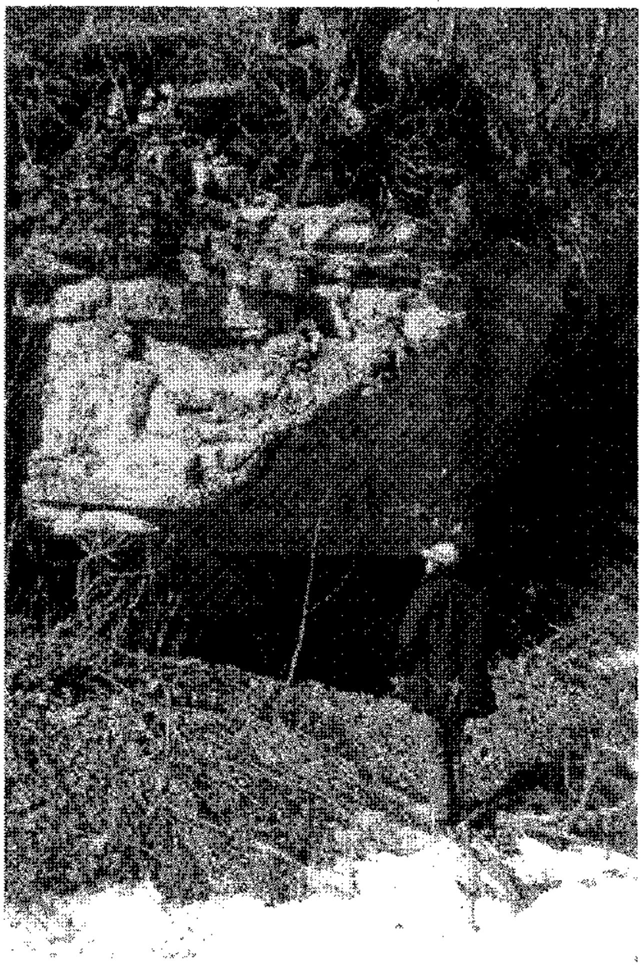

Figure 4. Photograph of the exposure at Stop 6, showing dolomites of the Silurian Tete des Mort Formation overhanging a reentrant that exposes the uppermost Ordovician Neda Member of the Maquoketa Formation.

Intermittent and poor exposures of upper Brainard strata can be seen on the opposite side of the road in the ditch area and valley slope, and these require some degree of trenching to better reveal their characteristics. A section of these beds was measured when highway construction was ongoing in the early 1980s (see Fig. 1). In general, the Brainard section closely resembles that seen at the Highway 151 exposure southwest of Dubuque (SW NW sec. 23, T88N, R2E); the carbonate interbeds contain abundant fossils of the *Thaerodonta-Cupulocrinus-Cornulites* association (see Stop 4 discussion). The uppermost part of the Brainard lacks fossiliferous interbeds, and is a relatively nondescript green-gray plastic shale. It shows discontinuous red mottles immediately below its contact with the

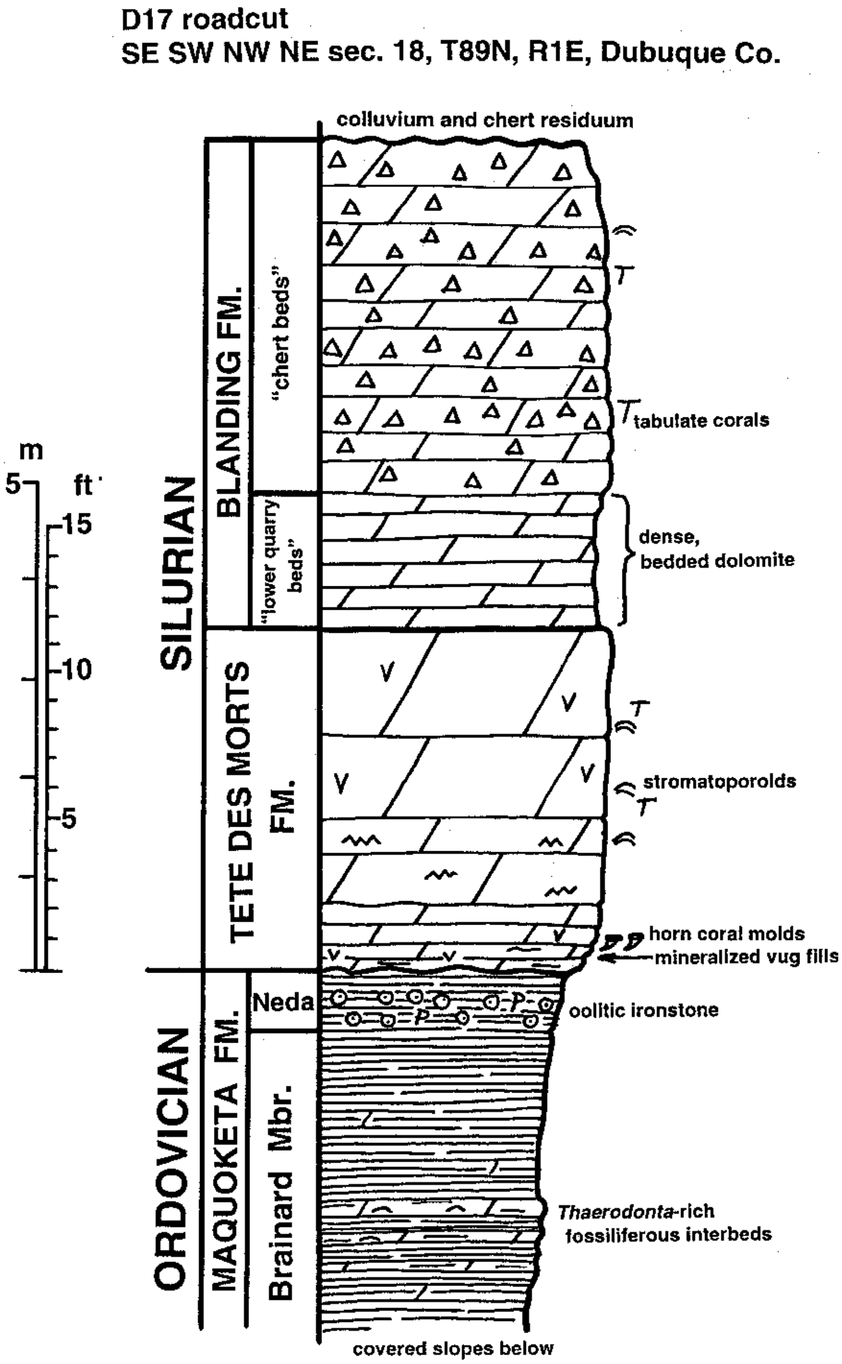

Figure 5. Ordovician and Silurian stratigraphic section exposed at the D17 roadcut, field Stop 6. Symbols as illustrated for Stop 5 and Figure 1.

Neda, possibly related to late-stage diagenetic mobilization and precipitation of hematite cements.

This is our only opportunity on the field trip to examine Silurian strata in Dubuque County (see Fig. 5). The Ordovician-Silurian unconformity is only slightly undulose; some reworked Maquoketa shale clasts are seen near the contact. The overlying Tete des Morts is relatively thin at this locality (about 3.5 m, half its usual thickness), possibly indicating that the Maquoketa shale hills were not flooded by marine waters at this site until the latter half of regional deposition of the formation. The basal part of the Tete des Morts at this stop displays some interesting mineralized vug fills, and a zone of abundant horn coral molds is also recognized at this general position (Fig. 5). The Tete des Morts is characterized above by relatively thick beds of vuggy dolomite with scattered stylolites. These strata include scattered molds of lamellar stromatoporoids, tabulate corals (mostly *Favosites*), and crinoid debris.

The overlying Blanding Formation includes an interval of dense, evenly-bedded dolomite in its basal part, the "lower quarry beds" of Calvin and Bain (1900). These beds are only sparingly fossiliferous. Overlying Blanding strata are notably cherty, with bands of white chert nodules and chert layers replete through the sequence. This interval forms the "chert beds" of Calvin and Bain (1900), which is the characteristic Blanding facies of eastern Iowa and northern Illinois. Scattered corals and stromatoporoids, silicified in part, occur within the cherty strata. This distinctive cherty unit was mistakenly included in the "Kankakee Formation" by many earlier workers (e.g., Brown and Whitlow, 1960). Willman (1973) correctly pointed out the miscorrelation of these strata with the Kankakee of northeastern Illinois, and proposed the Blanding as a replacement.

This concludes our field trip. Please have a safe journey home. Dubuque County offers a fascinating array of geologic features and interesting rocks and sediments. We hope that this trip will serve to stimulate continuing geologic investigations in the area – much work remains to be done.

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FIELD TRIP STOPS