RETURN TO KLEIN QUARRY - GLACIERS, CARBONATES, AND FOSSILS

edited by
Ryan J. Clark

Geological Society of Iowa

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Cover Image

Photos of various geologic aspects of the Klein Quarry set into the structural design of the new Iowa Geological Survey logo. From the top – down: quaternary strata in the newly expanded portion of the quarry, intermingling of sand and till, chatter marks and glacial striations on the bedrock surface, iron-filled mudcracks in Pennsylvanian bedrock, and Devonian limestone of the Coralville Formation. Artistically rendered by Phil Kerr.

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INTRODUCTION

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The 2015 Iowa Academy of Science annual meeting is at the University of Iowa in Iowa City, Iowa. Again this year it is followed by a field trip organized under the auspices of the Geological Society of Iowa (GSI). The GSI may not be an official membership-granting organization, but it remains one of the primary bridges between the Iowa Geological Survey (IGS) and the citizens of Iowa. Although many of the IGS geologists that were the unquestioned authorities regarding Iowa's geology have retired, and as the current IGS staff continues to expand their expertise, it is our hope to eventually restore the GSI to its former glory by leading more field trips accompanied by comprehensive guidebooks written in collaboration with a wide variety of experts in all things Iowa geology. We thank the GSI 'membership' for their continued support throughout this transitional period.

The Iowa City area is home to some of the most well-known Devonian-age bedrock sequences in the world. Many locations around the city show bedrock at the surface, due in large part to erosion from the Iowa River and its network of tributaries. It is no coincidence that people have taken advantage of that by excavating the versatile stone from numerous quarries that dot the surrounding countryside. Our gracious host today is River Products Company, Inc. (River Products), owner/operator of the Klein Quarry located in Coralville, Iowa. River Products has been in continuous operations providing stone products in the Iowa City/Coralville area for 95 years, and still going strong. They have opened their doors to countless groups of interested people, from amateur rock hounds to accomplished research geologist, all leaving with a greater knowledge and appreciation for the natural beauty and history presented by the geology seen in their quarries.

Today we thank River Products for their continued support and cooperation as they allow the 2015 GSI field trip into Klein Quarry, which has been operated by River Products since 1982. The 2010 fall GSI field trip took an in-depth look at comparing and contrasting the Quaternary and Paleozoic geology observed at two River Products' quarries in the Iowa City area, Conklin and Klein quarries. This trip was the first attempt to present the uniquely instructive geologic aspects seen in Klein Quarry in a general publication. The details of this trip can be found in GSI Guidebook No. 87. Much of the content of this guidebook is reiterated from that exemplary publication.

The emphasis of this year's field trip to the Klein Quarry is due to the recent expansion of quarry operations toward the east (Fig. 1). Current efforts to expand the quarry have exposed Quaternary deposits not previously seen, and will be the focus of study to build on the current understanding of the glacial history of the area. Expansion has not yet progressed to exposing new bedrock faces at the time of this field trip, so the information presented in Guidebook No. 87 relating to the Devonian stratigraphy seen in Klein remains pertinent.

Figure 1. 2013 aerial photo of the Klein Quarry. Recent expansion operations to the southeast is outlined in red. Core sample 'Klein #14' will be available to the field trip attendees for study and is described in this guidebook.

Finally we ask the field trip participants to use common sense and conduct themselves in a manner that will ensure their safety as well as the safety of those around them, so we can hope to maintain a positive relationship with River Products for years to come.

ACKNOWLEDGMENTS

Special thanks goes to the River Products Company, Inc. owner, Tom Scott, executive assistant Deb Tisor, and Klein Quarry superintendent Jeff McKenna. Without their support and cooperation, the GSI field trip would lack the educational value we desire to offer our participants.

The editor and authors wish to extend our gratitude to Rick Langel and Jason Vogelgesang of the IGS for their thoughtful review of portions of this guidebook; as well as H. Paul Liu for his insightful guidance. Phil Kerr provided much needed assistance in preparation of many of the figures and Megan Hauswirth was crucial in the final construction and production of this guidebook. The GSI appreciates the support of the director of the IGS, Nate Young, as well as the leadership of IIHR-Hydroscience and Engineering for allowing us the opportunity to continue this great tradition of joining the citizens of Iowa in our desire to embrace the geologic wonders in our backyard.

QUATERNARY GEOLOGY OF THE IOWA CITY AREA

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*The following article is mostly reproduced from the 2010 Geological Society of Iowa field trip into Klein and Conklin quarries (Bettis et al., 2010).

INTRODUCTION

A record of continental glaciation extending over the past 2 million years is preserved to varying degrees in the upper Midwest (Balco and Rovey, 2010). The record consists of deposits and weathering horizons formed during several glacial and interglacial intervals. Terrestrial sedimentary records are notoriously incomplete – they are replete with erosional unconformities and diastems marked by paleosols. Quarries, drill holes and natural outcrops in the Iowa City area encounter Quaternary sections that display relationships representative of those commonly encountered in the Southern Iowa Drift Plain near large river valleys.

REGIONAL SETTING

Iowa City is located in the Southern Iowa Drift Plain (SIDP) near its northern border with the Iowan Erosion Surface (Prior, 1991). Quaternary deposits in this area discontinuously cover an irregular surface cut into Paleozoic bedrock (Figure 1). The topography of the bedrock surface reflects the cumulative erosional effects of numerous glacial and interglacial periods.

The SIDP and Iowan Erosion Surface (IES) were glaciated several times during the interval from before 2.6 million to 500 thousand years before present (Hallberg, 1986; Rovey et al., 2010). Conklin Quarry, located five miles east of Klein Quarry, exposes the most complete documented pre-Illinoian glacial stratigraphic section in the continental interior (Hallberg et al., 1984; Kemmis et al., 1992). At various times this quarry has exposed six tills assigned to two formations and various members. The oldest recognized tills and intercalated fluvial and slope sediments and paleosols in the Iowa City area are grouped within the Alburnett Formation. Deposits of at least one Quaternary glaciation which predates the Alburnett are widespread throughout the Midwestern U.S. but have not yet been recognized in eastern Iowa (Hallberg, 1986; Balco et al., 2005; see figure 1 in Rovey et al., 2010). The Alburnet Formation is overlain by the Wolf Creek Formation which includes three members that encompass glacial tills and intercalated fluvial sediments and paleosols (Hallberg et al., 1980a, 1984; Kemmis et al., 1992). Glaciations during which Wolf Creek Formation tills were deposited occurred between about 780,000 and 500,000 year ago.

Upland Landscape

Following the last Pre-Illinoian glaciation of the area, an integrated drainage network developed by episodic erosion of the landscape. Two Wisconsin Episode loess sheets (Pisgah Formation and overlying Peoria Formation loess) mantle upland areas; these are differentially preserved across the modern landscape as a result of late Wisconsin and Holocene erosion.

The Quaternary record of the SIDP and IES is fragmentary because of multiple periods of glacial and subaerial erosion. No primary glacial landforms remain, although scattered loess-mantled tabular divides

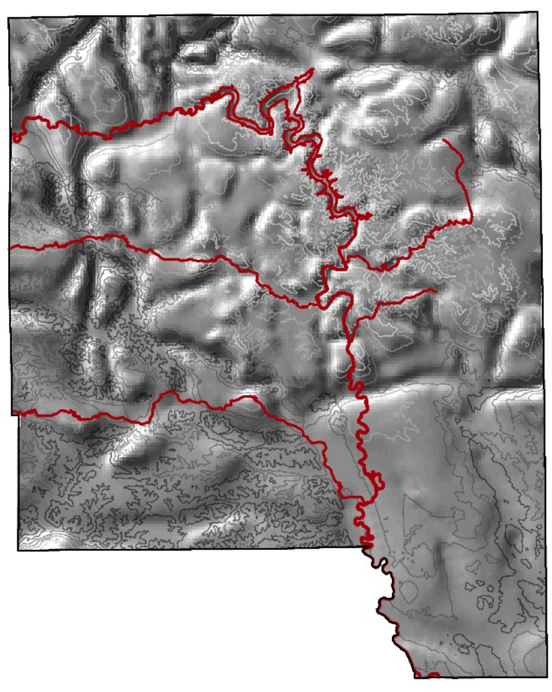

Figure 1. Hillshade and topography of the bedrock surface in Johnson County, Iowa. The lowest elevations on the bedrock surface are in the southwestern part of the county. A complex series of pre-Pleistocene and Pleistocene valleys are cut into the county's bedrock surface. Note that the Iowa River Valley cuts across a bedrock high in the Coralville Lake area and that most major tributary valleys (with the exception of Old Man's Creek in the southwest part of the county) cut across, rather than follow valleys in the bedrock surface.

underlain by 'Yarmouth-Sangamon' paleosols in the SIDP are considered to be possible remnants of the youngest Pre-Illinoian drift plain (e.g., Kay and Apfel, 1929; Ruhe, 1969). The present upland landscape is dominated by stream dissection and erosional landforms. Across the SIDP, at least four different sets of upland paleogeomorphic surfaces can be identified on the basis of topographic, stratigraphic and paleosol relationships: the Yarmouth-Sangamon, Late-Sangamon, Iowan and Holocene surfaces.

The loess-mantled Yarmouth-Sangamon surface is preserved only on the highest, nearly flat upland divides in the southeastern part of the county. This surface is perhaps a remnant of the youngest Pre-Illinois drift plain which was subject to weathering and local modification for several hundred thousand years until it was buried by Wisconsin loess. Generally, a thick gray (poorly drained) buried soil is developed on the Yarmouth-Sangamon surface. This soil was named the Yarmouth-Sangamon Paleosol (Ruhe et al., 1967) because it was presumed to transgress Yarmouth (end of pre-Illinoian glaciation to first Illinoian glaciation) and Sangamon (end of Illinoian glaciation to beginning of Wisconsin Episode – last Interglacial) time. Unfortunately, like many other Quaternary buried soils, it was named in the context of time terms rather than independently, as recommended by the present stratigraphic code (NACSN, 1983). In strict terms, the 'Yarmouth-Sangamon Paleosol' is a pedofacies of the Sangamon Geosol because Pisgah Formation loess buries and stratigraphically defines the paleosol formed in both surfaces.

The Late-Sangamon surface is a set of erosion surfaces cut into and inset below the Yarmouth-Sangamon surface. The break between the Yarmouth-Sangamon and Late-Sangamon surfaces is marked by topographic, geomorphic, and pedologic discontinuities (Ruhe et al., 1967; Hallberg et al., 1978b). The Late-Sangamon surfaces generally consist of several gently sloping loess-mantled pediments that step down the landscape toward drainage lines. Along the Iowa River Valley and some of its tributaries on other parts of the Late-Sangamon landscape, valley-slope fans, terraces and former floodplains, are preserved. As hillslopes began to stabilize during later stages of cutting of the Late Sangamon erosion surfaces, soil formation began and continued until the rate of Wisconsin Episode loess accumulation exceeded pedogenic mixing rates. The loess-mantled buried soil on the Late-Sangamon paleogeomorphic surface has been called the Late-Sangamon Paleosol in Iowa (e.g., Ruhe et al., 1967; Hallberg et al., 1978b). Compared to the Yarmouth-Sangamon paleosols, Late-Sangamon paleosols are generally less weathered, have thinner sola, and are better drained with generally red to reddish-brown colors (Ruhe, 1969; Hallberg et al., 1978b, 1980). Late Sangamon paleosols are typically developed in multiple parent materials: 1) an upper unit of "pedisediment," sediment derived from upslope erosion of the pediment; 2) a stone zone or gravel lag which marks the pediment/erosion surface; and 3) underlying glacial deposits (Canfield et al., 1984; Ruhe et al., 1967; Ruhe, 1969). The soil continued to develop during slow burial by Pisgah Formation deposits, resulting in upbuilding of the Late-Sangamon Paleosol and "welding" (pedogenic overprinting and joining together) of the Farmdale Geosol, formed in Pisgah Formation loess and colluvium to the Late Sangamon Soil. In strict terms, the Late-Sangamon Paleosol is also a facies of the Sangamon Geosol because the deposits which bury and define it (Pisgah Formation in Iowa, Roxana Silt in Illinois) are stratigraphically equivalent.

Another set of erosion surfaces, the Iowan erosion surfaces, are inset below the Late-Sangamon surfaces in the SIDP. This set of erosion surfaces has been referred to by various terms in previous literature: the "Iowan surface" (Ruhe et al., 1968; Prior, 1991), the "Iowan Erosion Surface" (Ruhe, 1969; Hallberg et al., 1978b), and the "Early Wisconsin pediment" (Ruhe et al., 1967). The break between the Late-Sangamon and Iowan erosion surfaces is again marked by topographic, geomorphic, and pedologic discontinuities. In the SIDP, the Iowan erosion surfaces are gently sloping, loess-mantled pediments which are generally shorter in length than the Late-Sangamon pediments. Again, only remnants of these pediments are preserved, and they occur as steps or levels down interfluves below Yarmouth-Sangamon and Late-Sangamon surfaces. The Iowan erosion surfaces represent a renewed period of relatively rapid downcutting that is marked by a stone zone or gravel lag overlain by a thin increment of slope sediment deposited on the pediment as the erosion surface developed upslope. The various steps comprising the Iowan erosion surface in the SIDP were cut just prior to and during the last glacial maximum (c.a. 21,000-16,500 B.P.; Bettis and Kemmis, 1992).

The Iowa Erosion Surface (IES) landform region in northern Johnson County encompasses lower-relief upland areas made up of long, gentle pediment surfaces cut during the same time as the Iowan erosion surfaces in the SIDP. In the IES late-Wisconsin erosion and pedimentation processes extended across the entire upland landscape and removed the older paleogeomorphic surfaces that are preserved in the SIDP. The southern boundary of the IES with the SIDP is marked by a significant increase in local topography produced by increases in the thickness of Peoria Formation loess (0-2 meters on the IES and up to 9 meters in the transition to the SIDP) and a dramatic increase in Peoria Formation eoilan sand. The sand most often occurs interbedded with the loess, but also forms dune fields (such as in the Hawkeye Wildlife Area northwest of North Liberty) and isolated linear dunes and sand sheets (cover sands).

Regionally, accumulation of Peoria Formation loess occurred during formation of the Iowan erosion surfaces. Peoria Loess is thinner on these erosion surfaces than on the Yarmouth-Sangamon and Late-Sangamon surfaces upslope, and basal radiocarbon ages of the loess are younger on the Iowan erosion surfaces (Hallberg et al., 1978b; Ruhe et al., 1968). Early increments of Peoria Formation loess accumulated on the relatively "stable" Yarmouth-Sangamon and Late-Sangamon surfaces, but did not accumulate where Iowan erosion surfaces were developing. During the later phases of Peoria Formation loess deposition, Iowan erosion surfaces and the southern portions of the IES stabilized and loess buried the erosion surface.

A final period of downcutting and headward extension of the drainage system has occurred during the Holocene (the last approximately 10,500 years). These Holocene erosion surfaces are present on portions of upland slopes and in the upper part of the drainage network as a result of headward stream extension. These surfaces descend to alluvial valleys that consist of a series of multiple, often subtle terraces underlain by deposits of the DeForest Formation (Bettis, 1990; Bettis et al., 1992).

Valley Landscape

Terraces and valley margin alluvial fan and colluvial slope complexes related to the Sangamon (Late-Sangamon and older?) and Iowan erosion surfaces occur in the region's valleys. Esling's 1984 study of the Lake Calvin Basin, formed by the junction of the Iowa and Cedar River valleys, concluded that the extensive level terrace surfaces in this area were underlain by loess-mantled alluvial deposits rather than lake sediments as had been presumed by many earlier workers. He identified two major terrace levels distinguished by topographic and stratigraphic sequence differences. The Early Phase High Terrace (EPHT) is the oldest and highest level (Esling, 1984). It is underlain by Peoria and Pisgah Formation loess that bury a well expressed Sangamon Geosol formed in fine-grained alluvium. EPHT usually occurs as small isolated remnants along the Iowa River Valley in Johnson County, except south of Iowa City and along the south side of the valley in the Hawkeye Wildlife Area where continuous larger tracts are preserved (Figure 2).

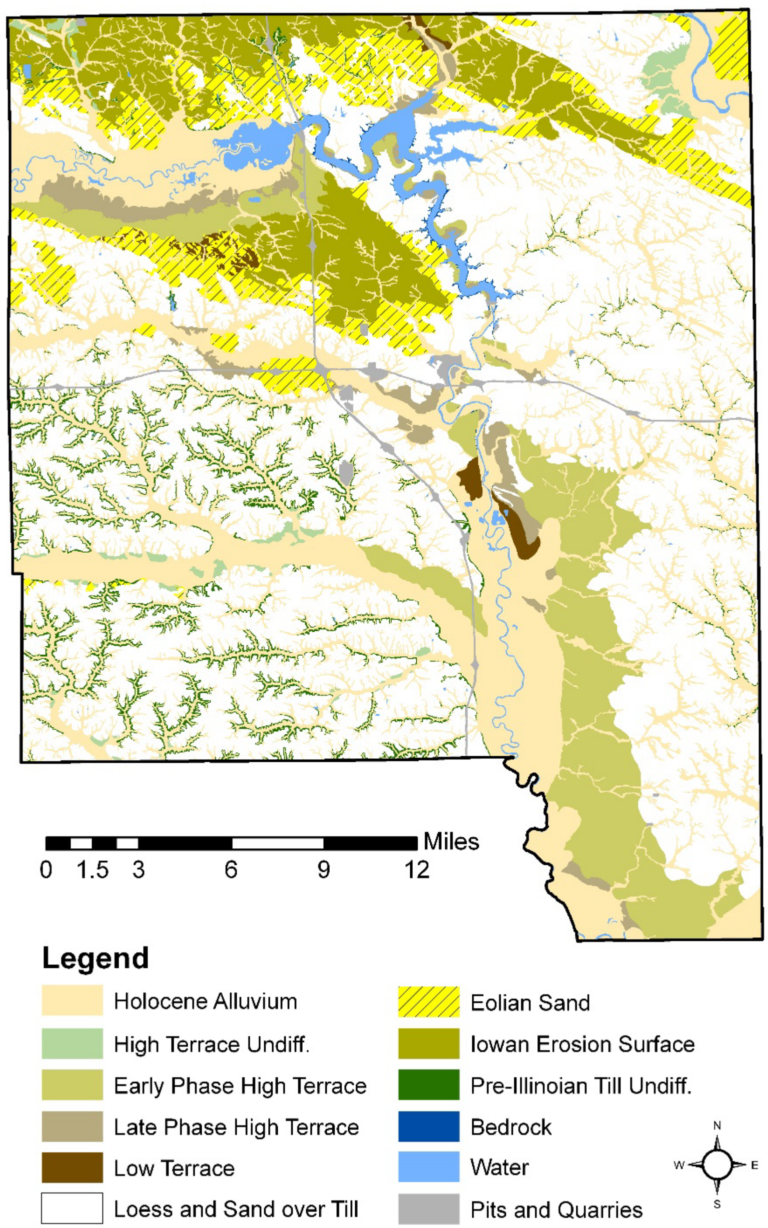

Figure 2. Generalized surficial geology map of Johnson County, Iowa (modified from Tassier-Surine et al., 2004). Areas of wind-blown (eolian) sand mark the margin of the Iowan Erosion Surface in the northern part of the county. Pre-Illinoian glacial deposits are extensively exposed along steep slopes in the southern part of the county where the last-glacial loess cover is relatively thin (< 4 meters). Remnants of Late Pleistocene terraces are intermittently preserved along the Iowa and cedar Rivers and their larger tributaries.

The Late Phase High Terrace (LPHT) occurs lower in the valley and is underlain by several meters of Peoria Formation loess or eolian sand that buries and often grades into alluvium with no intervening paleosol. This stratigraphic succession indicates that the base of the loess and the upper part of the underlying alluvium are closely related in time. LPHT remnants occur discontinuously along the Iowa River and its tributaries with continuous remnants along the south side of the valley in the Hawkeye Wildlife area, along the south side of Clear Creek Valley near its junction with the Iowa River Valley in Coralville and along the east side of the Iowa River Valley in Iowa City. Esling's Low terrace (LT) encompasses a series of lower sandy and loamy terraces that are not loess covered. The highest and oldest of these are above the level of modern floods (even the "great" floods of 2003 and 2008). The LT is underlain by deposits that accumulated during the late Wisconsinan and early Holocene. Low terraces, floodplain areas, alluvial fans and colluvial slopes boarder modern streams and rivers in the region. There are underlain by deposits of the DeForest Formation (Bettis, 1990; Bettis et al., 1992).

WEATHERING ZONES AND WEATHERING ZONE TERMINOLOGY

One of the most obvious features of sediment is its color. Some color variations in Quaternary deposits are the product of distinctive source rocks, such as the reddish tills deposited by glaciers flowing out of the Lake Superior Basin, however most glacial tills in the Upper Midwest were shades of gray or grayish brown when originally deposited, while loess was originally yellowish brown. The movement of water, the activity of microbes and fracture development in the sediments since deposition have altered the original colors, chemistry, and porosity in a systematic fashion below the modern soil profile, as well as beneath now buried soils formed on ancient landscapes. These systematic subsoil alterations are grouped into a series of "weathering zones" that display predictable relationships, and that can be used to identify stratigraphic breaks and to interpret water table history.

Weathering zone terminology refers to the short-hand phrases used to describe weathering-related features of sediments. The terminology is applied only to deposits that are below the solum (A and B horizons – topsoil).

Weathering zones in glacial sediments have been described on the basis of the presence or absence of matrix carbonates, presence or absence of fractures, and interpreted oxidation state as suggested by color and mottling pattern. The standard terminology discussed here concentrates on features that are easily and routinely observed in the field with the use of one's eyes, a Munsell color book, and an acid bottle.

Oxidation Zones

Oxidation in sediments is related to the state of aeration. Oxidized sediments exist in an environment where the oxygen supply is high, or exceeds the biological oxygen demand. Iron is the most commonly oxidized element in Midwestern glacial sediments. The oxidation of iron, from the ferrous to the ferric state, disrupts the electrical neutrality of the crystal lattice, promoting the formation of an oxide, hematite (Fe_2O_3) or hydrous oxides such as goethite and limonite. These iron minerals impart a brown color to the sediment.

Reduction (deoxidation) occurs in an environment where the oxygen supply is limited or the biological oxygen demand is high. Saturation or near saturation and the presence of organic matter and microbes are prerequisites for this process. In a deoxidized environment iron is reduced to a mobile ferrous form. Once in this form iron may be lost through net movement of the groundwater, it may remain in the sediment matrix and react with sulfides, or it may move into fractures, pores, or other small openings in the sediment and be oxidized. Matrix colors in a deoxidized or reduced zone range from gray to greenish gray, a condition reflecting relatively low free iron oxide content. In contrast to the grayish matrix, fractures and pores in the deoxidized zone, where iron has migrated and become oxidized, appear as brown and reddish brown stains, streaks, and mottles.

An unoxidized state occurs when the sediment has not been exposed to oxygen or oxygenated water. In this state most iron is in the ferrous form, and the sediment matrix is a uniform gray color without the brown or reddish brown stains, streaks, and mottles characteristic of the deoxidized or reduced weathering zone.

Carbonate Status - Leached and Unleached Zones

Most of the glacial tills and all of the loess in the Upper Midwest were originally deposited in a calcareous state – with finely divided carbonate in the sediment matrix. Leaching of sediments commences with the removal of matrix carbonates. This process involves the formation of weak acids as rain water passes through the atmosphere and the surface soil. These acids react with carbonate minerals to release the highly mobile calcium ion, which then moves with the soil water and groundwater. As calcium ions move downward with infiltrating water into calcareous deposits, or in evaporative situations, as water is evaporated, the water carrying the ions may become supersaturated with respect to calcium, and carbonate will precipitate to form coatings, patches, and nodules.

Weathering Zone Terminology

Hallberg et al. (1978a) developed shorthand weathering zone terminology that is applicable to unlithified sediments of the Upper Midwest. The descriptive system contains two sets of terminology, one for use with loess and another for till. The choice of which set to use with other kinds of sediments, such as alluvium, depends on whether the sediment is more like loess or till. Each weathering zone is defined in terms of a range of moist Munsell colors (if samples are allowed to dry they may change color irreversibly), reaction with dilute (10-15%) HCl, presence or absence of mottles, presence or absence of secondary accumulations of carbonates, and presence or absence of visible fractures.

Loess

First Symbol – color reference

O – oxidized; 60% of matrix has hues of 2.5Y or redder, values of 3 or higher, may have mottles

D – deoxidized; 60% of matrix has hues of 10YR, 2.5Y, and/or 5Y, values of 5 and 6, and chroma of 1 or 2 with segregation of iron (ferric oxides) into mottles, tubules or nodules

U – unoxidized; matrix has hues of 5Y, 5GY, 5GB, and 5G, values of 4, 5, or 6, and chroma of 1 or less, with no secondary segregation of ferric iron into mottles, tubules, or nodules

Second Symbol – leached or unleached state

U – unleached; matrix reacts virgorously with dilute HCl, primary carbonates present

U2 – unleached; primary carbonates present, has secondary accumulations of carbonate as coatings or nodules

L – leached; no carbonate detectable with dilute HCl

L2 – leached; primary carbonates absent, secondary accumulations of carbonate as coatings or nodules present

Modifier Symbols – when used precede first symbol

M – mottled; refers to zones containing 20-50% contrasting mottles

J – jointed; describes the presence of well-defined subvertical to vertical fractures, these often show oxidized and deoxidized colors and may have coatings of secondary iron oxides, manganese oxides, or other secondary minerals such as calcite or gypsum

Till

First Symbol – color reference

O – oxidized; 60% of matrix has hues redder than 2.5Y, or hues of 2.5Y with values of 5 or higher, may have mottles

R – reduced; 60% of matrix has hues of 2.5Y with values of 3 or less, hues of 2.5Y with values of 4 and chroma of 2 or less, hues of 5Y, N, 5GY, 5G, and 5BG, and values of 4 or higher. Colors in this zone are almost always mixed as diffuse mottles, streaks, and diffuse blends of colors. There may be considerable segregation of secondary iron compounds (with oxidized colors) into mottles, tubules, nodules, or sheets along fractures and other discontinuities.

U – unoxidized; matrix uniform color with hues of 5Y and N, values of 5 or less, 5GY, 5G, or 5BG with values of 6 or less, with no mottles, nodules, etc.

Secondary and modifier symbols are the same as those applied to loess.

Examples

Loess:

OL - oxidized, leached; yellowish brown (10YR5/3) matrix, leached (does not react with weak HCl)

MDU - mottled, deozidized, unleached ; grayish brown (2.5Y5/2) matrix with strong brown (7.5YR5/6) mottles and tubules, unleached (reacts strongly with dilute HCl)

Till:

UU - unoxidized, unleached; uniform very dark gray (5Y3/1) matrix, unleached

JUU - jointed, unoxidized, unleached; uniform dark greenish gray (5G4/1) matrix with few thin vertical fractures that have mottled olive (5Y5/6) and olive gray (5Y5/2) faces with thin discontinuous black (2.5Y2.5/1) patches of manganese oxide accumulation, unleached

MJOL2 - mottled, jointed, oxidized, leached with secondary carbonate accumulation; brownish yellow (10YR6/6) matrix with brown (7.5YR5/3) and grayish brown (2.5Y5/2) mottles, common vertical fractures with almost continuous strong brown (7.5YR4/6) iron segregations and thin discontinuous coatings of secondary carbonate on faces, few small secondary carbonate concretions (nodules), leached matrix

Discussion

Weathering zone boundaries are usually transitional. Oxidation and leaching proceed downward from a land surface in a predictable manner, producing a typical expected vertical sequence of weathering zones. The following table shows complete vertical sequences expected for loess and till.

Loess	Till
solum	solum
OL	OJL
JOL2	MOJL
MJOU	MOJL2
MDU	MOJU
DU	MRJU
UU	RJU
	MUJU
	UJU
	UU

With slight modifications to adjust for regional variations in primary matrix color and carbonate status, this terminology is applicable to most Quaternary continental glacial sequences.

Interpretation of Stratigraphic Breaks

Weathering profiles have predictable vertical sequences progressing downward from a land surface. The progression of weathering zones varies with landscape position, primarily in response to the position of the long-term water table and organic matter content (these factors strongly influence the oxidation state and distribution of iron-oxide compounds). The intensity of leaching, related in large part to macroclimate (seasonal distribution of rainfall, temperature, and thus vegetation composition), controls matrix carbonate status (assuming originally calcareous materials). Weathering zone characteristics, then, can provide reliable information on both macroclimate and local landscape relationships within a sequence of glacial deposits.

The vertical extent of the weathering profile is controlled by the depth to which oxygenated water is able to penetrate the deposits. In continental settings the percolation of oxygenated waters through matrix-dominated Quaternary glacial sequences is controlled in large part by relief on the landscape. Oxygenated waters penetrate to greater depths, and the oxygenated portion of the weathering profile thickens, as the local and regional drainage network develops and landscape dissection increases. In a general sense, a regional drainage network progressively develops as time passes following a continental glaciation. Since the development of the weathering profile and the evolution of a regional drainage network are linked, the thickness and character of the oxidized portion of the weathering profile beneath paleo-upland positions provides us with a reasonable way to compare the relative rank (interglacial vs. interstadial) of stratigraphic breaks in the glacial record (Bettis, 1998).

Applications in Environmental Geology

Secondary weathering profile properties of Quaternary deposits allow us to infer water-table history, redox conditions, and some hydrogeologic properties that are important considerations in understanding water and contaminant movement in these sediments. Hydraulic conductivity of glacial tills increases from unoxidized (UU) to oxidized (O) to fractured (JO) weathering zones. Fractures in these sequences provide avenues for rapid water movement. There are two categories of hydraulic conductivity in these sediments; primary or matrix conductivity and secondary – that associated with the fracture network. The latter is commonly two or three orders of magnitude greater than the primary conductivity.

Fractured tills are also characterized by two specific storage values; intergranular specific storage associated with the sediment matrix and the specific storage associated with the fracture network. During pumping of an underlying aquifer, changes in head are rapidly transmitted from fractures, producing rapid responses in wells whose screened intervals intersect open fractures, while piezometers screened in unfractured till respond much more slowly because their water is released by the much slower process of intergranular consolidation.

Fracture networks, then, are responsible for relatively rapid vertical and lateral movement of water and contaminants through these deposits that have low matrix permeability. Since fracture networks in these deposits become denser, and more interconnected from the unoxidized to the oxidized weathering zones (toward the land surface with which they are associated) recognition and description of weathering profiles in cores and auger samples, often too small or of insufficient quality to permit direct observation of fractures and fracture networks, provides a qualitative measure of fracture networks and the development of secondary hydraulic conductivity and specific storage associated with the fracture network.

Weathering zones also provide information about water-table history and redox conditions. Reduced zones form when oxygen availability is low or biological oxygen demand exceeds oxygen availability. These situations occur under saturated conditions and low eH. The presence of a reduced weathering zone therefore usually indicates a water table within or above that zone and strong reducing conditions. The outer fringes of organic contaminant plumes are often marked by a reduced weathering zone. If mottles or streaks of oxidized iron are present in a reduced zone, indicating fluctuating eH conditions, caution needs to be taken to ensure that the reduction features reflect present saturated conditions rather than relict saturated conditions of a former period.

QUATERNARY SUCCESSIONS IN RIVER PRODUCTS COMPANY'S KLEIN QUARRY

Wisconsin Loess

During the Wisconsin Episode two loess units were deposited across eastern Iowa (Bettis et al., 2003a). The oldest is a thin sheet that has largely been reworked by colluvial (including periglacial) processes and pedogenically altered. This unit is referred to as the Pisgah Formation. Its stratigraphic position is the same as the Roxana Silt of Illinois and the Gilman Canyon Formation of Nebraska, but its lithologic properties differ. The youngest loess is Peoria Formation loess. In eastern Iowa this loess is thickest near river-valley sources such as the Iowa and Cedar valleys and along the southern margin of the Iowan Surface.

Both loess units are present in the quarry exposures. About 7m of Peoria Formation silt (Peoria Loess) is present. Regional relationships indicate that the Peoria Formation began to accumulate on the late glacial landscape about 23,000 B.P. and continued to accumulate until about 11,000 B.P. Deposition was most rapid from about 21,000 to 16,000 years ago during the coldest and driest portion of the late glacial period. Tests of land snails that lived on the late-glacial forest floor are sometimes present in the lower half of the unit.

Much thinner Pisgah Formation loess is present beneath the Peoria. The Pisgah is slightly denser, grayer color, leached of carbonates and has occasional pods of transported Farmdale Geosol in its upper part. The Farmdale Geosol is formed in the upper part of the Pisgah Formation and is evident as a darker brown zone that exhibits weak to moderate soil structure. In places this paleosol has been partially eroded and transported downslope by solifluction. This took place under periglacial conditions during the early part of the full glacial period before the rate of Peoria Loess accumulation was great enough to bury the Pisgah Formation (Bettis et al, 2003b).

Pre-Illinoian Sequence

Pre-Illinoian glacial deposits of Iowa are monotonously similar; where unweathered, the diamictons (glacial tills) are all gray and have similar loam textures. As a consequence, it has been necessary to make regional stratigraphic differentiation using laboratory data rather than field properties. Further, the stratigraphic units are differentially preserved beneath different paleogeomorphic surfaces that have developed as the regional drainage system evolved following the last Pre-Illinoian glaciation. A definitive stratigraphic sequence was constructed only after an exhaustive regional drilling program that included transects across the different surfaces and across bedrock valleys where the thickest and often most complete stratigraphic sequences were preserved (Hallberg, 1980a, b).

Pre-Illinoian deposits in Iowa have been lithostratigraphically classified into the Alburnett Formation and younger Wolf Creek Formation (Hallberg, 1980a). Both formations consist predominantly of glacial diamictons (largely basal tills), but include other deposits as well. The formations and their members are differentiated by various physical and mineralogical characteristics, but clay mineralogy is the main property used to distinguish between deposits at the formation level (Hallberg, 1980a, b). Whereas some lithostratigraphic units, such as the Wedron and Glasford formations of Illinois may also correspond to diachronic intervals (Johnson et al., 1997), the Wolf Creek and Alburnett formations do not; each formation consists of multiple depositional units and paleosols, and includes deposits of several glacial and interglacial episodes. The Wolf Creek and Alburnett formations, therefore, are not correlative in any way to the former concepts of 'Kansan' and 'Nebraskan' glaciations, out dated concepts based on inadequate stratigraphic data (Hallberg, 1986; Boellstorff, 1978). In western Iowa and central Missouri stratigraphic units correlative to the Wolf Creek and Alburnett formations overlie still older glacial deposits (Hallberg, 1986; Balco and Rovey, 2010).

Recent work by Balco and Rovey (2010) has provided the first absolute ages for these tills (also refer to Rovey et al., 2010). The earliest advance of the Laurentide Ice Sheet into the region took place around 2.4 Ma and deposited tills of the Atlanta Formation in Missouri and “C tills” in western Iowa. The next expansion of the Laurentide Ice Sheet into the region was about 1.3 Ma, at the beginning of the mid-Pleistocene transition and deposited tills of the Moberly (Missouri) and Alburnett (Iowa) formations and the B and A4 tills of western Iowa. All these pre-middle Pleistocene tills have reversed magnetic polarity. At least two diamicton units are present within Iowa’s Alburnett Formation, however, they have virtually identical primary lithologic properties; and as yet there is no way to differentiate or correlate the individual till units across the region.

Studies of the detrital remnant magnetism (DRM) of tills at Conklin Quarry indicate that deposits of the Alburnett Formation have reversed polarity, and are thus interpreted to be older than 790,000 years ago (the Bruhnes reversed/Matuyama normal boundary; Johnson, 1982), whereas deposits of the Wolf Creek Formation have normal polarity, and post date the Bruhnes/Matuyama boundary (Baker, 1985; Baker and Stewart, 1984). At Conklin Quarry, the boundary occurs within sub-Wolf Creek Formation slopewash and alluvium in which Westburg Geosol is formed (Rovey et al., 2010).

The Wolf Creek Formation is dominated by massive, texturally and compositionally uniform basal tills, and is subdivided into members based on lithologic differences (calcite/dolomite ratio and sand-fraction lithology). Quarry operations over the past three decades have exposed glacial diamictons corresponding to all four of the Wolf Creek Formation's recognized members in Conklin Quarry (Hallberg et al., 1984; Kemmis et al., 1992). Detailed lithologic studies of the Wolf Creek Formation sequence have not occurred at Klein Quarry, but multiple Wolf Creek Formation tills are recognized there by the presence of paleosols, weathering zone relationships and glacial erosion surfaces. The Late Sangamon geomorphic surface, underlain by the late Sangamon soil and associated weathering profile cuts across the upper part of the till sequence. The paleosol is evident as a prominent reddish brown zone overlain by silty Pisgah Formation loess.

The current Quaternary sections at Klein Quarry have not been studied in detail, but on this trip we will visit accessible parts of the section to discuss:

- Weathering zone and lithologic criteria for recognizing stratigraphic breaks in these sections
- Glacial erosion features on the bedrock surface
- Glacial deformation structures in the sequence
- Evidence for buried paleosols and plant macrofossils
- The complete weathering profile associated with the Late Sangamon paleosol
- Hydrogeologic implications of the exposed Quaternary sequence

<u>Conklin Quarry</u>

Over the past thirty years of operation Conklin Quarry has exposed the most complete documented pre-Illinoian glacial succession in the continental interior (Hallberg et al., 1984; Kemmis et al. 1992). The quarry exposures have included as many as six tills; two Alburnett Formation tills and all four of the recognized members of the Wolf Creek Formation, and both Wisconsin loess sheets (Pisgah Formation and Peoria Formation). Several buried paleosols have also been exposed, including several facies of the Late-Sangamon Paleosol. Figure 3 presents the sections exposed in 1975-76 and 1983-84 and 1992. The section has been actively worked over the past 5 years and changes often. Over this period we have observed the following:

1. The lowest Alburnett formation till(s) overlie either Devonian limestone or Devonian Lime Creek shale. The shale appears to be thickest in karst openings in the underlying limestone. Where the shale is present, the lowest diamicton exhibits a variety of glaciotectonic features including folds, shallow shear planes (lystric faults) and smears and smudges. Where the shale is absent the limestone surface often exhibits glacial striations.
2. If a continuous zone of oxidized pebbly sand alluvium is present it occurs at the top of the Alburnett Formation. Earlier exposures to the south have consistently exposed alluvium in this stratigraphic position; often with the Westburg Soil formed in the upper part of the alluvium (Rovey et al., 2010).
3. Stratigraphic breaks marked by buried paleosols within the pre-Illinoian sequence in this area are generally poorly expressed and most often evident as slightly deformed organic-enriched zones that contain wood of coniferous trees (usually *Picea* sp.).
4. Stratigraphic breaks higher in the oxidized part of the section are marked by weathering profiles truncated by glacial erosion. These are most often evident as a weathering profile sequence that progresses upward from oxidized to mixed oxidized and unoxidized or reduced. A zone of deformed

sand bodies in the upper part of the pre-Illinoian section may represent the contact zone between the Hickory Hills and underlying Aurora till members of the Wolf Creek Formation (see Figure 3)

5. A complete weathering profile extends from the Late Sangamon Soil into the upper pre-Illinoian till(s). The upper part of the Late Sangamon Soil is formed in loamy pedisediment (slope deposits) that bury a stone zone composed of resistant lithologies.
6. The Late Sangamon Soil is buried by Pisgah Formation Loess. On close examination the boundary between the loess and paleosol is gradational over about 10 cm, likely because of mixing by pedogenic processes (burrowing, shrinking and swelling, surface wash, etc.) as loess began to accumulate on the paleosol surface.
7. Peoria Formation Loess caps the section and exhibits a lower deoxidized and leached (DL) weathering zone that grades upward into oxidized and unleached OU), then oxidized and leached (OL) weathering zones. Tests of land snails, if present, are found in the OU loess.

Klein Quarry

The Quaternary section at Klein Quarry has not been studied in as much detail as the Conklin Quarry sections. Canfield and others (1984) studied now-covered exposures located along the north east wall of the quarry. These exposed the Late Sangamon paleogeomorphic surface descending from upland landscape steps on pre-Illinoian glacial till onto valley-margin colluvial slope deposits and alluvium on a remnant of the Early Phase High Terrace. Carolyn Moeller undertook studies of clast orientation at macroscopic and microscopic scales in Alburnett and Wolf Creek Formation tills exposed in the northeast portion of the quarry in 2000-2001 for a senior thesis in Geoscience at the University of Iowa. At that time, two Alburnett Formation tills were observed. The lower till was 0.5 to 1m thick, loam texture and contained abundant subrounded and angular casts of local limestone. A thin, deformed organic-rich paleosol that contained spruce wood was formed in the upper part of this till and overlain by a second unoxidized and unleached (UU) loam diamicton Alburnett Formation till. The upper part of this younger Alburnett Formation till had a reduced, jointed and leached (RJU) weathering zone formed in it, and was abruptly overlain by unoxidized and unleached Wolf Creek Formation till.

Over the past 25 years quarry operations greatly expanded Klein Quarry to the south and west, and more recently to the east. In the early 1990's alluvium (fine-grained grading downward to sand and pebbly sand with a basal gravel with the Westburg Soil formed in it that cut into Alburnett Formation till) was present. No paleosols or weathering zone breaks were evident in the oxidized, unleached and jointed pre-Illinoian sequence above the paleosol. As quarry operations expanded to the southwest in the late 1990's, Lime Creek Formation shale was exposed atop the Devonian sequence in the southwest part of the quarry. Abundant streaks and blobs of Lime Creek shale were observed along shear planes extending from the bedrock contact upward into the pre-Illinoian sequence, and to the southeast (the general direction of glacier flow indicated by till fabric and glacial striations on the bedrock surface at both Klein and Conklin quarries) we observed large and small-scale deformation structures in Wolf Creek Formation tills. At the same time the alluvium with the Westburg Paleosol formed in it thinned, and unoxidized Alburnett Formation and Wolf Creek Formation tills thickened in the southeast part of the exposure. As the quarry expanded to the south the alluvium at the top of the Alburnett Formation disappeared from most of the exposure, the Lime Creek shale was no longer at the bedrock surface, and large-scale deformation structures were not present in the Pre-Illinoian till sequence. These features are again exposed as the most recent expansion has continued to the east.

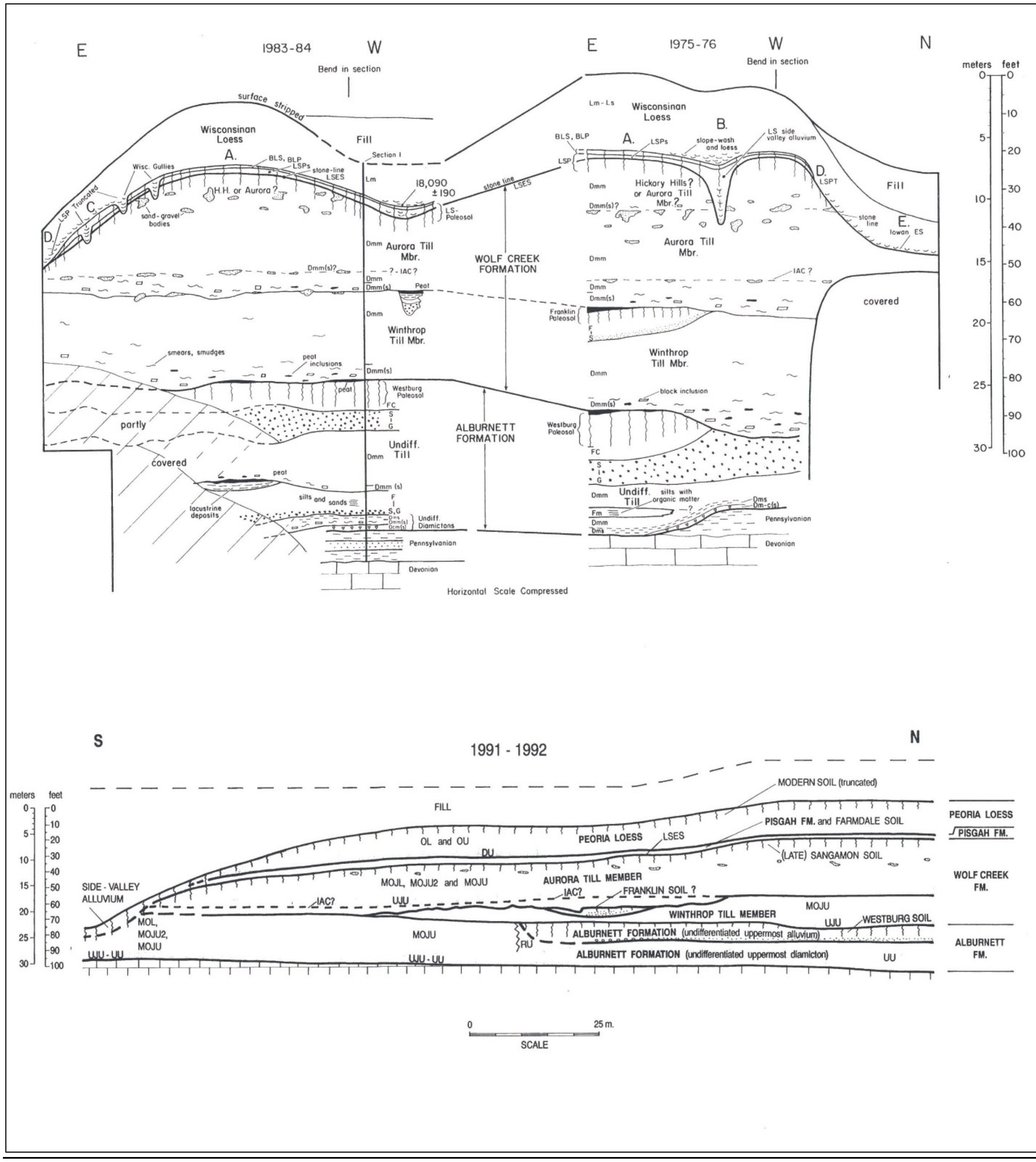

Figure 3. Quaternary sections exposed on the western side of Conklin Quarry in 1975-1984 (top) and 1991-1992 (bottom). Subsequent quarry operations have moved the quarry face several hundred meters west and south of the 1975-1984 section. The present Quaternary exposures in the quarry are located about 300 meters north of the 1991-1992 section.

Quaternary exposures have been described for previous trips in head walls exposed by large slump blocks along the upper part of the center-south wall (modern soil formed in Peoria Formation loess and upper part of the Peoria Formation loess) and along the southwest quarry wall (Late Sangamon paleogeomorphic sequence, upper pre-Illinoian sequence, and lower pre-Illinoian alluvial sequence). Currently, the most accessible exposures are in the southeast corner and east wall (base of the section and lower Pre-Illinoian till sequence) and along the northeast wall of the quarry (Peoria Formation silt over weathered Pre-Illinoian till overlying a thick alluvial sequence). General observations of the section exposed in these areas include:

Upper South Wall

1. A modern forest soil (Alfisol) formed in Peoria Formation silt is exposed in the headwall of a large slump block in this area. The soil profile grades into the oxidized and leached (OL) weathering zone of the loess. If the exposure extends deep enough it exposes an OL, OU, DU weathering zone profile in the loess. Slump failure is most likely occurring in the base of the loess where water is perched and excess pore pressure occurs at the contact with the Late Sangamon Soil formed in weathered Pre-Illinoian till.

Southwest Wall

1. The Late-Sangamon paleogeomorphic surface and associated weathering profile formed in Pre-Ilinoian glacial till is exposed here. The paleosol is overlain by Pisgah Formation loess which is poorly exposed. Note the contact between the loess and paleosol is gradational – likely because loess deposition began slowly and the initial accumulations were mixed into the paleosol's surface horizon by physical and biological processes. The upper grayish brown AB horizon of the paleosol is formed in loamy slope sediments and a well expressed stone zone composed of resistant lithology pebbles (quartz, chert, greenstone) occurs between the AB horizon and the underlying dark reddish brown Bt horizon of the paleosol. The upper part of the weathering profile is leached and they grade downward to a mottled, oxidized and unleached zone that has abundant large nodules and sheets of pedogenic carbonate.
2. Another feature to notice in this area is the occasional irregular bodies of medium sand (Figure 4) that occur generally in the zone of secondary carbonate accumulation. These may mark the contact zone between the Hickory Hills and underlying Aurora till members of the Wolf Creek Formation as is the case at Conklin Quarry (see Figure 3). Across the quarry bench and lower in the section oxidized sand and pebbly gravel occurs between overlying oxidized and underlying unoxidized tills. This is probably a remnant of the extensive alluvial deposit separating the Wolf Creek and Alburnett formations that we have observed in both Klein and Conklin quarries.

Southeast Corner and East Wall

1. Unoxidized and unleached (UU) Alburnett Formation till overlies Devonian limestone in this area. The limestone surface has been streamlined by glacial erosion- glacial striations (scratches and grooves in the rock indicating ice flow direction) and chatter marks (curved marks related to irregular movement of materials entrained at the base of the glacier) are present on the bedrock surface (Figure 5). A small, striated whaleback (a streamlined landform carved into bedrock) was noted in 2010 and striations on the rock surface were measured to cluster between N61W and N70W (measured by Tom Marshall and

Brian Witzke), consistent with the orientations of clasts in the Alburnett formation tills measured by Moeller in 2000.

2. At least two unoxidized tills are present in this area. Deformed sand bodies and sheared zones of diamicton mark the contact between these tills (Figure 6). Although we don't have clay mineral data to confidently identify the tills to the formation level the following arguments lead us to believe that the upper till is likely Wolf Creek Formation and the lower till is Alburnett Formation:
   a. As the quarry was expanded southward tills of both the Alburnett and Wolf Creek formations began to thicken toward the east.
   b. The till/till contact of interest drops in elevation from west to east.
   c. Deformed pods of oxidized sand and pebbly sand are common at the contact.
   d. Oxidized sand and pebbly sand was common at the Alburnett/Wolf Creek contact and still occurs at that contact on the west end of the Quaternary section. This is a likely source for the sand in the deformed bodies at the contact.

Northeast Wall

1. Peoria Formation silt (loess) overlying a Late Sangamon paleosol and oxidized Pre-Illinoian till.
2. A thick alluvial package with a fining-upward sequence and a basal pebble gravel (Figure 7). This unit is likely correlated to the exposure described in the 1990's and may be related to the sand and gravel that was formerly present along the south wall.
3. Alburnett Formation till present on top of bedrock and overlain by the alluvial unit.

Figure 4. South quarry wall. Note the presence of the till-till contact (dark gray unit overlying brown oxidized unit) and deformed sand body within the till.

Figure 5. Glacial striations and chatter marks located on the bedrock surface.

Figure 6. Body of deformed sand and shear structures at till-till contact near southeast corner of Klein Quarry.

Figure 7. Northeast quarry wall showing the thick alluvial unit.

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DEVONIAN STRATIGRAPHY OF KLEIN QUARRY:
Upper Rapid Member – Iowa City Member

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INTRODUCTION

The Devonian stratigraphy seen in River Products' Klein Quarry is one of the primary reference sections for the Cedar Valley and Wapsipinicon groups in the region. As noted in the introduction to this guidebook, the reader is urged to review the Geological Society of Iowa (GSI) Guidebook No. 87 (Witzke and Bunker, 2010) from the fall 2010 field trip to Klein and Conklin quarries for additional information and applicable references not included in this guidebook. The purpose of this guidebook is to serve as an updated field guide to introduce newcomers to the Klein Quarry and as a review for those who have clambered about this pit before.

ACKNOWLEDGEMENTS: PAST AND PRESENT

We (Brian and Bill) have had considerable assistance in studying and describing Cedar Valley and Wapsipinicon strata in the Iowa area by a number of colleagues, and we especially acknowledge the studies and support of Orrin Plocher and Greg Ludvigson through the years. Our geologic colleagues at the Iowa DOT, especially Brian Gossman and Adriana Reyes, have always been supportive and helpful of our Paleozoic studies, and our time together at Klein Quarry and elsewhere is highly valued. We gratefully acknowledge the strong support of Don Koch (as State Geologist) and Ray Anderson at the Iowa Geological Survey (IGS) during our ongoing studies of Iowa stratigraphy – we would have been unable to proceed without their support.

Our highly valued colleague and friend, Jed Day, has worked extensively on the biostratigraphy (conodonts, brachiopod), lithostratigraphy, chemostratigraphy, and deposition of Cedar Valley and Wapsipinicon strata in Iowa (and more), many studies done with colleagues from Europe and North America. His extensive publications constitute some of the primary references for the Devonian stratigraphic section of Iowa. Jed has been a significant part of our ongoing investigations of Cedar Valley strata for the past three decades,

including the Conklin and Klein quarries, and we gratefully acknowledge his considerable efforts and insights.

IGS geologists Brian J. Witzke and Bill J. Bunker were students of Iowa's Devonian record for the entirety of their distinguished careers, spanning more than three decades. I intend to spend the entirety of my career at the IGS to become half the geologist they were and it is regrettable that circumstances did not allow the mentorship process to propagate their wealth of knowledge to the next generation. I'll do my best.

HISTORY OF INVESTIGATIONS OF THE DEVONIAN OF JOHNSON COUNTY

Investigations by numerous geologists and students over many decades have made the Devonian of Johnson County, Iowa one of the best studied and best understood Devonian sections in the world. Sam Calvin's pioneering geologic studies in Iowa included the first major summary of the Devonian rocks in Johnson County (Calvin, 1897), and he described natural exposures and a quarry operation in Coralville strata in the area of the present-day Conklin Quarry. Michael and Welp (1957) published a description of the Devonian section at the Klein Quarry. Graduate studies at the University of Iowa of the Devonian section in Johnson County, especially the Conklin Quarry, began in earnest during the 1970s with the completion of several theses on the stratigraphy, deposition, and carbonate petrography of Cedar Valley (Zawistowski, 1971; Kettenbrink, 1973; Mitchell, 1977) and Wapsipinicon (Sammis, 1978) strata, primarily under the direction of Profs. Brian Glenister and P.H. Heckel. The rich stromatoporoid faunas of the Little Cedar and Coralville formations, especially specimens from the Johnson County area and the Klein Quarry, were studied by Danielle Jannusch (nee Shapo) in two graduate thesis projects (Shapo, 2003; Jannusch, 2008).

Biostratigraphic studies of Cedar Valley strata during the 1990s include conodont investigations from the Klein Quarry and elsewhere by Rogers (1990, 1998) and conodonts and palynomorphs from the Conklin Quarry and elsewhere by Klug (1990, 1992). These studies, under the direction of Prof. Gilbert Klapper, expanded on some of Klapper's earlier investigations of Cedar Valley strata in Johnson County (e.g. Klapper and Ziegler, 1967). Originally proposed for Iowa in reports by Klapper, Bunker, and Witzke, a recent study on the *Icriodus subterminus* conodont Zone by Narkiewicz and Bultynck (2010) expanded the recognition of this zone globally. Their work utilized many specimens from Johnson County and the Conklin Quarry.

FAULTING, KARSTIFICATION, AND OTHER STRATIGRAPHIC COMPLICATIONS

As first noted by Calvin (1897), the Devonian strata of Johnson County are locally complicated by a variety of small-scale folds and faults, extensive brecciation of some beds, and multi-stage erosion and karstification (solutional features in limestone). Sulfide and calcite mineralization has formed along some ancient karst areas (especially Pennsylvanian paleokarst) and can be seen at Conklin and Klein quarries. Gentle folding and small-scale faulting is evident in the Devonian strata at these quarries and elsewhere in Johnson County, locally offsetting beds (from a few inches up to 40 ft or more), making bed-tracing difficult in places. Folding and faulting is commonly associated with brittle deformation producing fractured and brecciated fabrics, and some features are prominently slickensided. Although there has been no systematic study and survey of these structures in the area, personal anecdotal observations of dozens of small-scale faults in Johnson County (Coralville Lake area and quarries), where the sense of throw is evident, has identified the majority of them to be reverse faults (in fact, a thrust fault is described at Lake Macbride State Park; Gilotti and Wood, 1999). However, some normal faults have been observed (see summary by Anderson, 2006).

The origin of some of these features may relate to evaporite (gypsum-anhydrite) dissolution and collapse in underlying Wapsipinicon Group strata, but it is far from clear that all of the many faults and folds in the area originated from such a process. The irregular and variable nature of the Wapsipinicon-Cedar Valley contact in the area is clearly associated with evaporite-solution collapse processes. There certainly is extensive regional brecciation of upper Wapsipinicon and lower Cedar Valley strata (Solon and Rapid members) that undoubtedly is related to evaporite solution collapse, and some small-scale faulting likely originated during such processes. However, the apparent preponderance of reverse faults suggests compressive forces, possibly associated with the distant tectonic deformation of the Ouachita Orogeny. Reverse faults with up to 15 to 40 ft (4.5-12 m) of displacement are known to cut across Little Cedar and Coralville strata in the Coralville Lake area. A much larger east-west fault, the Iowa City-Clinton Fault Zone, has recently been identified transecting several counties in eastern Iowa including the southern edge of Iowa City. This fault zone shows vertical displacement of Middle and Upper Devonian strata of 110 to 190 ft (33.5-58 m) (down to the south).

Episodes of limestone dissolution created networks (solutionally-enlarged fractures, sinkholes, caves) of paleokarst within the Devonian limestones of Johnson County. These features are commonly filled with sediments of Upper Devonian (Lime Creek) and Pennsylvanian (Morrowan-Atokan) age, as well as Cedar Valley limestone breccias and conglomerates, and some are associated with sulfide-calcite mineralization. These features are of varying scale, and locally disrupt the normal stratigraphic succession making bed-tracing difficult in places. The solutional degradation of the carbonate bedrock can best be seen at the bedrock surface where the Quaternary materials have been removed (Fig. 1).

Finally, recent studies in the Klein Quarry area (including exposures and cores) show lateral variation in bed thicknesses and lithologies over short distances within the Cedar Valley Group. These variations are part of the Devonian stratigraphic succession and provide evidence of sedimentary processes not heretofore recognized. In particular, significant lateral variation is seen in the lower Rapid Member, likely associated with the development of the transgressive systems tract of Iowa T-R Cycle 3B. In addition, the coral-stromatoporoid biostromes of the Little Cedar and Coralville formations display significant lateral variations in thickness, lithology, and fossil content, adding complexity to the stratigraphic succession.

WAPSIPINICON GROUP

Although the Klein Quarry extends down to the Kenwood Member of the Pinicon Ridge Formation, the field trip stops today will only view units of the Cedar Valley Group. The reader is referred to Witzke and Bunker (2010) for a detailed description of the Wapsipinicon Group stratigraphy of the Klein Quarry.

Figure 1. Evidence of solutional erosion (karst) of the bedrock surface (outlined in red). This surface is near the base of the Iowa City Member. (Photo by Ryan Clark, on 3/15/15)

CEDAR VALLEY GROUP - INTRODUCTION

The Cedar Valley Group is a widespread interval of limestone and dolomite strata, in places with evaporite (gypsum-anhydrite) beds that occurs across most of Iowa and adjoining areas of Illinois, Minnesota, Missouri, and Nebraska. It reaches a thickness of about 125 ft (38 m) in Johnson County where it includes three formations, in ascending order: Little Cedar, Coralville, and Lithograph City. The highest strata of the group, the Shell Rock Formation, are not recognized in southeast Iowa. The reader is referred to additional publications for regional stratigraphic, biostratigraphic, and depositional summaries (e.g., Witzke, Bunker, and Rogers, 1988; Witzke and Bunker, 2006; Day, 2006). In Johnson County, the Cedar Valley Group is entirely composed of Middle Devonian age rocks (upper Givetian), but Upper Devonian (lower to middle Frasnian) strata are recognized in the upper Cedar Valley Group elsewhere in Iowa. Unlike the underlying Wapsipinicon Group, the Cedar Valley Group is richly fossiliferous, and numerous studies have documented much (although not all) of the diverse marine fossil faunas that these strata have yielded to paleontologists and fossil collectors through the years. Intervals of Cedar Valley Group limestone strata seen at the Klein Quarry are discussed individually below.

A full description of the Cedar Valley Group stratigraphy exposed at the Klein Quarry is in Witzke and Bunker (2010). The section we will see today includes the upper Rapid Member of the Little Cedar Formation through the lower part of the Iowa City Member of the Coralville Formation. The descriptions and discussion of those units follows.

LITTLE CEDAR FORMATION – RAPID MEMBER

The Rapid Member of the Little Cedar Formation was named for exposures near the mouth of Rapid Creek in Johnson County. Witzke *et al.* (1988) designated the Conklin Quarry as the primary reference section for the member. The member is dominated by argillaceous limestone, variably fossiliferous, with beds commonly separated by thin shaly partings. It ranges from about 50 to 70 ft (15-21 m) in thickness in Johnson County, although minor changes in thickness are observed over short distances, primarily due to variations within the basal Rapid strata (as identified in the Klein Quarry cores). However, most of the Rapid Member is remarkably consistent in its bed-by-bed stratigraphy across the county. Nevertheless, an eastward increase in sparsely skeletal limestone facies is evident in the subsurface cores from eastern Johnson County (Witzke and Bunker, 2006), and a cross-bedded grainstone unit is present at the top of the Rapid Member northward in the county (Witzke and Bunker, 1994).

Witzke and Bunker (1994, 2006) recognized two or more smaller-scale transgressive-regressive (T-R) depositional sequences (or subcycles) within the larger T-R sequence that comprises the entire Rapid Member (T-R cycle IIa-2). The basal Rapid certainly represents a significant transgressive (deepening) event compared to the underlying and shallower facies of the upper Solon. We also interpreted the deepest-water depositional facies within the middle Rapid Member (the “Z-beds”), and the base of this interval may therefore correspond to another transgressive event. The upper Rapid (beginning at the base of the lower Rapid biostrome) was also interpreted to mark a discrete shallowing-upward T-R subcycle. Much of the Rapid Member contains open-marine faunas rich in brachiopods, crinoids, bryozoans, and other marine groups, indicating deposition in a marine subtidal shelf setting. Sedimentary features suggest episodic sediment reworking and redistribution by storm currents. However, units within the Rapid, especially the “Z-beds,” include sparsely skeletal to unfossiliferous argillaceous mudstones, and these facies were interpreted to have been deposited in subtidal shelf settings generally below storm wavebase that experienced bottom oxygen stresses, probably below the oxycline (Witzke and Bunker, 2006).

For discussion purposes, the descriptive summary of Rapid Member strata seen at the Klein Quarry today will only include the upper Rapid “biostrome beds” and upper Rapid “*Devonatrypa waterlooensis* beds.”

<u>Upper Rapid Member – Rapid Biostromes Interval</u>

The upper Rapid Member is marked by an interval containing two coral-rich biostromes, and these form a widespread and easily recognizable stratigraphic unit that is well displayed at the Klein Quarry (Fig. 2). The relatively thin biostrome beds are recognized across a vast area, occurring from the Quad Cities area to the east and northward to northern Iowa. They are best developed in the Johnson County area. The base of this interval generally is a thin argillaceous limestone reentrant that includes concentrations of dark

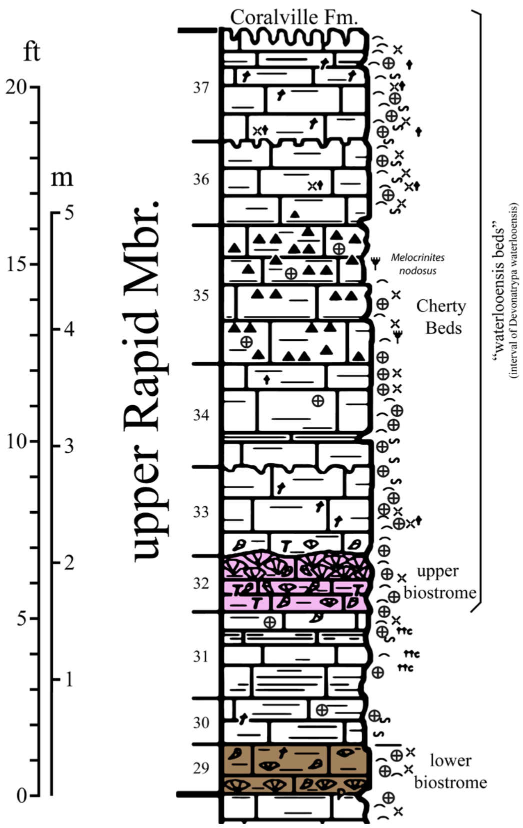


Figure 2. Graphic stratigraphic section of upper Rapid Member strata from exposures at the Klein Quarry. Symbols given in Appendix A.

phosphatic grains and is slightly glauconitic (“phosphatic marker bed”; Witzke and Bunker, 1994). The lower biostrome includes concentrations of corals and stromatoporoids, sometimes densely packed, in a matrix of skeletal wackestone to packstone (brachiopod, crinoid debris; Fig. 3), although the concentrations of corals and stromatoporoids varies significantly over short distances, and locally the interval contains only scattered corals. Nevertheless, the lower biostrome can be consistently identified across Johnson County. The coral fauna is dominated by colonial rugosans (*Hexagonaria*) and massive to branching favositid tabulates, but solitary rugosans (cup and horn corals, especially cystiphyllids) are also common. Massive and encrusting forms of stromatoporoids are also common in the lower biostrome (see taxonomic studies by Shapo, 2003), which contrasts with the upper biostrome where stromatoporoids are relatively rare.

The upper biostrome is especially conspicuous in Johnson County, where it is characterized by densely packed accumulations of colonial rugose corals (*Hexagonaria*), especially in the upper part. Most of the *Hexagonaria* are 4 to 12 inches (10-30 cm) in diameter, but specimens up to 20 to 30 inches (50-75 cm) also occur. These dense accumulations of *Hexagonaria*, with proportionately sparser massive to branching favositid corals and rare stromatoporoids, generally distinguishes the upper from lower biostromes. Horn corals are also more abundant in the upper biostrome, especially in the lower part, and small branching pachyporid tabulate corals are also present. The skeletal wackestone to packstone matrix of the upper biostrome is notably more argillaceous than the lower biostrome. Although the upper biostrome is consistently recognized at localities across Johnson County, local variations in thickness and coral abundance are observed. In the walls of the Klein Quarry, the upper biostrome is easily identified from a distance. At that locality the upper biostrome can be seen to vary in thickness over lateral distances of tens of meters, in places reaching thicknesses to about three feet (1 m) but in other areas thinning to four inches (10 cm, Fig. 4), and may even be absent for short distances. Similar variations are also observed at localities around Coralville Lake.

The skeletal limestone matrix of both upper and lower biostromes contains crinoid debris and rarer articulated stems and cups (*Megistocrinus*) as well as brachiopods (*Devonatrypa, Seratrypa, Strophodonta, Orthospirifer, Schizophoria, Tylothyris, Pentamerella, Gypidula, Cranaena*, others). Fenestellid bryozoans are also noted. The matrix volume generally decreases upward through the upper biostrome, and its upper part is dominated by packed *Hexagonaria* with less than 10% matrix.

A non-biostromal stratigraphic interval about 25 to 45 inches (70-110 cm) thick separates the upper and lower biostromes in Johnson County and this interval contains some interesting and distinctive fossil faunas and displays lateral lithologic variability. The lower part of this interval is generally characterized by an abundance of coarse crinoid grains, commonly including stems and articulated material (some surfaces with oriented stems). A variety of brachiopods are scattered (*Devonatrypa, Orthospirifer, Tylothyris, Eosyringothyris, Strophodonta, Schuchertella, Schizophoria, Cranaena*). Small branching pachyporid tabulate corals are generally present and are locally common and conspicuous. Horn corals, scattered small favositids, and small stromatoporoids are locally noted. Large trepostomes bryozoans (massive to branching forms) are commonly seen, in places reaching diameters of four to six inches (10 to 15 cm) (the most massive bryozoans noted in the entire Cedar Valley Group). Other bryozoan forms also occur, including fenestellids. The upper part of the interval at most localities is more argillaceous and less skeletal (wackestone).

Figure 3. Lower biostrome unit of the upper Rapid Member. Argillaceous, fossiliferous limestone with solitary rugose corals evident amongst crinoid and brachiopod debris. (Photo by Ryan Clark on 3/15/15)

The intra-biostrome interval at the Klein Quarry differs from that seen at Conklin Quarry in containing sparsely skeletal to nonskeletal burrowed argillaceous mudstone units, especially in the middle to upper parts (Fig. 2). A thin mudstone has been noted in the Coralville Lake area, but this is minor and inconspicuous compared to those at Klein. Mudstones also occur in this interval eastward in the subsurface of eastern Johnson County (Witzke and Bunker, 2006). There is variation in the thickness and lateral continuity of these mudstone units at Klein; a basal mudstone has been noted, but this is absent in most of the Klein cores. Skeletal limestone strata similar to those seen elsewhere in Johnson County also occur at Klein, and these interstratify with the mudstone units. As elsewhere, these skeletal beds are wackestones to packstones, part very crinoidal (stems and cups noted), and part rich in large trepostome bryozoans and branching pachyporid corals. Brachiopods and tentaculites also occur.

The interval of the Rapid biostromes is interpreted to represent a complex transgressive systems tract of the upper Rapid T-R depositional subcycle. The presence of mudstone units within the interval (as seen at Klein) suggests overall depositional deepening and decreased winnowing. The dense accumulations of corals seen in the biostromes and the paucity of matrix sediments (especially in the upper biostrome) may relate, in part, to decreased sediment accumulation during transgressive deepening. Strata of the overlying *waterlooensis* beds are interpreted to form the highstand and regressive systems tracts of this subcycle. Northward in Johnson County, the presence of cross-bedded crinoidal grainstones supports significant depositional shallowing at that position (Witzke and Bunker, 1994). Farther north into Benton County and points north, the highest beds of this subcycle include peritidal and mudflat facies of the Hinkle Member, but the Hinkle mudflats did not prograde as far as Johnson County as the seaway shallowed.

Figure 4. Brian Witzke pointing to the upper biostrome unit in the upper Rapid Member at Klein Quarry. The contact between the Cou Falls and Rapid members is near the bench in the rock face here, but it is mostly covered. (Photo by Ryan Clark on 4/10/15)

Upper Rapid Member – "*Devonatrypa waterlooensis* Beds"

Above the Rapid biostromes, an interval of limestone and cherty limestone strata has been termed the "*Devonatrypa waterlooensis* Beds" after a distinctive and moderately common brachiopod. However, this term may not be particularly apt for the interval as *D. waterlooensis* is known to range from the Rapid biostromes into overlying lower Coralville strata (Fig. 5). Regardless, the term is retained here for discussion purposes. The interval in Johnson County includes some distinctive lithologies typically not seen in underlying strata of the Little Cedar Formation: 1) many of the limestones are slightly dolomitic (and commonly weather to a distinctive red-brown color); 2) glauconitic enrichment is common (especially in the lower to middle beds); and 3) the middle beds include abundant chert nodules. Chert nodules (smooth to chalky chert, white to brown) occupy a thicker interval at Klein than at Conklin, and chert content generally increases northward in Johnson County. Correlative strata in Benton and Black Hawk counties are thicker and notably more cherty (Eagle Center Member).

Limestone strata of the *waterlooensis* beds are dominated by slightly argillaceous skeletal wackestones (slightly dolomitic) with abundant stringers and beds of skeletal packstone (primarily crinoidal). Minor argillaceous to shaly partings separate some beds. Carbonate mudstone also occurs within the interval at the Klein Quarry, primarily in the middle part and in the cherty units, although most of the mudstones are prominently burrowed and interswirled with skeletal wackestones and packstones. However, discrete mudstone beds are locally identified in the cherty unit at Klein (e.g., Fig. 2). The middle beds at Klein (units 34-35; Fig. 2) and elsewhere in Johnson County commonly show a variety of interesting burrowed fabrics (small to large horizontal burrows, large *Zoophycus* burrows, penetrative subvertical and vertical burrows). Two prominent and widespread vertically burrowed discontinuity surfaces (or hardgrounds), some penetrating up to four inches (10 cm) into the underlying strata, are seen at many localities in Johnson County (Fig. 2, contacts between beds 33/34 and 36/37). The top of the interval (the Rapid-Coralville contact) is also marked by a prominent vertically-burrowed discontinuity surface, and the burrows are infilled with sediment of the overlying Coralville Formation.

Figure 5. Bedding surface showing specimens of *Devonatrypa waterlooensis* in packstone at the Rapid-Coralville contact, Klein Quarry. Quarter for scale.

The fossil content of the *waterlooensis* beds is mostly dominated by crinoid debris, although a variety of other fossils are also present. Some beds include crinoid stems as well as articulated crinoid cups, and articulated specimens of *Melocrinites nodosus* (cup plates with prominent nodes) are the most common, and specimens have been found at Conklin and Klein quarries and elsewhere in Johnson County. Articulated *Megistocrinus* cups are also relatively common. Calhoun (1983) reported a remarkable assemblage of articulated crinoids from these strata in Johnson County and the Conklin Quarry, and reader is referred to his thesis for a more comprehensive listing. In addition to the crinoids, additional echinoderms from these stratra in Johnson County include beautiful slabs of articulated echinoids, as well as starfish, brittle stars, blastoids, and edrioasteroids. Articulated theca and isolated plates of the rhombiferan cystoid *Strobilocystites calvini* are seen in the upper *waterlooensis* beds of Johnson County, but this rhombiferan is even more abundant in correlative strata northward in Linn and Benton counties.

Additional fauna of the *waterlooensis* beds include a variety of brachiopods, although brachiopods overall seem less abundant in these beds than in underlying strata of the formation. *Devonatrypa waterlooensis* is characteristic, but *Orthospirifer, Tylothyris*, *Strophodonta*, and *Schizophoria* are commonly seen. Additional but rarer brachiopods include *Athyris, Cyrtina, Eosyringothyris, Pentamerella, Cranaena, Striatochonetes, Cupularostrum*, and others. Lower and upper strata of the *waterlooensis* beds contain faunas similar to some beds seen in the intra-biostrome unit, and include scattered to common small branching pachyporid corals and massive trepostomes bryozoans in crinoidal wackestones to packstones. Small solitary and colonial corals (*Hexagonaria*, favositids) locally occur in the basal part above the biostrome. Other bryozoans, trilobites, and tentaculites also occur in the *waterlooensis* beds.

CORALVILLE FORMATION

Keyes (1912) first proposed the Coralville as a stratigraphic unit, named in Johnson County for the City of Coralville, and Stainbrook (1941) designated the type locality at the Conklin Quarry in Coralville. Formerly regarded as a member within the Cedar Valley, Witzke *et al.* (1988) elevated it formational rank and included two new members, the Cou Falls and Iowa City, also named after localities in Johnson County. The reader is referred to Witzke and Bunker (1997) for a comprehensive summary of the stratigraphy and deposition of the Coralville Formation and the history of investigations in the Iowa area, particularly Johnson County. The limestone succession of the Coralville Formation reaches thicknesses of about 40 ft (12 m) in Johnson County, but is usually thinner at most localities due to sub-Pleistocene and, at Klein Quarry, sub-Pennsylvanian erosion. It is unconformably overlain in Johnson County by Devonian strata of the Lithograph City Formation or Lime Creek Formation. It disconformably overlies the Rapid Member at a prominent burrowed discontinuity or hardground surface (described briefly above). The Coralville Formation has been interpreted to form a general shallowing-upward transgressive-regressive (T-R) cycle (Devonian T-R cycle IIa-2).

Cou Falls Member

The Cou Falls Member in Johnson County is characterized by remarkable biostromal accumulations of corals and stromatoporoids that were deposited across an area that bordered the distal portions of the inner-shelf region of the Midcontinent (Witzke and Bunker, 1997). It includes four general limestone lithologies (Fig. 6): 1) Coral and stromatoporoid-rich biostromal units lacking branching stromatoporoids; 2) stromatoporoid-rich biostromal units with abundant fragments of branching stromatoporoids (usually referred to *Idiostroma*, but probably including additional taxa); 3) limestone strata with sparse to absent corals or stromatoporoids (see “corals absent” units; Figs. 6 & 7); and 4) oncolite bed (marble- to apple-sized concentrically laminated carbonate clasts, commonly encrusting large gastropods or other fossils). The first two lithologies typically have a matrix dominated by finely abraded skeletal grains, primarily packstones, but units with branching stromatoporoids include progressively more mud upward in the member. The sparse to non-coralline beds are also dominated by fine skeletal packstones, but mudstone to wackestone units are also recognized. The oncolite bed occurs at a few localities (not in Klein), and this unit was previously included with the overlying Iowa City Member. It is here included in the Cou Falls Member due to lateral continuity with upper Cou Falls strata, and it contains corals and stromatoporoids

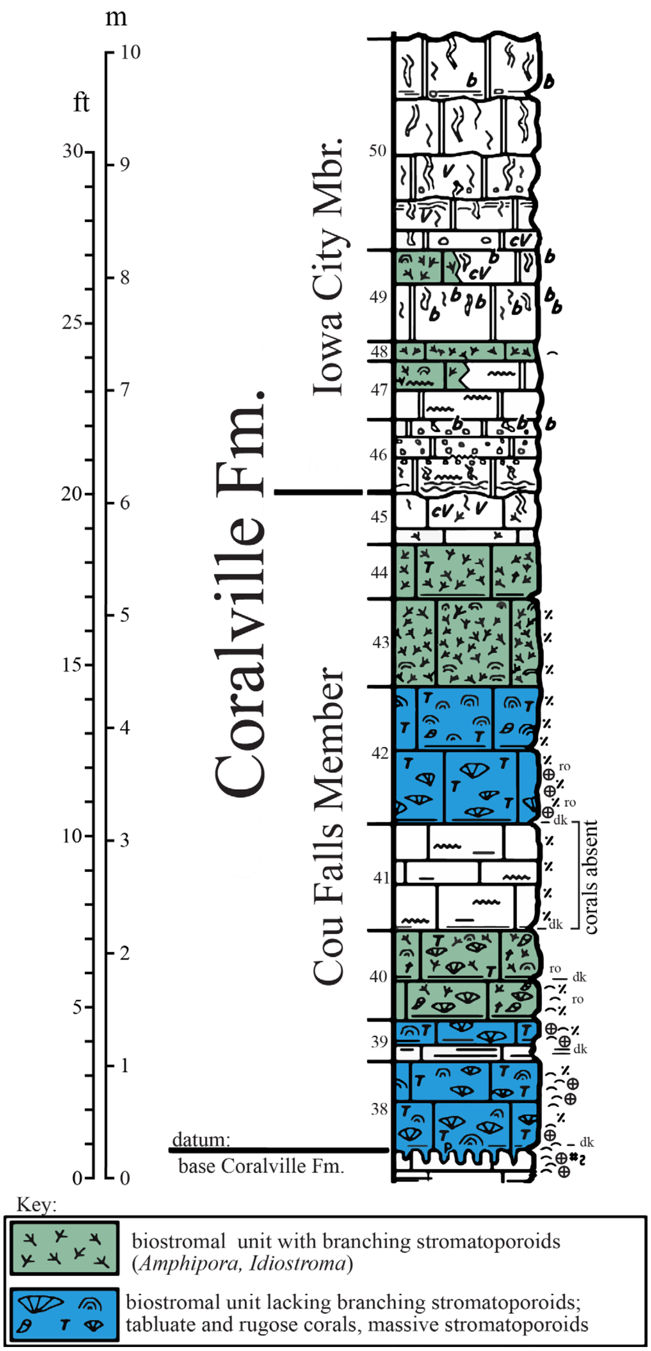


Figure 6. Graphic stratigraphic section of the Coralville Formation from exposures in Klein Quarry. Symbols given in Appendix A.

which are not present in basal Iowa City strata elsewhere. Some beds in the Cou Falls Member are slightly argillaceous, and stylolites are common. Thin organic-rich (bituminous) dark-colored (dark gray, dark brown, or black) shaly partings are commonly seen separating some beds in the lower Cou Falls (Fig. 8). The origin of these organic partings is unknown and deserves further study, as these occurrences seem anomalous with respect to the conjoining strata dominated by abraded-grain packstones.

Biostromal units that lack branching stromatoporoids (which have sometimes been termed the "*Cranaena* beds" or "*Stromatopora* beds") are best developed in the lower half of the Cou Falls, whereas biostromal units with abundant fragments of branching stromatoporoids (commonly termed the "*Idiostroma* beds") are best developed in the upper half of the member. However, these two types of biostromal strata show complex interbedding and lateral variation at localities across Johnson County, and the "*Cranaena* beds" and "*Idiostroma* beds" are not independent stratigraphic units but show biofacies and lithofacies variations. The incorporation of non-coralline facies within the Cou Falls succession likewise reflects complex facies variations within the member. The closely-spaced outcrop and core sections at the Klein Quarry are particularly instructive, where the non-coralline units are seen to vary significantly both in thickness and stratigraphic position. They are most common in the middle part of the member, but they also occur in the lower and upper parts of the member at Klein and other localities in Johnson County. The origin of this variation is not particularly clear, but it may indicate that coral and stromatoporoid growth was not uniform across the inner-shelf area. Such patchiness and variability may have been further influenced or controlled by bottom current activity. The abraded and broken grain packstones that characterize much of the interval indicate that vigorous bottom currents were clearly operating through much of Cou Falls deposition.

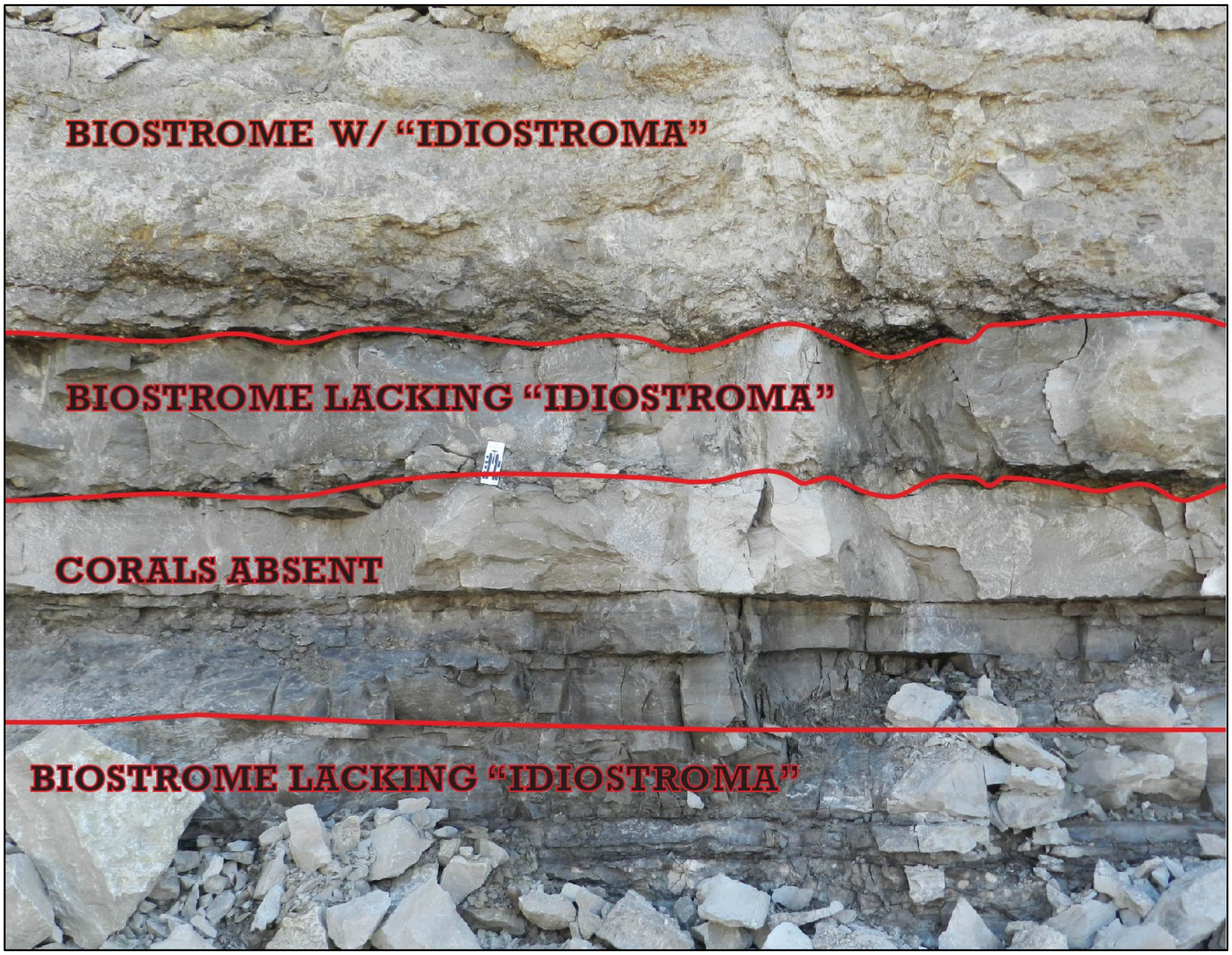


Figure 7. Upper two-thirds of the Cou Falls Member seen in Klein Quarry. Scale near the middle of the photo. (Photo by Ryan Clark on 3/15/15)

Nevertheless, the occurrence of shaly partings, as well as discontinuous units of lime mudstone-wackestone, indicates that quieter-water environments were also part of Cou Falls deposition. Accumulations of stromatoporoids and corals may have locally baffled currents in some areas, enabling localized patchy muddy sediment accumulation. Undoubtedly, other as yet undetermined factors were also at play.

The Cou Falls Member is richly fossiliferous, although the overall faunal diversity decreases upward through the succession (Kettenbrink, 1973; Witzke and Bunker, 1997) suggesting generally shallowing-upward deposition with increasing environmental restriction. Corals are abundant and diverse in the lower Cou Falls and include a variety of forms in Johnson County: colonial rugosans (*Hexagonaria*), solitary rugosans (*Tortophyllum, Tabulophyllum,* others), and tabulate corals (especially favositids but also including alveolitids and pachyporids). Corals are less abundant in the "*Idiostroma* beds," and *Hexagonaria* disappears upward in the succession. The stromatoporoid fauna is also abundant and diverse, commonly including massive to hemispherical forms in the lower strata, and smaller branching and irregular forms in the "*Idiostroma* beds." Jannusch (2008) documented the taxonomic diversity of stromatoporoids in the Cou Falls of Johnson County, and the reader is referred to her thesis for a more comprehensive listing of the taxa identified in her study.

Figure 8. Organic-rich (bituminous) shale partings in the Cou Falls Member seen in Klein Quarry. Photo from near the base of the section shown in Figure 7. (Photo by Ryan Clark on 3/15/15)

Crinoid debris is scattered in the lower half of the Cou Falls Member (rarely higher), and is most common in basal parts. Brachiopods are scattered to common in the member, with the greatest abundance and diversity noted in the lower beds. The lower strata contain a relatively diverse assemblage including species of *Strophodonta, Cyrtina, Elita, Eosyringothyris, Orthospirifer, Tylothyris, Athyris, Independatrypa, Pseudoatrypa, Cranaena, Pentamerella, Schizophoria, Productella, Atribonium, Schuchertella*, and others (see Day, 1992). However, the upper strata have a sparse and impoverished fauna typified by few taxa, commonly represented only by *Athyris*. Mollusk fossils include rare bivalve molds and moderately common rostroconchs (an extinct group of bivalved mollusks; *Conocardium*). Trilobites are moderately common in the lower strata (primarily proetids, rare aulacopleurids), which represent the highest stratigraphic occurrence of trilobites in the Cedar Valley Group of Iowa. Calcareous microfossils include calcareous algae, foraminifera, spirorbids, and ostracodes.

Iowa City Member

The Iowa City Member was named for limestone strata above the stromatoporoid-rich Cou Falls Member; its type locality is on the campus of the University of Iowa in Iowa City (Witzke *et al.*, 1988). The Iowa City Member is lithologically quite distinct from the underlying Cou Falls, and is dominated by pale-colored dense "sublithographic" limestone with thinner fossiliferous units, including branching stromatoporoids (Fig. 9). The dense "sublithographic" limestones are primarily composed of muddy pelleted lime sediment (pelmicrite), sometimes associated with small intraclasts. Some beds show faint horizontal laminations, possibly of stromatolitic origin. Stylolites are common in some beds. Many of "sublithographic" beds contain fenestral fabrics of small bubble-like calcite filled voids (sometimes known as "birdseye" structures). Fractured to slightly brecciated beds are common, and many beds in the upper Iowa City Member contain networks of fractures filled with limestone sediments (internal sediment fills) and spar-filled "stromatactis" structures. Mudcracks are locally seen, primarily in the upper beds. The "sublithographic" limestones were deposited in restricted very shallow peritidal environments associated with shallowing and withdrawal of the Devonian seaway at the end of the Coralville T-R cycle. The fenestral fabrics, internal sediment fills, and mudcracks all indicate that much of the deposition occurred on subaerially exposed carbonate mudflats. Restricted lagoons and other shallow-water environments were associated with these mudflats. An unusual spore-rich coal is locally associated with these facies at Conklin and in Iowa City, possibly deposited in a ponded environment on the mudflats.

Figure 9. Sublithographic limestone of the Iowa City Member with branching stromatoporoids in the lower portion (rock hammer for scale). (Photo by Ryan Clark on 4/10/15)

Fossils are generally sparse in the "sublithographic" limestones of the Iowa City Member, and include large gastropods (possibly grazers), ostracodes, calcareous algae, and calcispheres (small spherical algal structures). The peritidal units of the Iowa City Member are part of an extensive prograding wedge of carbonate and evaporite facies (inner shelf) associated with the withdrawal of the Coralville sea (Witzke and Bunker, 1997). Of interest to the field trip, Coralville and Iowa City occupy a position very close to the southeastern margin of these facies, and only a few miles to the east and south these facies are entirely absent (as seen in cores at the Mid-America gas pipeline terminal in east-central Johnson County), where upper Coralville strata are characterized by fossiliferous open-marine limestone facies (Witzke and Bunker, 1997). As such, the type area of the Iowa City Member occurs near the southeastern margin of the inner-shelf progradation.

Fossiliferous limestone units (wackestone to packstones commonly with a pelmicrite matrix) interbed with the "sublithographic" limestones of the Iowa City Member and include one laterally extensive biostromal unit in the lower part of the member. This biostrome is known as the "*Amphipora* beds" after the abundance of broken grains of a small branching stromatoporoid (taxonomic identification as *Amphipora* is uncertain, and other taxa may be present). This unit represents a minor marine transgression above the peritidal-mudflat facies of the basal Iowa City Member (Witzke and Bunker, 1997). This unit, in addition to the branching stromatoporoid grains, locally includes scattered domes of globular massive stromatoporoids and small ramose favositid corals. Brachiopods are rare but locally include *Athyris* and an atrypid. Gastropods are locally present. Additional stromatoporoid-bearing units are seen to interbed and interfinger with the "sublithographic" limestones at three different horizons in the upper Iowa City Member in Johnson County, and these are best seen at exposures on the campus of the University of Iowa. These higher stromatoporoid units are not recognized north of Iowa City-Coralville and the Coralville Lake area. By contrast, the "*Amphipora* beds" unit is known to extend as far north as Black Hawk County (Witzke and Bunker, 1997).

LITTLE CEDAR FORMATION – CORALVILLE FORMATION CONTACT: Core Description

Today we have a core sample that was drilled close to the location of the rock faces we will be inspecting (see map on page 2 of this guidebook, Klein core #14). It includes the lower 17 ft (5 m) of the Coralville Formation and the upper 19 ft (5.8 m) of the Little Cedar Formation. This core was drilled in 2005 along with several others for River Products to assess the additional reserves in the area. Below is a general description of this core (depths indicated are in feet below ground surface).

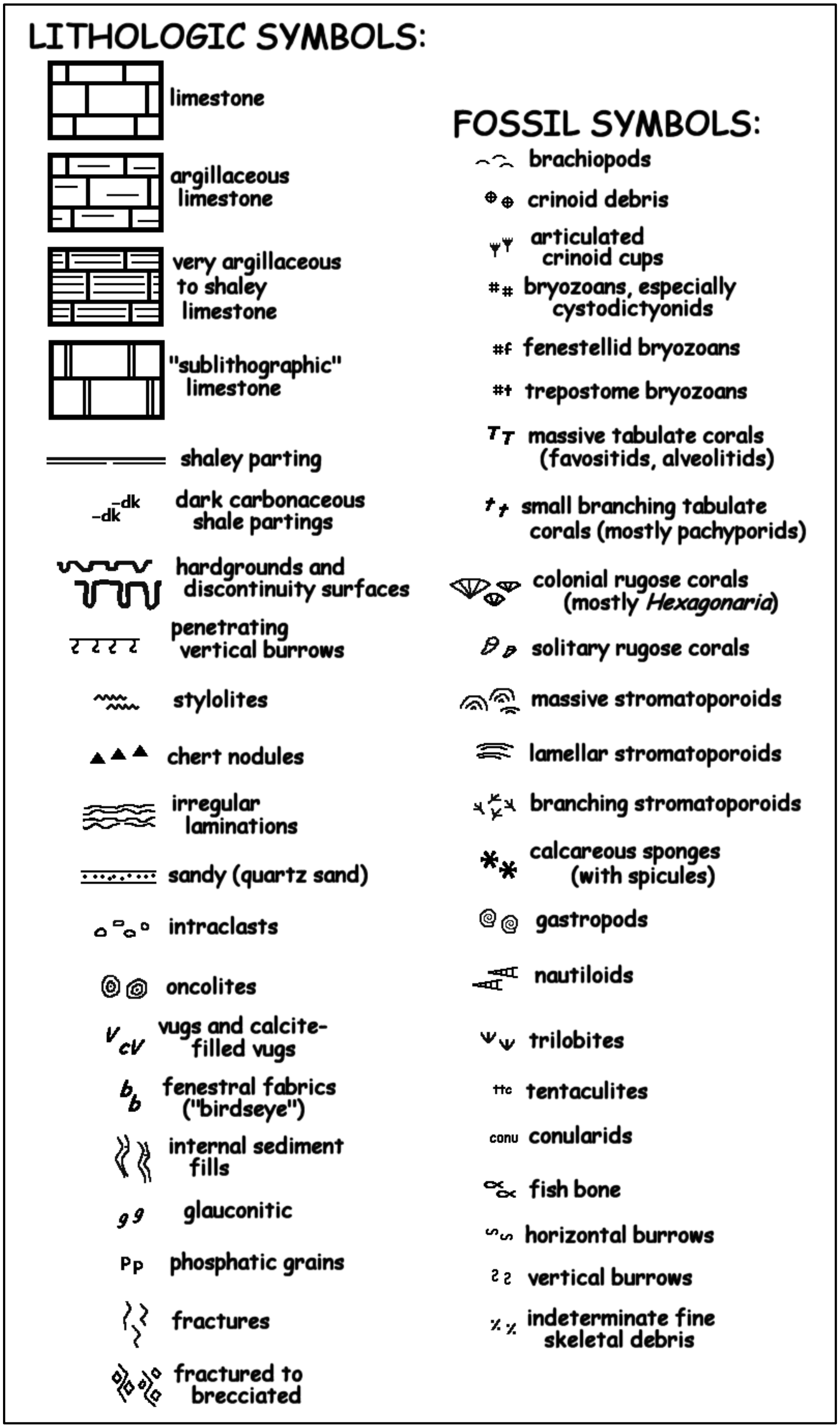
<u>Coralville Formation – Cou Falls Member</u>

79 – 83'	Limestone, gray – tan, abundant digitate stromatoporoids and corals (**"Idiostroma" bed**)
83 – 88.2'	Limestone, light gray – light tan, fine to medium grained, part skeletal wackestone (**"corals absent" bed**)
88.2 – 92.9'	Limestone, tan – gray, abundant corals and stromatoporoids, few digitate stromatoporoids (**"Idiostroma" bed**)
92.9 – 93.1'	Limestone, dark gray, very argillaceous to shaly, abundant brachiopods and stromatoporoids, crinoid debris (hardground?)
93.1 – 94.5'	Limestone, gray – brown, part argillaceous, few stylolites, brachiopods, few crinoid pieces (**"corals absent" bed**)
94.5 – 96'	Limestone, dark brown – gray, part argillaceous, part skeletal wackestone, brachiopods and stromatoporoids (**"lacking Idiostroma" bed**) basal contact is hardground

<u>Little Cedar Formation – Rapid Member</u>

96 – 97'	Limestone, light gray, fine grained, phosphatic grains
97 – 101'	Limestone, gray – brown, fine grained to argillaceous, abundant small tabulate corals, brachiopods, crinoid debris, sparse phosphatic grains
101 – 105'	Limestone, brown – gray, very argillaceous, abundant silty stringers and swirls, chert nodules, *Melocrinites modosus* zone from 103.2 – 104' (**cherty bed**)
105 – 108.3'	Limestone, gray, part argillaceous, crinoid debris, few corals
108.3 – 110'	Limestone, gray, large stromatoporoids, corals, crinoid and brachiopod debris
110 – 111.7'	Limestone, dark gray, very argillaceous to shaly, very fossiliferous with large stromatoporoids, corals, brachiopods, crinoids, bryozoans, and others (**upper biostrome**)
111.7 – 113.9'	Limestone, gray, micritic, abundant brachiopods, crinoids, and bryozoans
113.9 – 115' TD	Limestone, gray, part argillaceous, fossiliferous with brachiopods, crinoids, various corals (**lower biostrome**)

APPENDIX – A


LITHOLOGIC SYMBOLS:
limestone
argillaceous limestone
very argillaceous to shaley limestone
"sublithographic" limestone
shaley parting
-dk -dk
dark carbonaceous shale partings
hardgrounds and discontinuity surfaces
penetrating vertical burrows
stylolites
chert nodules
irregular laminations
sandy (quartz sand)
intraclasts
oncolites
V cV
vugs and calcite-filled vugs
b b
fenestral fabrics ("birdseye")
internal sediment fills
g g
glauconitic
Pp
phosphatic grains
fractures
fractured to brecciated
FOSSIL SYMBOLS:
brachiopods
crinoid debris
articulated crinoid cups
bryozoans, especially cystodictyonids
fenestellid bryozoans
trepostome bryozoans
massive tabulate corals (favositids, alveolitids)
small branching tabulate corals (mostly pachyporids)
colonial rugose corals (mostly *Hexagonaria*)
solitary rugose corals
massive stromatoporoids
lamellar stromatoporoids
branching stromatoporoids
calcareous sponges (with spicules)
gastropods
nautiloids
trilobites
ttc
tentaculites
conu
conularids
fish bone
horizontal burrows
vertical burrows
indeterminate fine skeletal debris

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FOSSILS OF THE MIDDLE DEVONIAN ROCKS OF JOHNSON COUNTY, IOWA

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INTRODUCTION

Iowa has a wonderful Paleozoic record that has been the focus of numerous stratigraphic and paleontologic investigations. In particular, the Middle Devonian age rocks in Johnson County have been well studied for more than 100 years including being the topic of numerous graduate theses at the University of Iowa (well summarized in Witzke and Bunker, 2010). These rocks in Johnson County range from Eifelian to Frasnian (approximately 370 to 390 million years ago). Exposures include parts of the Wapsipinicon Group and the Cedar Valley Group. The Wapsipinicon Group is subdivided into the Bertram, Otis, Spillville, and Pinicon Ridge formations and reaches about 100 ft (30 m) of thickness in Johnson County (Witzke and Bunker, 2010). The Spillville Formation is the stratigraphic equivalent of the Otis in the northern portion of the Devonian outcrop belt and is not recognized in Johnson County. Only the Pinicon Ridge Formation is exposed in the Klein Quarry, but we will not examine those exposures in detail on the field trip today. The Cedar Valley Group can be subdivided into the Little Cedar, Coralville, Lithograph City, and Shell Rock formations. The Shell Rock Formation is not recognized in Johnson County. Combined, the Cedar Valley Group reaches a thickness of about 125 ft (38 m) in Johnson County. The reader is referred to first article of this guide and to early publications for detailed descriptions of these formations. This article will give an overview of what is known about the Middle Devonian fossil records in Johnson County with some brief comments on the paleoecology and paleoenvironments represented. On the field trip today, we will have a chance to see part of this record in the exposures at Klein Quarry.

MAJOR FOSSIL GROUPS

Corals

One of the more obvious fossils in Johnson County are the corals. The corals (phylum Cnidaria, class Anthozoa) are related to jellyfish and sea anemones. Like these groups, corals have two tissues layers, tentacles, and a central mouth structure. Corals spend most of their life cycle attached to the seafloor with less time floating in the water column like the jellyfish do. In between their soft tissues, corals secrete a calcareous skeleton and as a result have a good fossil record. This skeletal material is useful for determining which species you may have preserved in the fossil record since it is directly related to the soft tissues.

The two major groups of Paleozoic corals are the subclasses Rugosa and Tabulata. The rugose corals have both colonial and solitary forms. The polyps each live in a tube like structure called a corallite. In general, the corallites for the rugose corals are larger than the ones found in the tabulate corals and have vertical skeletal partitions called septa, which are known to be directly related to the tentacles in modern corals.

These septa are sometimes present in tabulate corals, but in general are much reduced in size. The solitary rugose corals can have larger individuals than those in a colony. They can have various corallum shapes and commonly described as the horn corals, cup corals, and button corals.

On the field trip today, you will see the massive colonial rugose coral *Hexagonaria*, which is given that name based on the clear hexagon (six-sided) shape of the corallites. *Hexagonaria* can be found in many of the units in the county. In particular, they can be found in the upper and lower biostromes of the Rapid Member of the Little Cedar Formation. The word “biostrome” has been used to describe small carbonate build-ups on the ocean floor, but these build-ups are too small to be characterized as a reef. Some colonies of *Hexagonaria* reach sizes greater than 60 cm. Other colonial rugose corals found in Johnson County include *Asterobillingsa* and indeterminate fasciculate forms (Witzke and Bunker, 1994; Witzke and Bunker, 2010). *Asterobillingsa* has larger corallites than *Hexagonaria* (3 to 5 cm versus 1 cm) with the septa stretching outside the corallite wall and connecting with the adjoining corallite. For the fasciculate forms, the corallites are loosely packed and somewhat like little branches.

We will also see on the trip today many solitary rugose corals. The solitary corals will be found in units with the colonial corals and also in units where the colonial corals are sparse. At the outcrop level, the solitary forms are slightly more difficult to identify to the genus or species level, since most of their systematics is based on microscopic features. As such, it is common to describe them as “horn corals” or “cup corals”. They are generally 2 to 5 cm in length, but longer specimens reaching 20 cm are known (Witzke and Bunker, 1994). There has been good work done on the systematics of these corals using thin sections (Pitrat, 1962), but there is more work that could be done with the solitary corals in the region.

Tabulate corals only have colonial forms. The corallites for tabulate corals are general smaller with horizontal skeletal partitions called tabula. The polyps sit on top of the tabula and as the colony grows, new tabula are developed further up in the corallites. The large massive tabulate coral *Favosites* can be fairly obvious in the outcrops when present. This is commonly called the “honeycomb coral” due to its polygonal packed corallites. It is well known in the lower and upper biostromes of the Rapid Member of the Cou Falls Formation. Other tabulate corals are present including auloporid and pachyporid forms. Auloporid forms are loosely packed and typically encrust onto brachiopods or other corals (Witzke and Bunker, 1994). Pachyporid forms are smaller branching forms that appear to be particularly common in units where the larger massive corals are sparse.

Stromatoporoids

The stromatoporoids (phylum Porifera) are an extinct group with a dense calcareous skeleton that are considered to be related to sponges based on a peculiar group of living encrusting sponges. Unlike the majority of sponges, stromatoporoids do not have spicules. Their skeletons are composed of a series of layers or laminae with vertical pillars between them. At the outcrop level, stromatoporoids are described with terms like branching, digitate, massive, hemispherical, tabular or laminar. In order to identify species, they need to be examined in thin section, since these are the features that their systematics are based on. Several workers have identified species of stromatoporoids in the Cedar Valley Group (Shapo, 2003; Jannusch, 2008). The digitate forms *Idiostroma* and *Amphipora* have been well studied and have been used as important stratigraphic markers in the Cedar Valley Group (Jannusch, 2008; Witzke and Bunker, 2010).

At the outcrop level, these two taxa look like small stick-like forms with *Idiostroma* being thicker than *Amphipora.* In the Cou Falls Member of the Coralville Formation, there is a unit packed with *Idiostroma* and historically has been historically called the "*Idiostroma* bed" even though it is difficult to identify this to species or genus at the outcrop level (Witzke and Bunker, 2010). Likewise, the thinner branching form makes up an identifiable unit in the region called the "*Amphipora* bed" by many workers and is a key stratigraphic marker in the Iowa City Member of the Coralville Formation. Danielle Shapo-Jannusch (2003, 2008) did a comprehensive review of the systematics and paleobiology of stromatoporoids of Johnson County and the reader is referred to her work. One particularly interesting observation that she made was there seems to be a correlation between environment and which forms of stroms appear in the unit. The digitate forms seem to appear in environments with less current movement over the massive hemispherical forms (Jannusch, 2008).

Brachiopods

The brachiopods (phylum Brachiopoda) are the most diverse and abundant macrofossil group in the rocks found in Johnson County. Moreover, brachiopods are extremely useful in biostratigraphy for Middle Devonian rock units in Iowa (Day 1992, 2006). Brachiopods have two shells (valves), a soft tissue pedicle for attachment to the ocean floor, and a soft tissue arm-like structure called a lophophore used to capture food floating in the water column. Brachiopods may seem very close to bivalve mollusks due to both groups having two shells. However, the shells of brachiopods are each bilaterally symmetric. For the bivalves, the shells are not symmetric, but have a line of symmetry that is in between the two shells instead of through the shells.

Brachiopods are divided into two groups: inarticulates and articulates. The main difference between these groups is the presence and absence of structures, called teeth and sockets, that hold the two shells together. The inarticulate brachipods do not have teeth and sockets at the edge of their valves to hold them together. Instead, they use muscles to accomplish this feat. Also, the pedicle goes between the two shells in the inarticulate brachiopods where articulate brachiopods, in general, have an opening in the valve for the pedicle.

Inarticulate brachiopods are rare in the rock units of Johnson County, but they can be found (Witzke and Bunker, 1994, 2010). These include types with thin, phosphatic shells and the more prevalent types with calcareous shells. The phosphatic forms are found in the Solon and Rapid members of the Little Cedar Formation, while the somewhat round calcareous types can also be found in the Cou Falls Member of the Coralville Formation (Witzke and Bunker, 1994; Day, 1992).

Since articulate brachiopods are quite diverse and have many important taxa in Johnson county (Day, 1992), I will only focus on describing the prominent extinct orders of these brachiopods. There are several different characters used to separate these orders of brachiopods including shapes of the shells (convex, concave, flatten, elongate, rounded, etc.), ribbing on shells, lamellar growth rings, characteristics of the hinge area, presence of spines, and elevation or depression of the central area (fold and sulcus).

The orthids (Order Orthida) are characterized by having elliptical and bi-convex shell with fine ribbing. The genus *Schizophoria* is a representative of the orthids found throughout the Cedar Valley Group (Day, 1992). Strophomend brachiopods (Order Strophomenida) have one convex and one concave shell with a broad hinge area between them (Witzke and Bunker, 1994). Common forms found throughout the Cedar Valley Group include the genus *Strophodonta* and the suborders chonetids and productids (Day, 1992). *Strophodonta* is characterized by having a large and flattened shell, while chonetids have small, flat shells with finely ribbing and productids have spiny shells (Witzke and Bunker, 1994).

The pentamerids (Order Pentamerida) include the genus *Pentameralla* which is bi-convex with coarse ribbing (Witzke and Bunker, 1994). It is found in the Solon and Rapid members of the Little Cedar Formation and is in the lower part of the Coralville Formation (Day, 1992). The terebratulids (Order Terebratulida) are known for their smooth forms and include the genus *Cranaena*. *Cranaena* is an important stratigraphic marker with an elongate shell that occasionally will have preserved faint stripped color bands (Witzke and Bunker, 1994; Day 1992). *Cranaena* is found throughout the Cedar Valley Group, but is very common in the coral bearing units of the Cou Falls Member of the Coralville Formation (Witzke and Bunker, 1994; Day 1992). Forms of rhynchonellid brachiopods (Order Rhynchonellida) that have small shells with prominent ribs can be found in the Cedar Valley Group, but in general this order is not very common in the area (Witzke and Bunker, 1994; Day 1992). The last order of brachiopods, Spiriferida, has a diversity of forms in the Cedar Valley Group. The order is characterized by the spiral shape of the support structure for the lophophores (the soft tissue feeding arms), but the interior of the shells are not usually exposed at the outcrop level. Since this order is so diverse, it is better to break it down into a few suborders of atrypids, athyrids, and spiriferidina for this discussion. The atrypids have a biconvex shell with a more or less rounded outline and fine ribbing. Some forms have lamellar growth ridges or spiny shells (Witzke and Bunker, 1994). Athyrids have biconvex forms with small hinge areas and non-ribbed shells with fine growth ridges. These brachiopods display a wide tolerance to paleoenvironmental conditions (Witzke and Bunker, 1994). The last suborder, spiriferidina, is typified by the genus *Orthospirifera,* which have very large wing-like shells with a wide hinge area and nicely defined fold and sulcus (Witzke and Bunker, 1994).

Bryozoans

The bryozoans (phylum Bryozoa), which are sometimes called the moss animals, are a group of colonial organisms that considered to be close to the brachiopods, since they have a similar feeding arm called a lophophore. The individuals of these colonies are called zooids and are housed in a calcified structure called a zooecium. The zooids are very small in size and not easy to identify without some magnification.

The bryozoans are typically described by their various colony shapes from branching and twig-like forms to massive sheet-like and domal forms. In addition, the bryozoans encrust onto the skeletons of other organisms. One interesting group of bryozoans we may see in the Klein Quarry are the fenestellids. They are commonly called the “lacy” bryozoans, since they secrete a calcareous skeleton with parallel branches and crossbars. They are typically found in the Rapid Member of the Little Cedar Formation (Witzke and Bunker, 1994). Also found in the Rapid Member are the trepostomes or “stony” bryozoans which can have very large massive forms up to 10 cm in size (Witzke and Bunker, 1994).

Crinoids

The crinoids (phylum Echinodermata, class Crinoidea) have been given the nickname sea lilies due to their overall resemblance to a flower, but they are not a plant. Crinoids have a central plated head called a calyx with arm like structures extending from them. The calyx is attached to a long stalk or stem and is attached to the seafloor with a root-like structure. Crinoids are related to more well-known echinoderms of sea stars and sea urchins. As such, they have a skeleton composed of many calcite plates that protect its central structure and appendages (arms and stems). In addition, echinoderms are characterized by having a complex water vascular system. Crinoids can be disarticulated easily after death and typically you will find isolated parts of the stem, arms, or the plates of the calyx.

Crinoid debris is common in the units we will see in the Klein Quarry with some beds packed with them. Typically the parts of the stems and arms will look like little "cheerios" or "sphagettios" at the outcrop level. Articulated specimens, where the calyx are still attached to their stems, have been found in Johnson County. There are three extinct subclasses described from the known articulated specimens in the area, but we are less likely to see articulated specimens in the Klein Quarry today. A nice brief summary of these three subclasses can be found in Witzke and Bunker (1994).

Other Fossils

There are several other groups of fossils that are found in Cedar Valley Group, but they may not be as easily identifiable in the rock units of the Klein Quarry to the casual observer. These groups include trilobites, molluscs, fish fossils, graptolites, and several microfossil groups.

Trilobites are members of the phylum Arthropoda, which are characterized by having a segmented body and jointed appendages. Their name means "three lobes" and describes their division into three longitudinal segments. Since they have a chitinous exoskeleton, they generally have a good fossil record. Fragments of trilobites can be found in the rock units in the area and I refer you to the work of Hickerson (1992) for more detailed information about their systematics and stratigraphy. Other arthropods in these units include the shrimp-like phyllocarid crustaceans and microfossil members of the ostracod crustaceans (Witzke and Bunker, 1994).

Molluscs (phylum Mollusca) can be found in the rocks exposed in the Klein Quarry. Mollusca include the snails (class Gastropoda), clams (class Bivalvia), and cephalopods. They all have one or two calcareous shells and have a very good fossil record. In the Paleozoic, the molluscs have a smaller role in the ecosystem than their modern relatives. Molds of clams and snails can be found in the limestones in the region, but they are not very common. Preslicka et al. (2010) summarize the systematics and the stratigraphy of the cephalopods in the Cedar Valley Group and the curious reader should read their work.

Fish fossils can be found the Cedar Valley Group as well. Typically, these fossils are fragments of isolated bones, teeth, and dental plates from the Devonian fish classes Placodermi, and Ostreichthyes (bony and lobed fin fish) along with early relatives of the sharks (Witzke and Bunker, 1994). Most of the fossils for these groups will be a dark black to brown in color in contrast to the lighter limestone matrix.

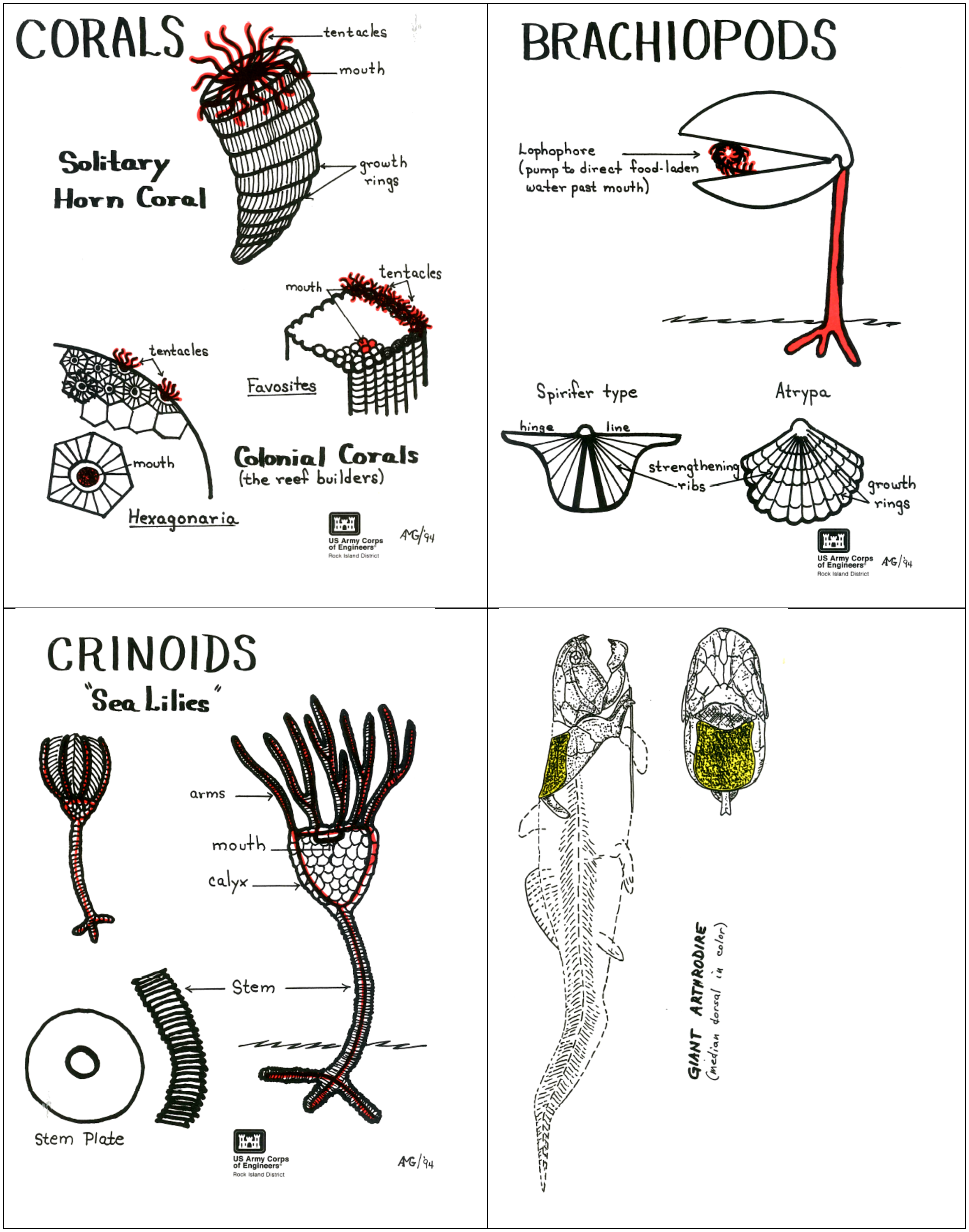

Figure 1: Representative drawings of some of the fossil groups we will see in the Klein Quarry.

Figure 2: Example fossils from the Cedar Valley Group. A) Colonial rugose coral *Hexagonaria*. B) Solitary rugose coral. C) Tabulate coral *Favosites*. D) Massive stromatoporid in center of image. E) Bed of digitate stromatoporoids and branching tabulate corals. F) Crinoid debris with solitary coral and brachiopod fossils in center of image. (Photos D-F by Ryan Clark)

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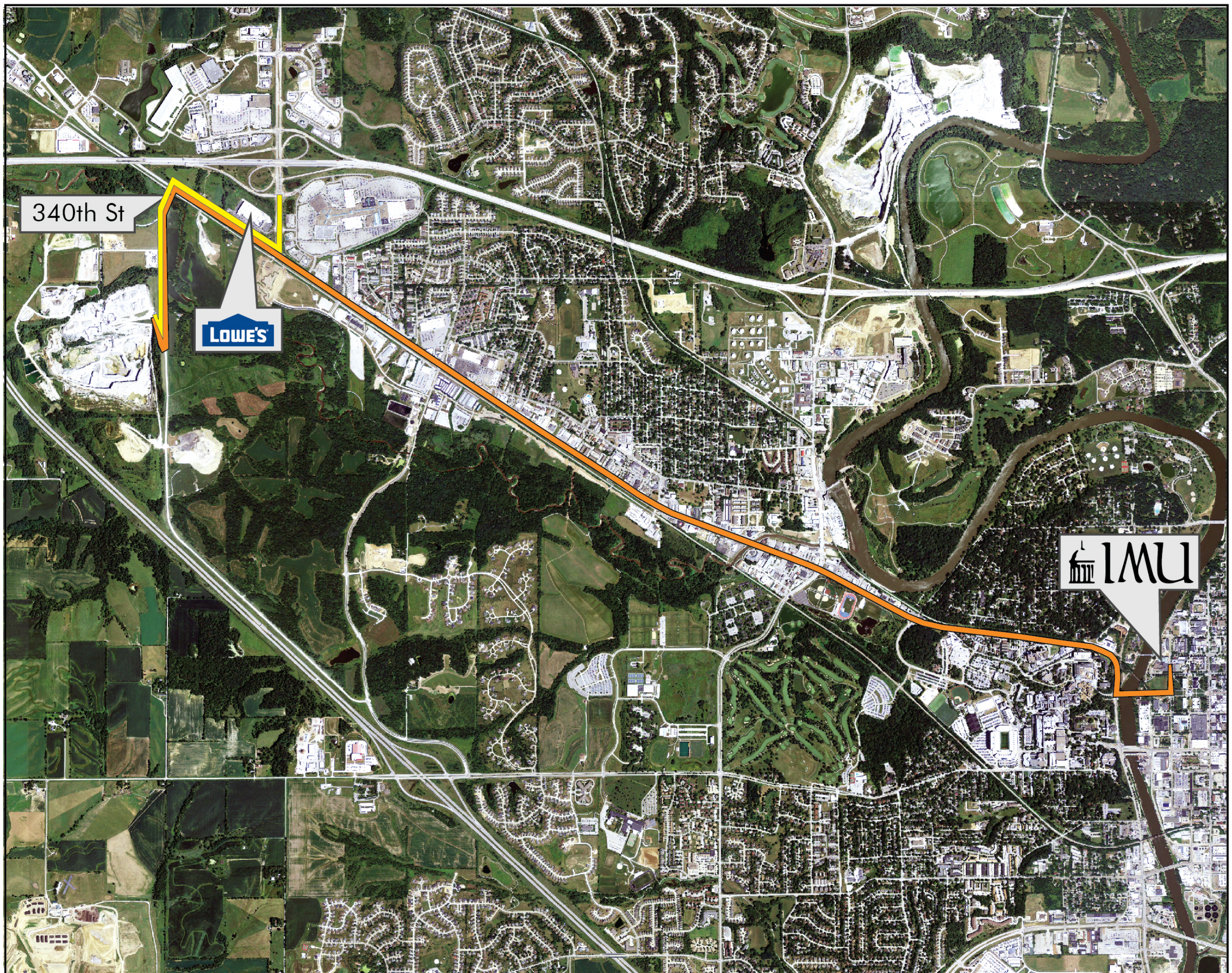

Directions from the IMU:
Turn west on Iowa Ave.
continue .2 miles
Turn north on Highway 6
continue 4.5 miles
Turn south on 340th Street

Directions from the I-80:
Exit south on Exit 240
continue .3 miles
Turn west on Highway 6
continue .5 miles
Turn south on 340th Street

Park by the scale house. Transportation to the bottom of the quarry will be provided.