THE GEOLOGY OF KLEIN AND CONKLIN QUARRIES, JOHNSON COUNTY, IOWA

edited by
Thomas Marshall and Chad Fields

Geological Society of Iowa

October 9, 2010 Guidebook 87

Cover Photograph

Geologists and quarry employees examine a Pennsylvanian sinkhole, developed in limestones of the basal Solon Member (Little Cedar Formation) and Davenport Member (Pinicon Ridge Formation) at Klein Quarry. This sinkhole yielded spectacular calcite crystals and other mineral samples that are discussed in this guidebook.

THE GEOLOGY OF KLEIN AND CONKLIN QUARRIES, JOHNSON COUNTY, IOWA

edited by:

Thomas Marshall
Iowa Geological & Water Survey
Iowa Dept. of Natural Resources
Iowa City, IA 52242-1319
thomas.marshall@dnr.iowa.gov

Chad L. Fields
Iowa Geological & Water Survey
Iowa Dept. of Natural Resources
Iowa City, IA 52242-1319
chad.fields@dnr.iowa.gov

with contributions by:

Raymond R. Anderson
Iowa Geological & Water Survey
Iowa City, IA 52242-1319
raymond.anderson@dnr.iowa.gov

Greg Balco
Berkeley Geochronology Center
Berkeley CA 94799
balcs@bgc.org

E. Arthur Bettis III
Department of Geoscience,
University of Iowa
Iowa City, Iowa 52242
art-bettis@uiowa.edu

Thomas E. Blume
President, Blackhawk Gem &
Mineral Society
1232 Piedmont Avenue, Sumner,
IA, 50674
blumet@tripoli.k12.ia.us

Bill J. Bunker
Iowa Geological & Water Survey
Iowa City, Iowa 52242-1319
bill.bunker@dnr.iowa.gov

Malcom R. Dawson
Iowa Department of Transportation
Office of Materials, Geology
Section
800 Lincoln Way, Ames, Iowa
50010
malcom.dawson@dot.iowa.gov

Jed Day
Department of Geography-Geology,
Campus Box 4400, Illinois State
University,
Normal, Illinois, 61790-4400
jeday@ilstu.edu

Paul L. Garvin
Cornell College
Mount Vernon, Iowa 52314
pgarvin@cornellcollege.edu

William F. Kean
Department of Geosciences
University of Wisconsin-Milwaukee
wkean@csd.uwm.edu

Thomas Marshall
Iowa Geological & Water Survey
Iowa Dept. of Natural Resources
Iowa City, IA 52242-1319
thomas.marshall@dnr.iowa.gov

Charles C. Monson
Iowa Geological & Water Survey
Iowa Dept. Natural Resources
Iowa City, IA 52242-1319
charles.monson@dnr.iowa.gov

Charles R. Newsom
Mid America Paleontology Society
Dept. of Physics and Astronomy
University of Iowa
Iowa City, IA, 52242
charles-newsom@uiowa.edu

James E. Preslicka
Mid America Paleontology Society
1439 Plum Street, Iowa City, IA,
52240
JamesP@IowaTelecom.net

Deborah J. Quade
Iowa Geological & Water Survey
Iowa Dept. of Natural Resources
Iowa City, IA 52242-1319
deborah.quade@dnr.iowa.gov

Adriana M. Reyes
Iowa Department of Transportation
Office of Materials, Geology
Section
800 Lincoln Way, Ames, Iowa
50010
adriana.reyes@dot.iowa.gov

Glen A. Rocca
2nd VP, Blackhawk Gem & Mineral
Society
P.O. Box 717, Shell Rock, IA,
50670
glenr@butler-bremer.com
319-885-6737

Charles W. Rovey II
Dept. of Geography, Geology and
Planning,
Southwest Missouri State,
Springfield, MO 65807
charlesrovey@missouristate.edu

Stephanie Tassier-Surine
Iowa Geological & Water Survey
Iowa Dept. of Natural Resources
Iowa City, IA 52242-1319
stephanie.surine@dnr.iowa.gov

Deb Tisor
Executive Assistant
River Products Company, Inc
Iowa City, Iowa 52244-2120
dtisor@riverproducts.com

Brian J. Witzke
Iowa Geological & Water Survey
Iowa Dept. of Natural Resources
Iowa City, IA 52242-1319
brian.witzke@dnr.iowa.gov

October 9, 2010
Geological Society of Iowa
Guidebook 87

This and other Geological Society of Iowa guidebooks may be downloaded as pdf files, or printed copies may be ordered from the GSI webpage at: www.iowageology.org

TABLE OF CONTENTS

A BRIEF HISTORY OF RIVER PRODUCTS COMPANY, INC.

Raymond R. Anderson
Iowa Geological & Water Survey
Iowa City, Iowa 52242-1319
raymond.anderson@dnr.iowa.gov

Deb Tisor
Executive Assistant
River Products Company, Inc
Iowa City, Iowa 52244-2120
dtisor@riverproducts.com

INTRODUCTION

The River Products Company, Inc. of Iowa City, the owners of the Conklin and Klein quarries and the gracious host of today's field trip, have been the principal aggregate producer in the Iowa City area for the last 90 years. The company has expanded and diversified to meet the changing demands of the ever-growing Iowa City market area. This brief history discusses some of the highlights of the company's growth since its formation in 1920.

EARLY HISTORY

River Products Company, Inc. began in 1920 when an Iowa City engineer, Stanley "Feet" Hands and his brother, Harold "Babe" Hands convinced a group of local citizens to join together to raise $20,000 to lease 32½ acres of land immediately north of the Iowa River in Penn Township north of Coralville. The land had been described as "a highly concentrated area of quality limestone." This was the area of an existing quarry, described by Calvin (1897) as the "Railroad" quarry on land owned by Ezekiel Clark. The early employees of the new Conklin Quarry worked the 600 foot long and 30 foot high Coralville limestone face (Fig. 1) with hand mauls, wheelbarrows, and mule-drawn wagons, but managed to produce 8,500 tons of stone in 1920. Of this production 4,004 tons of the stone was sold, with the remaining materials used for roads and other aspects of quarry development. As the number of employees grew to over 100, the company built laborer shacks and an employee cook shack.

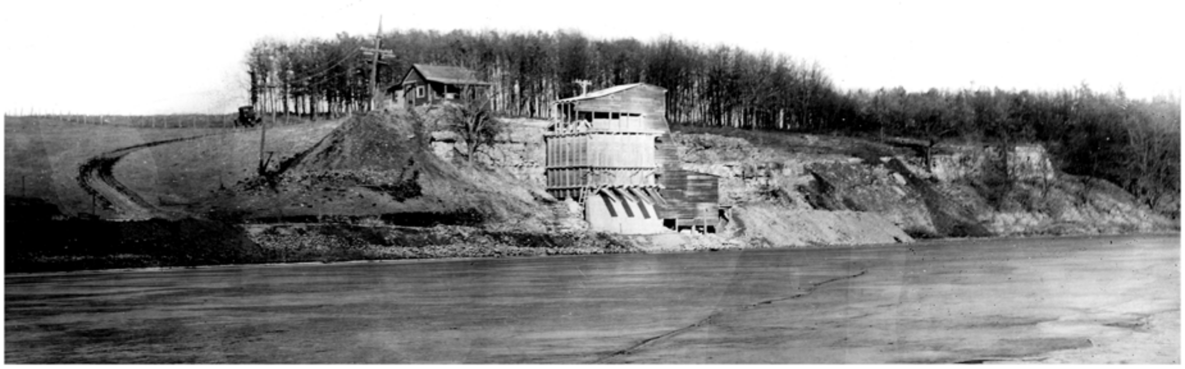


Figure 1. Early 1920s View of River Products Quarry from the south bank of the Iowa River.

Production at the quarry expanded rapidly and soon River Products added their first crushing plant, with the capability of 100 tons of 2" or smaller material per day. This expansion was rapidly followed by improved shipping facilities including 1¼ miles of railroad track to connect the quarry to the Chicago, Rock Island, and Pacific Railway tracks on the south edge of Coralville. With the installation of a second crushing facility, adding a capacity of 500 tons per day, the employee numbers were greatly reduced. By the mid 1920s, wages for quarry employees ranged from $15/day for the Plant Manager to $3.40/day for jack drillers, cable toters, car placers, dumpers, crusher watchmen, screen men, and others.

As Iowa City and the University of Iowa grew in the late 1920s so did the River Products Company's customer base, with large quantities of stone being used in the construction of many new University buildings and City High School. A fleet of model T trucks were acquired to deliver stone to the area (Fig. 2).

Figure 2. A fleet of early stone delivery trucks ca. 1930 at River Products Quarry.

Private automobile numbers also grew rapidly in the Iowa City area, and along with them came the demand for better roads. The Iowa Highway Commission (now Iowa DOT) designates specific beds at the quarry as suitable use as crushed road stone and other beds as aggregate for hard paving (see Reyes, this volume). Crushed stone from the River Products Company was largely responsible for creation of the extensive road network in Johnson County.

A new market for River Products Company's stone began to develop with the increased use of field-applied agricultural limestone. Application of finely crushed, high quality limestone, or aglime, to farm fields improves the physical condition of the soil, resulting in greater root proliferation and nutrient uptake. The limestone also buffers acidic soils, returning them to a proper pH and improving their fertility and physical characteristics.

Figure 3. Crushing operations at River Products Conklin Quarry in 1948.

Figure 4. Crushing operations at River Products Conklin Quarry in 1960.

Aglime increases microbial activity, effectiveness of certain herbicides, and ultimately crop production. It also raises the amount of calcium available for the plant to use in cell development. The development of specialized mechanical spreaders also increased the sales of aglime.

As the years passed the River Products Company continued to grow (Fig. 4 and 5). In June of 1963 the company acquired the operating assets of the Dillon Stone Company of Columbus Junction, which included the Columbus Junction Quarry, the Keota Quarry, and the Young America Quarry. By the early 1970s the company owned or leased nine quarries in three counties (see Table 1).

Table 1. Quarries and Pits Owned or Leased by River Products Company.
(* indicates currently active operations)

Johnson County	
*Conklin Quarry	Donovan Quarry
Stahle Quarry	Vogel Quarry
*Klein Quarry	*Ernst (Dingleberry)
Louisa County	
*Columbus Junction Quarry	Mabeus Quarry (Cairo)
*Fredonia Sand Pit	Morning Sun Quarry
Washington County	
Young America Quarry	Wilson Quarry
*Keota Quarry	Grace Hill Quarry
*Riverside Sand Pit	

In December of 1969 River Products Company began operating a new processing plant at the Conklin Quarry. This new plant, with a design capacity of 650 tons per hour (TPH), greatly increased the productivity and efficiency of the quarry operation, in both a full and split plant operation. With the addition of a new wash plant and upgrades of their primary crushing and screening plants in 1983 through 1985, the plant reached a peak design capacity or 1,000 TPH. This allowed the company to continuously produce a better quality and wider variety of products for their customers.

River Products Company expanded into the sand and gravel production business in 1977 with the opening of a sand dredging and processing plant at Fredonia in Louisa County. The sand and gravel production operation was further expanded in 1989 with the purchase of the Stevens Sand Plant and Pit in Riverside. In 2006 and 2007 they re-located the Riverside operation about 2 miles to the north, opening a new pit and constructing a new processing plant at 5716 Harry's Road SE.

Figure 5. 1960 aerial photograph (looking south) of Conklin Quarry West (foreground) and the Conklin Quarry East (the old Railroad Quarry) to the south.

In 1982 the River Products Company purchased the mining rights to the Klein Quarry west of Coralville in Johnson County (Fig. 6). As demand for crushed stone products grew, River Products Company expanded the scope of their operation at the Klein Quarry with the acquisition of adjoining land for expansion and the addition of two screening plants and a jaw crusher at the site in 1994. This addition increased the capacity of the facility to 450 tons per hour. The Klein operation was subsequently upgraded again, and a newly constructed, fully automated crushing facility with a design capacity of 800 TPH began production in March of 2005 (Fig. 7).

River Products Company constructed a fine-grind limestone drying facility at the Conklin Quarry in 1993. This crushed and dried stone was initially utilized by the University of Iowa Power Plant in their coal-fired fluidized bed boiler system to remove SO2 from the flue gas stream. The drier is also used to dry natural sand. This facility also produced feed grade calcium limestone for the livestock feed industry, as well as specialized dusting lime used in the pellet feed production process (Fig 8).

In 1996 the River Products Company acquired the Dingleberry Quarry located northeast of Iowa City. In 2001 development of the quarry began, with additional property acquired, a new entrance established, and the quarry was renamed the Ernst Quarry. Production start-up occurred in the fall of 2003.

Figure 6. Aerial photograph (looking northeast) of the Klein Quarry from 2005

River Products Company, Inc. currently employs 97 full-time people in Johnson, Washington, and Louisa counties. In 1999, the company's corporate offices were moved from downtown Iowa City and are now located at the Conklin Quarry, 3273 Dubuque Street N.E., Iowa City, Iowa.

The River Products Company produced just under 70,000,000 tons of material between the years of 1920-2010. The company maintains product prices to remain competitive through modernization and efficient use of all resources. River Products Company is active in a wide variety of community projects and was a major contributor to the development of the Devonian Fossil Gorge located at the Coralville Dam. To learn more about the River Products Company, Inc. visit their web site at http://www.riverproducts.com/www/about.php.

RIVER PRODUCTS MISSION IN 2010

River Products Company, Inc. is committed to providing the highest quality products and services in a courteous and safe manner. We place top priority on clearly understanding each customer's requirements and expectations. We are committed to sustained growth, while concentrating on long term profitability. We recognize that our employees, agents, independent contractors, and suppliers are partners in our business; their success is vital to ours. We believe it is our responsibility to support & participate in the communities we serve.

REFERENCES

Calvin, S.J., 1897, The Geology of Johnson County. Iowa Geological Survey, Annual Report, vol. 7, p. 33-116.

Figure 7. View of the new automated crushing facility at Klein Quarry.
Photos by Lynn Schnoebelen, 2003. .

Figure 8. Aerial photograph (looking northeast) of the Conklin Quarry, 2003.

OVERVIEW OF ECONOMIC GEOLOGY AS RELATED TO THE IOWA DOT AND CONKLIN AND KLEIN QUARRIES

Adriana M. Reyes and Malcom R. Dawson
Iowa Department of Transportation
Office of Materials, Geology Section
800 Lincoln Way, Ames, Iowa 50010
adriana.reyes@dot.iowa.gov
malcom.dawson@dot.iowa.gov

A BRIEF HISTORY OF CONKLIN & KLEIN QUARRIES

The oldest reference to material used from Klein Quarry by the Iowa Department of Transportation (DOT), for “road surfacing stone” dates to 1945. The first geologic section for Klein Quarry drawn by Iowa DOT geologists dates to 1956. According to Iowa DOT records there have been three producers at this location: Concrete Materials & Construction Co, Martin Marietta, and River Products Co. since 1982.

According to the River Products website, Conklin Quarry opened for business in 1920. The first geologic section for Conklin Quarry dates to 1960. The first concrete stone used for State projects appears around 1961. Both Conklin and Klein quarries were major sources for concrete and asphalt stone for the Interstate paving system in and around Johnson County. Other major construction projects include the Coralville Dam.

APPROVALS AND PAVEMENT PERFORMANCE

One of the primary focuses of economic geology for the Iowa DOT is to relate stratigraphy to aggregate quality and pavement performance. The DOT has standard specifications to assure the quality of each individual aggregate product used in highway construction. In order to produce aggregates for higher quality products, like Portland cement concrete (PCC) paving aggregate, or revetment stone (rip rap), a quarry ledge must be properly tested and meet Iowa DOT specifications.

The Iowa DOT source approval is the basis for how the PCC ledges are worked. This process begins by the DOT geologists drawing a geologic section for each source. Using these geologic sections, source approvals for working ledges can be obtained either through geologic correlation to already approved sources in the same units, or by determining the durability class of the units represented in the geologic section. The approval process categorizes concrete stone aggregates into three durability classes which are a prediction of pavement performance and service life. These are: Class 2 (20 yr. service life), Class 3 (25 yr. service life) and Class 3I (35 yr. service life). Class 2 aggregates are used in non-primary and county pavements, Class 3 are used in primary, non-interstate pavements, and Class 3I are used in interstate pavements. These classes can be determined through chemical and physical testing to be discussed later.

As quarries expand and move laterally through their properties, it can be necessary to draw updated geologic sections for the sources. The updates are most important when new units are encountered during production, the ledge changes in character, or footage changes occur that cause the need to adjust the working ledge height. Because of this, some quarries have a long litany of dates and names on the “headers” of their quarry sections. Figure 1 illustrates a typical quarry geologic section. Figure 2 is an example of a recent update to Klein Quarry’s geologic section.

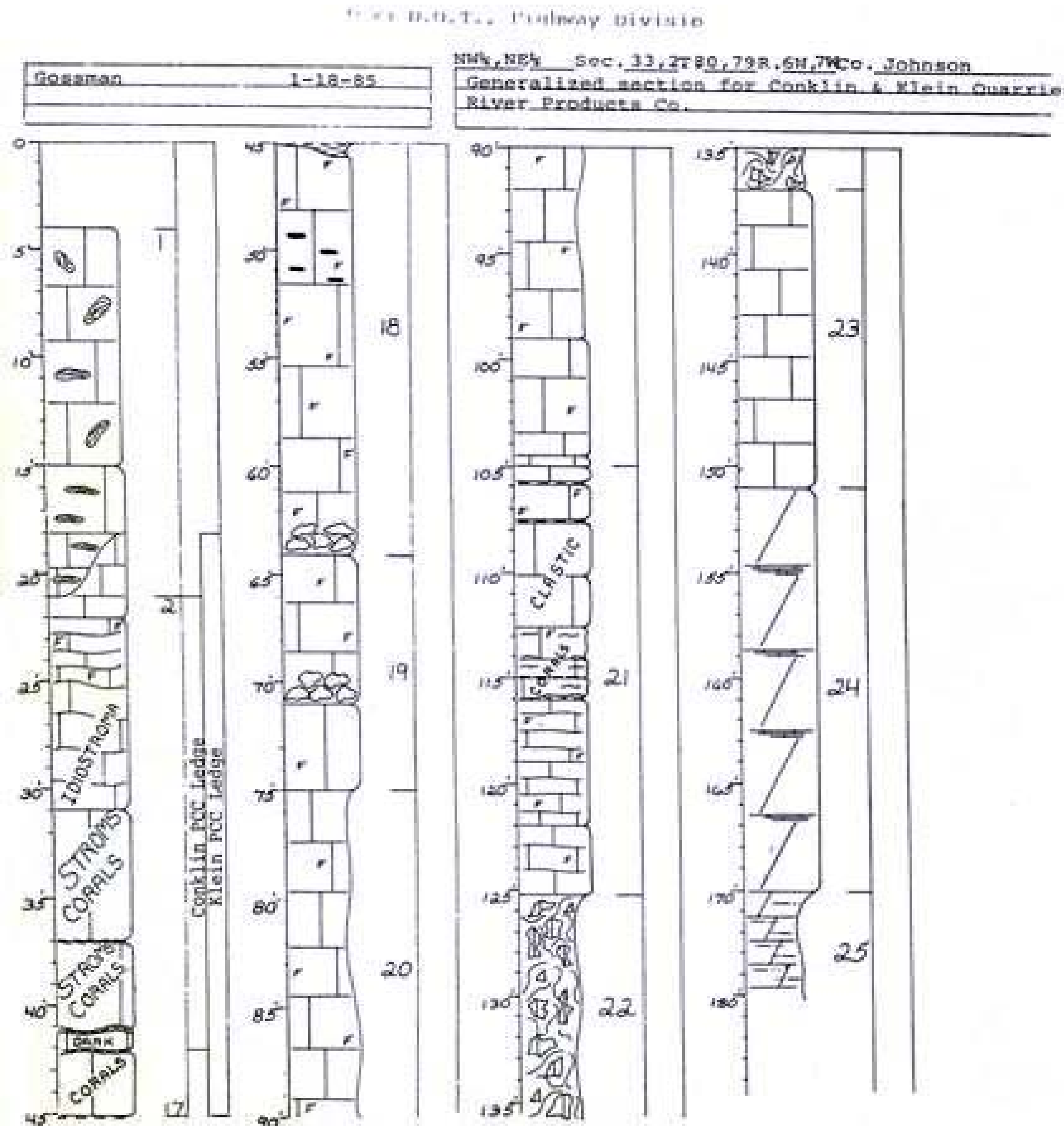
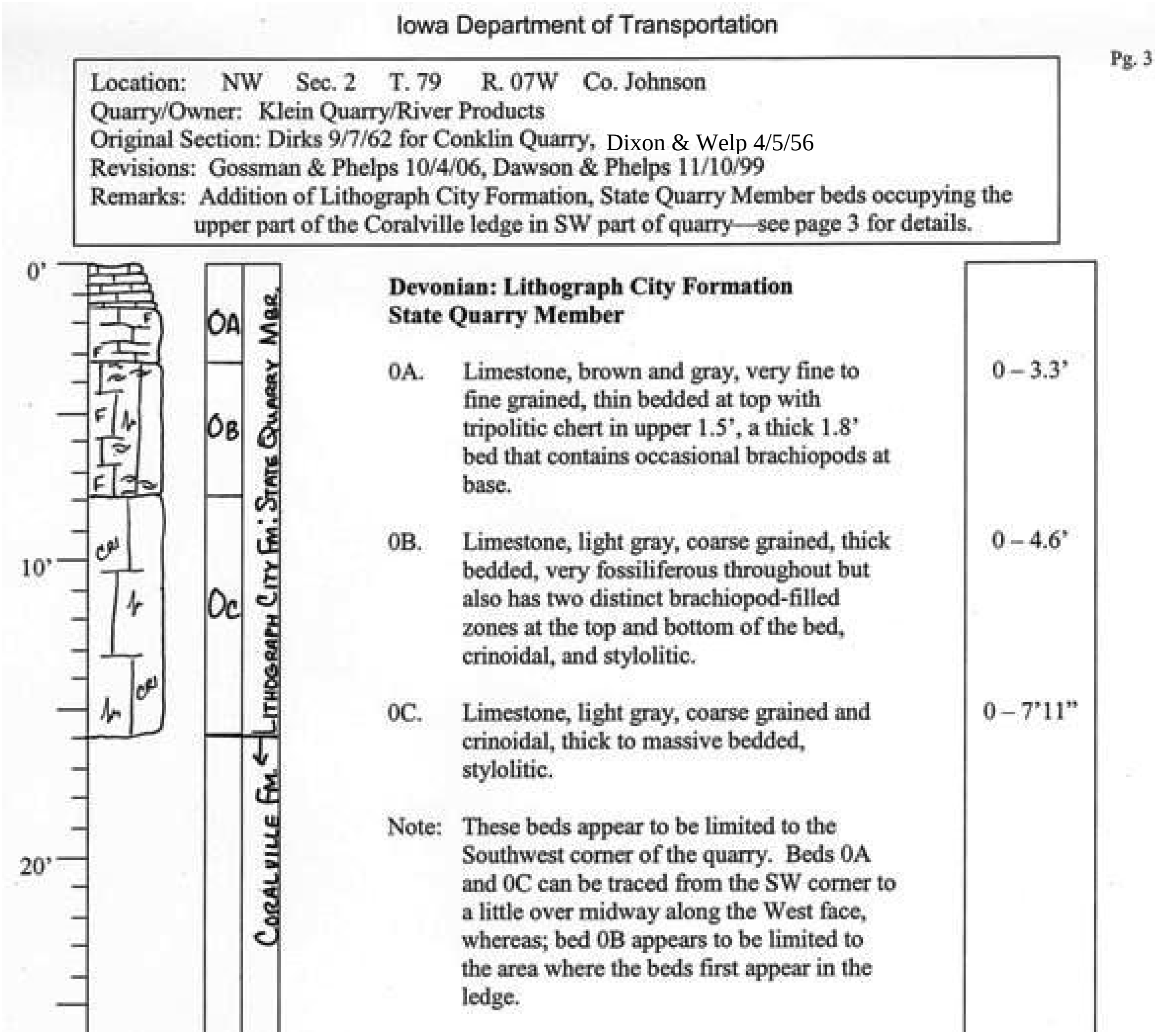


Figure 1. A typical geologic section.



Iowa Department of Transportation

Pg. 3

Location: NW Sec. 2 T. 79 R. 07W Co. Johnson
Quarry/Owner: Klein Quarry/River Products
Original Section: Dirks 9/7/62 for Conklin Quarry, Dixon & Welp 4/5/56
Revisions: Gossman & Phelps 10/4/06, Dawson & Phelps 11/10/99
Remarks: Addition of Lithograph City Formation, State Quarry Member beds occupying the upper part of the Coralville ledge in SW part of quarry—see page 3 for details.

Devonian: Lithograph City Formation
State Quarry Member

0A.	Limestone, brown and gray, very fine to fine grained, thin bedded at top with tripolitic chert in upper 1.5', a thick 1.8' bed that contains occasional brachiopods at base.	0 – 3.3'
0B.	Limestone, light gray, coarse grained, thick bedded, very fossiliferous throughout but also has two distinct brachiopod-filled zones at the top and bottom of the bed, crinoidal, and stylolitic.	0 – 4.6'
0C.	Limestone, light gray, coarse grained and crinoidal, thick to massive bedded, stylolitic.	0 – 7'11"
Note:	These beds appear to be limited to the Southwest corner of the quarry. Beds 0A and 0C can be traced from the SW corner to a little over midway along the West face, whereas; bed 0B appears to be limited to the area where the beds first appear in the ledge.	

Figure 2. Recent update to a geologic section.

QUARRY LEDGE SPECIFICS

There are four working ledges at Conklin and Klein quarries. The uppermost ledge is the Coralville Formation and it is classified as a Class 3I ledge. This ledge has multiple uses. For state projects, it is primarily a concrete stone source, but it can also be used as an asphalt stone. Many local ready-mixes also use this ledge for commercial paving and building projects in and around the Iowa City/Coralville metropolitan area. The second ledge is the Rapid Member. This ledge is primarily used for Roadstone, Backfill, and Subbases – of various types. Roadstone is a material that the DOT uses on unpaved shoulders and also commonly used on county "gravel" rock roads. The third ledge is the Solon Member and "Solon/Davenport Breccia". This ledge is used for a variety of different products: Asphalt Stone base and intermediate courses, Roadstone, Backfill, and Subbases – of various types. The lowermost ledge at Conklin and Klein quarries is the Davenport and Spring Grove Members. This is also a Class 3I concrete stone ledge, and also commonly used as a commercial concrete stone. This ledge is not used for asphalt stone due to the Lithographic nature of the Davenport Mbr., and also due to the higher absorptions encountered in the Spring Grove Mbr.

Aggregate producers prefer to work ledges in well defined footages for drilling and blasting patterns. In some units, however, where the beds roll across the deposit, this is not possible. Care must be taken to contour the approved ledge in order to avoid incorporating material from above or below the approved ledge. In some cases, this means sacrificing a foot or two at the top or bottom of the ledge. In units containing brecciated material, such as the Solon-Davenport Breccia, units that are normally above or below may have been eroded away completely. In such cases, the whole area where this occurs must be diverted to other products as it is not comprised of the approved beds.

STRATIGRAPHIC COMPARISONS

The Coralville Formation quarried at Conklin and Klein is a good example of a rock unit that varies in quality between sources. In Johnson County this unit is a Class 3I, the DOT's highest quality rating. In Benton County, this unit only makes a Class 2. Just prior to beginning paving on the Interstate 380 corridor between Waterloo and Cedar Rapids, DOT geologists began to see aggregate related deterioration, called d-cracking, on primary highways in Benton County on relatively young pavements. These pavements had been built using the local Coralville Formation aggregates. The worst deterioration was determined to be in areas where deicing salts were used most heavily, for instance, at intersections. Given that this aggregate sailed through Durability tests, there had to be another reason for this premature deterioration of the aggregate particles. It was this unit in Benton County that first caused DOT geologists to begin studying the concept of salt-susceptibility of construction aggregates.

In Blackhawk County, the Upper Solon has a couple of different manifestations. It occurs as either a Class 2 salt-susceptible limestone or a Class 3 pure biostromal limestone. There is a considerable quality difference between the two units. The key to keeping these ledges economically viable is being able to recognize the quality changes in the deposit before the material is produced into a large stockpile. If lesser quality material is incorporated into a higher quality stockpile, it will result in the rejection of the stockpile for the intended use. When this happens, it may increase costs for the paving project as substitute materials must be found. It also results in additional costs for the aggregate producer as they will have to make more material that meets the specifications for the class of material being produced. In worst cases, an aggregate producer will have to buy material from a competitor to complete their contractual obligations.

In Scott County, the Davenport and Spring Grove Members are both pure limestones. The Spring Grove, which is a dolomite across most of the outcrop belt, escaped the dolomitization process in this area. These units provide excellent pavement performance causing no pavement deterioration due to salt-susceptibility.

COMMERCIAL APPLICATIONS

Typical commercial uses for the aggregates quarried at Conklin and Klein quarries are: buildings and foundations, parking lots for businesses, city streets, sidewalks and driveways, agricultural lime "aglime" on fields, county rock roads, decorative and landscaping purposes, recreational trails, drainage materials, and erosion control. Many industries use aglime products, not the least of which is the construction industry. Aglime is used in boilers for desulfurization of the stacks in coal-burning power plants and in glass making.

IOWA DOT AGGREGATE USES AND TESTING METHODS

Figure 3 shows a typical highway cross-section and some of the aggregate products that may be used for these applications. The aggregate product is shown on the right, and the usage is shown on the left.

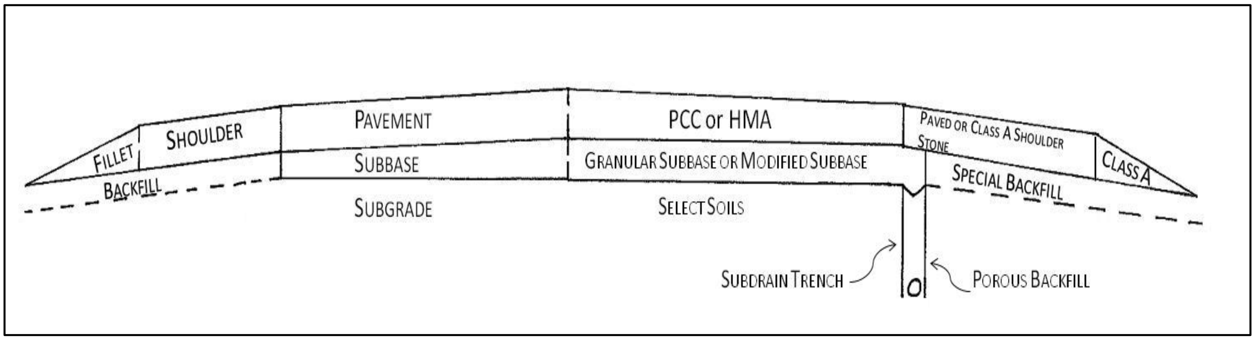


Figure 3. Highway Cross-section.

Apart from the uses illustrated in Figure 3, additional uses for aggregates include: PCC bridge decks and support beams, culverts and drainage pipes, and revetment stone for erosion control.

Testing Criteria

To provide aggregates for State projects, the aggregate producer must have a quality control program. The producer must also maintain the working ledge parameters that were established in the source approval process. There are baseline specifications that each of the individual aggregate products must meet. These specifications are tri-fold. The first two aspects of these specifications test for particle size distribution (gradation) and physical properties of the aggregate product. The third aspect of the specifications addresses the chemical composition of the aggregate.

Physical Testing

The Physical tests run by the Iowa DOT are standard to most states around the nation. These are Freeze & Thaw testing, Los Angeles Abrasion, Specific Gravity, and Absorption. Also quantified for each aggregate sample are deleterious substances like shale, clay, chert, coal, and organic material. Samples are obtained during the production process at the quarries. Gradation analyses are run on samples for any aggregate product that may go into State projects. Gradation is important because aggregate products provide the structure in the PCC and HMA pavements.

Chemical Testing Program

The chemical tests run by the Iowa DOT are not standard around the nation but have been heavily researched and tested by the Geology Section of the Materials Laboratory. These tests determine the clay content of an aggregate and the purity of the crystal structure. Using X-Ray Fluorescence, X-Ray Diffraction, Thermogravimetric Analysis along with the Iowa Pore Index Test, a Chemical Quality Salt-Susceptibility number can be generated to determine an aggregates suitability to be used in PCC paving. This number is the main determining factor for whether aggregates used in PCC paving are classified as 3I, 3, or 2. Aggregates unable to meet the criteria established for any of the aforementioned durability classes, are not approved for use as concrete stone.

This number is used as a predictor of whether an aggregate is going to be susceptible to deterioration from chemical reactions when salt brines are applied to the road surface. Aggregate particles that are salt-susceptible, can lead to the premature deterioration of the pavement. If that happens, a road will need costly repairs or reconstruction years before it would otherwise. Figure 4 shows the testing equipment used for the chemical analyses. Figure 5 shows the Iowa Pore Index Apparatus developed by the Iowa DOT's Materials Laboratory. Although this is a physical test, it measures the pore system of an aggregate and this information is used in the algorithm that determines the Salt-susceptibility Quality Number.

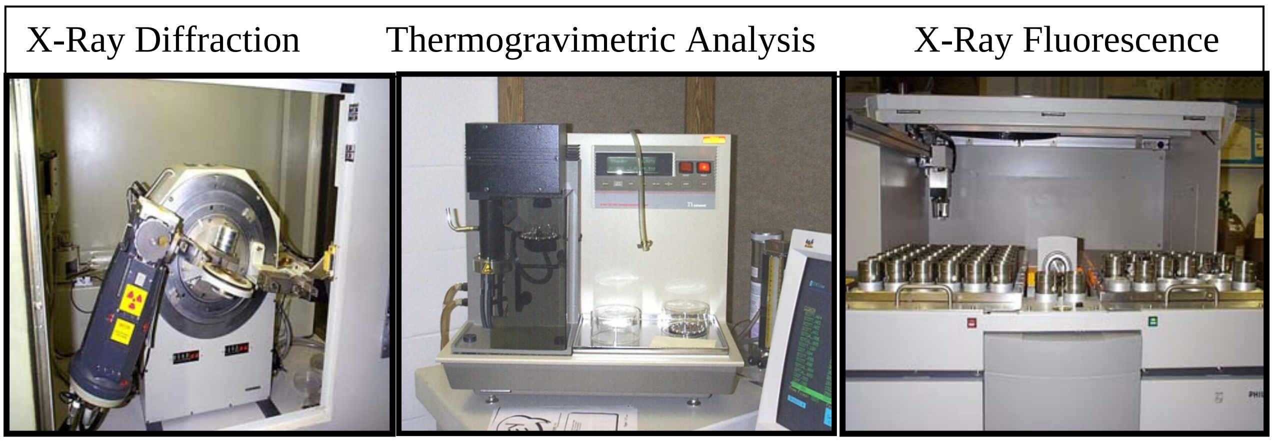


Figure 4. Chemical testing instruments.

Figure 5. Iowa Pore Index Apparatus.

CONCLUSION

Many factors are involved in the determination of the suitability of aggregates for construction materials. As new quarries are opened and existing quarries are expanded into new areas, we continue to learn new things about the chemical and physical properties of the geologic units worked in Iowa. With each new discovery comes a better understanding of how to lessen the impact of aggregate related deterioration on the roadway systems in Iowa.

HISTORY OF JOHNSON COUNTY QUARRIES

Raymond R. Anderson
Iowa Geological & Water Survey
Iowa City, Iowa 52242-1319
raymond.anderson@dnr.iowa.gov

INTRODUCTION

In Johnson County, Iowa, 26 quarries are known to have been operated since 1840. Most were in the northeast region of the county, where high quality Devonian (Cedar Valley and Wapsipinicon Gps) and Silurian (Gower Fm) limestone and dolomite bedrock occur at or near the land surface. This has led to a long history of mining of these carbonate rocks for building stone, aggregate, and other uses. Additionally, two quarries in northern Johnson County have produced building stones from Pennsylvanian sandstones and siltstones exposures, one in Iowa City, the other in the northwest part of the county.

HISTORICAL INFORMATION ON QUARRYING IN JOHNSON COUNTY

In one of the earliest geologic investigations of the area, Owen (1852, p. 84) described several quarrying operations. The following refers to Silurian rocks along the Cedar River in the northeast corner of the county.

> *"The Stonecutters of Iowa City are supplied with gravestones from a quarry of cream-colored limestone which lies in thin, even-bedded layers, to the height of from thirty to forty feet above the Iowa River · · ·" "The lowest strata, which are the thickest, hardly exceed eight inches." "The best of the slabs approximate in character to lithographic limestone".*

A few years later, Hall and Whitney (1858, p. 263) commented that:

> "*On the Iowa river, in Johnson county, the rocks are well exposed in the neighborhood of Iowa city, where there are numerous quarries, which have been opened to supply the town with lime and building materials. The layers are of very various lithological character. In a quarry opened about a mile above the city, on the east side of the river, nearly opposite the mill, there is an exposure of about forty feet of a thinbedded bluish limestone, which weathers of a dirty yellow*."

They (ibid, p. 264) continued:

> *"Nearer the town, on both sides of the river, the rock along the base of the bluffs is a dark-colored argillaceous limestone, which the general Favosites, Lithostrontion, Stromatopora are the most frequent. Higher up, the rock becomes more compact and less distinctly stratified: it is almost pure carbonate of lime, containing hardly more than one percent of other substances. It forms a durable building-stone, although not splitting or dressing handsomely. When polished the large coralline masses which it contains, especially the Lithostrontion, are very beautiful; and pieces have been worked up into small ornaments, such as paper-weights, and are well known under the name "Iowa marble".*

This rock was also known as "birds-eye marble" and was fashioned into cane handles by chair maker John A. Copenhager (Shambaugh, 1893, p. 47).

White (1870) included a chapter on Johnson County quarries in his discussion of Iowa geology. He (ibid, p. 308-309) included the following about the rock from the State Quarries:

"These are the quarries from which the best of the stone was obtained of which the old State House was built at Iowa City, the former capital of Iowa. They are located on the right bank of the Iowa river, in Penn township and about eight miles northwest from Iowa City. The strata are of Devonian age, and the best ever opened in strata of that age in the state. In composition the stone is common limestone, with a small proportion of carbonate of magnesia in some layers. Its color is uniform light gray, and its texture is that called "tough" by quarrymen; that is, it has not that compact and brittle texture so common with the limestone of Devonian age, in the Mississippi valley. This quality renders it very valuable as a building material, since stone of such texture is not so readily affected by frost and exposure, as the more compact and fine grained limestones usually are. The unchanged condition of this stone, either in character or color, during the thirty years that it has been tested in the old State House, and other buildings in the vicinity, affords the most complete practical proof of its great value. This test has been especially severe from the fact that the stone has been placed in the walls just where the surface of the ground meets them, as well as in equally exposed places.

None of the stone is suitable for polishing, but its great value lies in its suitableness for dressing for use in massive structures, and for the more important parts of ordinary masonry.

The layers are from a few inches to two or three feet in thickness, and the whole, over a large space, having but a slight covering of earth, the quarrying of the rock may be done with great facility; but the quarries have, of late years, been much neglected on account of being four or five miles from a railroad, or other abundant means of transportation."

In his manuscript on the "Geology of Johnson County", Samuel Calvin (1897, p. 98) mentioned and discussed numerous quarries in the county. Perhaps his most valuable information on the quarries was his geologic map of Johnson County (reproduced in part in Fig. 1) on which he used a symbol to identify quarry locations. In discussing the quarries in the Iowa City area, Calvin (1897, p. 98) comments that,

"*There are numerous small quarries in beds belonging to the Cedar Valley stage but none are worked on an extensive scale and none at present are engaged in shipping stone beyond the limits of the county. Still it must be said that the aggregate amount and value of the stone annually taken from these quarries is very great*."

On the quarrying of Devonian limestone for Railroad ballast, he states that,

"*For such purposes the material is excellent and the supply inexhaustible.*"

On page 99, Calvin (1897) discusses road paving in Johnson County. He notes that,

"*The products of the quarries near Iowa City have been used extensively in macadamizing the public streets and in making concrete foundations for brick paving. In the absence of available gravels it can only be a question of time until the use of macadam is extended to the clayey thoroughfares outside the cities. Throughout most of the northeastern half of the county stone for macadamizing the county roads will be found in convenient locations and inexhaustible abundance.*"

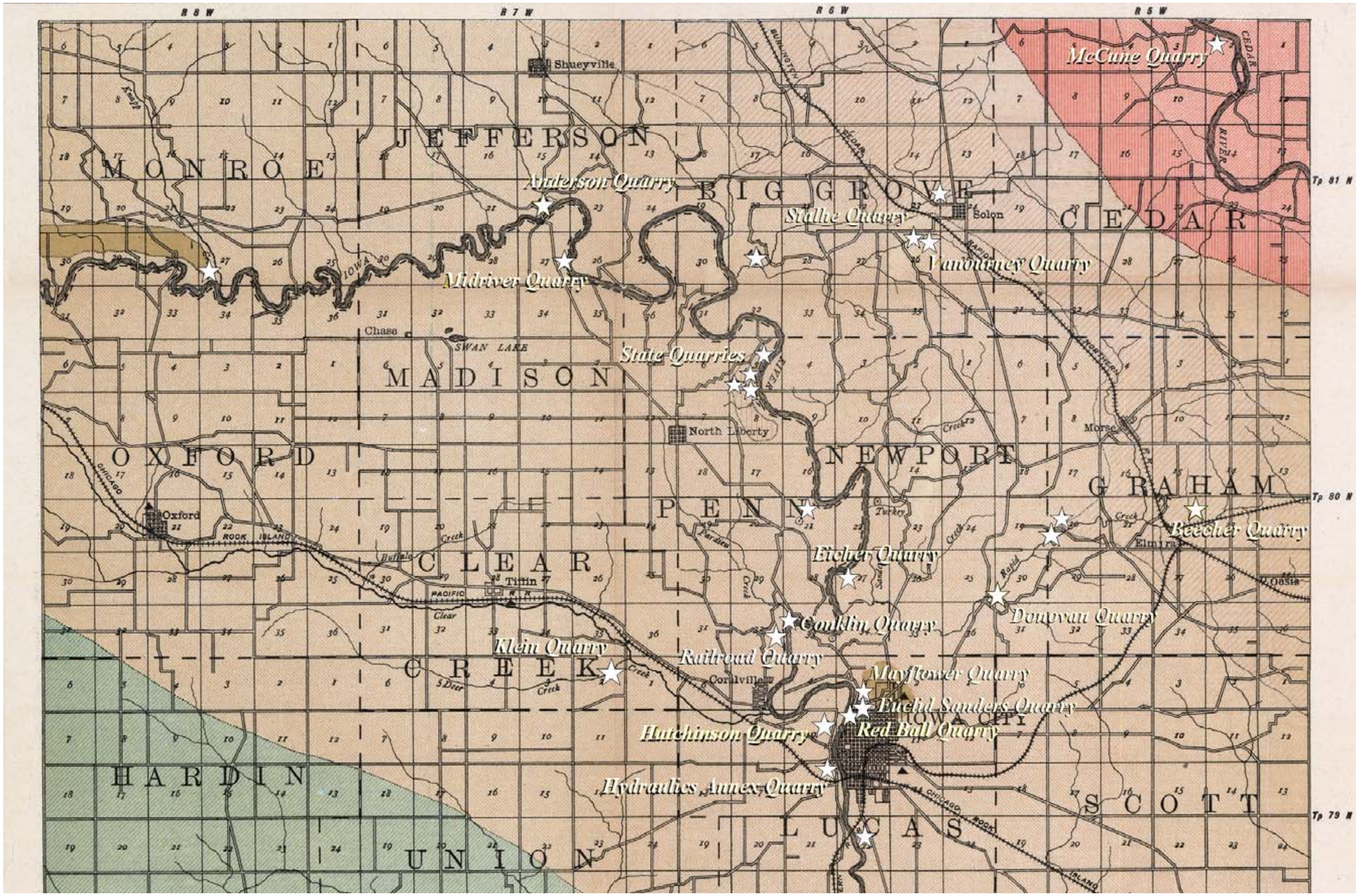


Figure 1. Map of known Johnson County Quarries on the northern portion of the 1897 Bedrock Geology of Johnson County by Calvin, 1897. (stars identify quarry locations; black dots are locations originally identified by Calvin, 1897.)

JOHNSON COUNTY QUARRIES

Following is a listing of all of the quarries in Johnson County that have been mentioned in the reviewed literature or are present in Iowa Geological & Water Survey records. They include the name(s) of the quarries if known and some limited information about the quarry and its history.

4 County Quarry Monroe Township T81N, R8W, Sec 4 NW¼, NW¼

Located at 1473 Linn-Johnson Road NW near Fairfax, in the northwest corner of Johnson County. The 4 County Quarry is an active quarry and is operated by Wendling Quarries, Inc. More information on the quarry can be found at:

www.wendlingquarries.com/locations/4county.html.

Figure 2. Color infrared aerial photo of the 4-County Quarry from 2002.

Figure 3. Google Earth photo of the 4-County Quarry, view looking east.

Anderson Quarry T81N, R7W, Sec 22 SW¼, NE¼
a.k.a. **Cou Falls Quarry**

Anonymous (1883, p. 777) mentioned the "*Anderson stone quarry in Jefferson township, near the Roberts ferry bridge*". He (ibid.) included a brief biography of Samuel Alloway, a farmer who moved to Johnson County in 1856 and purchased a 120 acre farm including the quarry. Anonymous (1883, p. 777) continued saying that "*He* (Alloway) *built a new lime kiln with a capacity of 300 bushel. He furnishes the Amana colonies with lime and they buy their stone at his quarry. The Anderson quarry was opened up 1862; it was first opened up near McCollister creek; it contains seven acres. Some beautiful fossil specimens are found at this quarry.*"

Figure 4. Photo of the Anderson Quarry ca. 1900. From Calvin Photograph Collection, Photo 92.

Figure 5. Google Earth photo of the Anderson Quarry, view looking north

---

Beecher Quarry T80N, R5W, Sec. 22, NE¼, SW¼

The only reference that was found to the Beecher Quarry was by Calvin (1897, p. 60) who stated, "*There are some exposures of the Fayette breccia on the headwaters of Rapid creek, the most important being that which occurs on the farm of Mr. J Beecher, near the northeast corner of section 22, Graham township (T.80N, R5W). Here the rocks have been quarried to a considerable extent*." No other references of photos of the quarry were found.

Conklin Quarry T80N, R6W, Sec. 33, NW¼, SW¼
a.k.a. as **Conklin North Quarry**

The Conklin Quarry is an active quarry owned by the River Products Company, Inc. It has expanded to the south along the river to include the Railroad Quarry. For more information on the Conklin Quarry see Anderson and Tisor in this volume.

Figure06. Oblique aerial photo of the Conklin North Quarry (view looking south) taken in 1960. Photo courtesy of River Products Quarry Company, Inc.

Figure 7. Current image of the Conklin Quarry (north to top) from Google Earth.

Donovan Quarry T80N, R5W, Sec. 30, SW¼, SW¼
a.k.a. as Sixt Quarry

The Donovan Quarry lies along Rapid Creek just east of Highway 1, north of Iowa City. The quarry is owned by Shirley Sixt, a graduate of the University of Iowa Geology Department, and was operated by the River Products Quarry Company.

Figure 8. Image of the Donovan Quarry (north to top) from Google Earth.

Eicher Quarry T80N, R6W, Sec. 27, NW¼, SW¼
a.k.a. as Vogel Quarry

The Eicher Quarry was mentioned by Calvin (1897, p. 64) who noted that "*At the Eicher quarry the uppermost member of the section is still below the Idiostroma horizon*." The quarry was later operated as the Vogel Quarry by River Products Company, Inc. in the 1960s.

Figure 9. Photo of the Eicher (Vogel) Quarry (north to top) taken in 1963.

Earnst Quarry T80N, R5W, Sec. 20, NW¼, SE¼
a.k.a. **Dingleberry Quarry**

The Dingleberry Quarry, located northeast of Iowa City, was acquired by the River Products Company in 1996. In 2001 they began to develop the quarry and after establishing a new entrance began production as the Earnst Quarry in the fall of 2003.

Figure 10. Image of the Earnst Quarry (north to top) from Google Earth.

Hutchinson Quarry T79N, R6W, Sec. 9, NE¼, SE¼

No information was discovered on the operation of the Hutchinson Quarry, located on the west bank of the Iowa River on the University of Iowa campus. The quarry is straddled by the University's $21 million Art Building West (Fig. 12) that was dedicated in 2006, then severely damaged by flooding in 2008. Stone from the quarry was used to construct the Hutchison Home at 119 W Park Road. This house, built in 1840, was part of a large farm and is oldest known home in Iowa City. The Hutchinson Quarry exposed Middle Devonian limestone, including the upper Little Cedar and the Coralville Formation and is the type section of the Iowa City Member of the Coralville Fm.

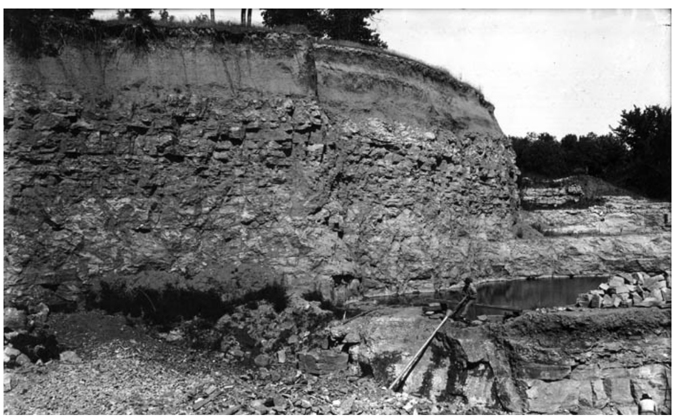


Figure 11. Photo of the Hutchinson Quarry ca. 1900. From Calvin Photograph Collection, Photo 101

Figure12. Google Earth photo of the Hutchinson Quarry and Art West, view looking west

Hydraulics Annex Quarry T79N, R6W, Sec. 16, SE¼, SE¼

Nothing was discovered about the operation of this quarry, located just below (southeast) of the University of Iowa Boyd Law Building. For many years it was the site of the University's Hydraulics Annex Building. The Annex Building was demolished by the University and the site is now an open space. Witzke and Bunker (1984) noted that "*The upper portion of the "Idiostroma beds" and lower portion of the upper Coralville are visible" about 12 – 15 feet*.

Figure 13. Photo of the Hydraulics Annex Quarry from Google Earth, view looking south

---

Klein Quarry T79N, R7W, Sec. 2, NE¼, SW¼
a.k.a. as **Concrete Materials Quarry**

The Klein Quarry was opened by Concrete Materials Company in the 1950s. It was later acquired and is currently being operated by River Products Company . For more information on the Klein Quarry see Anderson and Tisor in this guidebook.

Figure 14. Aerial photo of the Klein Quarry (north to the top) taken in the 1950s

Mayflower Quarry T79N, R6W, Sec 3, SW¼, NE¼
a.k.a. **Terrill Mill Quarry**

An exposure of Pennsylvanian strata is cut into the limestone bluffs on the east bank of the Iowa River in the northern part of Iowa City north of the Sanders Quarry. Calvin (1889) noted that during the early development of the city a number of housed were built of the laminate, shaly sandstone was quarried at this site during the 1840s and 1850s. He also mentioned that the stone had a tendency to discolor and split into thin laminae on weathering, however a number of these buildings remain standing today, perhaps the best preserved being the Murphy-Brookfield Books building at 219 N. Gilbert Street. The deposit consists of sandstones and siltstones that display extensive tidal rhythmites suggesting deposition in an estuarine environment. Witzke (1984) includes several articles describing these rocks in more detail. The quarry was mostly obscured by the construction of two condominium buildings (Fig. 17), but exposures can still be viewed behind the University of Iowa's Mayflower Dormitory.

Figure 15. Photo of the north end of the Mayflower Quarry, ca. 1900. From Calvin Photograph Collection, Photo 206.

Figure 16. Photo of the south end of the Mayflower Quarry, ca. 1900. From Calvin Photograph Collection, Photo 203.

Figure 17. Photo of the Mayflower Condominiums which now sit in front of the site of the Mayflower Quarry, just west of Dubuque Street. View looking southeast.

McCune Quarry T81N, R5W, Sec 2 NW¼, SW¼

The McCune Quarry, located along the Cedar River (see Fig. 1) is was the only known Silurian quarry in the Johnson County. As he explored the Cedar River in 1852, Owen (p. 84) noted that "*The lowest strata, which are the thickest, hardly exceed eight inches. In some of the layers, small hemispherical concretions run in the joints of the strata, as well as through the substance of the rock itself. The best of the slabs approximate in character to lithographic limestone. They are, however, of rather too coarse a texture for fine work.* The *upper strata are striped with yellow, obliquely to the bedding*". Calvin (1897, p. 95) included the McCune Quarry on his geologic map (see Fig. 1) and described the "Anamosa stage" rocks quarried there, stating that " *the stone is easily split along planes of lamination and so it is possible to take out smooth surfaced blocks of almost any desired dimensions*."

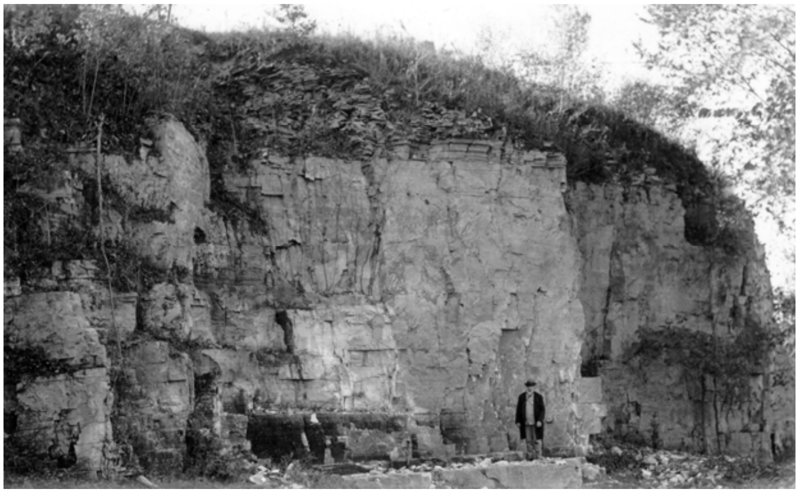


Figure 18. Photo of the McCune Quarry, ca. 1900. From Calvin Photograph Collection, Photo 168.

Mid River Marina Quarry T80N, R6W, Sec. 22, NW¼, NE¼

No discussion of the operation of the Mid River Marina Quarry was found in the literature. The quarry is located just east of Highway 965, north of the Mid River Marina. Bunker and Witzke (1989) noted that the quarry serves as the type section for the Cou Falls Member of the Coralville Formation.

Figure 19. Photo of the Mid River Quarry from Google Earth, view north to top.

Railroad Quarry T80N, R6W, Sec. 32, SE¼, NE¼
a.k.a. **E. Clark Quarry** and **Conklin South Quarry**

The Railroad Quarry was reported by Calvin (1897, p. 70) who published a measured section " *At the railway quarry, on land belonging to Mr. E. Clark, in the west bank of the river north of Coralville*". Later he (ibid., p. 95) stated that "*For some years the Chicago, Rock Island & Pacific Railway Co. operated a stone crusher at the quarry north of Coralville. The crushed stone was used for ballast along the line of the road. For such purposes the material is excellent and the supply inexhaustible*". The Railroad Quarry and additional exposures to the north were acquired by River Products Company, Inc. in 1922 and quarried as the Conklin Quarry. It has subsequently grown to join the Conklin North Quarry and is still active.

Figure 20. Photo of the Conklin South Quarry ca. 1930. Photo courtesy of River Products Company, inc.

Red Ball Quarry T79N, R6W, Sec. 10, NW¼, NW¼
a.k.a. as **Public Quarry** and the **North Capitol Street Quarry**

Coralville limestone exposures in the lower bluff face along the east bank of the Iowa River, extending from near Stanley Hall on the south to below the President's house on the north, are remnants of workings in the old Public Quarry. This area was quarried in the mid-1800s and supplied stone for construction of the Territorial Capitol. An exceptional weathered exposure of the "Idiostroma beds" is accessible at the south end. A series of upper Coralville exposures begin immediately north of the walkway (Witzke, 1984).

Figure 21. Photo of the Red Ball Quarry in Iowa City from Google Earth, view looking east

Sanders Quarry T79N, R6W, Sec. 3, SE¼, SW¼
a.k.a. as **Euclid Sanders Quarry**

The Sanders Quarry is located at the intersection of Dubuque Street and Kimball Road. Calvin (1897) noted that "*a very instructive section is found at the Euclid Sanders quarry south of the old Terrill mill near Iowa City*." The quarry was worked for some years by Mr. Gilbert Irish, and annually furnished "*a large amount of rock*" for "*market in the towns and farming communities in the county*" (ibid, p. 66, 69). The lowest beds exposed at the Sanders Quarry are accessible near the southern end of the quarry area, where the uppermost portion of the Rapid Member ("*waterlooensis* zone") can be seen. The lower Coralville is also exposed at the quarry.. The quarry exposes Middle Devonian limestone, including the upper Little Cedar and the Coralville Formation (Witzke, 1984).

Figure 22. Photo of the Sanders Quarry in Iowa City from Google Earth, view looking east

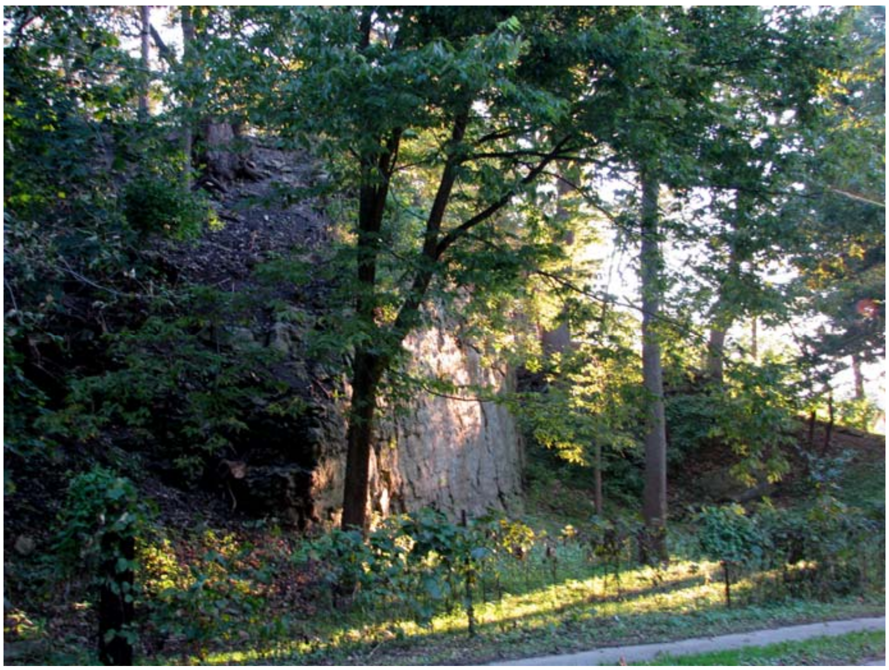


Figure 23. Photo of the Sanders Quarry in Iowa City as it looks today as viewed looking south from Kimball Road.

State Quarries T80N, R6W, Secs. 5 & 8
a.k.a. as **Old Capitol Quarry, North Bend Quarry,** and **Penn Quarry**

Calvin (1097, p. 70) first described the State Quarries, saying "*at the state quarries on the west side of the river in section 5 of Penn township . . . One of these valleys, in the left bank of which there are three of four quarries which may be called the south quarries of the state quarry stone*". Stone was quarried at this site in the early 1940s, producing stone for the old Territorial Capitol (later the State Capitol) in Iowa City and the current State Capitol building in Des Moines. Quarrying continued until the early 1900s. The quarry is the type section for the State Quarry Member of the Lithograph City Formation (Witzke and Bunker, 1994). The principal quarry was designated an Iowa State Geologic Preserve in 1969.

Figure 24. Photo of the State Quarry. From Calvin Photograph Collection, Photo 126.

Figure 25. Photo of the principal State Quarry along the Coralville Reservoir from Google Earth, view looking north.

Stalhe Quarry T81N, R6W, Sec. 26, NW¼, NE¼

A log of the Stalhe Quarry, located west of Solon, is archived in Iowa Geological & Water Survey outcrop books. The log is the only information found on the quarry.

Figure 26. Photo of the Stalhe Quarry west of Solon, from Google Earth, view looking east.

---

unnamed quarry 1 T81N, R6W, Sec. 23, NE¼, SE¼

This is an unnamed quarry location that was identified in northwest Solon on the map of Johnson County geology by Calvin (1897) but no name was given in the report, and the quarry could not be identified from aerial photography. It is believed that the quarry is now covered by the baseball diamond west of the Solon Library.

---

unnamed quarry 2 T81N, R6W, Sec. 29, center

This is an unnamed quarry location that was identified on the map of Johnson County geology by Calvin (1897) but no name was given in the report. The location is in what is now Lake Macbride State Park, just north of the dam. this quarry could not be identified from aerial photography. Stone for construction of the Macbride dam was taken from the south end of the dam where C.C.C. workers quarried the spillway and removed other stone needed for construction of the dam from 1933 – 1937. However, this quarry site is south of the Calvin (1897) location.

unnamed quarry 3 T80N, R5W, Sec. 20, SW¼, NW¼

This is an unnamed quarry location just southwest of the Earnst Quarry that was identified on the map of Johnson County geology by Calvin (1897) but no name was given in the report.

Figure 27. Photo of the unknown quarry just southwest of the Earnst Quarry, from Google Earth, view looking north.

---

unnamed quarry 4 T81N, R6W, Sec. 21, NW¼, SE¼

This is an unnamed quarry location that was identified on the map of Johnson County geology along with a lime kiln by Calvin (1897) but no name was given in the report. This quarry could not be found on aerial photography of the region.

---

unnamed quarry 5 T79N, R6W, Sec. 22, NW¼, SE¼

This is an unnamed quarry location that was identified on the map of Johnson County geology by Calvin (1897) but no name was given in the report. The quarry can be seen just south of the CRANDIC railroad track, east of the Iowa River, and west of Sand Road.

Figure 28. Photo of the unknown quarry on the south side of Iowa City just south of the Crandic Railroad tracks west of Sand Road, from Google Earth, view looking south.

unnamed quarry 6 T81N, R8W, Sec. 27, SE¼, NE¼

Unnamed quarries in Pennsylvanian sandstones described by Calvin (1897, p. 98) were producing a coarse non-laminated, rather friable sandstone for use as building stone. He (ibid.) stated that the quarries had "*been quite extensively worked by the Amana society. There is one quarry in the salient headland near the mouth of Knapp creek and a number of other exposures have been quarried more or less between Knapp creek and the western limit of the county*."

Figure 29. Photo of unnamed quarry 6 just north of the Iowa River and west of the mouth of Knapp Creek taken in the 1930s. This quarry produced sandstone building stones for the Amana Society.

Vanourney Quarry T81N, R6W, Sec. 26, NE¼, NE¼

The unnamed quarry was identified on the map of Johnson County geology by Calvin (1897) but no name was given in his report. Iowa Geological and Water Survey records indicated that this was the Vanourney Quarry.

Figure 30. Photo of the Vanourney Quarry west of Solon, from Google Earth, view looking north.

REFERENCES

Anonymous, 1883, The History of Johnson County, Containing a History of the County and its Townships, Cities, and Villages from 1836 to1882. Iowa City, Iowa.

Bunker, B.J. and Witzke, B.J., 1989, The Coralville and Lithograph City Formations of the Coralville Lake Area. *in* Plocher, O.W., Geologic Reconnaissance of the Coralville Lake Area, Geological Society of Iowa Guidebook 51, p. 37–46.

Calvin, S.J., 1897, The Geology of Johnson County. Iowa Geological Survey, Annual Report, vol. 7, p. 33-116.

Shambaugh, B., F., 1893, Iowa City a Contribution to the Early History of Iowa. State Historical Society of Iowa, 116 p.

Witzke, B.J.(ed.), 1984, Geology of the University of Iowa campus area, Iowa City. Iowa Geological Survey Guidebook 7, 76 p.

Witzke, B.J., and Bunker, B.J., 1994, Classic Geological Exposures, Old and New, Coralville Lake and Spillway, Devonian Fossil Gorge, Merrill A. Stainbrook Preserve & Old State Capitol Preserve. Geological Society of Guidebook 60, 68 p.

DEVONIAN STRATIGRAPHY OF JOHNSON COUNTY, IOWA; Conklin-Klein Quarries and Surrounding Area

Brian J. Witzke and Bill J. Bunker
Iowa Geological & Water Survey
Iowa City, Iowa 52242-1319
brian.witzke@dnr.iowa.gov
bill.bunker@dnr.iowa.gov

INTRODUCTION

The Devonian stratigraphic section of Johnson County, Iowa, which primarily includes strata of the Wapsipinicon and Cedar Valley Groups, has received extensive study over the past century by numerous geologists. The wonderfully complete and instructive sections exposed at the Conklin and Klein Quarries (River Products Co.) serve as the primary Devonian reference sections for the region, and the Conklin Quarry includes the type section of the Coralville Formation. The stratigraphy of the Wapsipinicon and Cedar Valley Groups was extensively revised by Witzke, Bunker, and Rogers (1988), and background information and the historical development of the stratigraphic nomenclature can be referenced in that paper. Their report includes significant reference to the section at the Conklin Quarry.

The Devonian section at the River Products Company's Conklin Quarry in Coralville has been visited on several previous field trips including the Geological Society of Iowa (authors unknown, 1960; Witzke and Bunker, 1984), the Geological Society of America (Bunker and Witzke, 1992), and the Tri-State Geological Field Conference (Heckel, Kettenbrink, and Klapper, 1975; Witzke, Bunker, and Glenister, 1999). Although the Klein Quarry has been visited by numerous geologists over the years, and has been the subject of numerous informal field trips (including numerous visits by the Iowa DOT, University of Iowa, MAPS, and the Cedar Valley Rock and Mineral Society), the extensive Devonian exposures there have never been the subject of a formal field trip with an associated guidebook. Today's field trip will visit both the Conklin and Klein quarries, and participants will have an opportunity to examine and compare the similar Devonian stratigraphic sections exposed at both quarries.

Although much information is available on the Devonian strata of Conklin Quarry and the Johnson County area, the availability of numerous Devonian core penetrations drilled during the mid-2000s from the Klein Quarry area (see Fig. 1 for location of cores) has provided significant new opportunities to investigate small-scale lateral variations in the bed-by-bed stratigraphy within the Cedar Valley Group. These cores were generously donated to the Iowa Geological Survey by the River Products Company and are stored at our Oakdale facility. These cores have been logged and pertinent details summarized in this chapter. Additional studies are underway using these cores for further sedimentary investigations of the Cedar Valley Group (e.g., Mara Brady, Univ. Chicago).

ACKNOWLEDGEMENTS AND HISTORY OF INVESTIGATIONS

We wish to gratefully acknowledge the cooperation and participation of the River Products Company in all aspects of various geologic studies summarized in this guidebook and elsewhere. The authors of this report, as well as countless other geologists, both professional and amateur, have been generously given access by the River Products Company to their quarry properties over many decades of study. More recently, they have given full access to numerous rock cores from the Klein Quarry area. We truly thank the management and quarry personnel for their ongoing generosity and cooperation in promoting the geologic study of the remarkably instructive Devonian carbonate strata seen in their quarries.

Although the authors of this chapter have been involved in personally studying the Devonian strata in the Conklin and Klein quarries for three decades, our work has not been isolated. The Devonian

Figure 1. Map view of Klein Quarry area showing quarry operations, area of Pennsylvania outcrop, and location of River Product's bedrock cores now stored at the Iowa Geological and Water Survey's Oakdale facility. Graphic sections of some of the Klein cores are shown Figs. 5 and 12. Base adapted from Bing.com and hillshade from 2010 Lidar coverage.

sections at these quarries have been studied by numerous geologists and students over many decades, and we must acknowledge their considerable efforts in making the Devonian of Johnson County one of the best studied and best understood Devonian sections in the world. The Conklin Quarry was the focus of many of these studies.

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. A graduate thesis by Calhoun (1983) described much of the remarkable crinoid fauna of the Cedar Valley Group, and many of his specimens came from Johnson County and the Conklin Quarry. This work expanded on the earlier descriptions of the Cedar Valley echinoderm fauna of Johnson County by Thomas (1924) and Strimple (1970). Theses by Bils (1983) and Trier (1993) described coral and stromatoporoid growth forms in the Coralville Formation, primarily specimens from the Conklin Quarry. Bill Hickerson (1992) described the trilobites of the Cedar Valley Group, including specimens from Johnson County and the Conklin Quarry. 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 Shapo/Jannusch 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), and we gratefully acknowledge his long-term interest and assistance with our studies of Cedar Valley strata. 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.

We 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 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.

Finally, we wish to dedicate this chapter to Prof. Brian F. Glenister for his unwavering support of sedimentary and paleontologic studies of Iowa geology through the decades. His great interest in the local Devonian geology was a major factor in enabling many graduate thesis projects, and our studies have benefited greatly from his insights and passion.

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). Some ancient karst (especially Pennsylvanian paleokarst) is the site of sulfide and calcite mineralization, as seen at the Conklin and Klein quarries (see Garvin, this guidebook). 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 feet or more) and 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 by 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, 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 feet 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 south edge of Iowa City. This fault zone shows vertical displacement of Middle and Upper Devonian strata of 110 to 190 feet (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. An erosional episode also separates the Coralville and Lithograph City formations within the Cedar Valley Group, and deep erosional channeling is evident in areas of Johnson County (the State Quarry Member channels seen at Klein Quarry, Dingleberry Quarry, and the Coralville Lake area).

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.

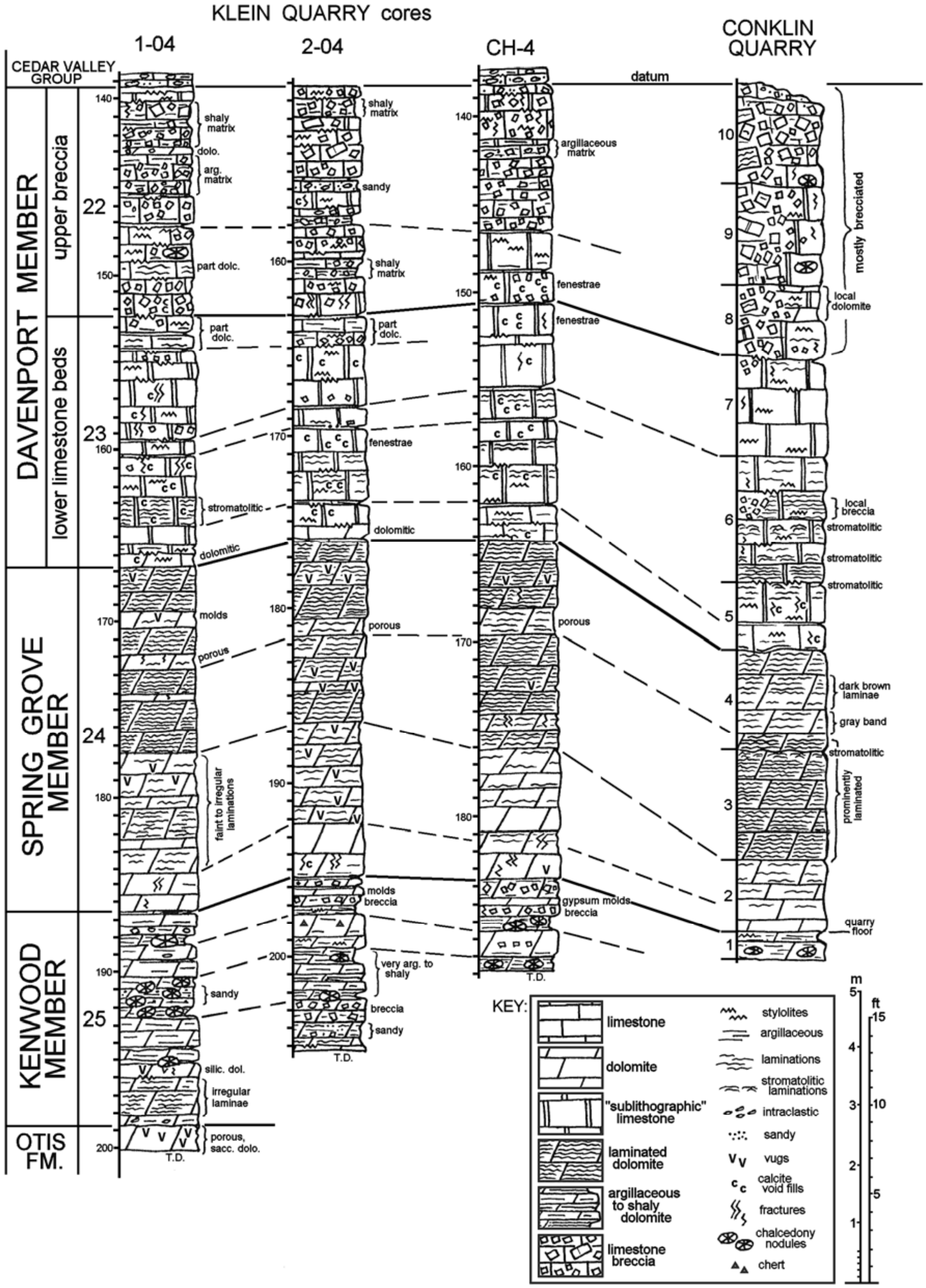


Figure 2. Graphic stratigraphic sections and correlation of Wapsipinicon Group at the Klein and Conklin quarries. Unit numbers for Conklin section from Witzke, Bunker, and Glenister (1999).

WAPSIPINICON GROUP

The oldest part of the Iowa Devonian succession comprises the Wapsipinicon Group (Bertram-Otis and Pinicon Ridge formations), which reaches thickness to about 100 ft (30 m) in the Johnson County area. Wapsipinicon exposures are limited in the Iowa City area to the lower levels and sumps of the Klein and Conklin quarries, where strata of the Pinicon Ridge Formation can be seen (Fig. 2). Summaries and descriptions of these strata are provided in other references, especially Witzke, Bunker, and Rogers (1988), Witzke, Bunker, and Glenister (1999), and Witzke and Bunker (2006a), and only salient details are provided here. Basal Wapsipinicon strata are not seen in the Conklin or Klein quarries, but core penetrations in Johnson County show these strata to be dominated by an upper vuggy saccharoidal dolomite interval (Otis Fm.) and a lower silty shale interval, including some nodular to bedded dolomite (?Bertram Fm.). Cores at the Klein Quarry have penetrated the upper vuggy dolomites of the Otis Formation (Fig. 2). The Otis Formation is of Middle Devonian age, probably deposited during the late Eifelian and earliest Givetian.

The overlying Pinicon Ridge Formation is nicely displayed at the Conklin and Klein quarries (Fig. 2), and the interval includes some high-quality limestone aggregate beds, especially in the lower Davenport Member. The formation is subdivided, in ascending order, into the Kenwood, Spring Grove, and Davenport members. The Pinicon Ridge is of Middle Devonian age; by stratigraphic position it is a lower to middle Givetian unit.

The Kenwood Member is dominated by argillaceous to shaley dolomite, part silty to sandy, and some beds are irregularly mottled to laminated. It contains lesser interbeds of green to gray silty shale, part dolomitic. Some of the dolomite beds are locally brecciated, especially in the upper part, and scattered gypsum crystal molds are noted (Fig. 2). Unusual chalcedony nodules and masses, some quite large (to 1 m), are scattered to common in the Kenwood (evident at Conklin and Klein quarries), and some chert nodules are present. The Kenwood Member includes gypsum-anhydrite evaporite beds in areas of southeast Iowa, but evaporite beds are absent in Johnson County (now dissolved producing collapse breccias). The Kenwood Member is interpreted to form a general transgressive-regressive (T-R) depositional sequence deposited in a restricted embayment of the Devonian epeiric sea (Witzke and Bunker, 2006a). The general absence of fossils and the presence of evaporite collapse breccias and gypsum molds suggest a highly restricted environment of deposition, certainly hypersaline at times, and probably with elevated salinities through much or all of its deposition.

The overlying Spring Grove and Davenport members have been interpreted to represent part of the same T-R depositional sequence (Witzke and Bunker, 2006a), and the interval disconformably overlies the Kenwood Member. The Spring Grove Member is dominated by dolomite strata, and much of the interval is thinly laminated. Some beds within the member are porous to vuggy. The dolomites are petroliferous to varying degrees, producing a distinctive fetid odor when freshly broken. The thin horizontal laminations show alternations between darker carbonaceous laminae and lighter dolomite laminae. Some of the laminations are decidedly organic-rich, and some unoxidized beds display dark brown organic laminae. The laminated Spring Grove dolomites have been interpreted to be of subtidal origin (Sammis, 1978), and in some beds the laminae show crenulations and small-scale domal forms likely of stromatolitic origin. The absence of benthic fossils suggests a restricted basin of deposition, probably with elevated salinities. Evaporite collapse breccias in the overlying Davenport Member indicate highly restricted hypersaline environments during deposition of that interval

The Davenport Member is dominated by limestone strata, and many of the limestone beds are dense and "sublithographic" (break with conchoidal fracture). These limestones are primarily mudstones, but pelletal and intraclastic units are also present. Minor dolomitic to argillaceous limestone beds also occur, and, like the Kenwood, some chalcedony nodules are locally seen. Some of the limestone beds are faintly and finely laminated, especially in the lower part, and some of the laminations are clearly of stromatolitic origin, showing domal and crenulated morphologies. Some of the limestones contain abundant calcite void fills and calcite-filled fractures, and fenestral fabrics ("birdseye") are evident in some beds. These latter fabrics suggest that some Davenport deposition occurred in peritidal-mudflat environments. The upper part of the Davenport Member in Johnson County is dominated by extensively brecciated limestone strata, although the degree and extent of brecciation shows significant lateral variation over short distances. Some limestone breccias also occur locally in the lower Davenport. The Davenport limestone breccias show a wide range in variation of clast sizes, which range from a few millimeters up to large blocks 1 to 2 meters in diameter. The clasts are primarily angular, but some rounded clasts also occur. The breccias generally occur in a limestone matrix, sometimes argillaceous, but some limestone breccias locally display a shaley matrix. Extensively brecciated beds can be seen to be replaced laterally over short distances by unbrecciated limestone strata in the quarry walls at both Conklin and Klein. Clasts derived from the overlying Solon Member are identified in the upper Davenport breccias, suggesting that brecciation may have been in part contemporaneous with Cedar Valley deposition. The Davenport breccias are clearly of evaporite solution collapse origin (Sammis, 1978; Witzke and Bunker, 2006a), and the often chaotic and laterally variable nature of the breccias is likely due to irregularities associated with solution of evaporite beds and the collapse and fracturing of intervening limestone strata.

CEDAR VALLEY GROUP – INTRODUCTION

The Cedar Valley Group is a widespread interval of limestone and dolomite strata, in places with gypsum anhydrite evaporite beds, that occurs across most of Iowa and adjoining areas of Illinois, Minnesota, Missouri, and Nebraska. It reaches thickness to about 125 feet (38 m) in Johnson County where it includes, in ascending order, three formations: 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, 2006b; Day, 2006). In Johnson County, the Cedar Valley Group is entirely of Middle Devonian age (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 limestone strata seen at the Conklin and Klein quarries are discussed individually below. A unit-by-unit description of the Cedar Valley succession at the Conklin Quarry is given in Witzke, Bunker, and Glenister (1999).

LITTLE CEDAR FORMATION – SOLON MEMBER

The basal interval of the Cedar Valley Group is assigned to the Solon Member of the Little Cedar Formation. The Solon derives its name from exposures at Solon in Johnson County. The Solon is a fossiliferous limestone interval that has been interpreted as a discrete transgressive-regressive (T-R) cycle that forms a general shallowing-upward depositional sequence. It is punctuated by one or more hardground disconformity surfaces in Johnson County, the most prominent and widespread of which is used to separate lower and upper Solon strata. The Solon Member forms a closely comparable interval at the Conklin and Klein quarries (Fig. 3).

The Solon Member records the initial transgression (the “Taghanic Onlap”) of open-marine seaways into Iowa and across vast areas of the continental interior of North America. The regional stratigraphic relations of the Solon Member in the Iowa area are discussed by Witzke, Bunker, and Rogers (1988) and Witzke and Bunker (2006b).

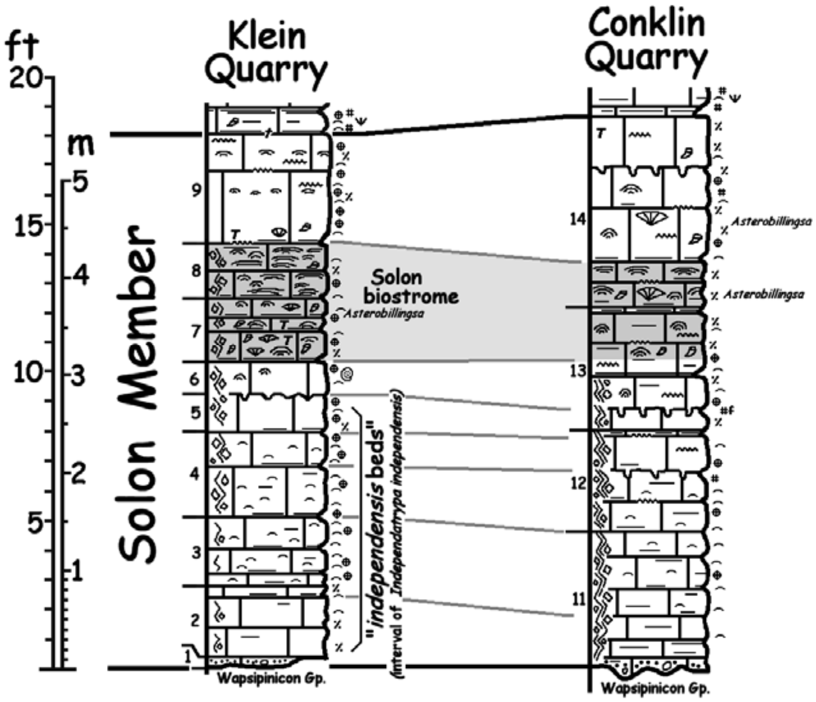


Figure 3. Graphic stratigraphic sections of Solon Member exposures at the Klein and Conklin Quarries. See Figure 4 for lithologic and paleontologic symbols. Unit numbers for Conklin section from Witzke, Bunker, and Glenister (1999).

The Solon-Davenport contact is disconformable, although brecciation above and below the contact often obscures its nature. Where visible, the contact commonly shows varying degrees of erosional relief, locally displaying up to 5 feet (1.5 m) or more of variation. In low-lying areas along the contact, a basal sandy to very sandy (quartz and chert sand) limestone, commonly with rounded clasts of limestone, is locally developed, and this sandy zone can be seen at places in both the Klein and Conklin quarries. The Solon Member, especially the lower half, commonly shows varying degrees of brecciation, although this brecciation is nowhere as well developed as it is in the underlying upper Davenport beds. The Solon breccias are laterally discontinuous and are replaced over short distances by well-bedded and unbrecciated Solon limestone strata, as seen at both the Conklin and Klein quarries. Brecciation of Solon strata likely accompanied solution-collapse brecciation in the underlying Davenport Member, and, as noted, Solon clasts locally occur within the Davenport breccias. Since normal-marine waters are undersaturated with respect to gypsum, it is likely that the Davenport evaporite beds began their dissolution as marine waters associated with the Solon marine transgression transgressed the region. Such dissolution likely progressed at the same time that deposition and submarine lithification of Solon carbonate sediments was occurring. Later-stage brecciation processes may even post-date Solon deposition, as similar breccias are locally evident in lower and middle Rapid strata higher in the section (as seen at Conklin and Klein quarries).

The lower Solon interval (above the basal sandy zone) has been termed the "*independensis* beds" (Klein Q units 2-5; Fig. 3) named after the characteristic and abundant atrypid brachiopod, *Independatrypa independensis*. It is characterized by slightly argillaceous fossiliferous limestone beds commonly separated by thin shaley partings. These strata are dominated by limestones, commonly brachiopod-rich, with skeletal wackestone to packstone fabrics. Although brachiopods are the most obvious fossils in these strata, crinoid debris (fine to coarse) is scattered to common, and bryozoans (including fenestellids and trepostomes), mollusks, cup corals, and trilobites are noted. The brachiopod fauna is diverse, although *Independatrypa*, *Spinatrypa*, *Schizophoria*, and *Strophodonta* typically dominate. Additional brachiopods noted in Johnson County include *Pseudoatrypa*, *Tylothyris*, *Cyrtina*, *Orthospirifer*, *Cranaena*, and others. At a genus-level, this fauna shares many similarities with that seen in the lower Rapid *Spinatrypa bellula* beds.

The upper Solon interval has been termed the "*profunda* beds" after the common and characteristic colonial rugose coral *Hexagonaria profunda*, although only portions of the upper Solon actually contain coral faunas. The lower portion of the upper Solon commonly contains dense, commonly packed, accumulations of corals and stromatoporoids, and this interval is known as the Solon biostrome (Klein Q units 6-8; Fig. 3). The basal bed of this interval (unit 6; Fig. 3) commonly contains only scattered corals and stromatoporoids, but is locally biostromal. The Solon biostrome beds are argillaceous to varying degrees, and shaly partings are commonly seen. The biostrome beds are widespread in the Solon Member, although the abundance and composition of the coral-stromatoporoid faunas show significant lateral variation over short distances. Especially at Klein Quarry, but also locally in the Conklin Quarry, the Solon biostrome commonly contains a great abundance of flat disc-shaped stromatoporoids (pancake-shaped), but in some areas these forms are not evident. The stromatoporoids in these beds variably display disc-shaped, hemispherical, and massive domal forms of varying size (some locally in excess of 50 cm diameter). Shapo (2003) described the rich stromatoporoid fauna from these strata at Klein Quarry, and the reader is referred to her study for the taxonomic identification of these forms. In addition to the stromatoporoids, the Solon biostrome contains a variety of coral taxa including massive to cylindrical tabulate corals (favositids, alveolitids, pachyporids), solitary rugose corals (cup and horn coral forms), and colonial rugose corals (*Hexagonaria*, *Asterobillingsa*). *Asterobillingsa* is a beautiful colonial coral with very large corallites that is restricted to upper Solon strata in Johnson County. The limestone matrix between the corals and stromatoporoids contains additional fossils, including brachiopods (*Independatrypa, Spinatrypa, Strophodonta, Cranaena, Pentamerella*, etc.), crinoid debris, and scattered bryozoans.

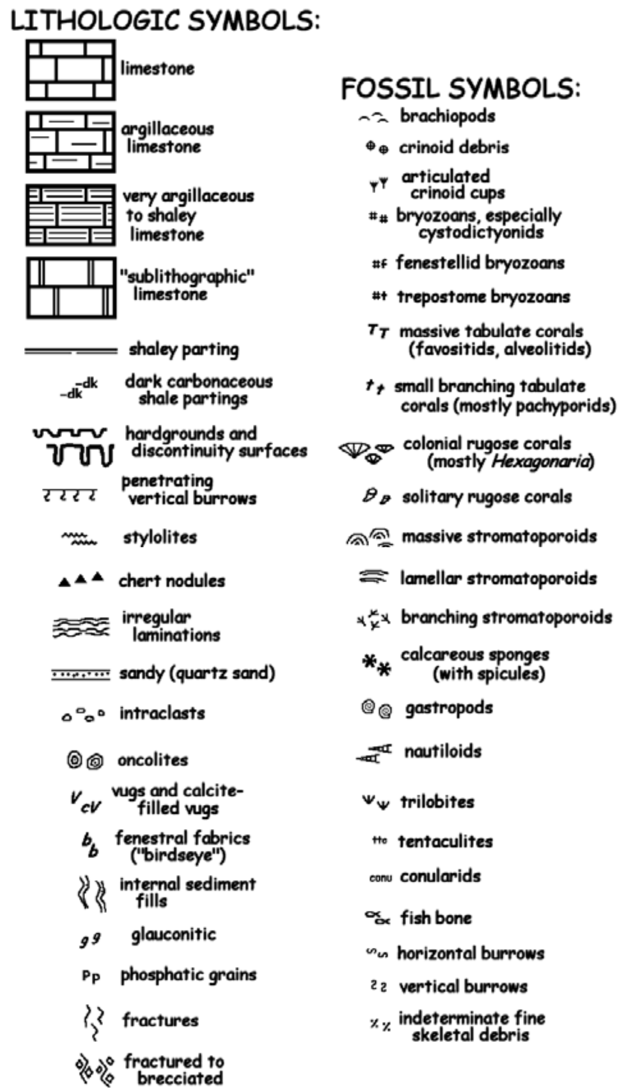


Figure 4. Key to lithologic and paleontologic symbols used in Figures 3, 5, 6, 8, 11, 12, and 15.

The upper part of the upper Solon is a distinctive interval (unit 9, Fig. 3) of dense limestone in massive thick beds, and it is commonly a distinctive light brown color. These limestone strata are dominantly a fine skeletal packstone, with scattered to common stylolites. This interval contains hemispherical to domal stromatoporoids and corals, but the coral-stromatoporoid content is laterally variable and is nowhere as abundant as that seen in the subjacent Solon biostrome. The coral and stromatoporoid fauna is similar to that identified in the biostrome, but is less abundant and of generally smaller size. An indeterminate fasciolate rugose coral was seen at Klein Quarry. The fine skeletal grains that make up the limestone matrix are commonly abraded, but larger fossils grains are locally evident as well, including brachiopods (similar fauna to the biostrome but including chonetids, ambocoelids, meristellids), fine crinoid debris, bryozoans (fenestellids, trepostomes), and occasional mollusks (bivalves, rostroconchs, nautiloids). At places in Johnson County (e.g. Lake Macbride area), these upper Solon strata locally contain rich accumulations of nautiloids. The calcareous microfauna includes algae and foraminifera at the Conklin Quarry (Kettenbrink and Toomey, 1975).

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 very close to the Conklin Quarry, and 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 shaley partings. It ranges between about 50 to 70 feet (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, 2006b), 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, 2006b) 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 rich 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 at Conklin and Klein quarries and the Johnson County area is subdivided into four parts corresponding to, in ascending order, the lower Rapid "*Spinatrypa bellula* beds," the middle Rapid "Z-beds," the upper Rapid "biostrome beds," and upper Rapid "*Devonatrypa waterlooensis* beds." Lateral lithologic changes within these units are illustrated in Figure 5.

Lower Rapid Member – "*Spinatrypa bellula* Beds"

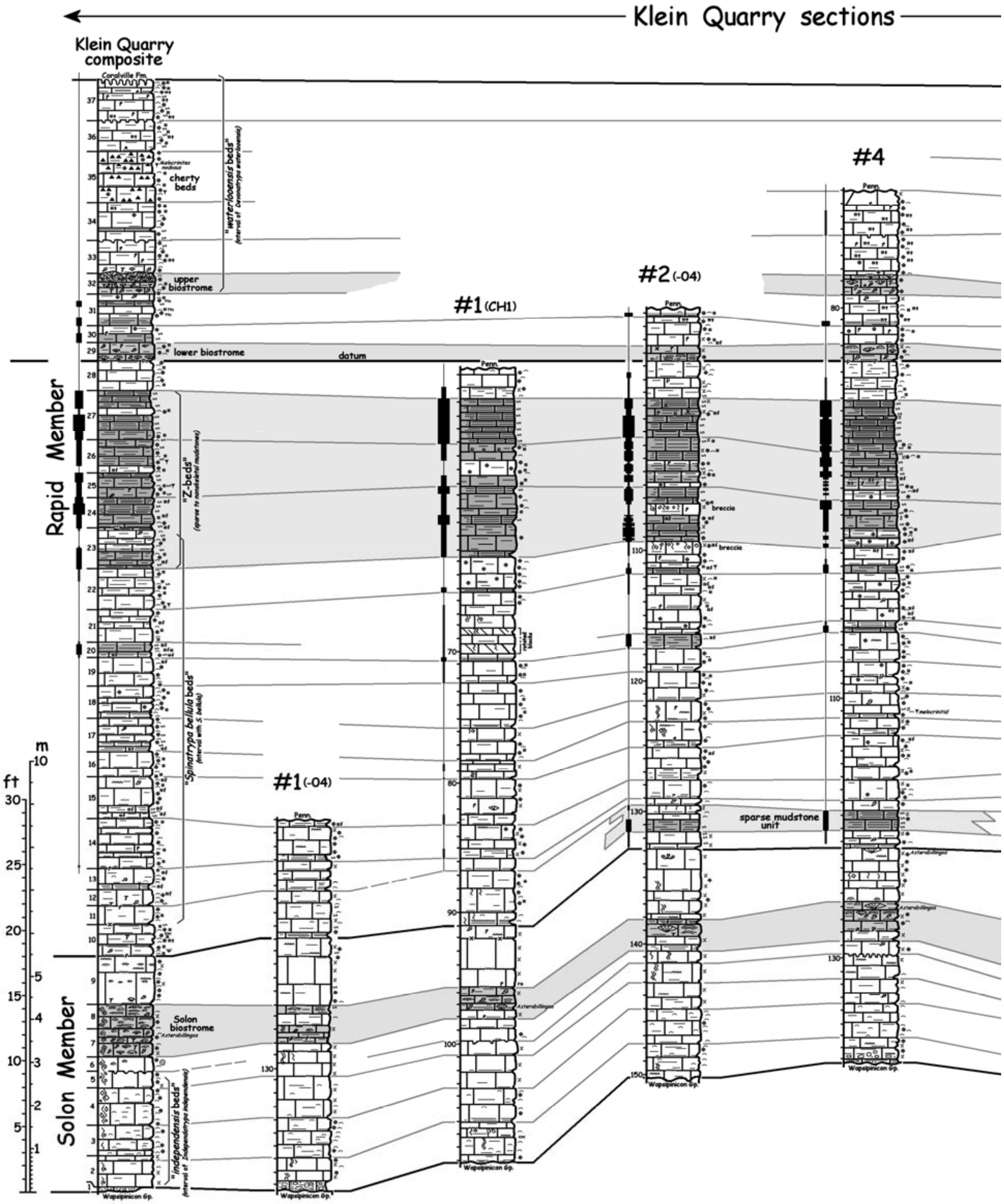
The contact between the Solon and Rapid members is marked by a change from light brown fine skeletal packstones (non-argillaceous to slightly argillaceous) of the Solon below, to conspicuously argillaceous less skeletal coarser wackestones to packstones above, and the basal Rapid is commonly very argillaceous to shaley. The contact is marked at some places in Johnson County by a vertically-burrowed discontinuity surface (Witzke and Bunker, 1994). However, the basal Rapid strata show considerable lithologic and thickness variations over both short distances (closely-spaced cores from Klein; Fig. 5) as well as longer distances (e.g. units 10-13 at Klein vs. unit 15 at Conklin; Fig. 6). We had not previously identified this aspect of the basal Rapid strata, and it was only by comparing the section in multiple Klein cores that we discovered these interesting variations. At Conklin Quarry and other localities in Johnson County (e.g., Devonian Fossil Gorge, Lake Macbride) the basal Rapid unit is seen as an argillaceous skeletal wackestone to wacke-packstone with prominent shaley reentrants at the top and bottom (unit is

50-70 cm thick). This interval includes fossil faunas typical of the overlying *bellula*-bed strata, but commonly includes articulated sponge fossils (*Astraeospongia*) not generally seen in units above. In addition, this interval has yielded beautiful articulated specimens of trilobites, crinoids, and blastoids in Johnson County.

By contrast, the basal *bellula*-bed strata at the Klein Quarry (units 10-13; Fig. 6) are generally thicker (1.2-2.0 m) than seen at Conklin, and they display significant lateral variations over short distances. Marked by a basal shaley to very argillaceous reentrant, the overlying limestone beds include both skeletal wackestone-packstones as well as nonskeletal mudstones separated into individual beds by multiple argillaceous to shaley partings. In addition, corals are not uncommon in this interval in both core and quarry exposure, and tabulates (favositids, alveolitids), solitary rugosans, and colonial rugosans (*Hexagonaria*) have been noted. The basal beds in most of the core sections at Klein include one or more beds with prominent vertical burrows (some are mudstone filled) indicating the development of multiple firm-ground surfaces representing minor hiatuses in deposition of the basal beds. Of particular surprise was the identification of sparse to nonskeletal burrowed argillaceous mudstone strata in two of the Klein cores (cores 2 and 4; Fig. 5; also shown by Witzke and Bunker, 2006). These mudstone units resemble those seen in the middle Rapid "Z-beds." The reasons for these lithologic variations in the basal Rapid at Klein are not yet clear, and the specific geometry of these strata has not yet been worked out. Because the basal Rapid represents a time of significant marine transgression, it is possible that complex onlapping or downlapping of various thin beds characterized the transgressive systems tract (TST) in this area, punctuated by hiatuses and the development of vertically-burrowed firm-grounds. Further study both at Klein Quarry and elsewhere in eastern Iowa is needed to better document the nature of the basal Rapid TST.

Unlike the basal Rapid strata, the bulk of the lower Rapid *bellula* beds is characterized by a remarkably consistent and repetitive stack of limestone beds, and individual beds can be readily correlated across Johnson County (Fig. 5). In general, the *bellula* beds include a succession of slightly argillaceous to argillaceous skeletal limestone beds (wackestones and packstones) separated by thin very argillaceous to shaley mudstones to wackestones. Individual beds show little variation in thickness across the county, but some of the upper beds locally display large-scale bedforms and minor thickness variations suggestive of storm-generated sedimentary features (Witzke and Bunker, 1994). The *bellula* beds are dominated by repetitive couplets of resistant thicker limestone beds (commonly 50-120 cm thick) and thinner less resistant shaley beds (3-35 cm thick). The upper part of the *bellula* beds shows finer-scale interbedding of skeletal wacke-packstones and sparse mud-wackestone. Each couplet apparently represents a small-scale shallowing-upward sedimentary succession (probably a parasequence-scale unit), with the basal shaley bed formed during deepening phases of deposition (unwinnowed muds, common unabraded to articulated fossils) and the thicker limestone bed deposited under slightly shallower and more winnowed conditions (packstone dominated, including abraded skeletal grains). Some of the basal shaley units include sparsely skeletal mudstones and shale (especially unit 20 Klein, upper unit 19 Conklin; Fig. 6) similar to the argillaceous mudstones of the middle Rapid "Z-beds." Some of the shaley units contain a different fauna than seen in the limestone beds, dominated by accumulations of delicate fenestellid bryozoans (e.g., units 15, 17, 20 Klein; Fig. 6). Many of the shaley units contain thin stringers of skeletal debris (probably storm-generated), and articulated crinoids are sometimes encountered in these beds (also similar to occurrences in the "Z-beds"). The thicker skeletal limestone beds are amalgamated skeletal wackestone and packstones, commonly slightly argillaceous. These beds locally contain brachiopod-rich stringers internally, although much of the skeletal material is disarticulated and may be partly abraded. Corals are locally scattered to common, especially in the upper part of individual beds.

The "*belulla* beds" contain an abundant and diverse marine fauna, among the richest known in the entire Cedar Valley Group. Brachiopods are particularly conspicuous (Fig. 7), dominated in most beds by the name-bearer *Spinatrypa bellula* as well as common to abundant *Pseudoatrypa, Schizophoria*, *Strophodonta*, *Tylothyris*, and *Orthospirifer*. *Schuchertella* is common in the upper part. Many additional brachiopod taxa also occur including *Productella, Cyrtina*, chonetids, *Pentamerella*, and others (see lists in Day, 1992). Crinoid debris is scattered to common through most of the interval, and some


Klein Quarry sections
Klein Quarry composite
Coralville Fm.
"waterlooensis beds"
cherty beds
upper biostrome
lower biostrome
datum
Rapid Member
"Z-beds"
"Spinatrypa bellula beds"
Solon biostrome
Solon Member
"independensis beds"
Wapsipinicon Gp.
#1 (-04)
#1 (CH1)
#2 (-04)
#4
Penn.
breccia
sparse mudstone unit
ft
m

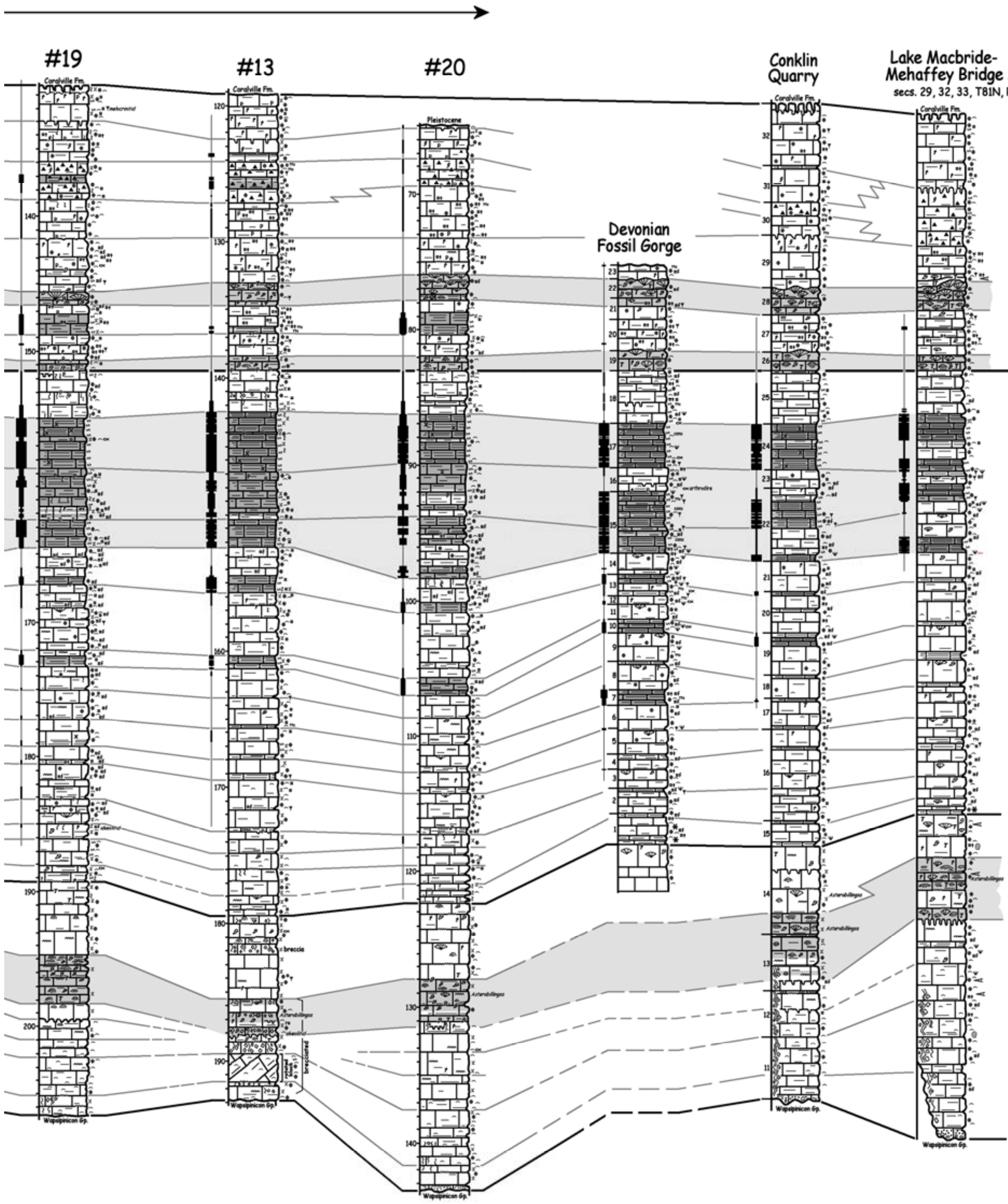


Figure 5. Graphic stratigraphic sections of Little Cedar Formation in Johnson County showing correlation of outcrop and core sections from Klein and Conklin quarries and selected exposures in the area of the Coralville Lake and Spillway. Core depths in feet. See Figure 1 for location of core sections. Symbols given in Figure 4. Black bars to the left of each section show position of sparsely skeletal to nonskeletal argillaceous mudstones; width of bar qualitatively illustrates skeletal content (widest are nonskeletal). Unit numbers from Conklin Quarry from Witzke, Bunker, and Glenister (1999); Devonian Fossil Gorge from Witzke and Bunker (1994).

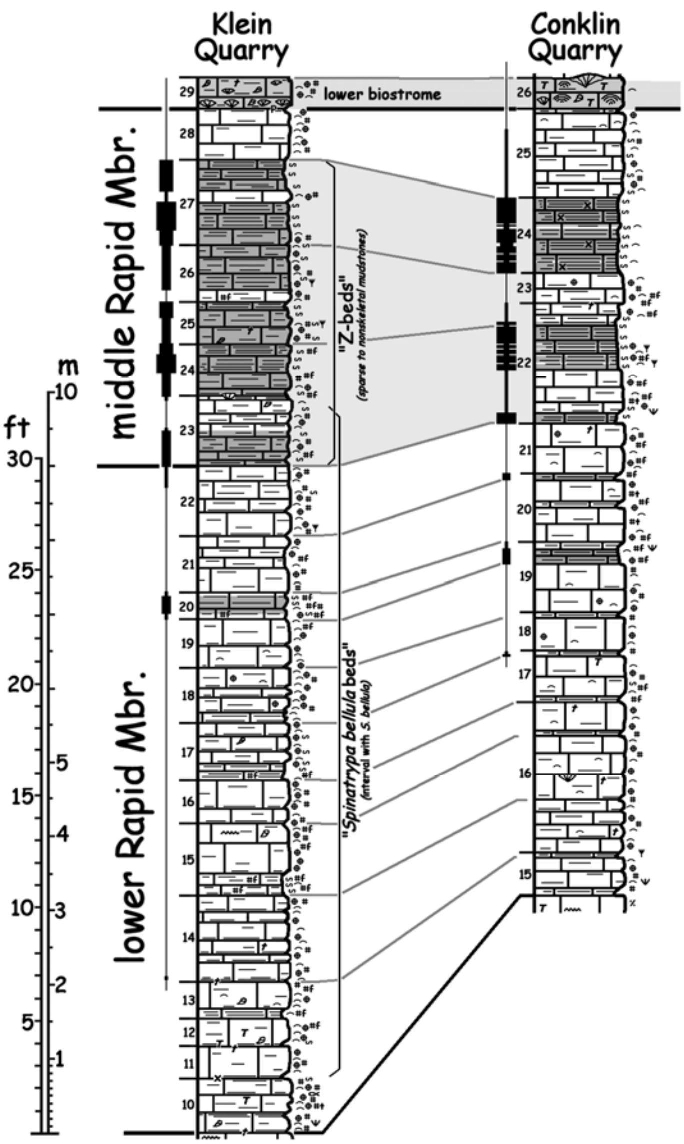


Figure 6. Graphic stratigraphic sections and correlation of lower and middle Rapid Member strata from exposures at the Klein and Conklin quarries. Symbols given in Figure 4 and Figure 5 caption (black bars show mudstone units).

crinoidal packstone beds occur. The crinoid fauna is diverse (see Calhoun, 1983; Strimple, 1970); articulated specimens of *Megistocrinus*, melocrinitids, and *Euryocrinus* are the most common. Blastoids (*Nucleocrinus*) are also noted. Bryozoans are scattered to abundant and primarily include various genera of fenestellids and cystodictyonids; trepostomes and other bryozoans occur as well. As noted above, sponges are noted, especially in the basal beds. Corals are scattered and locally common. Solitary rugose corals (cup corals) are the most common, although tabulate corals (favositids, alveolitids, auloporids), and colonial rugosans (*Hexagonaria*, indeterminate fasciolate forms) are commonly seen as well. Molds of mollusks include scattered bivalves, gastropods, and nautiloids. Trilobites (*Phacops, Greenops*, proetids) occur throughout the *bellula* beds and are most common in the basal and upper parts. Phosphatic fish remains are generally rare, but tritors of the placoderm *Ptyctodus* are the most common. The enigmatic small conical fossils known as tentaculites are present in some beds. Of interest, no calcareous algae or cyanobacterial fossils have been identified in the lower Rapid Member.

<u>Middle Rapid Member – "Z-Beds"</u>

A unique and distinctive interval dominated by argillaceous to very argillaceous sparsely fossiliferous to unfossiliferous slightly burrowed lime mudstones occurs above the "*bellula* beds." This interval was first recognized and studied in Johnson County by Zawistowski (1971), and Witzke and Bunker (1994) termed this interval the "Z-beds" in honor of Zawistowski's studies. Although not lithologically part of the "Z-beds," a brachiopod-rich limestone unit occurs between the top of the "Z-beds" and the base of the Rapid biostromes (e.g., unit 28 Klein, unit 25 Conklin; Fig. 6) and is included here for discussion purposes. Sparse mudstones of the "Z-beds" are seen to interbed at varying scales with fossiliferous skeletal wackestone to packstone units, including thin discontinuous stringers as well as discrete beds. This interbedding is not clearly correlatable at fine scales probably due to the discontinuous nature of these thin beds and stringers. However, at coarser scales, these skeletal units occur at specific intervals within the Z-beds, especially the lower and middle parts (Figs. 5, 6). The least skeletal part of the Z-beds generally occurs in the upper part of the interval.

The Z-beds generally thin northward in Johnson County, where they interbed with and are replaced laterally by units that are lithologically and paleontologically indistinguishable from the "*bellula* beds" (Witzke and Bunker, 1994). The upper part of the Z-beds is the most laterally extensive part of the interval in the county. However, the Z-beds occupy the same stratigraphic position at both Conklin and Klein quarries, although the interval at Conklin includes thicker and more common interbeds of skeletal limestone (Fig. 6). Eastward into the subsurface of eastern Johnson County, and extending to Scott County and southeastward in Iowa, Z-bed lithologic facies occupy progressively greater proportions of the Rapid Member, and ultimately become the dominant facies of entire Rapid Member in Lee County (Witzke and Bunker, 2006b). Because Z-bed lithologies decrease in thickness to the north (the ancient shoreward direction) and increase to the southeast (the ancient offshore direction), these facies are interpreted to be the deepest-water depositional facies of the Rapid Member.

As summarized by Witzke and Bunker (2006), the Z-beds interval is interpreted to have been deposited at depths at or below storm wave base under a stratified water column with oxygen-deficient bottom waters inhospitable for most benthic animals. However, scattered burrows indicate that some benthic organisms were capable of surviving in these environments, at least at times. The interbedding of skeletal stringers further suggests that episodes of oxygenated bottom conditions were developed at times during deposition. The abundance of mud (carbonate and clay) in the Z-beds indicates the general absence of current winnowing, although skeletal stringers and smothered-bottom crinoid associations indicate that episodic distal storm current activity occurred during at least parts of Z-bed depositon in Johnson County.

Thin skeletal stringers in the lower part of the Z-beds locally contain remarkable accumulations of fossils, including fully to partially articulated crinoids. Articulated crinoids were particularly noteworthy at this position at the Devonian Fossil Gorge exposure in Johnson County (Witzke and Bunker, 1994), and similar occurrences have also been noted at the Conklin and Klein quarries as well as other exposures in the Coralville Lake area. These crinoid faunas are dominated by camerate crinoids, especially *Megistocrinus* and an undescribed genus of melocrinitid. Additional crinoids also occur (e.g., *Eurycrinus*). This remarkable preservation indicates rapid burial of the crinoids, as crinoids quickly disarticulate into individual calcite plates shortly after death. Other skeletal limestone beds and stringers within the Z-beds interval contain fossil faunas generally similar to those seen in the *bellula* beds, including crinoid debris, bryozoans (especially fenestellids), and brachiopods (*Spinatrypa* at the base, *Pseudoatrypa, Orthospirifer, Cyrtina, Tylothyris, Schizophoria, Schuchertella, Strophodonta, Productella*, others). Scattered corals, trilobites, tentaculites, and fish bone also occur. Thin stringers rich in small chonetid brachiopods are also known from the Z-beds in Johnson County, and these stringers are unique to the Z-beds.

The sparsely fossiliferous to unfossiliferous burrowed argillaceous mudstone lithologies in the Z-beds, by contrast, contain a notably different and unique fauna conspicuoly lacking the normal shelly benthos seen through most of the Rapid Member (especially brachiopods, bryozoans, crinoids). Simple horizontal burrow forms of varying diameter are the most common trace fossil, and more complex *Chondrites* burrows occur in some beds. Rare fossils are scattered in some but not all beds, and beautifully preserved clusters of delicately phosphatized elongate triangular fossils (to 5 cm long) known as conularids (an enigmatic group of extinct medusoid cnidarians) are recognized in the Z-beds (especially the freshly exposed Devonian Fossil Gorge exposure). Occasional small inarticulate brachiopods (linguloids) are seen in the sparse mudstones of the lower Z-beds. Shrimp-like phyllocarid crustaceans and dendroid graptolites have also been recognized in the Z-beds of Johnson County.

An interval of argillaceous limestone, primarily a skeletal mudstone to wackestone, occurs between the top of the Z-bed mudstones and the lower Rapid biostrome (Figs. 5, 6). This unit includes some whole-shell brachiopod-rich wackestone to packstone (especially upward), and dark phosphatic grains are noted in the lower to middle parts. The interval generally shows an upward decrease in mudstone and a concomitant increase in skeletal grains. The unit is fossiliferous, generally dominated by a rich assemblage of brachiopods (*Pseudoatrypa, Orthospirifer, Eosyringothyris, Tylothyris, Cyrtina, Athyris, Strophodonta, Schizophoria, Schuchertella, Pentamerella, Cranaena*, others, Fig. 7). Crinoid debris and bryozoans (fenestellids, cystodictyonids, trepostomes) are scattered, and tentaculites and trilobites are occasionally seen.

Figure 7. Brachiopod-rich bedding surface (including *Spinatrypa bellula*) from the lower Rapid "*bellula* beds" at Klein Quarry. Finger for scale.

Upper Rapid Member – Rapid Biostromes Interval

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 Conklin and Klein quarries (Fig. 8). 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 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), although the concentrations of corals-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 10-30 cm in diameter, but specimens up to 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 1 m but in other areas thinning to 10 cm (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.

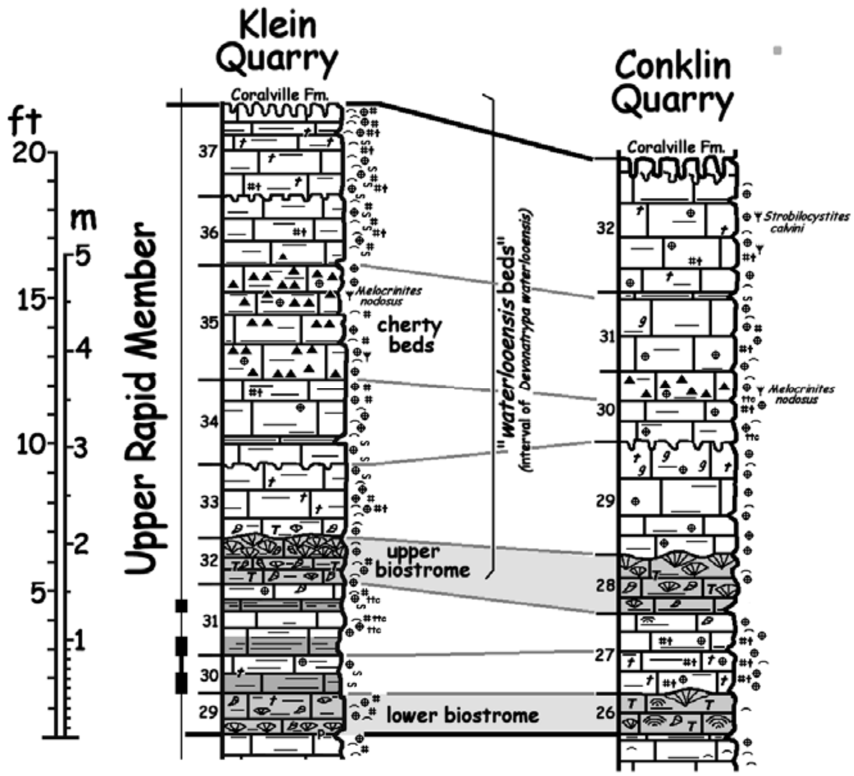


Figure 8. Graphic stratigraphic sections and and correlation of upper Rapid Member strata from exposures at the Klein and Conklin quarries. Symbols given in Figure 4 and Figure 5 caption (black bars show mudstone units).

A non-biostromal stratigraphic interval about 70-110 cm thick separates the upper and lower biostromes in Johnson County (Fig. 8), 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 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).

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 (Figs. 5, 8). 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, 2006b). There is variation in the thickness and lateral continuity of these mudstone units at Klein (Fig. 5 cores); 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.

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. 9). 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 (Fig. 8), 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).

Figure 9. Bedding surface showing specimens of *Devonatrypa waterlooensis* in packstone at the Rapid-Coralville contact, Klein Quarry. Quarter for scale.

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 shaley partings separate some beds. Carbonate mudstone also occurs within the interval at 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 (Fig. 10). However, discrete mudstone beds are locally identified in the cherty unit at Klein (e.g., Fig. 5, cores 13 and 19). The middle beds at Klein (units 34-35; Fig. 8) 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 10 cm in underlying strata, are seen at many localities in Johnson County (e.g., Figs. 5, 8). 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.

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 (including Conklin), but this rhombiferan is even more abundant in correlative strata northward in Linn and Benton counties.

Figure 10. Prominently burrowed cherty limestone from upper Rapid Member, Klein Quarry. Note chert nodules, mudstone filled vertical and horizontal burrows, and inter-swirled mudstone and wackestone-packstone fabrics. Rock hammer handle for scale.

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 (Figs. 11, 12). 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 to about 40 feet (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 a area that bordered the distal portions of the inner-shelf region of the Midcontinent (Witzke and Bunker, 1997). It includes four general limestone lithologies (Figs. 11, 12): 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; see Fig. 13); 3) limestone strata with sparse to absent corals or stromatoporoids (see "corals absent" units; Figs. 11, 12); 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 (including Conklin Quarry and areas around Coralville Lake), and this unit was previously included with the overlying Iowa City Member. It is here included in the Cou Falls Member (Fig. 11) because of laterally continuity with upper Cou Falls strata, and it contains corals

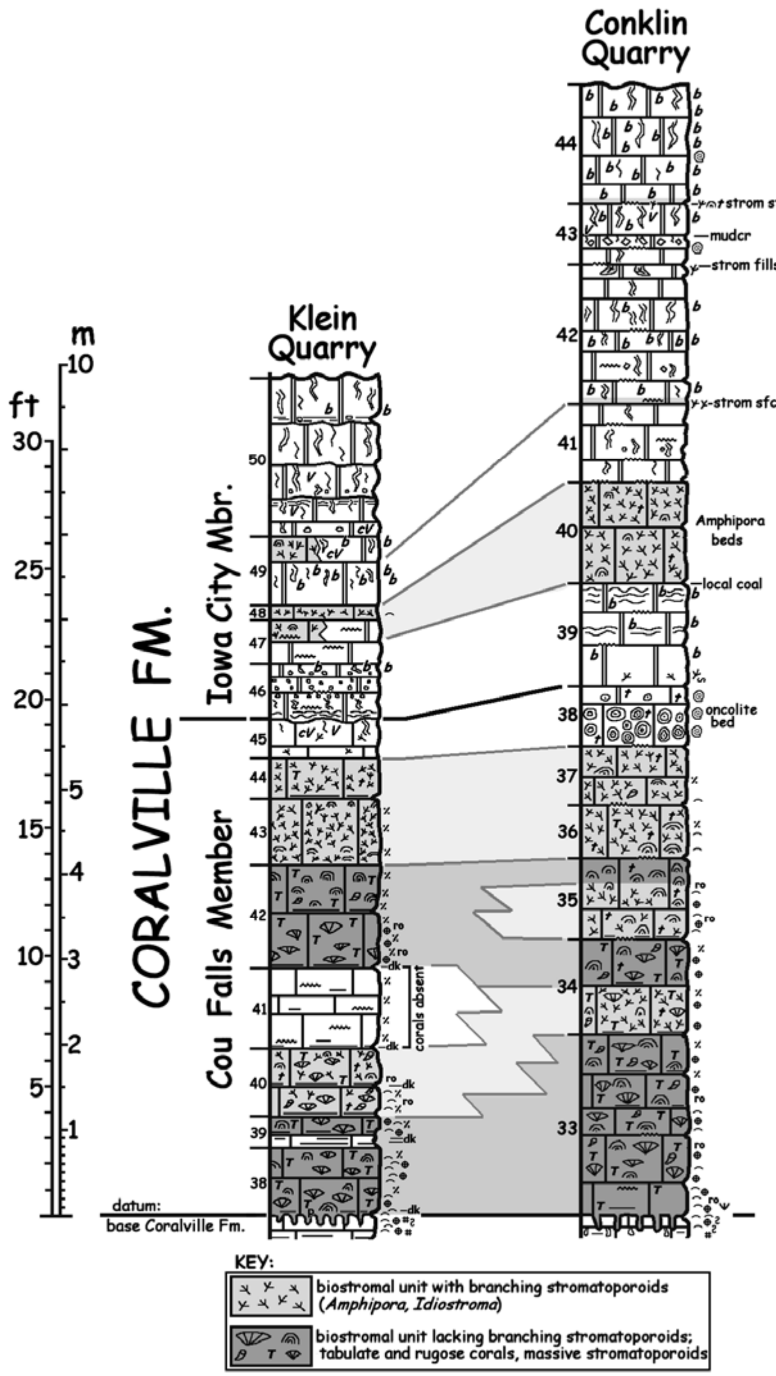


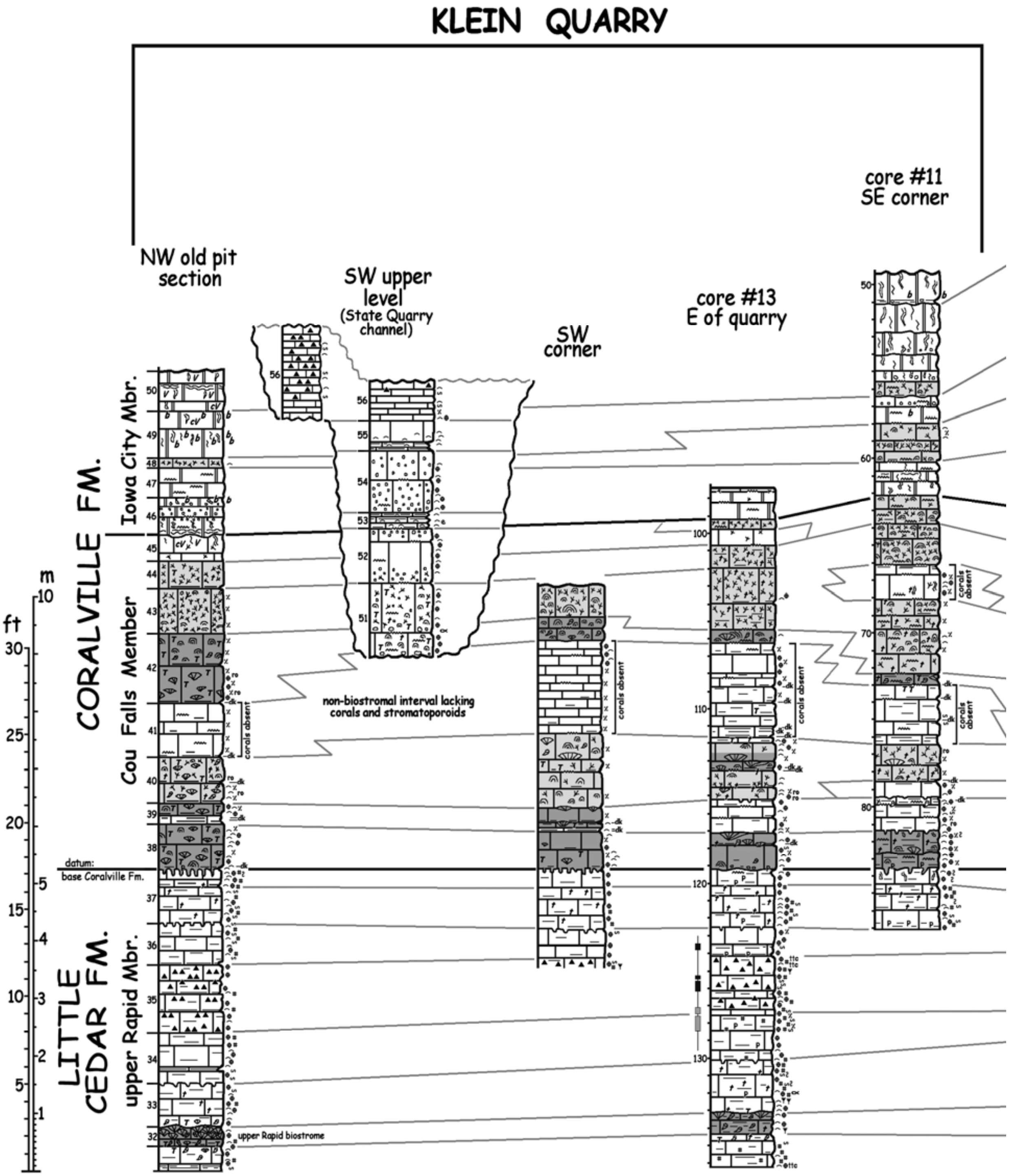
Figure 11. Graphic stratigraphic sections and correlation of Coralville Formation from exposures at the Klein and Conklin quarries. Symbols given in Figure 4.

and stromatoporoids which are not presnt 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) shaley partings are commonly seen separating some beds in the lower Cou Falls (Fig. 14). 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 (Figs. 11, 12), 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 (Fig. 12) are particularly instructive, where the non-corallline 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 (Fig. 12). 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. 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.

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.


KLEIN QUARRY
NW old pit section
SW upper level
(State Quarry channel)
SW corner
core #13
E of quarry
core #11
SE corner
CORALVILLE FM.
Iowa City Mbr.
Coralville Member
Cou Falls Member
LITTLE CEDAR FM.
upper Rapid Mbr.
non-biostromal interval lacking corals and stromatoporoids
corals absent
datum:
base Coralville Fm.
upper Rapid biostrome
ft
m

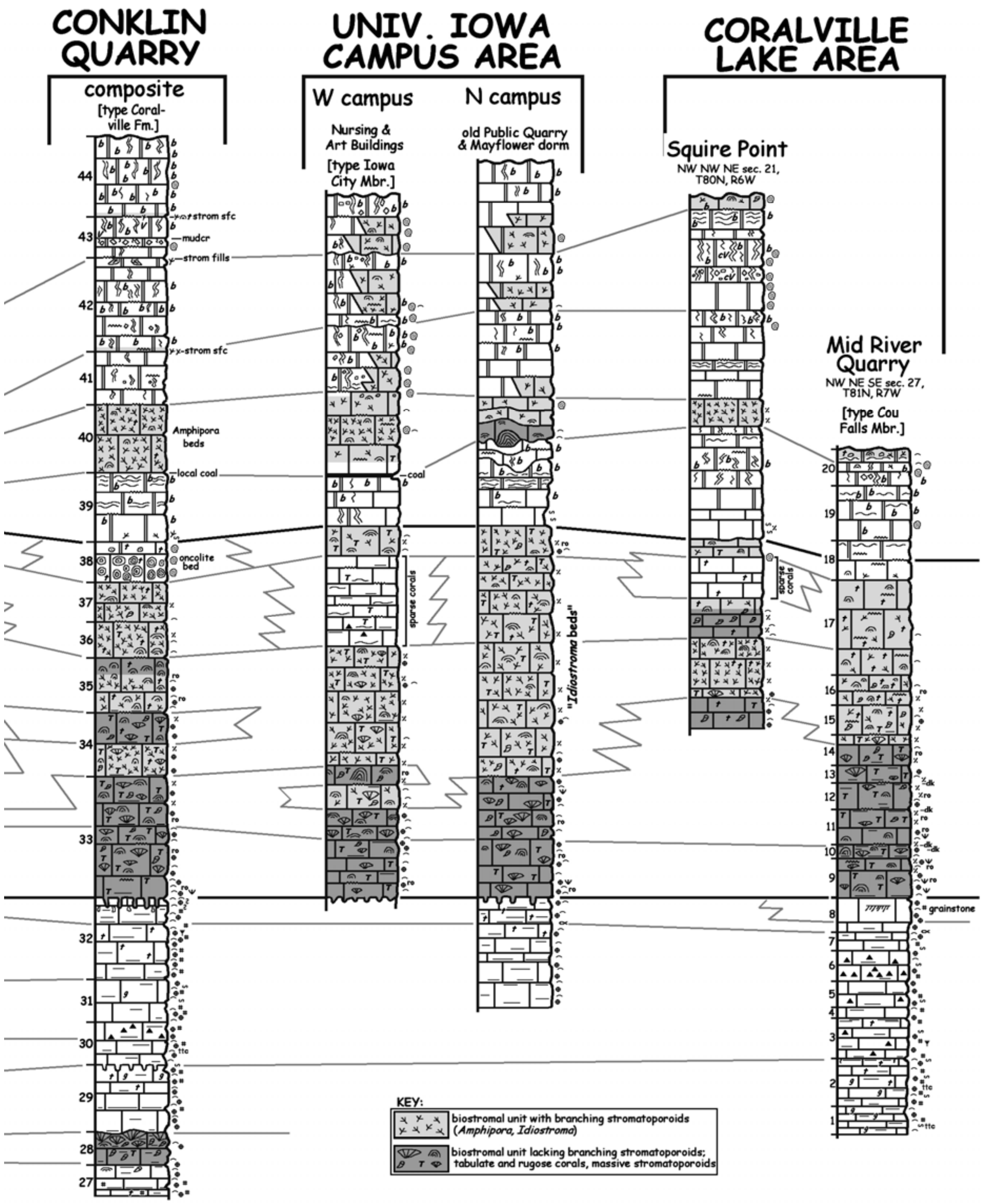


Figure 12. Graphic stratigraphic sections and correlation of upper Rapid, Coralville, and State Quarry strata in Johnson County from exposures and cores at Klein and Conklin Quarries and selected exposures from the University of Iowa campus and Coralville Lake area. Core depths in feet. Symbols given in Figure 4. Unit numbers from Conklin Quarry sections from Witzke, Bunker, and Glenister (1999) and the Mid River Quarry from Plocher, Bunker, and Witzke (1989).

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). 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 of 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 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 (top unit 39, Conklin, Fig. 11) and in Iowa City, possibly deposited in a ponded environment on the mudflats.

Figure 13. Stromatoporoid-rich limestone from the "*Idiostroma* beds" at Klein Quarry. Both branching and massive stromatoporoids are evident. Rock hammer for scale.

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 identify 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 domal 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 (Fig. 12). At Conklin these three horizons are represented by thin concentrations of *Amphipora* along bedding surfaces or in sediment fills. 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).

LITHOGRAPH CITY FORMATION – STATE QUARRY MEMBER

Figure 14. Organic-rich dark shale parting in lower Cou Falls Member, Klein Quarry. Light-colored lumps are colonial corals forming an irregular surface. Rock hammer for scale.

Although the Coralville Formation marks the top of the Cedar Valley Group at most localities in Johnson County, the third formation of the group, the Lithograph City Formation, is known to locally overlie Coralville strata. Where seen, the Lithograph City Formation in the county is mostly represented by channel-filling limestone deposits of the State Quarry Member which are incised into underlying strata of the Coralville Formation and Rapid Member. This channel-filling succession is best seen in the area of the Old State Quarry (type locality) and Mehaffey Bridge in the Coralville Lake area of Johnson County, where the member reaches thicknesses to 50 ft (15 m) (Witzke and Bunker, 1994). This area includes most of the known exposures of the member, although small exposures are known in the area of the Dingleberry Quarry (River Products Co.) northeast of Iowa City. The deep incision of the State Quarry channels indicates that there was a major period of erosion in the area following Coralville deposition, and the two formations are unconformably separated by an erosional hiatus. Smaller-scale channel fills are recognized in the basal Lithograph City Formation as far north as central Benton County, supporting the widespread and significant nature of this erosional unconformity. Outside of the State Quarry Member channels, dolomite and limestone strata of the Andalusia Member (the basal unit of the Lithograph City Formation at most localities in eastern Iowa) locally overlie the Coralville Formation between Coralville Lake and North Liberty (Witzke and Bunker, 1994), and possibly in a core at the University of Iowa campus.

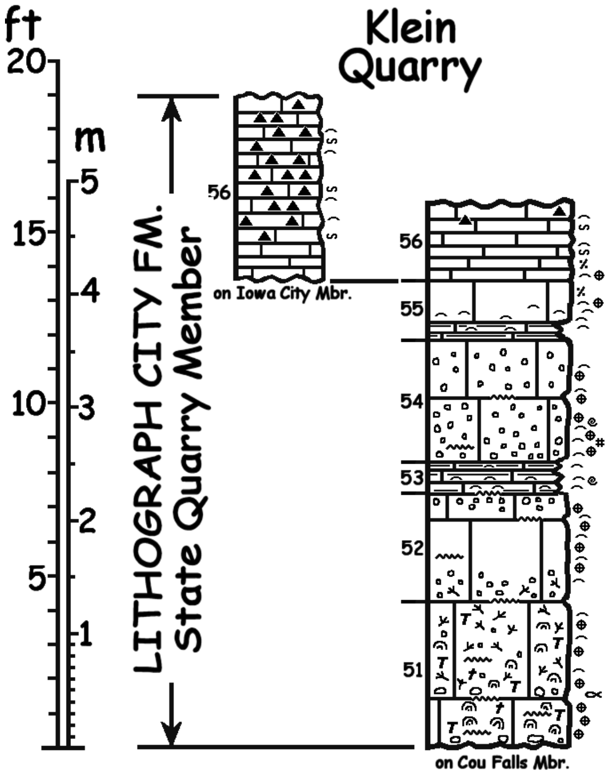


Figure 15. Graphic stratigraphic section of State Quarry Member channel measured at Klein Quarry in 2006. Symbols given in Figure 4.

Because of the limited extent of the Lithograph City Formation in Johnson County, it came as a bit of surprise when strata of the State Quarry Member were recognized at the Klein Quarry during quarrying activities along the south wall (immediately adjacent to the large Pennsylvanian channel cut-out) in 2005 and 2006. The section was measured and described at that time (B. Witzke, J. Day, B. Bunker, A. Reyes), although much of the original section has been subsequently quarried away. Nevertheless, State Quarry strata can still be seen in this area of the Klein Quarry. The State Quarry Member at Klein occupies an erosional channel that is incised through the Iowa City Member and into the middle part of the Cou Falls Member at its deepest position (see Figs. 12, 15, 16). The incision cuts at least 16 feet (5 m) into Coralville strata, and the maximum width of the channel is estimated to exceed 300 feet (90 m). The limestone strata that fill the channel progressively onlap the channel margins, and the lower strata (units 51-52, Fig. 15; Fig. 12) are seen only in the central and deepest part of the channel. The highest unit (unit 56, Figs. 12, 15) is seen to overstep the channel margin to the east, where it directly overlies the upper Iowa City Member.

The limestone units in the lower part of the State Quarry channel fill at Klein (units 51-52; Fig. 15) are dominated by fine to coarse skeletal packstone, part very crinoidal and with scattered whole-shell brachiopods, with common to abundant small limestone lithoclasts or intraclasts (to 5 cm diameter). This interval also includes common reworked clasts of stromatoporoids (branching to massive forms) and tabulate corals (favositids). The reworked nature of the coral-stromatoporoid clasts is underscored by the stratigraphic position of the units containing these clasts, which occupies a position in the channel coincident with the top of the *Idiostroma* beds in the Cou Falls Member (see. Fig. 12). Channel deposits above this level do not contain reworked stromatoporoidal clasts, as sources in the *Idiostroma* beds were already buried. Similar relations are observed in the State Quarry channel in the Coralville Lake area, where lower strata include reworked corals-stromatoporoids in lithoclastic limestone units (Witzke and Bunker, 1994).

The middle part of the State Quarry deposits at Klein (units 53-55, Fig. 15) includes two units with shaly partings and common to abundant well-preserved brachiopods, primarily *Independatrypa scutiformis* (Fig. 17) along with lesser *Strophodonta* and *Athyris*. *I. scutiformis* is a brachiopod known only from the Lithograph City Formation, and its occurrence further confirms that stratigraphic placement of the State Quarry channel fill at Klein. Additional brachiopods (*Strophodonta, Athyris*), crinoid debris, and gastropods also occur. Massive-bedded limestone strata between and above the brachiopod-rich units are dominated by lithoclastic to peloidal packstones with skeletal grains (small brachiopods, crinoid debris, bryozoans).

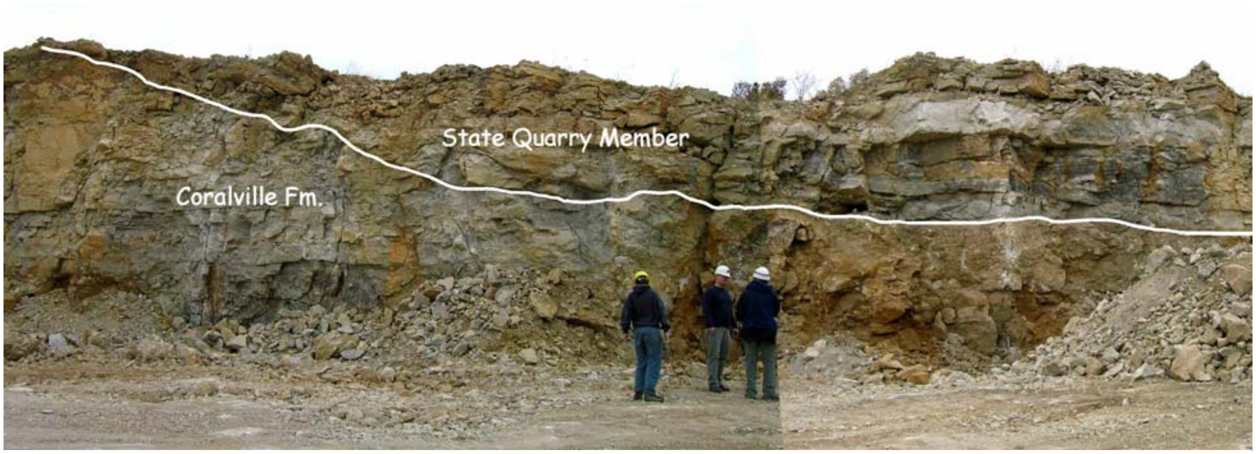


Figure 16. Photo showing State Quarry channel incised into Coralville Formation (2006).

Thinner-bedded cherty limestone strata (unit 56, Fig. 15) cap the succession in the channel fill and overstep the channel fill to directly overlie the Iowa City Member. These strata are dominated by sparsely skeletal mudstones, in part with horizontal burrows; small brachiopods (including *Independatrypa*) are present. Some finely skeletal wackestone to packstone is present near the base. The interval is cherty to very cherty, in part with interconnected networks of white smooth to chalky chert nodules (Fig. 17). Identical cherty mudstone facies are observed in the Coralville Lake area below Mehaffey Bridge, where sparsely skeletal cherty limestone strata overstep the State Quarry channel margins (Witzke and Bunker, 1994).

Figure 17. Brachiopod-rich limestone slab from middle State Quarry Member, Klein Quarry. All specimens are Independatrypa scutiformis. Slab diameter is 1 foot.

UPPER DEVONIAN – LIME CREEK FORMATION

The highest Devonian stratigraphic unit seen at the Conklin and Klein quarries belongs to the Upper Devonian (upper Frasnian) Lime Creek Formation, where erosional remnants are locally seen overlying the Iowa City Member of the Coralville Formation. Additional exposures of the Lime Creek strata above the Coralville Formation have also been noted on the campus of the University of Iowa as well as west of Coralville Lake near North Liberty (Witzke and Bunker, 1994). In addition, Lime Creek stratigraphic leaks are known to infill paleokarst systems into underlying Devonian and Silurian stratigraphic units in eastern Iowa, suggesting that a significant period of erosion and karstification preceded Lime Creek deposition (Witzke and Bunker, 2006b). The Lime Creek Formation unconformably overlies the Cedar Valley Group at most localities.

Only the basal 3 to 8 feet (1-2 m) of the Lime Creek Formation is locally seen at the Conklin and Klein quarries. The Lime Creek strata there are dominated by green-gray silty shale with no apparent fossils or burrows (but these strata contain conodonts of the formation). The basal 2 to 5 inches (10 cm) that directly overlies the Coralville surface is an argillaceous siltstone, commonly pyritic. This basal

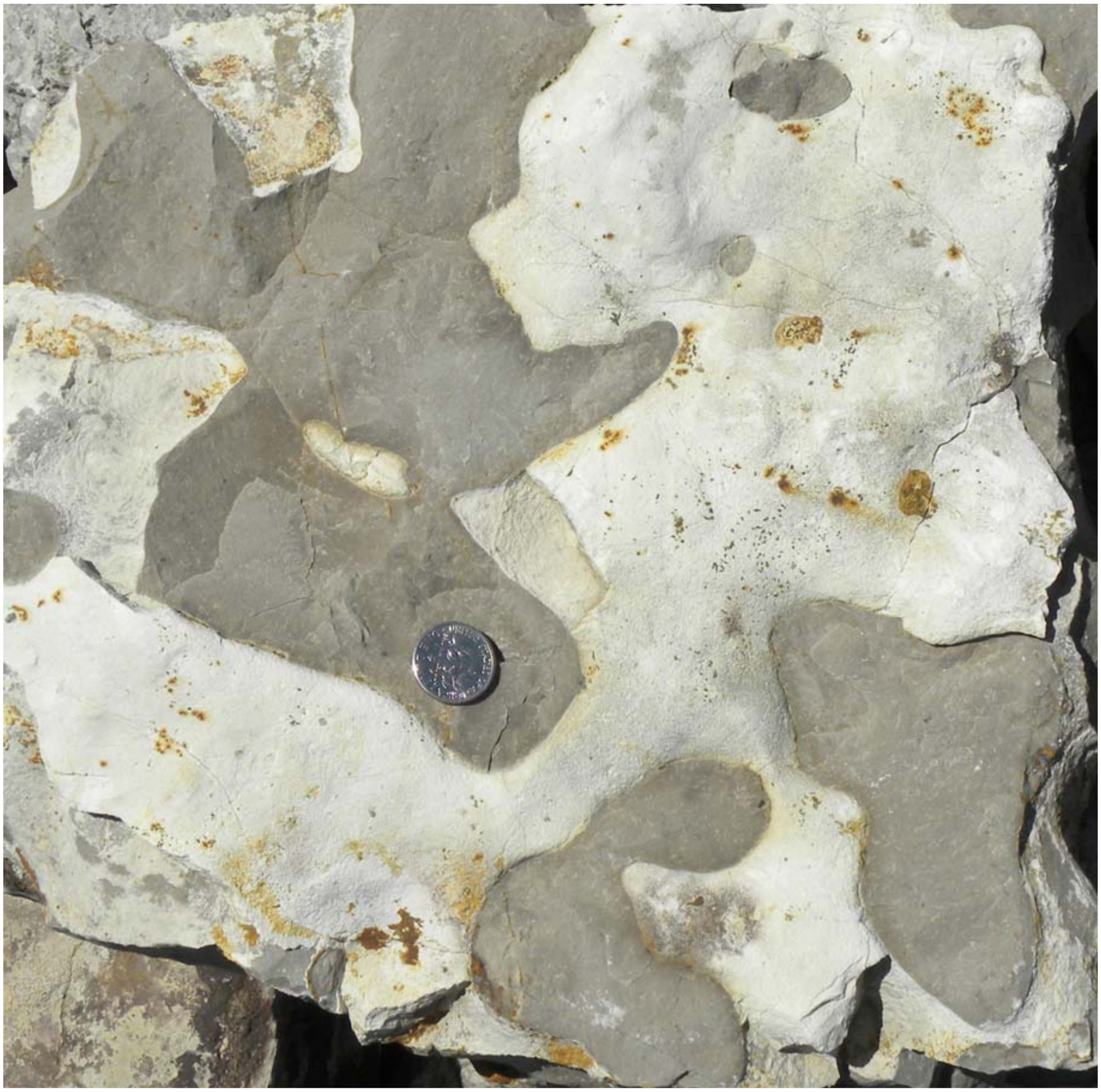


Figure 18. Network of white chert nodules from bedding surface in upper State Quarry mudstone (unit 56). Quarter for scale.

siltstone contains horizontal burrows, and small linguloids brachiopods are present. Lime Creek exposures at Klein Quarry were evident during quarrying activities along the south wall during the early 2000s, but these exposures are now quarried away (and were also erosionally truncated southward by the prominent sub-Pennsylvanian channel incision). Exposures at the Conklin Quarry are still evident in the northwest quarry area beneath the Pleistocene cover. In both quarries the Lime Creek shales show localized deformation that was formed by loading and ice movements when Pleistocene glaciers flowed over the plastic shales. Folds, detachments, and flow structures (intercalated with the basal Pleistocene till) are seen, and the basal till locally contains large clasts and masses of Lime Creek shale.

Younger post-Lime Creek Devonian shale and siltstone strata (Famennian formations) occur southward from Iowa City in the subsurface of Johnson County, and these strata are exposed near Kalona just south of the Johnson County line. However, these younger Devonian units are not exposed in the Iowa City area.

REFERENCES

Anderson, R.R., 2006, Geologic structures at the Lake Macbride spillway and in the area of Lake Macbride State Park, Iowa: Geological Society of Iowa, Guidebook 79, p. 31-36.

Authors unknown, 1960, Field trip to the River Products Company Quarry: Geological Society of Iowa, Guidebook 3, 3 p.

Bils, J. 1983, Morphometric trends in tabulate corals, Coralville Member, Cedar Valley Limestone (Devonian), Johnson County, Iowa: unpublished M.S. thesis, University of Iowa, 67 p.

Bunker, B.J., and Witzke, B.J., 1992, Stop 4, Conklin Quarry, *in* Day, J.E., and Bunker, B.J., eds., The stratigraphy, paleontology, depositional and diagenetic history of the Middle-Upper Devonian Cedar Valley Group of central and eastern Iowa: Iowa Department of Natural Resources, Geological Survey, Guidebook Series no. 16, p. 189-195.

Calhoun, S.H., 1983, Echinoderms of the Devonian Cedar Valley Limestone in Iowa: unpublished M.S. thesis, University of Iowa, 153 p.

Calvin, S., 1897, Geology of Johnson County: Iowa Geological Survey Annual Report, v. 7, p. 33-104.

Day, J.E., 1992, Middle-Devonian (late Givetian-early Frasnian) brachiopod sequence in the Cedar Valley Group of central and eastern Iowa: Iowa Department of Natural Resources, Geological Survey, Guidebook Series no. 16, p. 53-105.

Day, J.E., 2006, Overview of the Middle-Upper Devonian sea level history of the Wapsipinicon and Cedar Valley groups, with discussion of new conodonts data from the subsurface Cedar Valley Group of southeastern Iowa, *in* Day, J., Luczaj, and Anderson, R., eds., New perspectives and advances in the understanding of Lower and Middle Paleozoic epeiric carbonate depositional systems of the Iowa and Illinois basins: Iowa Geological Survey, Guidebook Series no. 25, p. 3-21.

Gilotti, J.A., and Wood, C., 1999, Some observations of structures at the Macbride spillway outcrop, *in* Anderson, R.R., eds., Pleistocene and Paleozoic Rocks of East-Central Iowa: 62nd Annual Tri-State Geological Field Conference Guidebook, University of Iowa, Department of Geoscience, p. 67-69.

Heckel, P.H., Kettenbrink, E.D., and Klapper, G., 1975, Trip #1, Devonian Limestone Facies: Cedar Valley and State Quarry limestones in the Iowa City region: Guidebook for the 39th Annual Tri-State Geological Field Conference, University of Iowa, Department of Geology, p. 1-19.

Hickerson, W.J., 1992, Tirlobites from the Little Cedar Formation of eastern Iowa and northwestern Illinois: unpublished M.S. thesis, University of Iowa, 166 p.

Jannusch, D.E., 2008, Systematics and paleoecology of Devonian stromatoporoids from Cou Falls, Iowa City, and Osage Springs members, east-central Iowa: unpublished Ph.D. thesis, University of Iowa, 265 p.

Kettinbrink, E.C., 1973, Depositional and post-depositional history of the Devonian Cedar Valley Formation, east-central Iowa: unpublished Ph.D. dissertation, University of Iowa, 191 p.

Kettinbrink, E.C., and Toomey, D.F., 1975, Distribution and paleoecological implications of calcareous foraminifera in the Devonian Cedar Valley Formation of Iowa: Journal of Foraminiferal Research, v. 5, p. 176-187.

Keyes, C.R., 1912, Sundry provincial and local phases of the general geologic section of Iowa: Proceedings of the Iowa Academy of Science, v. 19, p. 147-151.

Klapper, G., and Ziegler, W., 1967, Evolutionary development of the *Icriodus latericrescens* group (Conodonta) in the Devonian of Europe and North America: Palaeontographica Abt. A, v. 127 (1-2), p. 68-83.

Klug, C.R., 1990, Miospores and conodonts of the Cedar Valley Group (Middle to Upper Devonian) of Iowa: unpublished Ph.D. thesis, Univeristy of Iowa, 280 p.

Klug, C.R., 1992, Distribution and biostratigraphic significance of miospores in the Middle-Upper Devonian Cedar Valley Group of Iowa: Iowa Department of Natural Resources, Geological Survey, Guidebook Series no. 16, p. 111-121.

Michael, R.D., and Welp, T.L., 1957, The Devonian section at the Klein Quarry, Johnson County, Iowa: Proceedings of the Iowa Academy of Science, v. 64, p. 443-447.

Mitchell, J.C., 1977, Biostromes and bioherms of the Solon Member of the Cedar Valley Limestone, Middle Devonian, eastern Iowa: unpublished M.S. thesis, University of Iowa, 179 p.

Narkiewicz, K., and Bultynck, P., 2010, The upper Givetian (Middle Devonian) *subterminus* conodont zone in North America, Europe, and North Africa: Journal of Paleontology, v. 84, p. 588-625.

Plocher, O.W., Bunker, B.J., and Witzke, B.J., 1989, Stop 4, Mid-River Marina Quarry, *in* Plocher, O.W., ed., Geologic Reconnaissance of the Coralville Lake Area: Geological Society of Iowa, Guidebook 51, p. 113-118.

Rogers, F.S., 1990, Stratigraphy, depositional history, and conodonts of the Little Cedar and lower Coralville formations of the Cedar Valley Group (Middle Devonian) of Iowa: unpublished Ph.D. thesis, University of Iowa, 97 p.

Rogers, F.S., 1998, Conodont biostratigraphy of the Little Cedar and lower Coralville formations of the Cedar Valley Group (Middle Devonian) of Iowa and significance of a new species of *Polygnathus*: Journal of Paleontology, v. 72, p. 726-737.

Sammis, N.C., 1978, Petrology of the Devonian Wapsipinicon Formation from a core and reference exposures, central-eastern Iowa: unpublished M.S. thesis, University of Iowa, 232 p.

Shapo, D.E., 2003, Systematics and morphometric analysis of stromatoporoids from the Little Cedar Formation, Middle Devonian, east-central Iowa: unpublished M.S. thesis, University of Iowa, 92 p.

Stainbrook, M.A., 1941, Biotic analysis of Owen's Cedar Valley Limestone: Pan-American Geologist, v. 75, p. 321-327.

Strimple, H.L., 1970, Echinoderm zonules in the Devonian of Iowa: Proceedings of the Iowa Academy of Science, v. 77, p. 249-256.

Thomas, A.O., 1924, Echinoderms of the Iowa Devonian: Iowa Geological Survey Annual Report, v. 29, p. 385-550.

Trier, S.M., 1993, Trends in growth form of stromatoporoids and corals, Coralville Formation (Devonian), Iowa: unpublished M.S. thesis, University of Iowa, 123 p.

Witzke, B.J., and Bunker, B.J., 1984, The underburden: The Devonian stratigraphic sequence at Conklin Quarry, *in* Bunker, B.J., and Hallberg, G.R., eds., Underburden-Overburden: An examination of Paleozoic and Quaternary strata at the Conklin Quarry near Iowa City: Geological Society of Iowa, Guidebook 41, p. 2-10.

Witzke, B.J., and Bunker, 1997, Sedimentation and stratigraphic architecture of a Middle Devonian (late Givetian)) transgressive-regressive carbonate-evaporite cycle, Coralville Formation, Iowa area, *in* Klapper, G., Murphy, M.A., and Talent, J.A., eds., Paleozoic Sequence Stratigraphy, Biostratigraphy, and Biogeography: Studies in Honor of J. Granville ("Jess") Johnson: Geological Society of America, Special Paper 321, p. 67-88.

Witzke, B.J., and Bunker, 2006a, Stratigraphy of the Wapsipinicon Group (Middle Devonian) in southeastern Iowa: *in* Day, J., Luczaj, and Anderson, R., eds., New perspectives and advances in the understanding of Lower and Middle Paleozoic epeiric carbonate depositional systems of the Iowa and Illinois basins: Iowa Geological Survey, Guidebook Series no. 25, p. 47-58.

Witzke, B.J., and Bunker, 2006a, Middle shelf facies of the Cedar Valley Group (Devonian) and their stratigraphic relationships in eastern Iowa, *in* Day, J., Luczaj, and Anderson, R., eds., New perspectives and advances in the understanding of Lower and Middle Paleozoic epeiric carbonate depositional systems of the Iowa and Illinois basins: Iowa Geological Survey, Guidebook Series no. 25, p.23-46.

Witzke, B.J., Bunker, B.J., and Glenister, B.F., 1999, Bedrock geology at the River Products Co., Conklin Quarry, Coralville, Iowa, *in* Anderson, R.R., eds., Pleistocene and Paleozoic Rocks of East-Central Iowa: 62nd Annual Tri-State Geological Field Conference Guidebook, University of Iowa, Department of Geoscience, p. 23-38.

Witzke, B.J., Bunker, B.J., and Rogers, F.S., 1988, Eifelian through lower Frasnian stratigraphy and deposition in the Iowa area, Midcontinent, U.S.A., *in* McMillan, N.J., Embry, A.F., and Glass, D.J., eds., Devonian of the World: Canadian Society of Petroleum Geologists, 2nd International Symposium on the Devonian System, v. 1, p. 221-250.

Zawistowski, S.J., 1971, Biostromes in the Rapid Member of the Cedar Valley Limestone (Devonian) in east-central Iowa: unpublished M.S. thesis, University of Iowa, 120 p.

KLEIN QUARRY COMPOSITE SECTION OF THE CEDAR VALLEY GROUP

NW sec. 2, T79N, R7W, Johnson Co., Iowa (supplemented with core sections in secs. 1 and 2, T79N, R7W).
Brian J. Witzke; measured Sept. 2010

Solon Member descriptions based on measured section along south-central wall of main pit below second bench, B.J. Witzke and B.J. Bunker (July 2010) and upper Solon section in north quarry by B.J. Witzke and F.S. Rogers (May 1989); Rapid Member description based largely on measured sections along the north side of the main pit and old quarry face in northwest quarry area by B.J. Witzke and F.S. Rogers (May 1989); upper Rapid Member descriptions supplemented with sections in southwest quarry area (B.J. Witzke; June-July 2010); Coralville Formation descriptions based on measured section along old quarry face, northwest quarry area by B.J. Witzke and F.S. Rogers (May 1989); Coralville descriptions supplemented with measured sections in southwest quarry area by B.J. Witzke (July 2010); State Quarry Member described along upper bench in south-central quarry area by B.J. Witzke, B.J. Bunker, and A. Reyes (October 2006); lithologic variations of individual units based on comparisons of quarry sections and numerous core sections in the area drilled by River Products Company (2004-2006; see Fig. 1 for core locations).

Abbreviations used in descriptions: Ls. – limestone; sh. -- shale; mudst. – lime mudstone; wk. – skeletal wackestone; pk. – skeletal packstone; m.-w. – mixed skeletal mudstone to wackestone; w.-p. –mixed skeletal wackestone to packstone; arg. – argillaceous; v. – very; f. – fine; m. – medium; c. – coarse; sm. – small; sc. – scattered; horiz. – horizontal; vert. – vertical; abnt. – abundant; sc. – scattered; cm. – common; indet. – indeterminate; skel. – skeletal; dk. – dark; sl. – slightly; cm – centimeters; mm – millimeters; m -- meters

MIDDLE DEVONIAN
CEDAR VALLEY GROUP; LITHOGRAPH CITY FORMATION
STATE QUARRY MEMBER

(Units 51-56 fill a channel incised through Coralville units 43 through 50; base of unit 51 overlies middle part of unit 42; units 53-55 overstep units 51-52 along channel margin)

UNIT 56. Ls., dominantly sparse skeletal mudstone, includes v.f. to f. w.-p. in basal part (indet. skel. debris); mudstone beds break with conchoidal fracture; scattered to abundant white chert nodules and networks of nodular chert, smooth to chalky; chert content generally increases upward in interval; in beds 5 to 15 cm; sc.sm. brachiopods (including *Independatrypa*), sc. horiz. burrows (some v. long); unit oversteps State Quarry channel margin to east where it overlies units 49 and 50; unit is truncated beneath sub-Pleistocene and sub-Pennsylvanian erosional surfaces; maximum thickness 1.5 m.

UNIT 55. Ls., w-p, arg. lower half; shaly partings in basal 23 cm; prominent shale partings at base and 6 cm above; lower half is a whole-shell brachiopod w-p (abnt. large *Independatrypa*, sc. *Strophodonta*); upper half sc. to cm. brachiopods in a matrix of f.-c. pk., indet. fine skel. grains, crinoid debris.; 55-60 cm thick.

UNIT 54. Ls., skel.-intraclastic pk., abundant small intraclasts (< 1 cm); becomes intraclastic-peloidal pk. to grainstone in upper part; scattered stylolites; fossils include small brachiopods (including *Independatrypa*), crinoid debris, bryozoans, rare gastropods lower part; 1.1 m thick.

UNIT 53. Ls., w-p, arg. to shaley, numerous shaley partings; cm. to abnt. whole-shell brachiopods primarily *Independatrypa* (to 3 cm) but also including scattered *Athyris* and *Strophodonta*; rare gastropod noted; 25 cm thick.

UNIT 52. Ls., skel. to skel.-intraclastic pk.; scattered stylolites, prominent stylolite at top; lower part includes sm. ls. intraclasts or lithoclasts (< 5 cm) and scattered reworked clasts of branching stromatoporoids (*Idiostroma*); upper part includes intraclastic-peloidal pk.; sc. whole-shell brachiopods; part crinoidal; 95 cm thick.

UNIT 51. Ls., f.-c. skel. pk. to skel-lithoclastic pk., scattered stylolites; basal 41 cm is crinoidal pk., weakly graded f. to c. upward, ls. lithoclasts at base to 15 cm, reworked massive stromatoporoids and favositid corals to 20 cm, small corals and stromatoporoids upward; upper 85 cm includes reworked favositid corals and stromatoporoids (branching to massive) throughout, ls. lithoclasts to 5 cm, part very crinoidal, sc. brachiopods, sc. fish bone near base; 1.25 m thick.

CORALVILLE FORMATION
IOWA CITY MEMBER

UNIT 50. Ls., "sublithographic," mudst. to pelmicrite, sc. sm. intraclasts in some beds; common fractures, common voids and calcite-filled fractures and voids, some with green-gray shaley fills; part with common internal sediment fills (ls.); 40 cm above base is thin interval with irregular faint laminations and small intraclasts; fenestral fabrics ("birdseye") noted in upper part; highly variable in thickness due to sub-Pleistocene, sub-Pennsylvanian, and sub-State Quarry erosion, maximum thickness about 2.0 m.

UNIT 49. Ls., part "sublithographic," mudst. to pelmicrite, sc. stylolites; part fractured, part with internal sediment fills; locally intraclastic; sc. voids, part calcite-filled; cm. to abnt. fenestral fabrics ("birdseye"); upper 30 cm locally biostromal (southeast quarry area) with small branching stromatoporoids (*Amphipora*) and small massive to irregular stromatoporoids; 70-80 cm thick.

UNIT 48. Ls., w-p, cm. to abnt. sm. branching stromatoporoids (*Amphipora*, locally *Idiostroma*), biostromal; indet. f. skel. grains in matrix, matrix in part a f. pk.; rare to sc. sm. brachiopods (*Athyris*); includes sm. massive to irregular stromatoporoids where interval is thickest; variable thickness 15-70 cm (probably shares lateral facies relations with upper unit 47, lower unit 49).

UNIT 47. Ls., "sublithographic," dense mudst., possibly a pelmicrite; cm. stylolites; part fractured; locally flaggy bedded in lower part; upper part may share lateral relations with *Amphipora*-bearing ls. in lower unit 48; unit probably thins eastward in quarry, maximum thickness about 53 cm.

UNIT 46. Ls., "sublithographic," mudst. to intraclastic mudst., probably a pelmicrite in part; basal 12 cm locally finely laminated; locally cm. stylolites; sc. to cm. fractures and internal sediment fills; upper part locally intraclastic to brecciated, intraclasts sm. (1-10 mm); upper part locally with fenestral fabrics ("birdseye"); overlies irregular surface at base locally with up to 10 cm relief; unit probably thins eastward in quarry, maximum thickness 60 cm.

COU FALLS MEMBER

UNIT 45. Ls., w.-p., sc. to abnt. sm. branching stromatoporoids (*Idiostroma*), unit includes biostromal beds eastward in quarry area with pk. accumulations of branching to massive stromatoporoids in f. skel. w.-p. to m-w matrix; sc. to cm. stylolites; locally fractured to vuggy, some calcite spar fills; top may be irregular exposure surface; unit averages 45 cm thick (40-50 cm).

UNIT 44. Ls., pk., wk. upwards, matrix of f. skel. pk., biostromal, abundant stromatoporoids include branching (*Idiostroma*) and massive to irregular forms (to 12 cm), sc. sm. ramose favositids (mostly in lower part); locally with abundant massive stromatoporoids (to 20 cm); stromatoporoid-coral content decreases upwards; sc. stylolites; faint arg. streaks locally noted, shaley parting locally at base; unit probably with some variation in thickness, average 45 cm thick.

UNIT 43. Ls., dominantly a stromatoporoid-rich biostrome, abundant branching forms (*Idiostroma*), locally with massive to irregular stromatoporoids (to 15 cm), locally with sc. to abnt. sm. ramose favositids; matrix dominantly f. w-p, rare crinoid debris and brachiopod noted; faint arg. streaks in lower part; laterally the unit includes (core 11) non-biostromal limestone to 60 cm thick, dense, f.-m. pk., includes crinoid debris and indet. brachiopods, rare to sc. branching stromatoporoids and favositids, stylolites; unit probably varies slightly in thickness, average 75 cm thick.

UNIT 42. Ls., biostromal pk. with large corals and massive stromatoporoids, matrix f. skel. pk.; sc. stylolites; lower bed with large *Hexagonaria* (to 45 cm), massive favositids (to 30 cm), sc. to cm. solitary rugose corals, massive stromatoporoids (to 20 cm), shaley parting locally at top; upper bed with abnt. massive hemispherical to irregularly-shaped stromatoporoids (to 10 cm), ramose to massive favositids (to 15 cm), sc. solitary rugose corals, locally includes sc. branching stromatoporoids (*Idiostroma*); upper unit locally with (core 11) cm. to abnt. *Idiostroma*; lower bed locally with crinoid debris, rostroconchs; base locally with dk. shale parting; upper bed replaced laterally by non-biostromal limestone, upper unit 41 (where thickest) and lower unit 42 are probably lateral equivalents; maximum thickness unit 42 approximately 1.2 m.

UNIT 41. Ls., dense, part sl. arg. to arg., f. pk., part f.-c. pk., non-biostromal; includes dk. arg. streaks, locally black, stylolites; coarser grains include crinoid debris, upper part locally very crinoidal, sc. brachiopods; may be part burrowed; upper part locally includes sc. favositid corals; 95-107 cm thick; thicker to east (1.6-1.65 m) where the unit shares lateral facies relations with unit 42.

UNIT 40. Ls., f. pk. matrix, part biostromal, sc. to cm. branching stromatoporoids (*Idiostroma*), cm. massive to encrusting stromatoporoids; sc. to cm. massive to ramose favositid corals especially upward; sc. solitary corals; locally common *Hexagonaria* (to 60 cm); basal part locally non-biostromal f.-m. pk. part arg., dk. wispy arg. streaks; sc. to cm. crinoid debris, sc. to cm. brachiopods (especially *Athyris*), rostroconchs; basal surface locally irregular with subrounded ls. clasts (to 2 cm); 65-108 cm thick.

UNIT 39. Ls., f. and f.-c. pk., mostly non-biostromal but locally includes biostromal units (cm. *Hexagonaria*, ramose to massive favositids, massive to encrusting stromatoporoids, solitary corals); may be part burrowed; stylolites; arg., v. arg. basal interval commonly with dk. to black arg. streaks; includes c. crinoid debris; sc. to cm. brachiopods (atrypids, *Athyris*, *Pentamerella*, *Cranaena*, others); rostroconchs; burrowed discontinuity surfaces locally present at base and top; 37-58 cm thick.

UNIT 38. Ls., f. and f.-c. pk. matrix, part. arg., part biostromal with cm. *Hexagonaria* (to 40 cm), sc. massive to ramose favositids, massive to irregular stromatoporoids, sc. solitary corals; cm. brachiopods (atrypids, *Cranaena*, *Pentamerella*, *Pholidostrophia*, others); crinoid debris (f.-c.), rostropconchs, trilobites; prominent burrowed discontinuity surface at base (penetrates up to 10 cm into unit 37) filled with f. pk; f.-c. pk locally present at base with cm. to abnt. *Devonatrypa*, sc. *Strophodonta, Orthospirifer*, others, shells part encrusted with bryozoans and spirorbids, shells part bored; basal unit locally with dk. phosphatic grains (1-3 mm), ls. clasts (2-5 cm); 63-92 cm thick.

LITTLE CEDAR FORMATION
RAPID MEMBER

"*Devonatrypa waterlooensis* beds"

UNIT 37. Ls., arg., may be sl. dolomitc (weathers red-brown), wk. and w.-p., part includes thin skel. stringers and burrowed m.-w.; swirls and irregular burrow mottles of f.-m. w.-p. and f. pk. in wk.; cm. to abnt. crinoid debris (f.-c.), local crinoid cups (*Melocrinites*); sc.-cm. trepostomes bryozoans (to 4 cm), sc. cystodictyonid bryozoans; sc. to cm. pachyporid corals; sc. to cm. brachiopods (*Devonatrypa*, *Strophodonta*, *Tylothyris*, *Orthospirifer*, others); sc. phosphatic grains noted in upper part and at base; top surface is irregular burrowed hardground discontinuity surface with up to 10 cm of relief (infilled with unit 38 lithologies); additional dk. discontinuity surface locally noted 20 cm below top; base marked at prominent burrowed discontinuity surface with up to 6 cm relief; 81-102 cm thick, average about 93 cm.

UNIT 36. Ls., sl. arg., wk. to m.-w., with thin stringers and burrowed swirls of f.-m. pk; part may be sl. dolomitic; cm. subhorizontal to subvertical burrows; vertical burrows penetrate from upper discontinuity surface; glauconitic in part; dk. phosphatic grains (<1 mm) sc. in middle and basal parts; locally includes sparse to nonskeletal burrowed arg. mudst. near middle; rare sc. chert nodules near base; cm. crinoid debris (some c.), sc. brachiopods (*Devonatrypa, ?Pseudoatrypa, Tylothyris*, others); sc. trepostomes bryozoans, rare fenestellid bryozoans; 44-95 cm thick, averages 70 cm.

UNIT 35. Ls., sl. arg., part sl. dolomitic, dominantly w.-p., v. crinoidal; includes w.-p. and pk. stringers and burrowed swirls in wk. to m.-w.; includes m.-w. and sparse arg. mudst. especially in middle part; prominent burrow networks, horizontal to subvertical, small to large, variably filled with mudst. to pk.; unit is glauconitic in part; cm. nodules and nodular bands of chert through unit, white to light brown, smooth to chalky, cherts show replacive mudst. to crinoidal pk. fabrics; crinoid debris abnt. (f.-c.), articulated crinoids noted (especially *Melocrinites nodosus*); sc. brachiopods (*Devonatrypa*); sc. bryozoans; 79-117 cm thick.

UNIT 34. Ls., sl. arg. to arg., part sl. dolomitic (especially upper part), mixed wk. and m.-w. with cm. stringers and burrowed swirls of w.-p. and pk.; more pk. in upper part; some skeletal grains are silicified; v. arg. m.-w. locally in lower part; sc. dk. phosphatic grains, pt. may be sl. glauconitic; arg. to shaley parting at base; base locally developed as irregular burrowed discontinuity surface; cm. crinoid debris (f.-c.); sc. brachiopods (*Devonatrypa, Orthospirifer, Strophodonta, Tylothyris, Schizophoria*); sc. to cm. trepostome bryozoans especially in upper part; 85-91 cm thick.

UNIT 33. Ls., sl. arg. to arg., part sl. dolomitic, wk. and m.-w. with stringers and burrowed swirls of w.-p. to pk.; more arg. downward; burrowed discontinuity at top; sc. to abnt. crinoid debris, some stringers with articulated stems; bryozoans locally sc. to abnt., includes local masses of sheet-like trepostomes, large branching trepostomes, fenestellids (locally abnt. in upper part); sc. to cm. branching pachyporid corals, especially in upper part; sc. brachiopods (*Devonatrypa, Strophodonta, Orthospirifer, Cupularostrum*, others); corals locally sc. at base, especially where unit overlies areas where unit 32 is thinner, includes sm. *Hexagonaria*, favositids, solitary corals; unit shares complementary thickness relations with unit 32; 76-110 cm thick.

Rapid biostromes interval

UNIT 32. Ls., biostromal, arg. to v. arg. matrix, shaley in part, matrix dominantly wk., matrix volume decreases upward; corals increase in size and abundance upward in unit; matrix includes cm. m.-c. crinoid debris (some stems), sc.-cm. brachiopods (*Devonatrypa, Strophodonta*), sc. bryozoans; cm. sm. to large massive to irregular favositid corals, sc. alveolitid corals, sc. to cm. solitary corals (especially lower), mostly cystiphyllids; cm. to abnt. *Hexagonaria* corals, packed in upper part, largest specimens upward (to 60 cm); rare stromatoporoids, massive to encrusting forms; upper surface of unit locally irregular due to variations in vertical dimensions and size of *Hexagonaria* colonies; biostrome locally varies laterally in thickness and abundance of corals across quarry area, 10-90 cm; unit is generally 40-50 cm thick.

UNIT 31. Ls., arg., variably sparse skel. mudst. to wk. and pk., includes thin skel. stringers and burrowed swirls of w.-p. and pk.; dominantly a sparse skel. burrowed mudst. in lower to middle part; sc. dk. phosphatic grains in upper part; base shaley; sc.-cm. f.-c. crinoid debris; sc. brachiopods (*Devonatrypa, Pseudoatrypa, Orthospirifer*, others); sc. to abnt. bryozoans, local masses and dense accumulations of sheet-like and large branching trepostomes in upper part, sc. to cm. fenestellids, sc. cystodictyonids; sc. pachyporid corals in upper part; sc. solitary corals especially near top; sc. tentaculites; 56-72 cm thick.

UNIT 30. Ls., arg., dominantly wk. and w.-p., locally includes sparse skel. m.-w. in lower and upper parts; part burrowed swirls of w.-p.; cm. arg. to shaley streaks; sc. to abnt. f.-c. crinoid debris; sc. brachiopods (atrypids, *Schizophoria*, others); sc. to cm. bryozoans include large trepostomes; sc. to cm. pachyporid corals; thickness complementary with unit 29; 40-76 cm thick.

UNIT 29. Ls., arg., biostromal, matrix wk. with pk stringers; arg. increase downward, sc. dk. arg. streaks; lower part with sc. dk. phosphatic grains (up to 3-7 mm), increase in abundance and size at base; skel. stringers and matrix with sc. brachiopods, sc. m.-c. crinoid grains, bryozoans (fenestellids, cystodictyonids); sc. to abunt. corals include solitary rugosans (mostly cystiphyllids), *Hexgonaria* (10-40 cm), massive favositids, rare pachyporids; sc. to cm. massive to lamellar stromatoporoids; unit is locally thinned with rare corals (mostly solitary rugosans); generally 30-40 cm thick.

"Z-beds"

UNIT 28. Ls., arg., mostly burrowed m.-w., with lenses and burrowed swirls of w.-p. to pk.; increasing m.-w. in lower part; most fossiliferous in upper part; sc. dk. phosphatic grains in middle to upper part, locally concentrated in vertical burrows; dk. hardground discontinuity locally noted near top; cm. brachiopods (*Pseudoatrypa*, *Athyris*, *Orthospirifer*, *Eosyringothyris*, *Cyrtina*, *Strophodonta*, *Schizophoria*, chonetids, others); sc. crinoid debris, rare bryozoans; rare auloporid corals; 70-110 cm thick.

UNIT 27. Ls., arg. to v. arg., dominantly nonskeletal mudst., sc. to cm. sm. horizontal burrows; includes zones with thin wk. and w.-p. stringers/lenses and burrowed swirls especially in lower to middle part; skel. zones laterally discontinuous; cm. sm. pyrite inclusions; sc. sm. phosphatic grains in lower to middle part; skel. stringers include brachiopods (*Orthospirifer*, *Cyrtina*, *Strophodonta*, others), sc. to cm. crinoid debris, sc. fenestellid bryozoans; 1.1-1.3 m thick.

UNIT 26. Ls., arg. to v. arg., dominantly nonskeletal mudst., sc. to cm. sm. horizontal burrows; includes zones with stringers and burrowed swirls of skel. w.-p. and pk. especially in lower part, but skel. zones are laterally discontinuous; cm. sm. pyrite inclusions; sc. dk. phosphatic grains; skel. stringers include brachiopods (*Pseudoatrypa*, *Orthospirifer*, *Strophodonta*, chonetids, others), sc. to cm. crinoid debris, articulated crinoids noted (melocrinitid, *Megistocrinus*, *Eurycrinus*); sc. bryozoans (fenestellids, trepostomes); average thickness about 55 cm, varies laterally.

UNIT 25. Ls., arg. to v. arg., part shaley, dominantly nonskeletal to sparse skel. mudst.; sm. horizontal burrows, locally with subvertical burrows; part includes stringers/lenses and burrowed swirls of w.-p. and pk, skel. abundance varies laterally, wk. to w.-p. abundance locally subequal with mudst.; sc. sm. dk. phosphatic grains at base; sc. crinoid debris, articulated crinoids noted (melocrinitid, *Megistocrinus*); sc. brachiopods (*Schizophoria*, others), sc. bryozoans (fenestellids, cystodictyonids, trepostomes); locally with sc. corals (solitary coral, pachyporid); average thickness about 55 cm, varies laterally (probably sl. thins to east).

UNIT 24. Ls., arg. to v. arg., dominantly a nonskeletal to sparse skel. mudst., sm. horizontal burrows, sc. vertical burrows; may be horiz. laminated in part; includes sc. stringers and lenses of skel. wk.. to w.-p. especially in lower part; sc. brachiopods (*Cyrtina*, others); sc. bryozoans (fenestellids, cystodictyonids); sc. crinoid debris; 60 cm thick where measured to north, unit thins (<50 cm) eastward in quarry area (where it is locally difficult to distinguish from unit 23).

UNIT 23. Ls., arg. to v. arg., mixed sparse to nonskeletal mudst. (horizontal burrows) and skel. wk., with cm. thin lenses and stringers (part burrowed) of skel. pk. every 0.5 to 3 cm; upper part locally dominated by thickened interval of wk. and w.-p., part with subvertical mudst.-filled burrows; sc. to cm. crinoid debris; sc. to cm. brachiopods (*Pseudoatrypa*, *Spinatrypa*, *Strophodonta*, *Orthospirifer*, others); sc.-cm. bryozoans (especially fenestellids); locally includes sc. corals near top (sm. favositids, solitary coral, *Hexagonaria*); 94 cm thick where measured to north, unit thins (<50 cm) eastward in quarry area (where it is locally difficult to distinguish from unit 24).

"*Spinatrypa bellula* beds"

UNIT 22. Ls., arg.; v. arg. to shaley sparse skel. mudst. in lower part, burrowed (noted at most but not all sections, 10-35 cm thick), sc. sm. dk. phosphatic grains near base; upper beds are dominantly arg. wk. and w.-p. with m.-w. and mudst., part swirled by burrow mottling, part with c. crinoidal to mixed skel. stringers, arg. streaks and partings; vertical burrows locally seen penetrating from top surface; sc. to cm. crinoid debris, articulated crinoid cups noted (*Megistocrinus*); sc. brachiopods

(*Spinatrypa, Pseudoatrypa, Schizophoria*, others); sc. to cm. bryozoans (fenestellids, cystodictyonids), trilobite fragments, fenestellids locally abundant in upper part; 75-105 cm thick.

UNIT 21. Ls., arg., w.-p., included burrow swirled wk. and m.-w. upward; sc. to cm. f. to v.c. crinoid debris, some articulated; sc. to cm. brachiopods (especially *Schizophoria*, includes *Spinatrypa, Pseudoatrypa*, others); sc. to cm. fenestellid bryozoans (locally abnt. upward), sc. to cm. cystodictyonid bryozoans, sc. corals upward (sm. favositids, pachyporids, solitary coral, *Hexagonaria*); unit shows considerable lateral variation in thickness, 82-178 cm thick, average about 1.35 m.

UNIT 20. Ls., v. arg. to shaley, dominantly sparse mudst. with dk. arg. laminations and horizontal burrows; minor burrowed swirls and stringers of skel. wk. and w.-p.; common fenestellid bryozoans, sc. cystodictyonid bryozoans; sc. f.-c. crinoid debris, rare articulated crinoids; sc. brachiopods (*Spinatrypa, Schizophoria, Orthospirifer*, chonetids, others); 30-40 cm thick.

UNIT 19. Ls., arg., wk. and w.-p., part swirled by subhorizontal to subvertical burrows especially in upper part; locally includes burrowed m.-w. in upper part; base with arg. to shaley partings, arg. shaley parting locally in middle part; sc. to cm. f.-c. crinoid debris; sc. to cm. brachiopods, some whole-shell stringers (cm. *Spinatrypa, Schizophoria*); sc. to cm. fenestellid bryozoans, especially in shaley zones and upper part; 58-64 cm thick.

UNIT 18. Ls., arg., w.-p., part with stringers and burrowed swirls of pk. and w.-p.; sc. arg. to shaley partings through, wispy arg. stylolites; shaley to thin shale at base; sc. to cm f.-v.c. crinoid debris; cm. brachiopods (*Spinatrypa, Pseudoatrypa, Cyrtina, Strophodonta, Schizophoria*, others); sc. bryozoans (cystodictyonids, fenestellids); tentaculites noted; sc. solitary corals in middle to upper parts; 64-76 cm thick.

UNIT 17. Ls., arg., wk. and w.-p.; f. pk. locally in middle part with light burrowed mudst. fills; locally includes burrowed m.-w. with pk. in upper part; basal shaley zone (to 11 cm thick), part with abnt. fenestellid bryozoans, sc. brachiopods (*Strophodonta*), crinoid debris, rare articulated crinoids (melocrinitid); upper w.-p. includes abnt. crinoid debris in part, sc. brachiopods (*Spinatrypa, Schizophoria, Strophodonta*, others), sc. bryozoans, rare corals in middle to upper part (solitary rugosans, sm. favositids, *Hexagonaria*); 64-78 cm thick.

UNIT 16. Ls., arg., wk. to w.-p., pk. increase upper part; basal zone with arg. to shaley streaks and partings; crinoid debris (abnt. in upper part), articulated crinoid cup noted in lower part; sc. to cm. brachiopods (*Spinatrypa, Pseudoatrypa, Orthospirifer, Schizophoria*, others), sc. bryozoans, fenestellids locally cm. in lower part; rare sm. favositid corals; 40-57 cm thick.

UNIT 15. Ls., arg., wk. to w.-p. upward; arg. to shaley partings and wispy arg. stylolites sc. in lower to middle part; basal 20-30 cm more arg., locally with cm. fenestellid bryozoans and other bryozoans (cystodictyonids, trepostomes), burrowed with swirls of f. pk. and m.-w., rare brachiopods, sc. to cm. dk. phosphatic grains at base, local sl. irregular disconformity surface at base; upper w.-p. sc. to cm. f.-c. crinoid debris (rare articulated cups), sc. to cm. bryozoans (cystodictyonids, fenestellids), sc. to cm. brachiopods (*Spinatrypa, Pseudoatrypa, Orthospirifer, Schizophoria*, others); rare sm. solitary corals, *Hexagonaria*, sm. favositids mostly in upper part; 81-116 cm thick.

UNIT 14. Ls., arg., wk. to w.-p., part burrow swirled w.-p.; arg. to shaley streaks at base, basal zone locally includes m.-w.; several thin arg. to shaley partings or wispy arg. stylolites above separating unit into 10-20 cm thick beds where unit is thickest; top locally penetrated by subvertical burrows with dk. phosphatic grains in fill (from basal unit 15); sc. dk. phosphatic grains locally in middle or basal parts; wk. to w.-p. beds with sc. to cm. f.-c. crinoid debris, sc. to cm. brachiopods (*Spinatrypa, Pseudoatrypa, Orthospirifer, Schizophoria, Strophodonta*, others), sc. to cm. fenestellid bryozoans, sc. cystodictyonid bryozoans; rare to sc. pachyporid corals locally; *Hexagonaria* noted; unit apparently varies significantly in thickness, maximum thickness 1.1 m to north, south and eastern sections 45-55 cm thick.

NOTE: Units 12 and 13 were originally distinguished in the north quarry area. However, these units are not clearly differentiated in the southern and eastern core sections, where the combined interval of units 12-13 apparently is considerably thinner. These will be described separately.

UNIT 13. Ls., arg., wk. to w.-p.; basal 14 cm prominent shaley zone with wk. lenses, sc. to cm. crinoid debris, sc. to cm. bryozoans (fenestellids, trepostomes), sc. brachiopods (*Spinatrypa*, *Orthospirifer*, *Strophodonta*, others); w.-p. bed above more fossiliferous, part with burrowed pk. swirls, cm. to abnt. brachiopods including whole shells (*Spinatrypa*, *Cyrtina*, *Orthospirifer*, *Schizophoria*, others), sc. f. crinoid debris, fenestellid bryozoans upper, rare solitary coral; 40-60 cm thick.

UNIT 12. Ls., arg., wk. and w.-p.; prominent shaley partings at base and 37 cm above base separates two ls. beds; sc. to cm. crinoid debris, cm. brachiopods (*Spinatrypa*, *Pseudoatrypa*, *Orthospirifer*, *Cyrtina*, *Strophodonta*, others), sc. fenestellid bryozoans; sc. massive favositid corals noted in both beds (6-15 cm diameter), sc. solitary rugose corals; up to 80 cm thick.

UNITS 12-13 combined. Ls., arg., f. w.-p., locally f.-c. pk, part burrow swirled w.-p; locally with subvertical burrows at top; cm. arg. streaks, locally shaley base; upper part locally with sm. dk. phosphatic grains; f.-c. crinoid debris, bryozoans; sc. brachiopods; sc. to cm. bryozoans locally include v. large fenestellids; sc. corals (mostly sm. solitary corals, rare alveolitid); combined interval 30-35 cm thick.

NOTE: Units 10 and 11 originally described in north quarry area. However, these units are not clearly differentiated in southern and eastern core sections, where additional lithofacies are also identified. These will be described separately.

UNIT 11. Ls., arg., wk., thin pk. near base (pyritic); arg. to shaley parting at base; crinoid debris, brachiopods, bryozoans, sc. sm. favositid corals near top; 45 cm thick.

UNIT 10. Ls., arg. to v. arg., wk. and w.-p. with pk. lenses; cm. shaley partings every 10 to 15 cm; sc. crinoid debris, sc. to cm. brachiopods (*Pseudoatrypa*, *Orthospirifer*, *Eosyringothyris*, *Strophodonta*, *Schizophoria*, others), sc. bryozoans, cm. large fenestellids in upper part; trilobite (*Phacops*) and fish bone noted; sc. to cm. corals in lower to middle part include small solitary corals (cystiphyllids), sm. favositids, rare larger flat favositid (12 cm diameter); 76 cm thick.

UNITS 10-11 combined. Ls., arg. to v. arg., wk. and w.-p., includes f. and f.-c. pk.; part burrowed, locally includes one to three surfaces penetrated by vertical burrows, some burrows mudst.-filled; shaley base with thin arg. to shaley partings locally noted above; sc. to cm. f.-c. crinoid debris; sc. to cm. brachiopods (atrypids, *Strophodonta*, others); sc. to cm. bryozoans (fenestellids, others); fish bone (*Ptyctodus*) noted; sc. corals in lower part mostly sm. solitary rugosans, *Hexagonaria* noted; cores #2 and #4 include v. arg. sparse skel. to nonskeletal burrowed mudstone in upper part (30-50 cm thick; not seen in any other Klein sections), part faintly laminated, horizontal burrows, sparse skel. (indet. grains, f. crinoid); combined interval 80-125 cm thick.

SOLON MEMBER

NOTE: All units within the Solon Member at Klein Quarry are locally brecciated to varying degrees. Normally-bedded units are replaced abruptly by brecciated units in the quarry walls. Where brecciated the Solon units can be significantly thinned locally. Solon breccias variably include small clasts (1-10 cm) to large blacks (to 3 m) derived from one or more Solon units. The breccias are extensively fractured, and calcite fills are common. The basal contact (Solon-Davenport) is commonly difficult to distinguish where the basal Solon and underlying Davenport units are brecciated. The contact locally displays 2 m or more of local relief; lower Solon units (units 1, 2, and 3) are locally thinned and may onlap the contact.

"*Hexagonaria profunda* beds"

UNIT 9. Ls., light brown, dense massive beds; non-arg. to sl. arg., includes minor faint wispy arg. streaks; stylolites common; dominantly f. skel. pk, probably includes some f. w.-p.; mostly indet. f. skel. grains; sc. c. crinoid debris, includes stems; rare rostroconchs; sc. brachiopods (mostly *Independatrypa*, lesser *Strophodonta*, *Cranaena*, *Spinatrypa*, others); non-biostromal, but locally prominent sc. corals include solitary corals (cystiphyllids), colonial rugose corals (*Hexagonaria*, *Asterobillingsa*), rare fasciolate rugosans, sm. ramose to larger massive favositids, sc. alveolitids; sc. massive hemispherical to tabular stromatoporoids; 1.1-1.6 m thick.

UNIT 8. Ls., arg., biostromal, f. pk. matrix; arg. to shaley partings internally and at top; sc. stylolites; locally contains non-biostromal bed in lower part; matrix includes sc. crinoid debris and sc. brachiopods (*Independatrypa*); unit commonly (but not everywhere) includes abnt. thin lamellar stromatoporoids (1-10 mm thick, 10-30 cm diameter); locally with massive hemispherical to tabular stromatoporoids; sc. corals noted locally include solitary rugosans, colonial rugosans (*Hexagonaria*, *Asterobillingsa*), small favositid tabulates; 48-52 cm thick, may be locally thinner.

UNIT 7. Ls., arg., matrix f. pk., cm. to abnt. coral-stromatoporoids, biostromal in part, locally includes non-biostromal non-coralline beds in lower part; cm. shaley partings internally, shale parting at base; cm. stylolites; matrix includes sc. crinoid debris, sc. sm. brachiopods; sc. to cm. corals include solitary rugosans (cystiphyllids), colonial rugosans (*Hexagonaria*, *Asterobillingsa*), ramose favositid, massive favositids; sc. to cm. lamellar to tabular stromatoporoids, sc. massive hemispherical stromatoporoids; 62 cm thick, locally thinner.

UNIT 6. Ls., sl. arg., f.-m. pk.; sc. crinoid debris, sc. indet. brachiopods, rare gastropod mold; locally with sc. corals (solitary rugosans, sm. favositids); locally with sc. sm. massive to irregular stromatoporoids; base of unit is prominent darkened hardground surface (2-5 cm relief), bored; 35-45 cm thick (locally forms single continuous bed with unit 5).

"*Independatrypa independensis* beds"

UNIT 5. Ls., sl. arg., f.-m. pk., sc. stylolites; sc. crinoid debris, sc. indet. brachiopods; 30-50 cm thick (locally forms continuous single bed with unit 6).

UNIT 4. Ls., sl. arg. to arg., f.-c. w.-p.; stringers of whole-shell brachiopods sc. to cm. through; arg. to shaley partings near middle and top; sc. crinoid debris; rare sm. solitary coral; cm. to abnt. brachiopods (dominated by *Independatrypa*, also includes *Strophodonta*, *Schizophoria*, *Athyris*, others); 60-85 cm thick.

UNIT 3. Ls., sl. arg. to arg., wk. and pk., abnt. stringers of whole-shell brachiopods (especially in lower half); arg. partings separate beds 10-35 cm thick; arg. to shaley parting at top; sc. f.-c. crinoid debris, brachiopods dominated by *Independatrypa*, *Strophodonta*, also includes *Spinatrypa*, *Orthospirifer*, *Schizophoria*, *Cranaena*, others; averages 70 cm thick, locally to 1.3 m.

UNIT 2. Ls., sl. arg., light brown, dominantly f. pk., mostly indet. skel. grains; includes scattered larger skeletal grains (brachiopods, crinoid debris); sc. stylolites; hardground locally noted at or near base; sc. large brachiopods (probably *Independatrypa*); sc. f.-c. crinoid debris; fish bone noted; units varies in thickness 25-90 cm (probably because of relief on Solon-Davenport contact), average 70 cm thick; unit directly and unconformably overlies the Davenport Member over most of quarry area.

UNIT 1. Ls., arg., to shale, dk. gray; sandy with abnt. f.-m quartz and chert sand; sc. to cm. limestone lithoclasts (Davenport Member lithologies), rounded (3mm-6 cm); sharp contacts above and below; unit 1 occurs locally in lows along the Solon-Davenport unconformity, laterally discontinuous in quarry walls, absent in many places; 10-25 cm thick.

EPIGENETIC MINERALS AND PROCESSES OF FORMATION AT CONKLIN AND KLEIN QUARRIES

Paul L. Garvin
Cornell College
Mount Vernon, Iowa 52314
pgarvin@cornellcollege.edu

INTRODUCTION

Conklin and Klein quarries in Johnson County, Iowa are well known to mineral collectors. Both are owned and operated by River Products Company, and both are located within a few miles of each other (Figure 1). Epigenetic mineral deposits that are exposed in the two quarries have produced museum-quality specimens that can be found in Iowa mineral museums and other repositories, as well as in the cabinets of numerous private collectors. Conklin Quarry has been in operation for one hundred years or so, whereas Klein Quarry has a much shorter history of production.

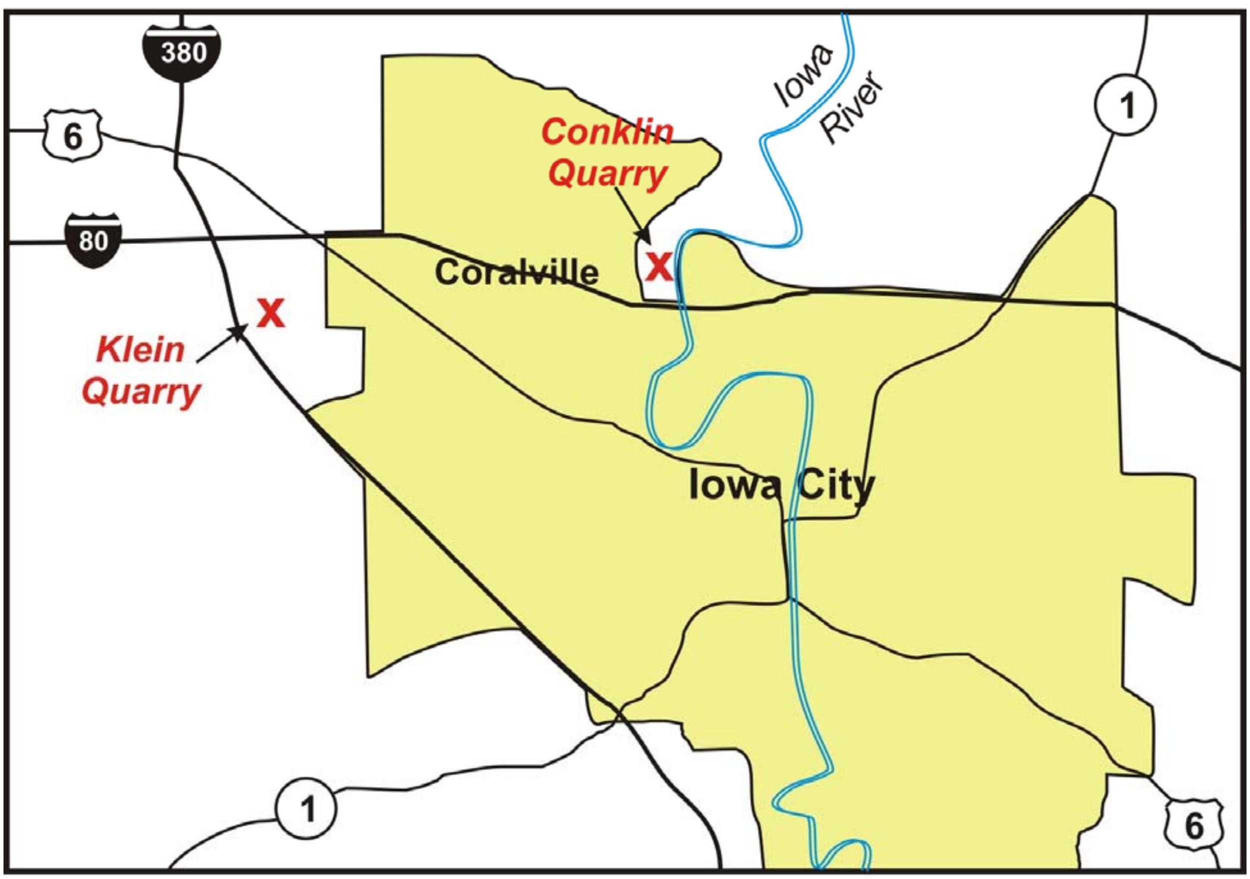


Figure 1. Location map for Conklin and Klein quarries.

BEDROCK GEOLOGY

Rocks exposed in the two quarries consist of Devonian marine carbonates which are locally overlain and truncated by Pennsylvanian fluviatile sediments (Figure 2). For detailed descriptions of the bedrock geology, see Glenister and Heckel, 1984; Bunker et al, 1985; Garvin and Ludvigson, 1993.

In ascending order the stratigraphic units are:

1. **Wapsipinicon Group** (Devonian – Eifelian)
   - a. Pinicon Ridge Formation
     - 1) Spring Grove Member –dolostone, brownish gray, arenaceous to micritic, unfossiliferous, except for widely scattered algal laminations
     - 2) Davenport Member–limestone, gray to brownish gray, micritic, finely laminated, unfossiliferous; organic-rich clay partings along bedding-parallel surfaces; extensive brecciation, with clasts up to a half meter or more in size, but averaging a few centimeters across
2. **Cedar Valley Group** (Devonian – Givetian)
   - a. Little Cedar Formation
     - 1) Solon Member – limestone, brown, arenaceous, fossiliferous
     - 2) Rapid Member – limestone, bluish gray, argillaceous, fossiliferous
   - b. Coralville Formation (Conklin only) – limestone, brown, arenaceous to micritic, fossiliferous
3. **Caseyville Formation** (Pennsylvanian – Morrowan) – intercalated sandstones and mudstones, light to very dark gray; fossiliferous, carbonized remains of plant leaves, twigs, seeds, limbs and root balls.

Post-depositional modifications of the bedrock units include:

1. dolomitization (Spring Grove), which increased the porosity of the carbonate rock.
2. carbonate rock dissolution, which produced vug- and local cavern-sized openings and collapse breccias.
3. stylolitic partings and other bed-parallel dissolution, resulting in insoluble clay residues.
4. the formation of large (25 cm or more long) ellipsoidal nodules (Davenport).
5. jointing and minor faulting, with some fractures enlarged by dissolution. Fractures and karst are partially to completely infilled with Pennsylvanian fluviatile sediment (Figure 3). At Klein a large Pennsylvanian channel cut into the Devonian carbonate rock, effectively removing all of the Coralville Formation. At Conklin, Caseyville sediment filled several large karst openings in Cedar Valley Group limestones.

These modifications are important, as they exerted a significant influence upon mineral deposition and distribution.

SYSTEM	SERIES	GROUP	FORMATION	MEMBER	LITHOLOGIES: DOMINANT	LITHOLOGIES: SUBORDINATE	THICKNESS (M)
PENN.	MORROWAN		Casey-ville		Sh	Ss	0-?
DEVONIAN	GIVETIAN	CEDAR VALLEY	Coralville	Iowa City	Ls		0-10
				Cou Falls	Ls		5-10
			Little Cedar	Rapid	Ls	Sh	15
				Solon	Ls		2-6
	EIFELIAN	WAPSI-PINICON	Pinicon Ridge	Davenport	Ls	Dol	6-8
				Spring Grove	Dol	Ls	6-8

Figure 2. Generalized stratigraphic section for rocks in eastern Iowa.

Figure 3. Paleokarst filled with Pennsylvanian sediment- Conklin; Northwest part of old quarry. Trenching exposes mudstone layering.

MINERALS

Conklin Quarry

Pyrite (FeS_2). Pyrite is a common mineral in Pennsylvanian sediments and Devonian carbonates. In the former, it appears as finely-divided microcrystals, as single and intergrown euhedral crystals up to 3 cm across, as nodular subhedral clusters, as pore-filling cements in clean sandstone, and as pseudomorphic replacements of woody plant fragments (Figure 4a). Large tubular masses of pyrite, up to 25 cm across, appear to have resulted from replacement of root balls (Figure 4b). A pyritized limb 8 cm in diameter and 25 cm long was discovered in a karst fill in the northern part of the quarry. In the latter, pyrite lines and fills fractures and it appears as scattered crystals and encrustations on corroded limestone surfaces that were formerly in contact with Pennsylvanian karst-filling sediments. It occurs as microcrystalline inclusions in, and dustings on calcite, and in the northern part of the quarry as subhedral growths on calcite crystal surfaces (Figure 4c). Color is brass yellow on freshly broken surfaces.

Marcasite (FeS_2). Marcasite occurs as encrustations on limestone cavern and vug walls, where it may be interlayered with pyrite. Open space growth produced wedge-shaped crystals and cockscomb intergrowths up to a centimeter or more in length. Like pyrite, microcrystalline marcasite is present as inclusions in calcite, and as subhedral growths on calcite surfaces. Color is greenish silver on freshly broken surfaces (Figure 4c).

Sphalerite (Zn,FeS). Sphalerite is widely distributed, though uncommon, in the quarry. It may appear as sparry infillings of fractures in the limestone host rock, and as scattered small subhedral crystals on limestone cavern walls. In the Davenport limestone it occurs locally as individual crystals a centimeter or more in length, which are contained in shaly insoluble residues which are parallel to bedding planes (Figure 4d). Color is dark brown, indicative of high iron content.

Chalcopyrite ($CuFeS_2$). Rare chalcopyrite is always associated with calcite, where it occurs as scattered inclusions of pseudo-tetrahedral crystals up to 4 cm long (Figure 4e).

Millerite (NiS_2). Millerite, for which this quarry is famous to collectors, is of capillary habit, with individual needles 5 cm or more in length. Most often, it occurs as inclusions in, and growths from calcite. Millerite brushes almost invariably have microcrystalline pyrite or chalcopyrite crystals at their bases (Figure 4f).

Calcite ($CaCO_3$). Calcite is by far the most abundant mineral in Conklin Quarry. In occurs as sparry infillings of dissolution-enlarged fractures in the host rock and as euhedral modified or unmodified acute scalenohedral crystals on host rock surfaces (Figure 4g). In small vugs it may be rhombohedral (Figure 4h). Calcite is most commonly colorless, but locally is white, amber or orange-pink. Rhombohedral calcite is colorless with brown coatings. Individual crystals may reach 8 cm in length. Basal and rhombohdedral twinning has been observed locally (Figure 4i). As stated previously, calcite commonly contains zoned inclusions of microscopic sulfide minerals, which record the growth history of the mineral.

Dolomite ($CaMg(CO_3)_2$. Dolomite is very rare at Conklin. It occurs on fracture surfaces as scattered tiny pinkish-tan crystals which exhibit a twisted rhombohedral habit (Figure 4j).

Barite ($BaSO_4$). Barite is uncommon at Conklin. It occurs as thin-to-thick tabular pale yellow or colorless crystals and intergrowths, and as a fine druse on calcite crystal surfaces (Figure 4k).

Quartz (SiO_2). Quartz occurs as microcrystalline lenses in the Rapid Member, where it pseudomorphically replaced disarticulated invertebrate fossils. In the Davenport it appears as large ellipsoidally-shaped cellular masses (up to 20 cm long). Individual cells are lined with colorless quartz druse and locally contain microcrystals of pyrite, marcasite or millerite (Figure 4l).

Figure 4 a-f. Minerals of Conklin Quarry.
a. pyrite nodules; left nodule is 5.5 cm across
b. pyritized root ball- 28 cm across
c. pyrite and marcasite perched on calcite- 11 cm across
d. euhedral sphalerite- 2 cm across
e. chalcopyrite (black) on calcite- largest crystal is 3 mm across
f. millerite on calcite- needles are 7 cm long

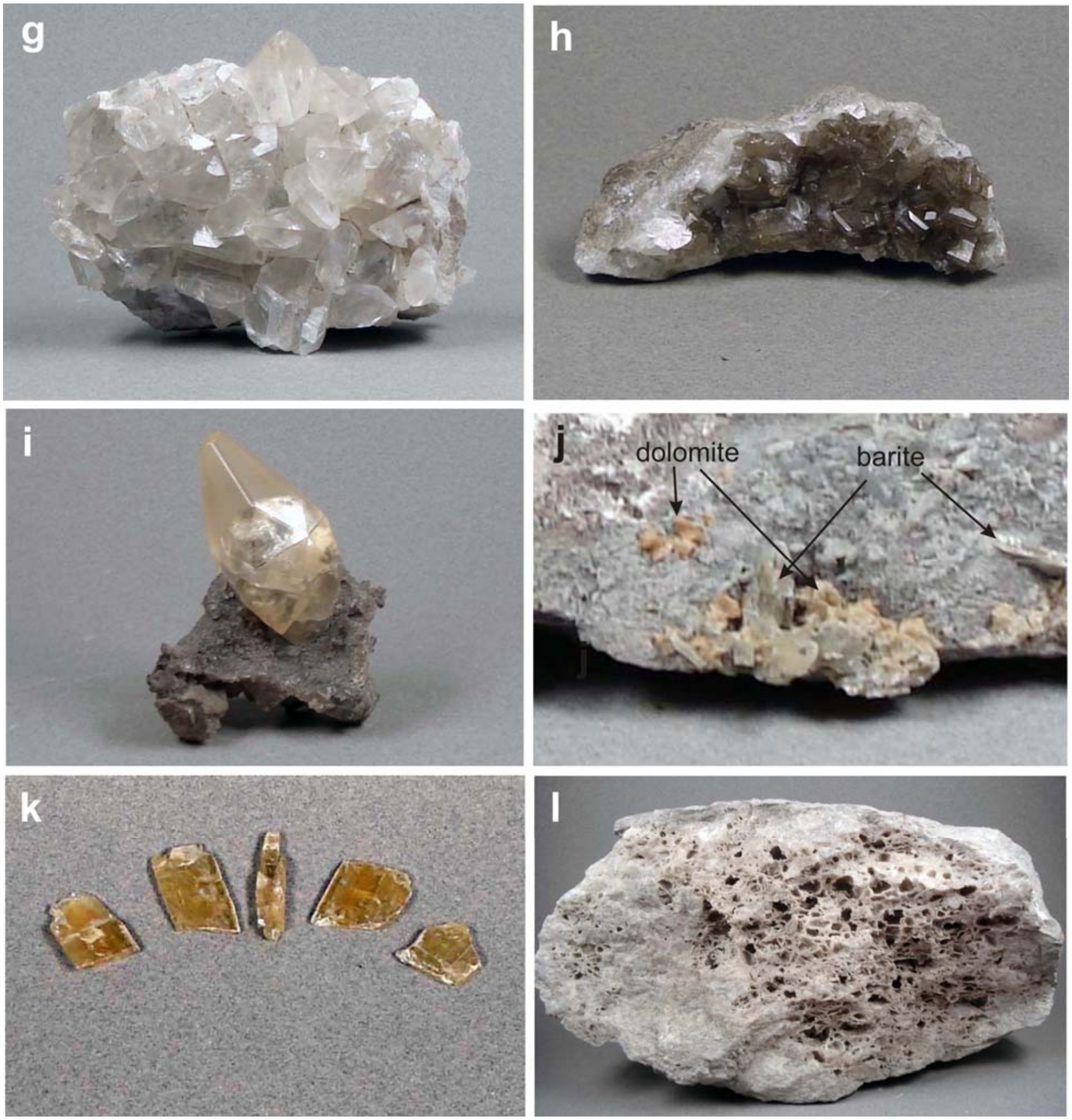


Figure 4 g-l. Minerals of Conklin Quarry continued.
g. calcite scalenohedra- 11 cm long
h. calcite rhombohedra- 8 cm long
i. calcite basal twin- crystal is 6.5 cm high
j. dolomite with barite- individual dolomite crystals 3 mm across
k. barite crystals- middle crystal 2.5 cm high
l. cellular quartz- 28 cm across

Limonite ($Fe_2O_3 \cdot xH_2O$). Limonite occurs as stains on quarry walls and coatings on iron-sulfide minerals. Because of its intense rusty color it is a good guide to the presence of sulfides and associated minerals.

Note: The surfaces of the iron-bearing sulfides- pyrite, marcasite and chalcopyrite- commonly are coated with a micro-thin oxide layer, which gives these minerals a gold, red, blue or green iridescent tarnish. Mineral collectors often mistake pyrite and marcasite in this and other mineral deposits for chalcopyrite. Crystal form/habit is much more reliable than color as a means of identifying these minerals.

Klein Quarry

*Pyrite (FeS_2).*Pyrite occurs as disseminations in Pennsylvanian shales, and as dustings, coatings and infillings of fractures and karst openings in limestone. Encrustations up to several centimeters thick occur locally. Where open-space growth occurred, cubo-octahedral crystals up to 2 cm across have been observed. Pyrite is also present as dustings and inclusions of microcrystals in calcite. Color is brass yellow on freshly-broken surfaces (Figure 5a).

Marcasite (FeS_2). Marcasite is present as scattered crystals and encrustations on limestone fracture surfaces. Single prismatic crystals a centimeter or more in length and cockscomb intergrowths have been observed (Figures 5b and 5c). Color is greenish silver on freshly broken surfaces. Microblades of what appears to be marcasite are abundant as inclusions in calcite (Figure 5d).

Sphalerite (Zn,FeS). Sphalerite occurs as sparry infillings of fractures in limestone, and as subhedral crystals and intergrowths on cavity walls. Color is dark brown (Figure 5e).

Millerite (NiS_2). Fine specimens of millerite have been reported by collectors, but I have not seen the mineral, nor have I observed it as inclusions in calcite (a common occurrence at Conklin).

Calcite ($CaCO_3$). As at Conklin, calcite is the dominant epigenetic mineral at Klein. It occurs as linings and fillings of fractures and karst openings and dissolution-collapse breccia cement. Unusually large calcite crystal intergrowths were discovered in a lopolith-shaped cavern 8 m across and 8 m deep. Individual crystals approach 1m in length (Figures 5g, 5h, 5i). Crystal form is modified and unmodified acute scalenohedron (Figure 5f). Calcite colors are colorless, white, and amber. Large masses appear blue-gray due to the abundance of FeS_2 microinclusions. Crystals are generally zoned, with interior growth surfaces accentuated by inclusions (Figures 5d, 5j).

Barite ($BaSO_4$). Barite was observed in single specimen. It appears as randomly-oriented colorless, wafer-thin blades (Figure 5a).

Quartz (SiO_2). See description for Conklin.

Limonite ($Fe_2O_3 \cdot xH_2O$). See description for Conklin.

PARAGENESIS

The sequence of epigenetic mineralization at Conklin is complex. Disseminated and possibly nodular FeS_2 minerals in Caseyville karst-filling sediments are probably early diagenetic. Secondary overgrowths on nodules, pore-filling cements, replacements of woody plant material, paleokarst clast coatings, and cavity-lining and fracture-filling mineralization came later. FeS_2 precipitation was intermittent throughout Conklin's diagenetic and epigenetic history. Mineralization that was 1) spatially associated with paleokarst proceeded in the order sulfides--calcite, while minerals found in 2) disjunct fractures in Little Cedar limestones is the reverse, i.e. calcite--sulfides. That these two sequences are products of different mineralizing events is evidenced by the results of sulfur isotope analyses. For sequence 1) δ 34 S o/oo values are strongly negative, whereas for sequence 2) they are weakly to moderately positive (Garvin et

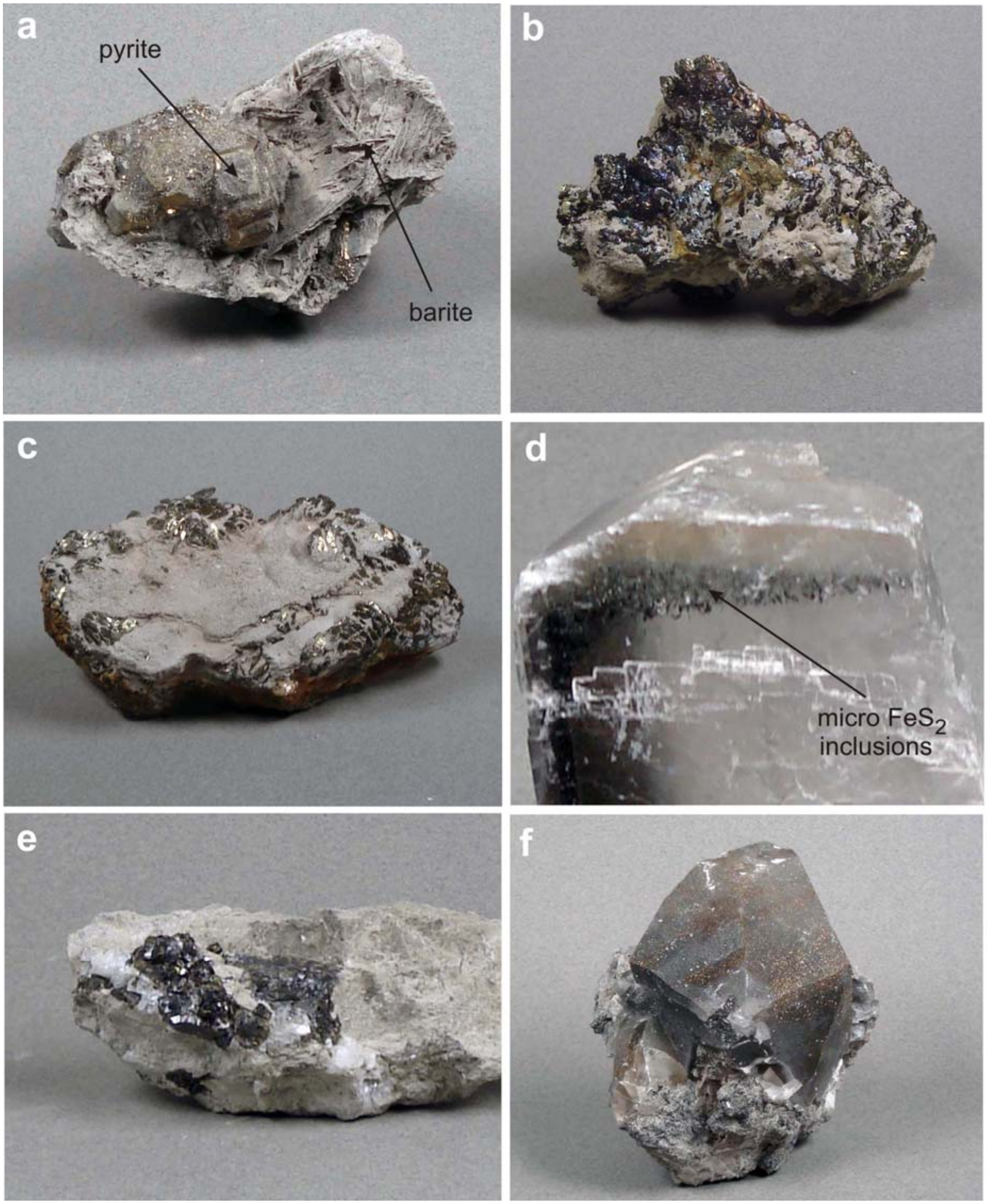


Fig. 5 a-f. Minerals of Klein Quarry.
a. cubo-octahedral pyrite and bladed barite-specimen is 10 cm across
b. iridescent marcasite-specimen is 10 cm across
c. bladed marcasite, which appears to grow into host rock-specimen is 14 cm across
d. marcasite microinclusions in calcite-specimen is 5.5 cm across
e. sparry sphalerite-specimen is 8 cm across
f. scalenohedral calcite coated with pyrite dust-specimen is 8 cm across

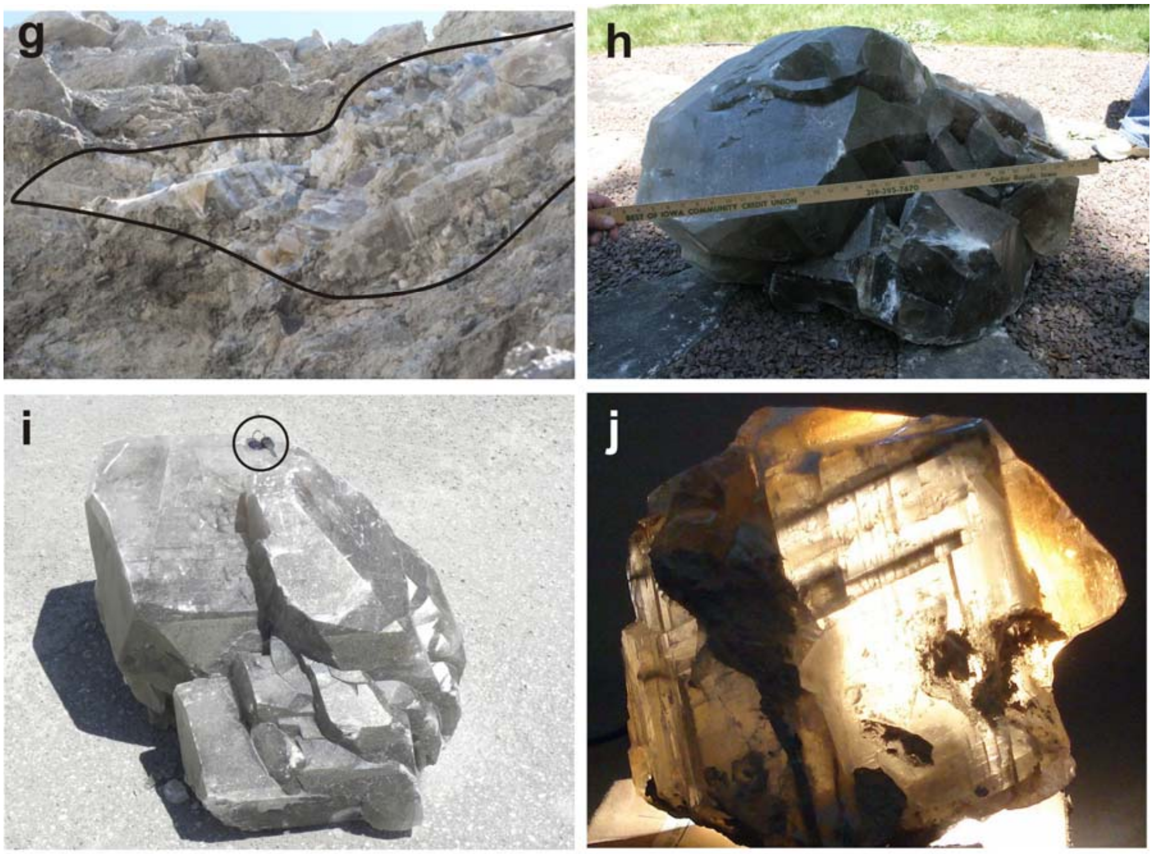


Fig. 5 g-j. Minerals of Klein Quarry continued.
g. mineral-filled karst-fill is 8 m across, photo by Tom Marshall
h. giant calcite crystals with yardstick for scale, photo by Marvin Houg
i. giant calcite crystals with car key for scale, photo by Brian Witzke
j. zoned calcite crystal-specimen is 12 cm across

al, 1985; Garvin and Ludvigson, 1988, 1993). Barite is always late, following all minerals except very late microcrystalline FeS_2.

At Klein, based on a limited survey of the quarry, all mineralization appears to be in the order sulfides first, calcite later. Evidence of FeS_2 precipitation after calcite, with the exception of minor sulfide dusting of crystal surfaces, was not observed.

Paragenetic diagrams for the two quarries are presented in Figure 6.

MINERAL–FORMING ENVIRONMENTS

Any reasoned effort to determine the origin of epigenetic mineralization at Conklin and Klein quarries requires the identification and analysis of the physical and chemical parameters that influenced the precipitation of the minerals and their spatial and temporal distribution. These include 1) the primary and secondary permeability of host sediments and sedimentary rocks (since all of the epigenetic minerals in the two deposits are believed to have resulted through precipitation from aqueous fluids), 2) sources of metals and sulfur (since all of the minerals, with the exception of quartz, are metal sulfides or metal carbonates or sulfates), 3) variations in the activities of oxygen (aO_2 or Eh) and hydrogen (pH), and 4) temperature of precipitation. Variations in Eh might have been controlled by fluctuations in the position

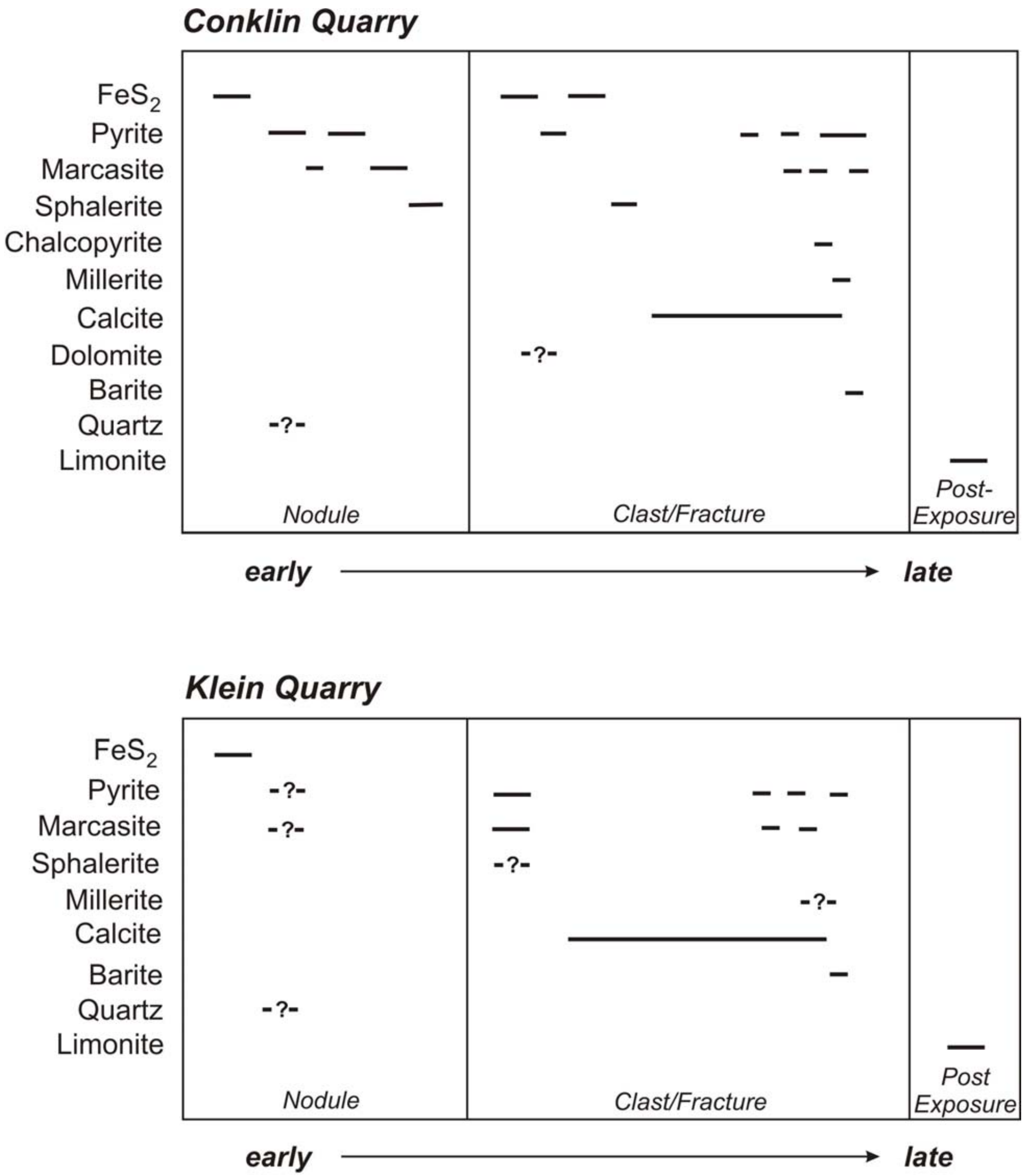


Figure 6. Paragenetic diagrams for epigenetic mineralization

of the groundwater table (phreatic – low Eh, and vadose- typically high Eh) and by decomposition of organic matter in paleokarst-filling muds. Variations in pH were influenced by oxidation of microcrystalline pyrite (decrease pH) and reaction of aqueous fluids with carbonate rock (increase pH). It is very likely that microbial organisms, directly or indirectly, played an important role in mineral precipitation in these deposits.

Possible sources of sulfur include: organic-rich karst-filling mudstones, shaly partings in carbonate rocks, and evaporitic sedimentary rock. Base metals (Ca, Mg and Ba) might have been derived from the surrounding carbonate host rock, or from locally available evaporites. It is generally believed that widespread brecciation of the Davenport Limestone resulted from dissolution of evaporite-rich horizons. The same mudstones could have supplied transition element metals (Fe, Ni, Cu, and Zn), since these are known to concentrate in organic-rich sediments, having derived from incompletely decomposed invertebrate animal remains (Vine and Tourtelot 1970).

The early diagenetic (defined here as occurring shortly after sediment deposition in a backwater fluvial area or in a karst opening) microcrystalline FeS_2 found in the paleokarst-filling mudstones at Conklin Quarry, and as pore-filling cement in sandstone, might have resulted from the reaction of mudstone-derived Fe^{2+} with sulfur that was present as S^{2-} in the same sediment or obtained by reduction of SO_4^{2-} that was dissolved in supra-adjacent waters.

The formation of macrocrystalline pyrite, marcasite and sphalerite as nodules (Figure 4a) and replacements of woody plant material (Figure 4b) that are wholly contained with the Caseyville sediment, and as encrustations on foundered carbonate rock clasts and cavern walls in contact with sediments (Figures 4c, 5b, 5c), resulted in part from remobilization of early microcrystalline FeS_2. Increase in pH through reaction of sulfide-bearing fluids with carbonate rock, or through bacterial mediation, might have been a motive force for precipitation of mineral sulfides. The organic-rich shaly partings in the Davenport at Conklin could have provided both metals and sulfide for the formation of contained subhedral sphalerite crystals (Figure 4d).

Euhedralism observed in later-stage pyrite and marcasite (Figures 4g, 4i, 5a, 5f) can be attributed to open-space growth or pseudomorphic replacement of mudstone or carbonate host rocks.

All sulfide precipitation is presumed to have taken place under low-Eh phreatic groundwater conditions. Alternatively, a closed-system vadose environment, with trapped H_2S filling karst openings, might also have produced the low Eh conditions necessary for sulfide precipitation. These conditions have been used to explain the existence of pyrite stalactites, which are known to occur in scattered locations of the world (for example at the Linwood Mine in Scott County – Garvin, 1998), and the so-called "snot-tites" of Cueva de Villa Luz in southeastern Mexico (Hose et al, 1999).

Fluctuations in the positions of groundwater tables influenced the mineralization history at both quarries. Exposure of mudstones to vadose conditions would have caused oxidation of microcrystalline FeS_2, and the generation of acid-rich fluids, with an increased capacity to mobilize metals and sulfur in the sediments. Downward migration of these charged waters below the water table would have provided a suitable environment for sulfide mineral precipitation. Intense iron oxide staining, which coats limestones on the high walls of both quarries, immediately below the contact with Caseyville mudstones, is a consequence of exposure of microcrystalline sulfides to air, during quarrying operations.

Calcites at both quarries generally exhibit high degrees of euhedralism and transparency. These characteristics require open-space growth in a stable, controlled phreatic environment (Jennings, 1985; Ford, 1988). Very large crystals, such as those obtained from the karst opening at Klein, indicate very low rates of nucleation and rapid, but controlled, growth (Figures 5h, 5i). Limited growth space resulted in the formation of calcite spar, which is commonly observed in Davenport breccias in both quarries. The history of growth of some calcite crystals is recorded by changes in mineral color and by the presence of microcrystalline FeS_2 inclusions on interior growth surfaces (Figures 5d, 5j). The causes for changes in crystal habit are not known with certainty, but may relate to variations in fluid pH, Mg or other chemicals, or growth rate (Devery and Ehlmann, 1981). The presence of FeS_2-rich zones, indicates that calcite precipitation was episodic, interrupted by periodic incursions of metal-sulfide-rich fluids. Alternations between sulfide and calcite precipitation indicate alternating reducing and oxidizing conditions.

Millerite at Conklin occurs always in association with calcite (Figure 4f). Brushes of this mineral appear to have nucleated from tiny crystals of pyrite or chalcopyrite. Reasons for these associations are not known.

As stated above, barite forms after all sulfides and calcite. Euhedralism suggests precipitation under phreatic conditions. Both Ba^{2+} and SO_4^{2-} could have been derived from local evaporitic sources.

The ellipsoidal form of the cellular quartz suggests replacement of a concretionary precursor (Figure 4l). These masses are restricted to the lower part of the Davenport Limestone. I have observed similar-appearing concretions that are exposed near the same horizon in the Davenport at the Sperry Gypsum Mine in Des Moines County, but the masses there are anhydrite. I suggest that prior to the removal of evaporitic layers from the Davenport at Conklin and Klein; the anhydrite was replaced by quartz. Replacement was partial, occurring along closely-spaced, randomly-oriented fractures, following which the remaining anhydrite was dissolved out, leaving the empty cells. The source of the silica is not known.

The extent to which Caseyville sediment filled cavities in the underlying carbonate rock strongly influenced the nature of mineralization, where the openings were completely filled, only FeS_2 minerals (pyrite and marcasite) formed (as disseminations, nodules and replacements). Where cavities remained empty or partially filled, the complete range of minerals was precipitated. Exceptions to this general rule occur where woody plant material or foundered breakdown are present. Fractures or other open spaces in these materials provided avenues for the ingress of fluids and deposition of minerals.

With regard to temperature of mineral precipitation, early diagenetic sulfides were likely formed from near-surface waters of normal temperature. Fluid inclusions studies were performed on epigenetic sphalerite and calcite taken from linings of dissolution-enlarged fractures in limestone at Conklin Quarry (Coveney and Goebel, 1983). Homogenization temperatures for 14 primary inclusions in sphalerite range from 78^{o} to 118^{o}C, demonstrating that this mineral formed under hydrothermal (epithermal) conditions. Calcite values range from 40^{o} to 70^{o}C, which falls at the lower limit for epithermal mineralization. Both minerals are from the paragenetic sequence FeS_2—sphalerite—calcite. Fluid inclusion analyses have not been performed for the limestone fracture-related sequence calcite—sphalerite—FeS_2. How the mineralizing fluids were heated is not known.

RELATIONS TO OTHER EPIGENETIC MINERAL DEPOSITS IN EASTERN IOWA AND ADJACENT WISCONSIN AND ILLINOIS

The mineral deposits at Conklin and Klein quarries are two among many similar-appearing occurrences in eastern Iowa and adjacent Illinois and Wisconsin (see Garvin, 1998, for a listing and descriptions of deposits in Iowa, and Garvin and Tribbe, 2005, for deposits in western Illinois). All epigenetic mineralization is associated with carbonate host rocks, calcite is the dominant mineral, and pyrite, marcasite and sphalerite are present in all deposits. Differences between deposits are the presence or absence of specific minerals, such as galena, fluorite, barite, millerite and chalcopyrite. With regard to paragenesis, the sequence FeS_2—sphalerite—calcite—+/- barite is most common. The Conklin sequence calcite—FeS_2—sphalerite is also observed in deposits in Blackhawk County (Pint's, Peske and Waterloo South quarries). Mineral form, paragenesis, fluid inclusion and stable isotopic compositional similarities between some Conklin deposits and pitch-flat deposits in the formerly commercial Upper Mississippi Valley Zinc-Lead District (UMV), suggest a cogenetic relationship (Garvin and Ludvigson, 1987, 1993; Spry and Kutz, 1988; Spry and Kutz, 1990). Cogenesis indicates that mineral-forming processes operated on a region-wide scale. Deposition of minerals that are more dissimilar to UMV might have been controlled by local events and conditions. It is clear that wherever carbonate rocks are spatially associated with organic-rich sediment, whatever its source, sulfide-bearing mineral deposits are very likely to form.

ACKNOWLEDGMENTS

I gratefully acknowledge the kind assistance of the owners and operators of the River Products Company for allowing access to the Conklin and Klein quarries, and for providing helpful information about the mineral deposits. Brian Witzke, Marvin Houg and Tom Marshall supplied photographs of the rocks and minerals at Klein. Ray Anderson read the manuscript and provided many helpful suggestions.

REFERENCES

Bunker, B. J., Ludvigson, G.A., and Witzke, B.J., 1985, The Plum River Fault Zone and the structural and stratigraphic framework of eastern Iowa: Iowa Geological Survey Technical Information Series 13, 126p.

Coveney, R. M., Jr. and Goebel, E.D., 1983, New fluid inclusion homogenization temperatures for sphalerite from minor occurrences in the Mid-continent area. *in* G. Kisvarsanyi, S.K. Grant, W.P. Pratt, and J.W. Koenig, eds., International Conference on Mississippi Valley-Type Lead-Zinc Deposits—Proceedings Volume, Univ. of Missouri-Rolla Press, Rolla, MO., p. 234-242.

Devery, D.M. and Ehlmann, A.J., 1981, Morphololological changes in a series of Mg-calcites: American Mineralogist 66, p. 592-595.

Ford, D.C., 1988, Characteristics of dissolutional cave systems in carbonate rocks: in N.P. James, and P.W. Choquette, eds., "Paleokarst", Springer-Verlag, p. 25-57.

Garvin, P.L., 1984, Mineralization at Conklin Quarry: *in* Bunker, B.J. and Hallberg, G.R., eds., Underburden-Overburden: An Examination of Paleozoic and Quaternary Strata at the Conklin Quarry Near Iowa City, Geological Society of Iowa Guidebook 41, p. 19-20.

Garvin, P. L., 1995, Paleokarst and associated mineralization at the Linwood Mine, Scott County, Iowa: Journal of the Iowa Academy of Science 102, p. 1-21.

Garvin, P.L, 1998, "Iowa's Minerals", University of Iowa Press, Iowa City, IA, 260p.

Garvin, P.L. and Ludvigson, G.A., 1988, Mineralogy, paragenesis, and stable isotopic reconnaissance of minor metal sulfide deposits associated with late Paleozoic karst fills in Johnson County, Iowa: *in* G.A. Ludvigson and B.J. Bunker, eds., New Perspectives on the Paleozoic History of the Upper Mississippi Valley: An Examination of the Plum River Fault Zone, Iowa Department of Natural Resources, Geological Survey Bureau, Guidebook Series No. 8, p. 145-160.

Garvin, P.L. and Ludvigson, G.A., 1993, Epigenetic sulfide mineralization associated with Pennsylvanian paleokarst in eastern Iowa, U.S.A.: Chemical Geology 105, p. 271-290.

Garvin, P.L, Ludvigson, G.A., and Ripley, E.M., 1988, Sulfur isotope reconnaissance of minor metal sulfide deposits fringing the upper Mississippi Valley Zinc-Lead District: Economic Geology 82, p. 1386-1394.

Garvin, P.L. and Tribbe G., 2005, The minerals of West Central Illinois: The Mineralogical Record 36, p. 421-431.

Glennister, B.F. and Heckel, P.H., 1984, The Devonian Cedar Valley Limestone at Conklin Quarry – Environments of deposition: *in* Bunker, B.J. and Hallberg, G.R., eds., Underburden-Overburden: An Examination of Paleozoic and Quaternary Strata at the Conklin Quarry Near Iowa City, Geological Society of Iowa Guidebook 41, p. 11-14.

Hose, L. D., and Pisarowicz, J. A., 1999, Cueva de Villa Luz, Tabasco, Mexico: Reconnaissance study of an active sulfur spring cave and ecosystem: Journal of Cave and Karst Studies 61, p. 13-21.

Jennings, J.N., 1985, "Karst Geomorpholoy", Basil Blackwell, 293p.

Kutz, K.B. and Spry, P.G., 1990, The genetic relationship between upper Mississippi Valley District lead-zinc mineralization and minro base metal mineralization in Iowa, Wisconsin, and Illinois: Economic Geology 84, p. 2139-2154.

Spry, P.G. and Kutz, K.B., 1988, A fluid inclusion and stable isotope study of minor upper Mississippi Valley-type sulfide mineralization in Iowa, Wisconsin and Illinois, *in* G.A. Ludvigson and B.J. Bunker, eds., New Perspectives on the Paleozoic History of the Upper Mississippi Valley: An Examination of the Plum River Fault Zone, Iowa Department of Natural Resources, Geological Survey Bureau, Guidebook Series No. 8, p. 145-160.

Vine, J.D. and Tourtelot, E.B., 1970, Geochemistry of black shale deposits—a summary report: Economic Geology 65, p. 253-272.

NEW DEVELOPMENTS AND REFINEMENTS TO LOWER CEDAR VALLEY GROUP CONODONT BIOSTRATIGRAPHY IN EASTERN IOWA

Jed Day
Department of Geography-Geology,
Campus Box 4400, Illinois State University,
Normal, Illinois, 61790-4400
jeday@ilstu.edu

INTRODUCTION

The conodont biostratigraphy of the Cedar Valley Group in eastern Iowa (Fig. 1) is well documented in investigations by Bunker and Klapper (1984), Witzke et al. (1985, 1989); Rogers (1998), Kralick (1992), Witzke and Bunker (1999), and Day (1996, 1997, 2000, 2006). The Conklin Quarry section (Fig. 2) is the key reference section for the Little Cedar and Coralville formations of the lower Cedar Valley Group in east-central Iowa. In southeastern Iowa, the IPSCO # 3 Core (Fig. 3) in eastern Muscatine County serves as the principle subsurface reference for the Cedar Valley Group as it transitions into the Illinois Basin. Recent near-continuous sampling of the IPSCO (Day, 2006) core from the subsurface Cedar Valley Group (Fig. 3) permits recognition of the base of the Upper *varcus* Zone (= *ansatus* Zone of Bultynck, 1987) in the upper part of the Solon Member in the southeastern Iowa.

Studies of shallow water Middle and Upper Devonian conodont sequences by Nakriewicz and Bultynck (2007) in Belgium, northern France, and North Africa presented evidence that the base of the Lower *Icriodus subterminus* Fauna of Klapper and Bunker (in Witzke et al., 1985) is within the upper part of the *hermanni* Zone (Fig. 1). Recently Nakriewicz and Bultynck (2010) proposed a shallow water Icriodus *subterminus* Zone (subdivided into Lower, Middle and Upper intervals) for the upper part of the Upper Givetian (see Fig. 1). The base of their Lower *subterminus* Zone is defined on the first occurrences of *I. subterminus* α and β morphotypes (see illustrated specimens in their study), and coincides directly with the Lower *subterminus* Fauna as currently defined (Witzke et al., 1985, 1989; Rogers, 1998) in North America. Their Middle *subterminus* Zone (Fig. 1) is defined by the first occurrence of *Mehlina gradata* and/or *Polygnathus angustidiscus* with *I. subterminus*, and as such corresponds directly to the base of the Upper *subterminus* Fauna of the North American shallow water zonation as initially defined based on the conodont sequence in the Conklin and the nearby Klein quarries in Johnson County, and the Lafarge Quarry in Scott County (see Witzke et al., 1989, 1999; Klug, 1990, Rogers, 1990, 1998). As has been long assumed by mid-continent Devonian conodont workers, the Lower *subterminus* Fauna/Zone (Figs. 1-3) spans the upper part of the *hermanni* and Lower *disparilis* Zone as revised and defined by Klapper and Johnson (1990). Nakriewicz and Bultynck (2010) aligned the base of their Middle *subterminus* Zone with the base of the offshore Upper *disparilis* Zone (Fig. 1) of Klapper and Johnson (1990). The base of the Upper *subterminus* Zone as defined correlated directly with the base of the offshore *norrisi* Zone (Fig. 1). These new studies by Nakriewicz and Bultynck permit refinement to correlations of the upper part of the Little Cedar and Coralville formations of the Cedar Valley Group as shown in Figures 1 to 3.

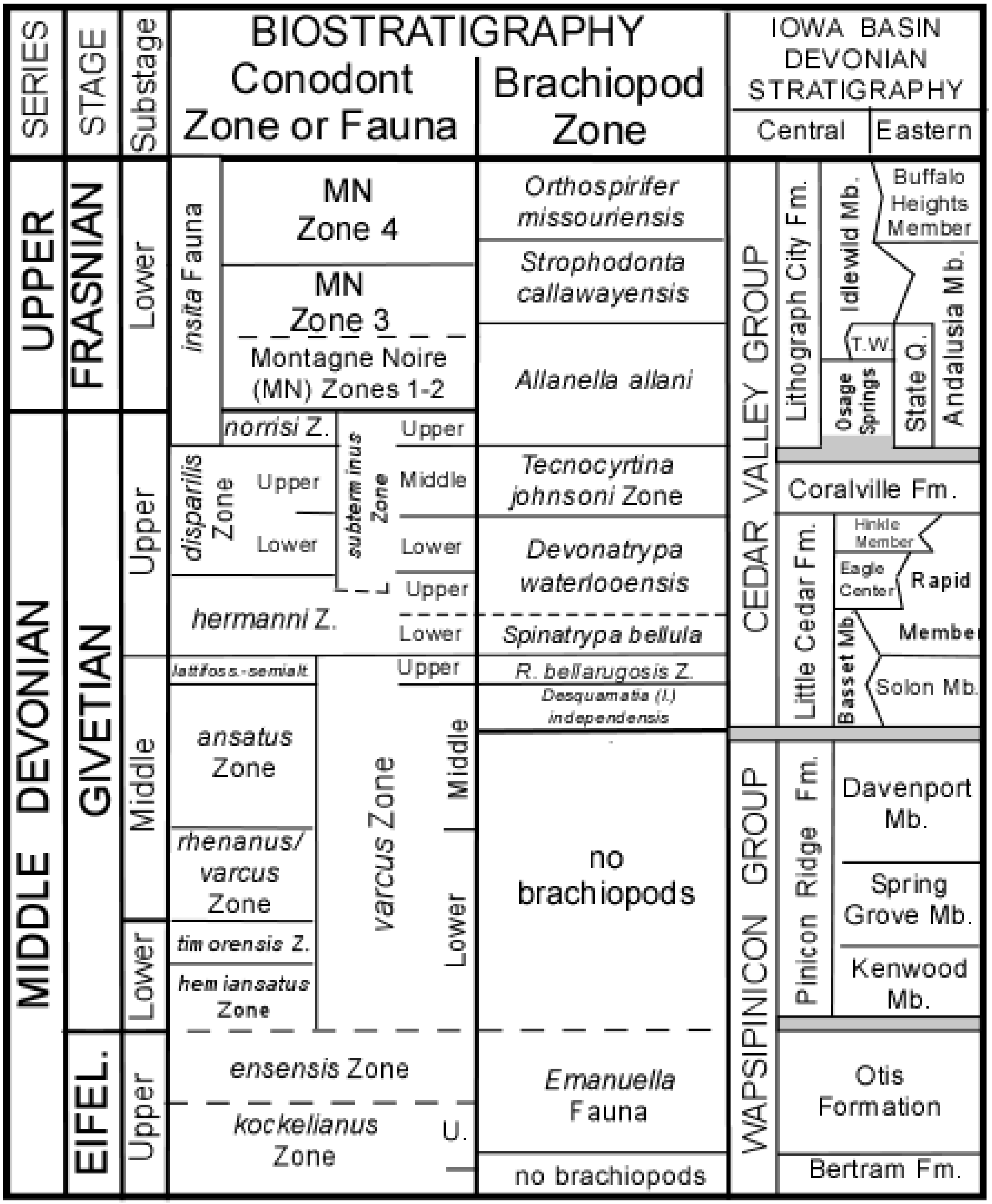


Figure 1. Stratigraphic and biostratigraphic framework for the Middle-Late Devonian (late Eifelian-early Frasnian strata of eastern Iowa. Small Iowa map shows locations of the River Products Conklin Quarry (Johnson County) and Iowa Geological Survey's IPSCO# 3 core (Muscatine County). Iowa Basin Devonian stratigraphy after Witzke et al. (1989), Witzke and Bunker (1992, 1996), Day (1997). Middle Devonian conodont biostratigraphy follows Witzke et al. (1985, 1989), Klapper and Johnson (1990), Johnson and Klapper (1992), Bunker & Witzke (1992), Witzke and Bunker (1996), Day (1990, 1992, 2006), Zeigler et al. (1976). New shallow water *Icriodus subterminus* Zonation is that of Nakriewicz and Bultynck (2010). Frasnian Montagne Noire (M.N.) conodont zones after Klapper (1989). Devonian brachiopod biostratigraphy from Day (1989, 1992, 1996, 1997), Day and Koch (1994) and Koch and Day (1996). Abbreviations: Fm. = Formation, Mb. = Member, L = Lower, M. = Middle, U. = Upper; *lattifoss-semialt.* = *latifossatus-semialternans*.

conodonts into the upper Cou Falls Member of the Coralville indicate widespread emergence of the middle shelf facies of the Cou Falls Member of the Coralville Formation during the latter part of the *disparilis* Zone prior the transgression that initiated Lithograph City Formation deposition in the Iowa Basin during the *norrisi* Zone (Fig. 2). The mid-shelf region of the Coralville platform was previously assumed to have remained subtidal during the post-Coralville sea level lowstand in the Late Givetian. New data also document stratigraphic leaks of Lithograph City Formation sediments with conodonts of the *Pandorinellina insita* Fauna in the upper 0.6 meters of the Coralville Formation in the IPSCO # 3 core (Fig. 3), and up to two meters in the Sullivan Quarry Core south of Burlington in Des Moines County (not discussed in detail in this report). Stratigraphic leaks of Lithograph City Formation

CEDAR VALLEY GROUP CONODONT SEQUENCE IN EASTERN IOWA

In all reference sections (Figs. 1 and 2), the lower Solon Member yields conodonts of the Middle *varcus* Zone (Fig. 1 samples 1 to 10) including: *Polygnathus linguiformis linguiformis* gamma, *Icriodus brevis, and Icriodus latericrescens latericrescens.* Day (2006, table 1) recovered *Schmidtognathus latifossatus* at 2.55 meters above the base of the Solon in the IPSCO # 3 core by reported in the IPSCO core (Fig. 2, sample 7) permitting identification of the base of the Upper *varcus* Zone in southeastern Iowa. A similar sequence has been documented in the Solon Member at the Conklin Quarry in its type area in Johnson County (Fig. 1). The interval of the Upper *varcus* Zone in North America coincides directly with the base of the European *semialternans/latifossataus* Zone of Bultynck (1987).

In both the Conklin Quarry and the IPSCO #3 core sections (Figs. 1 and 2) the base of the *hermanni* Zone is coincident with the base of the Rapid Member, marked by the first occurrences *Schmidtognathus wittekindti, Icriodus difficilis, Polygnathus xylus xylus* (Figs. 1 and 2). Of note is the first occurrence of *I.* aff. *I. subterminus* in the interval of the *hermanni* Zone in the IPSCO # 3 core section (Fig. 2, sample 20), with its highest occurrence in the lower part of the Andalusia Member of the Lithograph City Formation (Fig. 2, sample 89). This species is presumed to be the immediate ancestor of *I. subterminus* (G. Klapper, personal communication) and the ranges of both overlap in the upper part of the Rapid Member in the IPSCO core (Fig. 2, samples 52 to 89). The base of the Lower *Icriodus subterminus* Fauna of Bunker and Klapper (in Witzke et al., 1985) is defined at the first occurrence of that species just below the base of the lower biostrome in the middle part of the Rapid Member at the Conklin Quarry (Fig. 1, sample 18), and middle Rapid in the IPSCO core (Fig. 2, sample 52).

As mentioned above, the base of the Lower *subterminus* Fauna of Bunker and Klapper (in Witzke et al., 1985) is now aligned within the upper part of the *hermanni* Zone (Figs. 1-3). Witzke et al. (1989) and Rogers (1998) speculated that the base of the Lower *subterminus* Fauna in eastern Iowa might be correlated with part of the *hermanni* Zone, although in earlier conodont studies no taxa indicative of the *hermanni* Zone had been recovered with *Icriodus subterminus* in the Iowa Basin. Nakriewicz and Bultynck (2007, text-fig. 3; 2010, fig. 9) place the base of the *subterminus* Fauna/Zone within the *hermanni* Zone based the occurrence of *Polygnathus latifossatus* with *I. subterminus* in their sample 2353.5 m (Nakriewicz and Bultynck,2007, table 1) in the Komarow IG 1 well section in the subsurface of the Radon-Lublin area of southeastern Poland.

In the Iowa Basin, the base of the Upper *subterminus* Fauna (Figs. 1 and 2) and equivalent Middle *subterminus* Zone is marked by the first occurrence of *Polygnathus angustidiscus* with *Icriodus subterminus* in the lower Cou Falls Member of the Coralville Formation in the Conklin Quarry in Johnson

County (Fig. 2, sample 26) and northern Iowa (Witzke et al., 1989; Witzke and Bunker, 1992; Rogers, 1998). *Polygnathus angustidiscus* does not occur in the basal Cou Falls in sections at the Buffalo Quarry (see Day, 1992, 1997) and in the IPSCO PPW 3 # Core where the Coralville sequence (Fig. 3, samples 73 to 87) is dominated by *I. subterminus*, with *I.* aff. *subterminus*, and *Polygnathus klugi*?.

Strata of the lower part of the Lithograph City (Andalusia, State Quarry, and Osage Springs members) contain conodonts of the *insita* Fauna. *Skeletognathus norrisi*, associated with *Pandorinellina insita,* is reported from the State Quarry Member by Watson (1974) from his section S2 near the U.S. Army Corps of Engineers Sugar Bottom campground in Johnson County (Witzke et al., 1985; Day, 1992, 1996; Johnson and Klapper, 1992). This occurrence, as well as other reported occurrence of first occurrences of *P. insita* with *S. norrisi* in the Late Givetian of northern Alberta (Norris and Uyeno, 1981, 1983) and southwest Manitoba (Norris et al., 1982; Uyeno, in Braun et al., 1989, Day and Uyeno, in Day et al. 1996) indicates correlation of the basal Lithograph City and base of the *P. insita* Fauna within the *norrisi* Zone (Figs. 1 and 3). The incoming of the lowest *Pandorinellina insita* in the basal Andalusia and coeval rocks within the Iowa Basin (Witzke et al., 1989), Witzke and Bunker (1992, 1996), Day (2006), Day et al. (1996, 2008), and Alberta basin of western Canada (Uyeno and Wendte, 2005; Day and Whalen, 2005; Whalen and Day, 2008) is correlated the *norrisi* Zone. In the IPSCO # 3 core (Fig. 3) conodont faunas
recovered from subtidal carbonates and shales of the lower Andalusia Member are assignable to the *P. insita* Fauna and lack diagnostic species of *Skeletognathus* and *Ancyrodella* permitting precise correlations with the latest Givetian *S. norrisi* Zone and early Frasnian Montagne Noire Zones 1 to 4 of Klapper (1989).

Day (1992, 1997) documented the conodont sequence in most of the Coralville and Lithograph City formations in the Buffalo Quarry. There, the uppermost part of the Andalusia Member contains *Ancyrodella alata* late form, *A. africana*, *A. rugosa*, and *Mesotaxis asymmetrica* and is correlated with Early Frasnian Montagne Noire (M.N.) Frasnian Zone 4 of Klapper (1989). The lower two conodont samples in the Buffalo Heights Member yield a M.N. Zone 4 fauna similar to that in the upper Andalusia Member (Fig. 1).

STRATIGRAPHIC LEAKS OF *PANDORINELLINA INSITA* FAUNA

The first occurrence of *Pandorinellina insita* in all sampled sections in central and north-central Iowa (Bunker and Klapper, 1984; Witzke et al., 1989; Day, 1992, 1997; Day et al., 1996, 2008; Kralick, 1994; Rogers, 1998) is in the basal Lithograph City Formation that onlapped the regional unconformity developed on the top of, and truncating the Coralville and Little Cedar formations in central (Johnson County) and eastern Iowa (Fig. 2). As mentioned above, the first entry of this form is known to be no lower than the base of the *Skeletognathus norrisi* Zone.

Day (2006, 2010) reported *P. insita* from shales filling presumed burrows that penetrated 70 cm below the Coralville-Lithograph City contact in the IPSCO # 3 core from Muscatine County (see Fig. 3, unit 37, sample 87). In the Sullivan Quarry Core just south of Burlington, Iowa, samples in the upper two meters of the Cou Falls Member also yield *P. insita*. These anomalous occurrences are explained as stratigraphic leaks of shales and skeletal carbonates from the lowest Andalusia Member infilling burrows, or more likely karst cavities, extending downward to this position from the hardground discontinuity at the Cou Falls-Andalusia contact (Fig. 3, between 368-366 feet).

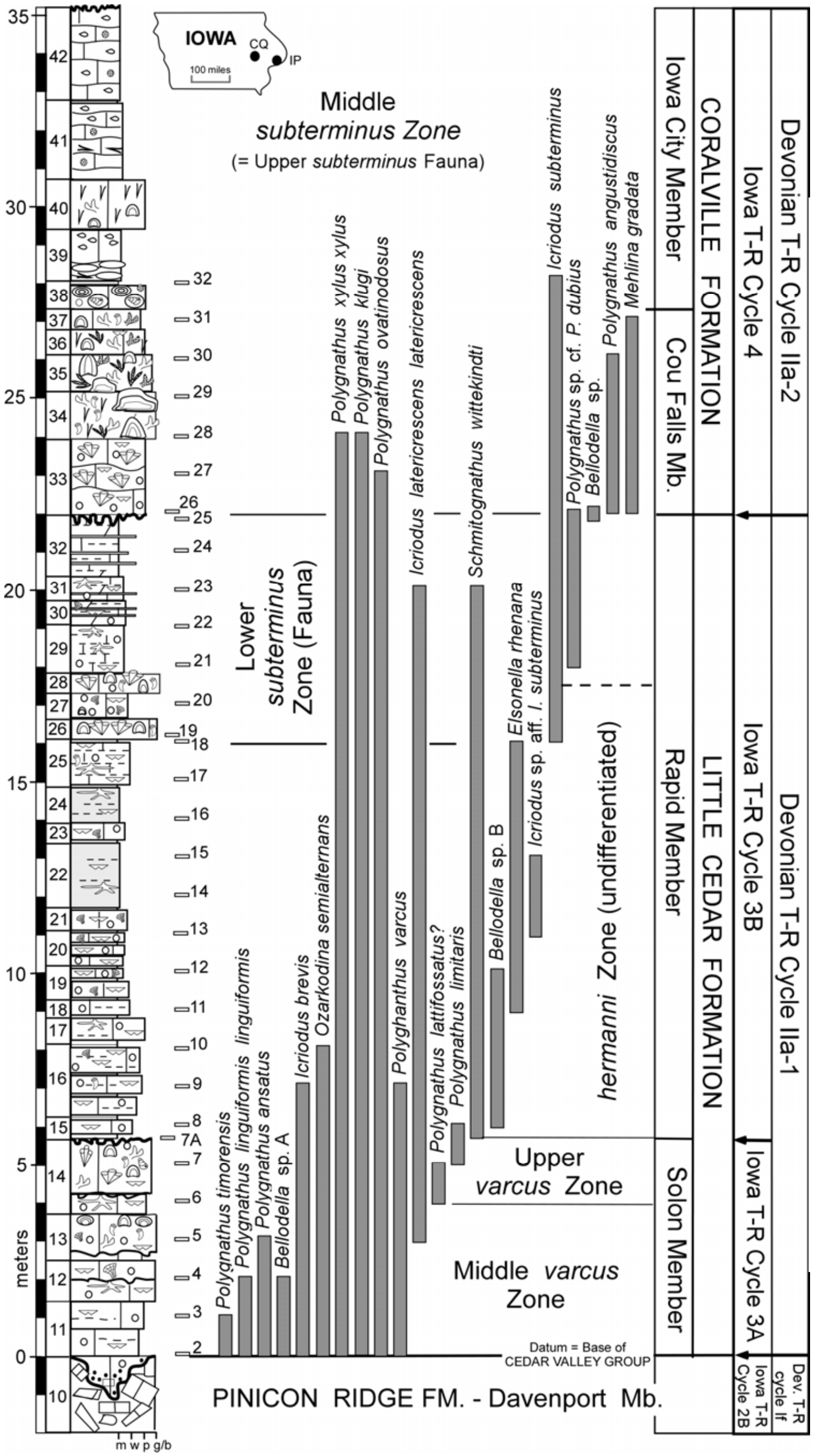


Figure 2.—Stratigraphy, cyclostratigraphy, and conodont biostratigraphy in the Cedar Valley Group section exposed in the River Products Company's Conklin Quarry in Johnson County, eastern Iowa (Fig. 1, locality CQ). Adapted from figs. 1 to 3 of Bunker and Witzke (1992), figs. 3 to 5 and section description of Witzke et al. (1999). Numbered rectangles are conodont sample positions of Klug (1990), supplemented by additional data in Rogers (1990), and IGS collections of Bunker and Witzke. Units 22 and 24 (light gray) are Z-beds of Witzke and Bunker (1999). Location of the Conklin quarry section (shown as CQ shown in small map) available in the IGS Geosam database (www.igsb.uiowa.edu/webapps/geosam).

TIMING AND MAGNITUDE OF POST-CORALVILLE REGRESSION

A significant and widely recognized sea level lowstand terminated Coralville carbonate platform deposition in the Iowa Basin near the end of the Upper *disparilis* Zone (Witzke et al., 1989, 2009; Witzke and Bunker, 2006; Day et al., 1996, 2008). This Late Givetian sea level lowstand is observed across the western Euramerican epeiric seaway in central western Canada (see discussion in Day et al., 1996), and the Cordilleran continental margin in the Great basin where it is referred to as the "Upper d*isparilis*-Zone Regression by Johnson and Sandberg (1989).

Regionally, evidence for this lowstand is best illustrated by the post-Coralville/sub-Lithograph City Formation surface along portions of the distal inner shelf in areas where the State Quarry Member of the basal Lithograph City Formation infills deep erosional channels cut into underlying Coralville and Little Cedar strata in the Solon and Coralville Reservoir areas, and recently discovered State Quarry Member channels filled with skeletal wackestones with *Desquamatia* (*Independatrypa*) *scutiformis* and *Strophodonta* (*S.*) *plicata* in the Klein Quarry west of Coralville. State Quarry channels downcut up to 25 meters in Johnson County, Iowa (Witzke and Bunker, 1994, 2006), and when the northward thickening of underlying strata is considered, an erosional incision of 32 to 35 meters is displayed across the distal inner-shelf (Witzke and Bunker, 2006; Day et al., 2008). These values provide minimum estimates of the magnitude of sea-level fall that occurred between deposition of the Late Givetian Coralville and very Late Givetian-Early Frasnian Lithograph City (Figs. 1-3) formations on the inner shelf. Absolute sea-level changes would have been even greater than this, as the total maximum depth of the seaway during deposition of the lower Lithograph City Formation across the inner shelf must also be added to the erosional relief to provide the full magnitude of total sea-level change associated with the terminal Coralville regression (Witzke and Bunker, 2006a; Day et al., 2008). The discovery of stratigraphic leaks of the *Pandorinellina insita* Fauna into the upper Cou Falls Member of the Coralville in southeastern Iowa is evidence of that Coralville middle shelf was emergent and exposed as far east as the western edge of the Illinois Basin. This new evidence indicates an ever greater magnitude for the Upper *disparilis* Zone sea level lowstand-regression. Based on the magnitude of the estimated sea level fall, this event can be characterized as a forced regression terminating deposition the Coralville epeiric carbonate platform and is a likely trigger for the coincident North American extinction bioevent of corals, bryozoans, trilobites and brachiopods at that time (see Day, 1996).

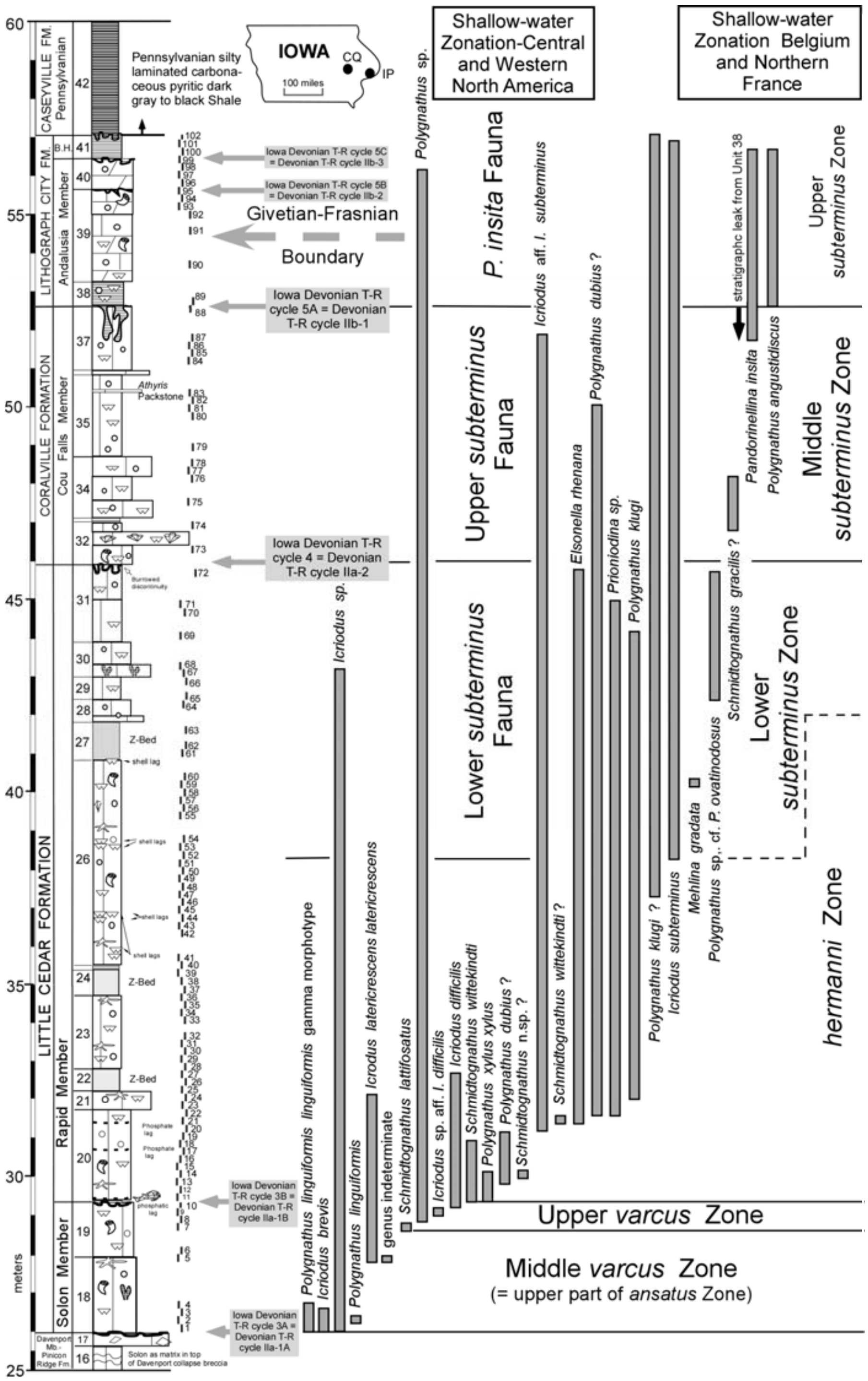


Figure 3. Stratigraphy, cyclostratigraphy and conodont biostratigraphy of the Cedar Valley Group in the IPSCO PW # 3 core from Muscatine County, Iowa. Gray arrows denote positions of major marine flooding surfaces and define Iowa Devonian T-R cycle boundaries. Stratigraphic section modified from fig. 7 of Day (2006). Black rectangles are 20 cm conodont samples yielding identifiable conodonts (modified from table 1 of Day, 2006). Dashed light gray arrow identifies the projected position of the Givetian-Frasnian stage (Middle-Upper Devonian Series) boundary within unit 39 in the lower part of the Andalusia Member of the Lithograph City Formation identified on the basis of the magnetic susceptibility records of Ellwood and Day (2006). Vertical Scale = meters above Silurian-Devonian contact. Units 22 and 24 (light gray) are Z-beds of Witzke and Bunker (1999). Location of the IPSCO #3 well section (shown as IP in small map) available in the IGS Geosam database (www.igsb.uiowa.edu/webapps/geosam).

ACKNOWLEGDEMENTS

The author wishes to thank my former ISU students Steven Travers, Susan Taha, Laura Crause who assisted in field work, in the conodont lab and sample picking since the early 1990s. Special thanks Gil Klapper who continues to visit ISU and assisted with identification of conodonts from the IPSCO # 3 core and Sullivan Quarry core sections. The biggest thanks go to my long-time friends and colleagues at the Iowa Geological Survey (IGS) Billy Bunker and Brian Witzke who engaged in extensive field work on the Devonian of Iowa with the author and who have provided open access to cores at the IGS Oakdale Core Library. Funding supporting this work has been provided by the Donors of the Petroleum Research Fund of the American Chemical Society, and Illinois State University Faculty Research grants to the author since 1990. River Products Company, Lafarge Corporation, and Wendling Quarries Inc. have provided access to Devonian quarry exposures throughout eastern Iowa since the mid-1980s.

REFERENCES

Braun, W.K., Norris, A.W., and Uyeno, T.T., 1989, Late Givetian to early Frasnian biostratigraphy of western Canada: the Slave Point-Waterways boundary and related events. *In* McMillan, N.J., Embry, A. F., and Glass, D.J., (eds.), Devonian of the World. Canadian Society of Petroleum Geologists Memoir 14, v. 3, p. 93-112.

Bultynck, P. 1987, Pelagic and neritic conodont successions from the Givetian of pre-Sahara Marocco and the Ardennes. Bulletin Institut Royal Sciences Naturelles de Belgique, Sciences de la Terre, v. 57, p. 149–181.

Bunker, B.J., and Klapper, G., 1984, Conodont zones and correlation of the Cedar Valley-State Quarry interval of eastern Iowa. *In* Bunker, B.J., and Hallberg, G.R., (eds.), Geological Society of Iowa Guidebook 41, p. 15-18.

Bunker, B.J., and Witzke, B.J., 1992, An upper Middle through lower Upper Devonian lithostratigraphic and conodont biostratigraphic framework of the Midcontinent carbonate shelf area, Iowa: Iowa Geological Survey, Guidebook Series no. 16, p. 3-25.

Bunker B.J., Witzke, B.J., and Day, J., 1986, Upper Cedar Valley stratigraphy, north-central Iowa, Lithograph City Formation. Geological Society of Iowa Guidebook 44, 41 p.

Day, J., 1986, The brachiopod fauna of the Lithograph City Formation of north-central and eastern Iowa. *In* Bunker, B.J., Witzke, B.J., and Day, J., Upper Cedar Valley Stratigraphy, North-Central Iowa, Lithograph City Formation. Geological Society of Iowa Guidebook 44, p. 14-22.

Day, J., 1989, The brachiopod succession of the late Givetian-Frasnian of Iowa. *In* McMillan, N.J., Embry, A.F., and Glass, D.J., (eds.), Devonian of the World: Canadian Society of Petroleum Geologists Memoir 14, v. 3, p. 303-326.

Day, J., 1992, Middle-Upper Devonian (late Givetian-early Frasnian) brachiopod sequence in the Cedar Valley Group of central and eastern Iowa. *In* Day, J. and Bunker, B.J., (eds.), The Stratigraphy, Paleontology, Depositional and Diagenetic History of the Middle-Upper Devonian Cedar Valley Group of central and eastern Iowa. Iowa Department of Natural Resources, Guidebook Series, no. 16, p. 53-105.

Day, J., 1994, The late Givetian and early Frasnian (Middle-Upper Devonian) Brachiopod Faunas of Southeastern Iowa and Northwestern Illinois. *In* Bunker, B.J., (ed.), Paleozoic Stratigraphy of the Quad-Cities Region of East-Central Iowa, Northwestern Illinois, Geological Society of Iowa Guidebook 59, p. 65-84.

Day, J., 1996, Faunal Signatures of Middle-Upper Devonian depositional sequences and sea level fluctuations in the Iowa Basin: US mid-continent. In B.J. Witzke, G.A. Ludvigson, and Day, J., eds., Paleozoic Sequence Stratigraphy, views from the North American Craton. GSA Special Paper 306, p. 277-300.

Day, J., 1997, Phylogeny and biogeography of *Tecnocyrtina* (Brachiopoda-Spiriferinida) in the Devonian (Givetian-Frasnian) of North America, *in* Klapper, G., Murphy, M.A., and Talent, J.A., eds., Paleozoic Sequence Stratigraphy, Biostratigraphy, and Biogeography: Studies in Honor of J. Granville ("Jess") Johnson: Geol. Soc. Amer., Spec. Pap. 321, p. 245-261.

Day, J., 2006, Overview of the Middle-Upper Devonian Sea level event history and biostratigraphy of the Wapsipinicon and Cedar Valley groups, with discussion of new conodont data from the subsurface Cedar Valley Group of southeastern Iowa. In Day, J, Luczaj, J., and R. Anderson, (eds.), New perspectives and advances in the understanding of Lower and Middle Paleozoic Epeiric carbonate depositional systems of the Iowa and Illinois basins. Iowa Geological Survey Guidebook Series No. 25, p. 3-21.

Day, J., 2008, Lime Creek Formation in the vicinity of the Rockford Brick and tile Quarry. Iowa Geological Survey Guidebook 28, Stop 7, p. 85-95.

Day, J., 2010, Middle and Upper Devonian (Late Givetian-Early Famennian) Conodont Sequence in the subsurface of southeastern Iowa: Stratigraphic Condensation, Leaks and Submarine erosional Reworking along the western Margin of the Illinois Basin. GSA Abstracts with Programs, vol. 42, no. 2, p. 50.

Day, J., and Koch, W.F., 1994, The Middle Devonian (late Eifelian-early Givetian) Brachiopod Fauna of the Wapsipinicon Group of Eastern Iowa and Northwestern Illinois. *In* Bunker, B.J., (ed.), Paleozoic Stratigraphy of the Quad-Cities Region of East-Central Iowa, Northwestern Illinois. Geological Society of Iowa Guidebook 59, p. 31-44.

Day, J., Uyeno, T.C., Norris, A.W., Witzke, B.J., and Bunker, B.J., 1996, Middle-Upper Devonian relative sea-level histories of North American cratonic interior basins. In B.J. Witzke, G.A. Ludvigson, and Day, J., eds., Paleozoic Sequence Stratigraphy, views from the North American Craton. GSA Special Paper 306, p. 259-276.

Day, J. and Whalen, M.T., 2005, Thornton Creek Member (new) of the Flume Formation and the initial Middle Devonian Onlap of the West Alberta Arch: Canadian Rocky Mountains. Bulletins of American Paleontology, 369, p. 123-150.

Day, J., Witzke, B.J., and B. Bunker, 2008, Overview of Middle and Upper Devonian Cedar Valley Group and Lime Creek Formation Carbonate Platform Facies, Faunas, and Event Stratigraphy of Northern Iowa. Iowa Geological Survey Guidebook 28, p. 15-39.

Klapper , G., and J. G. Johnson. 1990. Revisions of Middle Devonian conodont zones, p. 934– 941. In, J. G. Johnson, Lower and Middle Devonian brachiopod-dominated communities of Nevada, and their position in a biofacies-province-realm model. Journal of Paleontology, v. 64.

Johnson, J.G., and Klapper, G., 1992, North American midcontinent T-R cycles. Oklahoma Geological Survey Bulletin 145, p.

Johnson, J. G., and Sandberg, C. A., 1989, Devonian eustatic events in the western United States and their biostratigraphic responses, in McMillan, N.J., Embry, A. F., and Glass, D. J., eds., Devonian of the World. Canadian Society of Petroleum Geologists, Memoir 14, v. 3, p. 171-178.

Klapper, G., 1989, The Montagne Noire Frasnian (Upper Devonian) conodont succession. *In* McMillan, N.J., Embry, A.F., and Glass, D.J., (eds.), Devonian of the World. Canadian Society of Petroleum Geologists Memoir 14, v. 3, p. 449-468.

Klapper, G., Sandberg, C. A., Collinson, C. Huddle, J. W., Orr, R. W., Rickard, L.V., Schumacher, D., Seddon, G., and Uyeno, T. T., 1971, North American Devonian conodont biostratigraphy, *in* Sweet, W. C., and Bergstrom, (eds.), Geological Society of America, Memoir 127, p. 285-316.

Klug, C.R., 1990, Miospores and conodonts of the Cedar Valley Group (Middle to Upper Devonian) of Iowa. Unpublished Ph.D. Dissertation, University of Iowa, Iowa City, 280 p.

Koch, W.F., and Day, J., 1996, Middle Devonian (late Eifelian-early Givetian) brachiopod paleobiogeography of central and eastern North America. In Copper, P., and Jin, J., eds., Brachiopods, Proceedings of the Third International Brachiopod Congress. A.A. Balkema Press, Rotterdam, Netherlands, p. 135-144.

Kralik, J., 1992, Conodont faunas of the Lithograph City Formation (Cedar Valley Group, upper Givetian-lower Frasnian in north-central and eastern Iowa, *in* Day, J., and Bunker, B.J., eds., The stratigraphy, paleontology, depositional and diagenetic history of the Middle-Upper Devonian Cedar Valley Group of central and eastern Iowa: Iowa Geological Survey, Guidebook Series, no. 16, p. 107-110.

Narkiewicz, K., and P. Bulthynck, 2007, Conodont biostratigraphy of shallow marine deposits from the Radom-Lublin rea, SE Poland. Geological Quarterly, v. 51, no. 4, p. 419-442.

Narkiewicz, K., and P. Bulthynck, 2007, The Upper Givetian (Middle Devonian) *subterminus* Conodont Zone in North America, Europe and North Africa. Journal of Paleontology, v. 84, p. 588-604.

Norris, A.W. and Uyeno, T.T., 1981, Stratigraphy and paleontology of the lowermost Upper Devonian Slave Point Formation on Lake Claire and the lower Upper Devonian Waterways Formation on Birch River, northeastern Alberta. Geological Survey of Canada Bulletin 334, 53 p.

Norris, A.W. and Uyeno, T.T., 1983, Biostratigraphy and paleontology of the Middle-Upper Devonian boundary beds, Gypsum Cliffs area, northeastern Alberta. Geological Survey of Canada, Bulletin 313, 65 p., 8 pls., 6 figs.

Norris, A.W., Uyeno, T.T. and H.R. McCabe, 1982, Devonian rocks of the Lake Winnipegosis-Lake Manitoba outcrop belt. Geological Survey of Canada Memoir 392, 280 p.

Rogers, F.S., 1990, Stratigraphy, depositional history, and conodonts of the Little Cedar and lower Coralville formations of the Cedar Valley Group (Middle Devonian) of Iowa: Unpub. Ph.D. dissertation, Univ. Iowa, Dept. Geology, 97 p.

Rogers, F.S., 1998, Conodont biostratigraphy of the Little Cedar and lower Coralville formations of the Cedar Valley Group (Middle Devonian) of Iowa and significance of a new species of *Polygnathus*: Jour. Paleontology, v. 72, p. 726-737.

Uyeno, T.T., 1998, Biostratigraphy and taxonomy of Middle Devonian conodonts from south side of Great Slave Lake, District of Mackenzie. Geological Survey of Canada Bulletin 522, Part 2:145-191.

Uyeno, T.T., and Wendte, J.C., 2005, Conodont biostratigraphy and physical stratigraphy in two wells of the Beaverhill Lake Group, Upper Middle to Lower Upper Devonian, south-central Alberta, Canada. Bulletins of American Paleontology, 369, p. 123–149.

Watson, M. G., 1974, Stratigraphy and environment of deposition of the State Quarry Limestone, Johnson County, Iowa. Unpublished M.S. thesis, University of Iowa, 140 p.

Wendte, J., and T. T. Uyeno, 2006, Sequence stratigraphy and evolution of Middle to Upper Devonian Beaverhill Lake strata, south-central Alberta. Bulletin of the Canadian Society of Petroleum Geology, v. 53, p. 250-354.

Whalen, M.T., and Day,J. E., 2008, Magnetic Susceptibility, Biostratigraphy, and Sequence Stratigraphy: Insights into Devonian Carbonate Platform Development and Basin Infilling, Western Alberta. Papers on Phanerozoic Reef Carbonates in Honor of Wolfgang Schlaeger. Society for Sedimentary Geololgy Special Publication 89, p.291-316.

Witzke, B.J., and Bunker, B.J., 1996, Relative sea-level changes during Middle Ordovician through Mississippian deposition in the Iowa area, North American craton, *in* Witzke, B.J., Ludvigson, G.A., and Day, J., eds., Paleozoic Sequence Stratigraphy: Views from the North American Craton: Geol. Soc. Amer., Spec. Pap. 306, p. 307-330.

Witzke, B.J., and Bunker, B.J., 1994, Classic geological exposures, old and new, Coralville Lake and spillway: Geological Society of Iowa, Guidebook 60, 68 p.

Witzke, B.J., and Bunker, B.J., 2006, Middle Shelf Facies of the Cedar Valley Group (Devonian) and their Stratigraphic Relationships in Eastern Iowa. Iowa Geological Survey Guidebook Series no. 25, p. 23-46.

Witzke, B.J., Bunker, B.J., and Klapper, G., 1985, Devonian stratigraphy in the Quad Cities area, eastern Iowa-northwestern Illinois, *in* Hammer, W.R., Anderson, R.C., and Schroeder, D.A., eds., Devonian and Pennsylvanian stratigraphy of the Quad-Cities region, Illinois-Iowa, Society of Economic Paleontologists and Mineralogists, Great Lakes Section, 15th Annual Field Conference Guidebook, p. 19-64.

Witzke, B.J., Bunker, B.J., and Glenister, B.F., 1999, Bedrock geology at the River Products Co., Conklin Quarry, Coralville, Iowa: 62nd Annual Tri-State Geological Field Conference Guidebook, Univ. Iowa, Dept. Geoscience, p. 23-38.

Witzke, B.J., Bunker, B.J., and Rogers, F.S., 1989, Eifelian through lower Frasnian stratigraphy and deposition in the Iowa area, Midcontinent, U.S.A. *In* McMillan, N.J., Embry, A.F., and Glass, D.J., (eds.), Devonian of the World. Canadian Society of Petroleum Geologists Memoir 14, v. 1, p. 221-250.

Ziegler, W., Klapper, G., and Johnson, J.G., 1976, Redefinition of the *varcus*-Zone (Conodonts, Middle-?Upper Devonian) in Europe and North America. Geologica et Palaeontologica, v. 10, p. 109-140.

CEPHALOPODS OF THE LOWER CEDAR VALLEY GROUP: A GENERAL OVERVIEW

James E. Preslicka
Mid America Paleontology Society
1439 Plum Street, Iowa City, IA, 52240
jamesp@iowatelecom.net

Charles R. Newsom
Mid America Paleontology Society
Dept. of Physics and Astronomy
University of Iowa
Iowa City, IA, 52242
charles-newsom@uiowa.edu

Thomas E. Blume
President, Blackhawk Gem & Mineral Society
1232 Piedmont Avenue, Sumner, IA, 50674
blumet@tripoli.k12.ia.us

Glen A. Rocca
2nd Vice President, Blackhawk Gem & Mineral Society
P.O. Box 717, Shell Rock, IA, 50670
glenr@butler-bremer.com
319-885-6737

INTRODUCTION

The strata of the Middle Devonian Lower Cedar Valley Group (Figure 1) are highly fossiliferous in the field trip area, and many fossil groups from these rocks have been studied extensively. However, to our knowledge, with the exception of the single ammonoid species *Tornoceras* (*Tornoceras*) *iowaense* Miller 1936 (see Figure 7) the cephalopods from these rocks have not been systematically studied.

It has been our experience that many collectors can overlook cephalopod fossils or assume that they belong to a single species when in fact many genera or species may be present. This article will pass along our observations on the cephalopod fauna that the strata of this interval hold.

Both field trip stops expose complete sections of the Little Cedar & Coralville Formations, the two basal formations of the four that comprise the Middle Devonian Cedar Valley Group (Witzke et al., 1988, p. 222). The authors have all collected extensively for many years in both formations, and have amassed a fairly sizable collection of cephalopod fossils from these units.

Cephalopods are among the most advanced invertebrate animals, and are important components in modern marine ecosystems. Two main groups of cephalopods exist today: the Coleoids, which include the familiar squids, octopus, and cuttlefish; and the Nautiloids, which include *Allonautilus* and the chambered (or pearly) *Nautilus*. Two more groups are important in the fossil record: the Ammonoids, who went extinct along with the dinosaurs at the end of the Cretaceous; and the Belemnoids, squidlike animals which had an internal shell. It is the *Nautilus* which is most similar to the majority of fossil cephalopods.

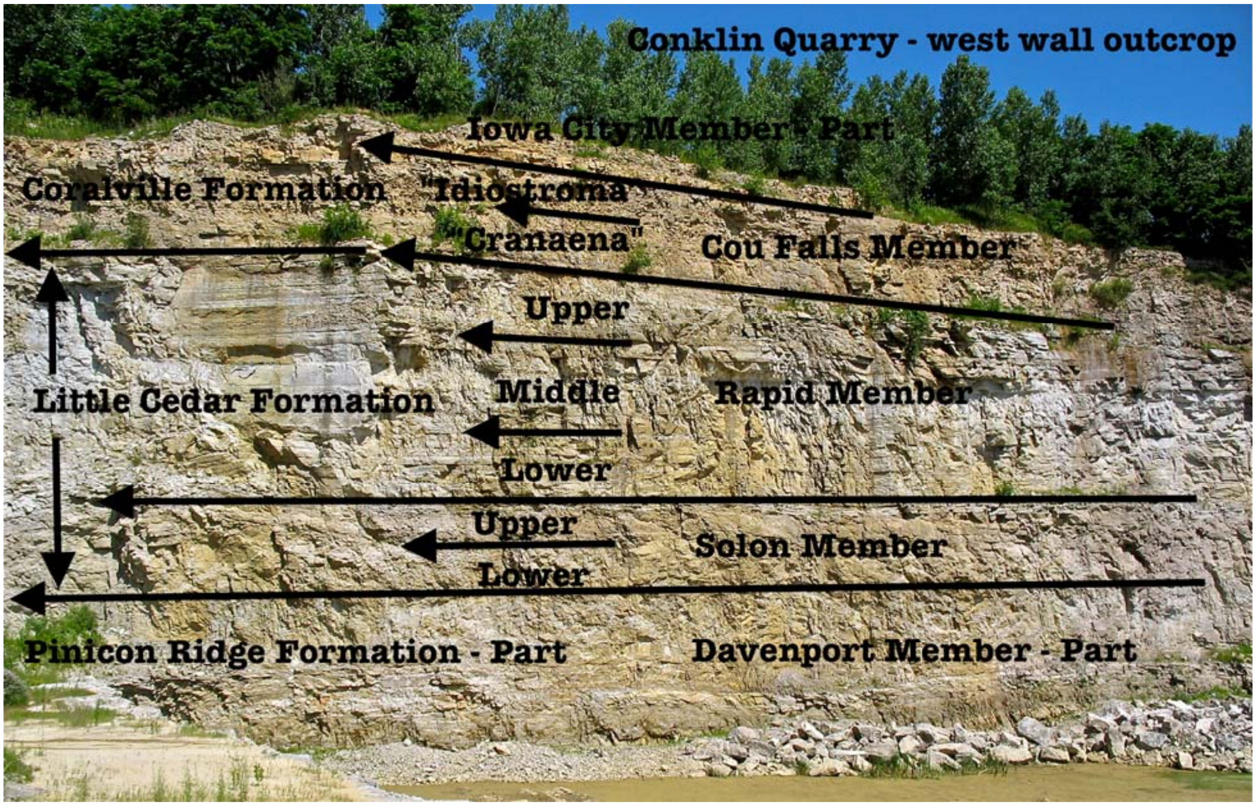


Figure 1: Outcrop of Middle Devonian strata of the Lower Cedar Valley Group along the west wall of Conklin Quarry. Unit contacts are approximate.

The function of the Nautiloid shell is twofold: to provide protection and support for the animal's soft parts; as well as to serve as a floatation device for the animal. The shell of a nautiloid is divided into chambers by partitions which are called **septa** (Figure 2), generally at right angles to the long axis of the shell. The places where the septa fuse to the inside of the shell are called **sutures** (Figure 2). The final and largest chamber is called the **body chamber** (Figure 2) and holds the soft parts of the animal. A small tube called the **siphuncle** (Figure 2) extends from the back of the body chamber through all the previous chambers (Thompson, 1982). The animal uses this tube to add or remove fluid from the chambers of the shell through a system of osmosis, thereby adding or removing mass from the shell as needed to maintain neutral buoyancy in sea water (Ward, 1988, pp. 157-160). This neutral buoyancy allows the animal to swim effectively using a relatively small amount of energy.

The Devonian was a time of change for the cephalopods - ammonoids had their origins in this period, as do the first members of the Nautilida, the family which includes the modern *Nautilus*. Many nautiloid families which had dominated Ordovician and Silurian faunas began to decline or go extinct during this time. The rocks of the Cedar Valley Group (part of "Dev. M" in Figure 3) provide a glimpse into the composition of the changing cephalopod faunas of the time - an admixture of older holdover taxa, and the first appearances of new forms that would later come to dominate younger cephalopod faunas (See Figure 3, from Moore, 1964, p. K101, figure 70).

In providing this summary, many of the problems with nautiloid description should become apparent. In order to properly classify many nautiloids, it is necessary to examine some of their internal shell structures which can be a very labor intensive process. Speciation in ammonoids is generally much easier, as that is based on the suture pattern, which is often readily apparent on specimens with little or no preparation required.

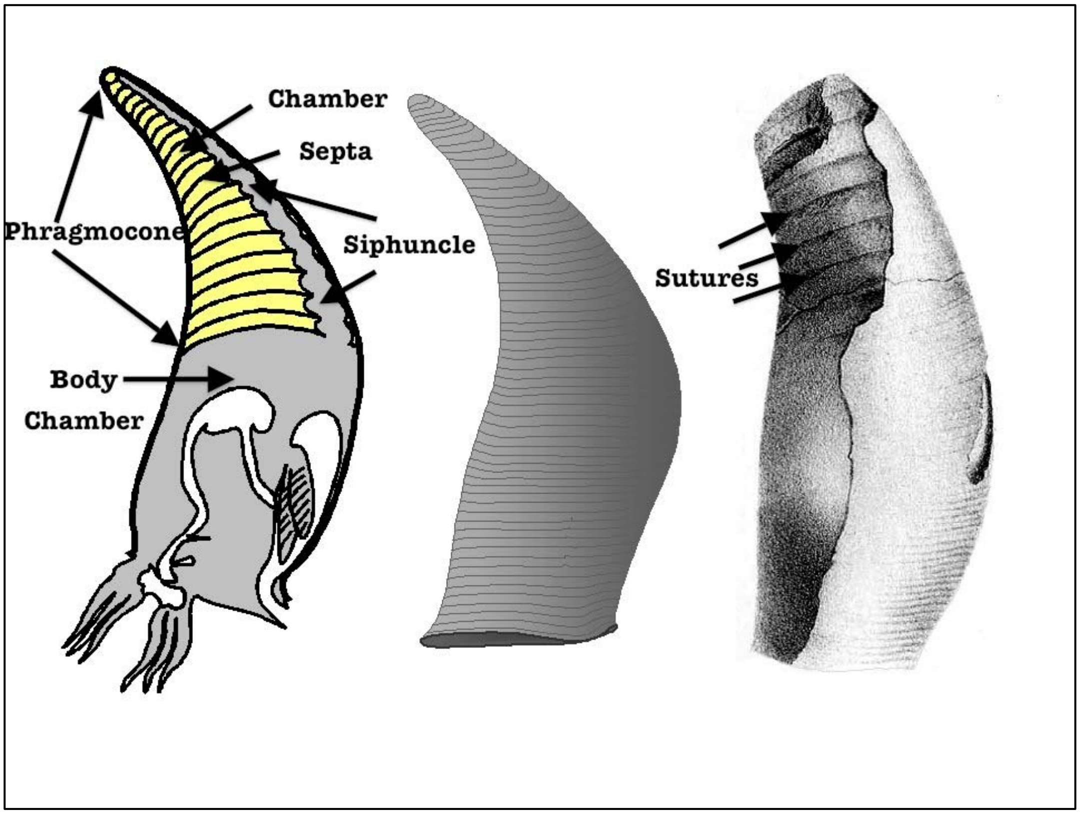


Figure 2: Diagram showing features of the shell of the nautiloid cephalopod *Oncoceras*. Left drawing is a cross section of a reconstructed living *Oncoceras*. Middle drawing shows the growth lines as they would appear on the outside of the shell. Right drawing is an internal mold of an *Oncoceras* fossil. Modified from Wikipedia Commons.

As the nautiloids of the Cedar Valley Group have not been extensively studied, many of them are still simply referred to form genera, where many often unrelated specimens with a similar shell shape were lumped together into one bunch, e.g. *Gyroceras* or *Brevicoceras*. Most of those names are no longer valid. We will use such names in quotes to denote that name has been or will one day likely be discarded.

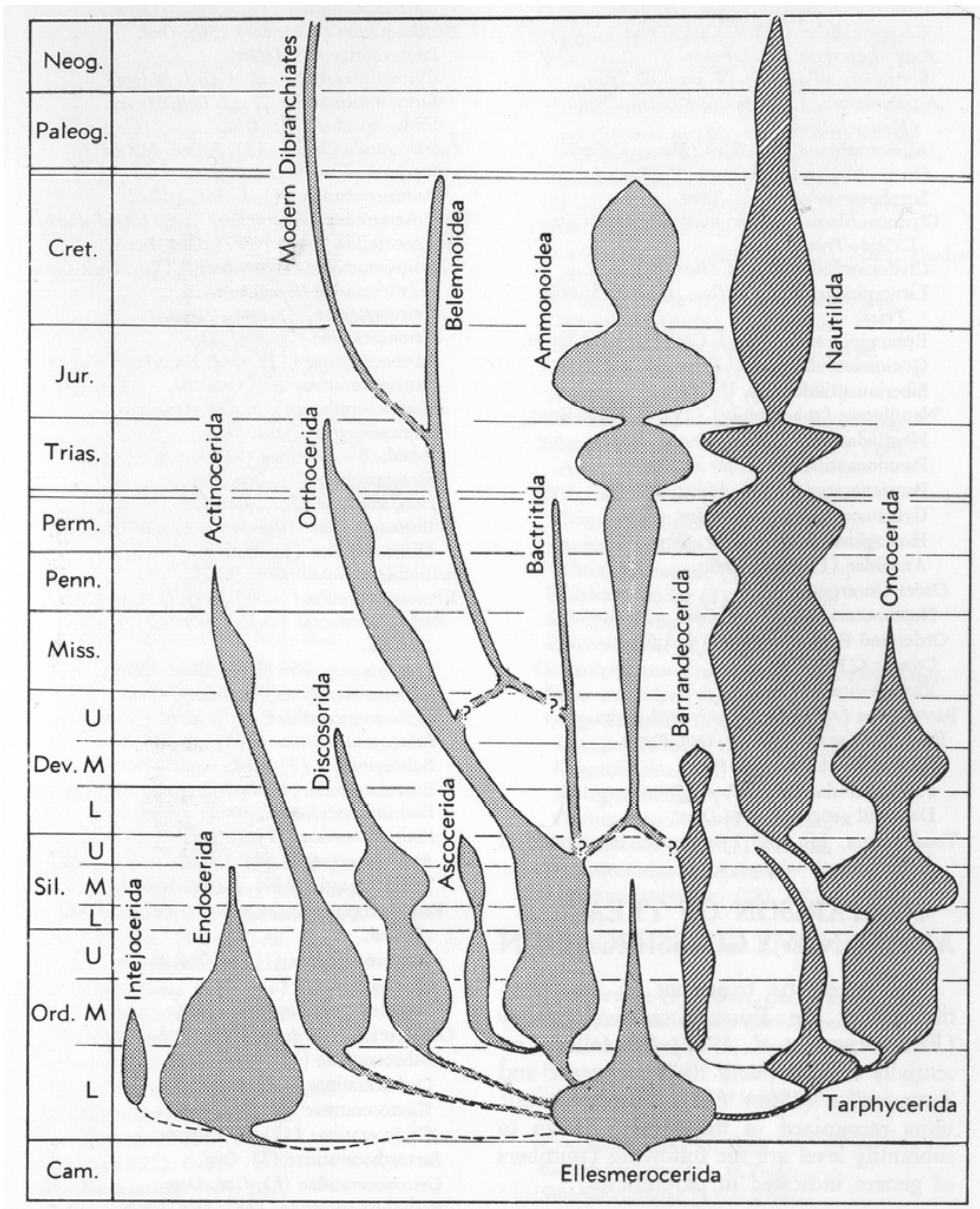


Figure 3: Inferred phylogeny of nautiloid orders and suggested relationships to other cephalopod groups. Approximate abundance in various geologic periods is indicated by width of pattern. From Moore 1964, p. K101, Fig. 70.

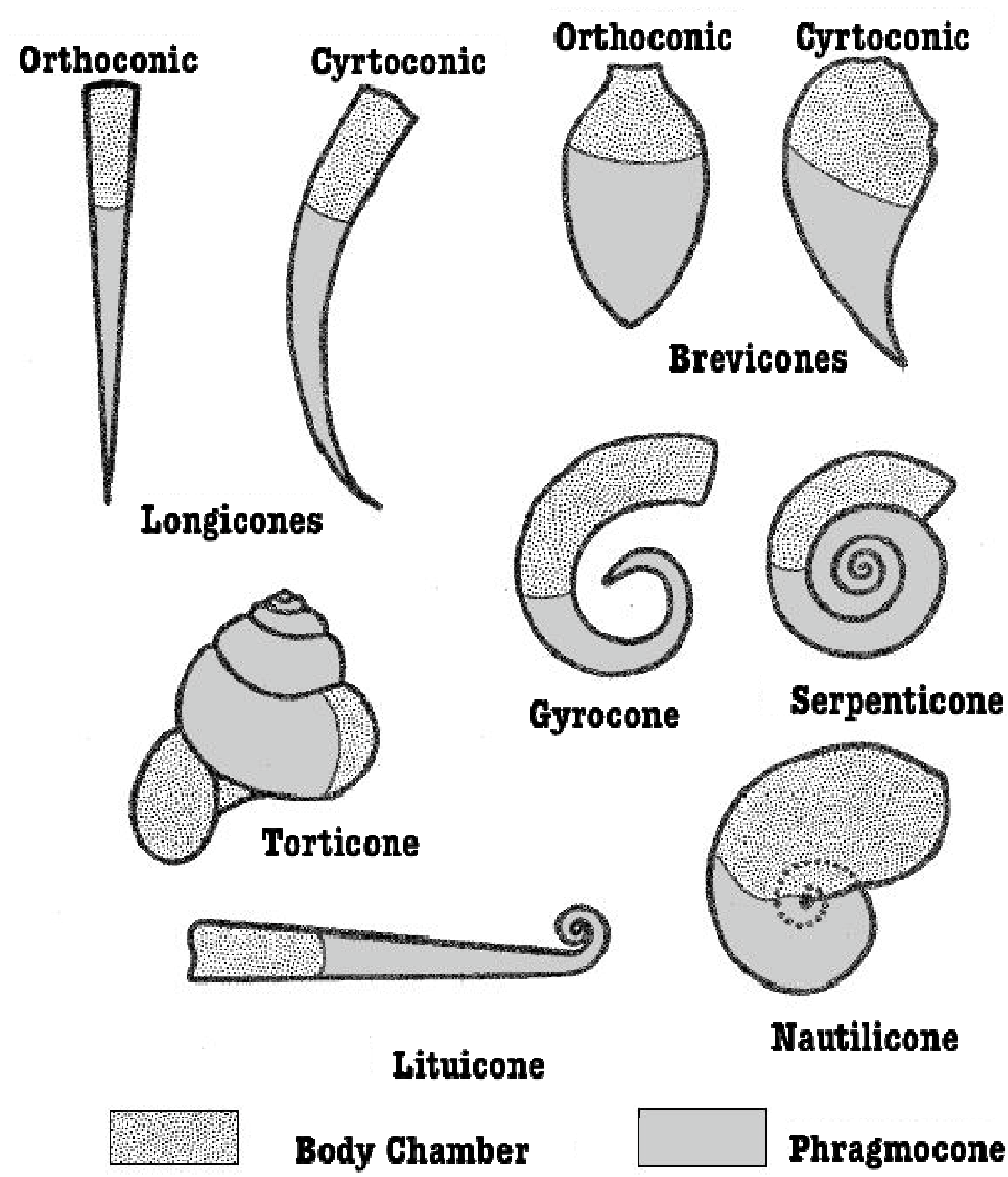


Figure 4. Various shell shapes of fossil Nautiloid cephalopods. All of these forms except the Torticones & Lituicones can be found in the strata of the Lower Cedar Valley Group. (From Wikimedia Commons.)

CEPHALOPOD FOSSIL SUMMARY, LOWER CEDAR VALLEY GROUP: (see figure 1 for unit references)

LITTLE CEDAR FORMATION, LOWER SOLON MEMBER: "INDEPENDENSIS ZONE" (STAINBROOK 1941A)

Table 1: Lower Solon Member cephalopod fauna summary.

Cephalopod Type	Name or Shell Form	Approx. # of species present	Relative Abundance
Ammonoid	*Tornoceras (Tornoceras) Iowaense* Miller 1936	1	Exceedingly rare in Johnson County, IA.
Nautiloid	Orthocones	~2	Both relatively abundant
Nautiloid	Brevicones (Includes *Acleistoceras sp.*)	~2	Both relatively common
Nautiloid	Cyrtocones	1	Relatively common
Nautiloid	Gyrocones	1	Uncommon
Nautiloid	Nautilicones	2	1 relatively common, 1 exceedingly rare

Discussion

The Lower Solon Member interval provides the most abundant and diverse cephalopod fauna known from the entire Cedar Valley Group. Nine species are present in the Johnson Country area, but even more abundant faunas have recently been discovered to the north in the area of Buchanan County. The Blackhawk Gem & Mineral Society (in a joint effort with the Mid America Paleontology Society, the Cedar Valley Rocks & Minerals Society, and the University of Iowa Geoscience Repository) is currently in the process of collecting and documenting this fauna, which contains approximately 13 cephalopod species. The work on future articles describing this fauna is already underway.

Other fossil groups such as the trilobites show a pattern of cosmopolitan species migrating in with the major sea level rise at the base of the Solon Member, and establishing communities, which then later give rise to endemic species higher in the Cedar Valley Group section. Trilobite diversity and abundance rapidly decrease moving upsection (Personal communication, Bill Hickerson, 2008).

A similar pattern appears evident with the cephalopods which show a general decrease in individual abundance and species diversity moving upsection through the Lower Cedar Valley Group (see Table 8). As of yet we cannot state for certain that any endemic cephalopod species arose from the more cosmopolitan faunas at the base of the Solon Member.

The orthocones (Figures 4, 6) are the most common cephalopods from this interval, but are notoriously difficult to classify. The brevicones (Figure 4) include the ubiquitous *Acleistoceras* sp. (Table 1; Figure 11), the only nautiloid genus that has been properly identified in these strata. It is present in nearly all Lower Cedar Valley Group cephalopod faunas, and is second to only the orthocones in relative abundance. The nautilicones (Table 1, also Figure 4) include an unnamed species that is very similar in size and appearance to the modern *Nautilus*, helping illustrate why the *Nautilus* is often called a "living fossil". Gyrocones (see Fig. 4) are represented by the form genus "*Gyroceras*", specimens of which can be quite large (see Fig. 5).

Tornoceras (*Tornoceras*) *iowaense* Miller 1936 (Table 1; Figure 7) is Iowa's oldest known ammonoid species, and is extremely rare in the Johnson County area. It is more common to the north in the Buchanan County faunas. It is not known to range above the Lower Solon Member.

Paleozoic ammonoids are known to have preferred deeper water offshore environments, while the nautiloids tended to dominate the shallower water shelf environments. The inferred deepest water environments of the entire Cedar Valley Group are preserved in the Lower Rapid Member of the Little Cedar Formation (Witzke et al., 1988, p. 246, figure 13). So logically, that is the place where one would most expect to find ammonoids in the Cedar Valley Group, and yet none are known from the Rapid Member.

Figure 5: Specimen of "*Gyroceras*" sp, Lower Solon Member, Buchanan County. Found by T. Blume. Prepared by Jack Peterson of the Blackhawk Gem & Mineral Society.

Figure 6: Orthoconic nautiloid from the Lower Solon Member, Coralville Lake area, Johnson County. Found by J. Preslicka.

Figure 7: Specimen of *Tornoceras* (*Tornoceras*) *iowaense* Miller 1936, Lower Solon Member, Buchanan County. Found, prepared, & photographed by John Catalani. Actual diameter is 8.0 cm.

Figure 8: Coiled nautiloid specimen from the Lower Solon Member in Conklin Quarry, found by G. Rocca. This species belongs to the same family as the modern day *Nautilus*: the Nautilida (see Figure 3).

LITTLE CEDAR FORMATION, UPPER SOLON MEMBER: "PROFUNDA BEDS" (STAINBROOK 1941A)

Table 2. Upper Solon Member cephalopod fauna summary.

Cephalopod Type	Name or Shell Form	Approx. # of species present	Relative Abundance
Nautiloid	Orthocones	~1	Relatively common
Nautiloid	Brevicones (Includes *Acleistoceras sp.*)	~2	Both relatively common
Nautiloid	Cyrtocones	1	Relatively common
Nautiloid	Gyrocones	1	Exceedingly rare
Nautiloid	Nautilicones	1	Sporadically abundant

Discussion

The Upper Solon cephalopod fauna shows a decrease in species diversity. Only ~6 species occur in the Johnson County area, and the gyrocones are known only from a single specimen of "*Gyroceras*" sp. In general individual specimens are less abundant as well, except locally at the top of the unit. The Uppermost Solon in the Johnson County area preserves bioherms (life mounds), which are patch reef like structures, and sporadically abundant nautiloid cephalopods can be found in pockets in this interval, including a coiled species very similar in appearance to the modern *Nautilus* (Figure 9).

Nautilus (Figure 9) and *Allonautilus* live offshore from coral reefs and follow a diurnal life habit. They prefer to remain within a few feet of the sea bottom, and migrate up into shallower water to feed during the night, and dive down to very deep water (up to 1200-1400 feet) during the day to hide when their predators are most active (Ward 1988, pp. 174-175).

One might wonder if the habits of the nautiloids seen in the Upper Solon bioherm interval might be similar to their modern day relatives. However, the epicontinental seas that covered Iowa during Cedar Valley time did not get more than a few hundred feet deep at maximum and were generally quite shallow, so if the Solon nautiloids had a diurnal life habit, they did not have to deal with as large a range in depth as the modern *Nautilus* does.

Another feature of this interval is the presence of trilobites inside the shells of some cephalopods. Disarticulated trilobite material can be found (Figure 10), and on very rare occasions an articulated trilobite (usually *Phacops* sp.) can turn up inside cephalopod shells (Davis et al., 2001, p. 41). It is tempting to think that perhaps some trilobites were using these empty shells as shelters.

Figure 9: Specimen of a coiled nautiloid from Upper Solon strata in the Coralville Lake area, next to a similar sized shell of the modern day *Nautilus pompilius*. Found by J. Preslicka.

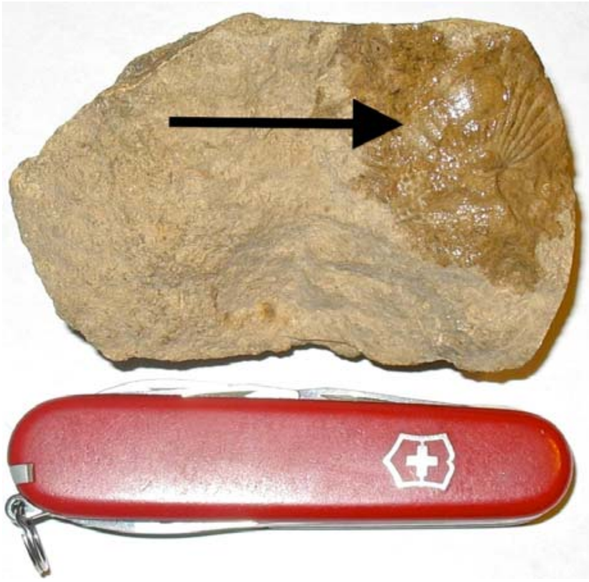


Figure 10: Tail of the trilobite *Scutellum depressum* Cooper and Cloud 1938, found inside the body chamber of an *Acleistoceras* sp. nautiloid. Upper Solon Member, Coralville Lake area, Johnson County. Found by J. Preslicka.

Figure 11: Specimen of *Acleistoceras* sp. from the Upper Solon Member, Coralville Lake area, Johnson County. Found, prepared, & photographed by John Catalani. Note dime for scale.

LITTLE CEDAR FORMATION, LOWER RAPID MEMBER: "BELLULA ZONE" (STAINBROOK 1941A)

Table 3: Lower Rapid Member cephalopod fauna summary.

Cephalopod Type	Name or Shell Form	Approx. # of species present	Relative Abundance
Nautiloid	Orthocones	~1	Relatively common
Nautiloid	Brevicones (Includes *Acleistoceras sp.*)	~2	Both relatively common
Nautiloid	Cyrtocones	1	Relatively common
Nautiloid	Serpenticones	1	Uncommon

Discussion

Cephalopods in the Lower Rapid Member tend to be poorly preserved, which hampers proper identification. Sedimentation rates were slow, and bottom conditions occasionally were dysoxic. Low oxygen conditions can chemically dissolve cephalopod shells relatively quickly, before they get the chance to be buried in the sediment and preserved. Rapid Member cephalopods are often compressed, or only preserve an impression of one side of the shell. *Acleistoceras* sp. (Figure 12) is the most common cephalopod in this interval.

Overall species diversity is similar to that of the underlying Upper Solon Member, but individual abundance is greatly reduced. Still, cephalopods turn up with some regularity in this interval.

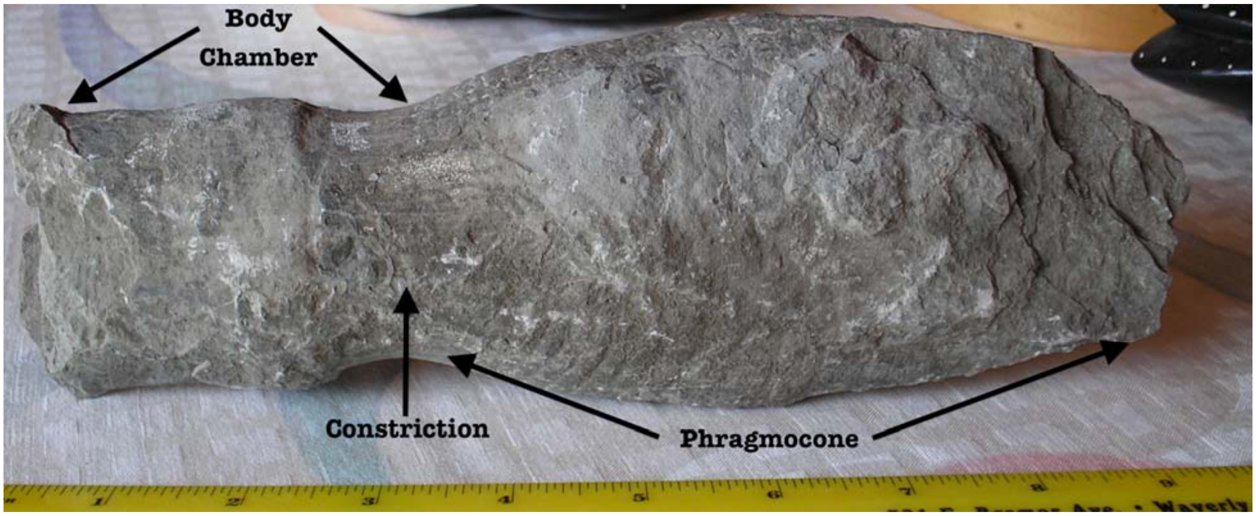


Figure 12: Specimen of *Acleistoceras* sp. from the Lower Rapid Member at Klein Quarry. Found and photographed by G. Rocca. Note the constriction of the body chamber - an important characteristic of this genus.

LITTLE CEDAR FORMATION, MIDDLE RAPID MEMBER:

Table 4: Middle Rapid Member cephalopod fauna summary.

Cephalopod Type	Name or Shell Form	Approx. # of species present	Relative Abundance
Nautiloid	Orthocones	~1	Uncommon
Nautiloid	Brevicones (Includes *Acleistoceras sp.*)	~2	Both uncommon
Nautiloid	Cyrtocones	1	Uncommon
Nautiloid	Serpenticones	1	Uncommon

"PENTAMERELLA ZONE" (STAINBROOK 1941A)

Discussion

The Middle Rapid fauna is very similar overall to the Lower Rapid fauna: generally not well preserved, and low in abundance. Again, the most common cephalopod in this interval is *Acleistoceras* sp. Strata of the Middle Rapid Member can readily be viewed at the Devonian Fossil Gorge below the Coralville Lake Emergency Spillway.

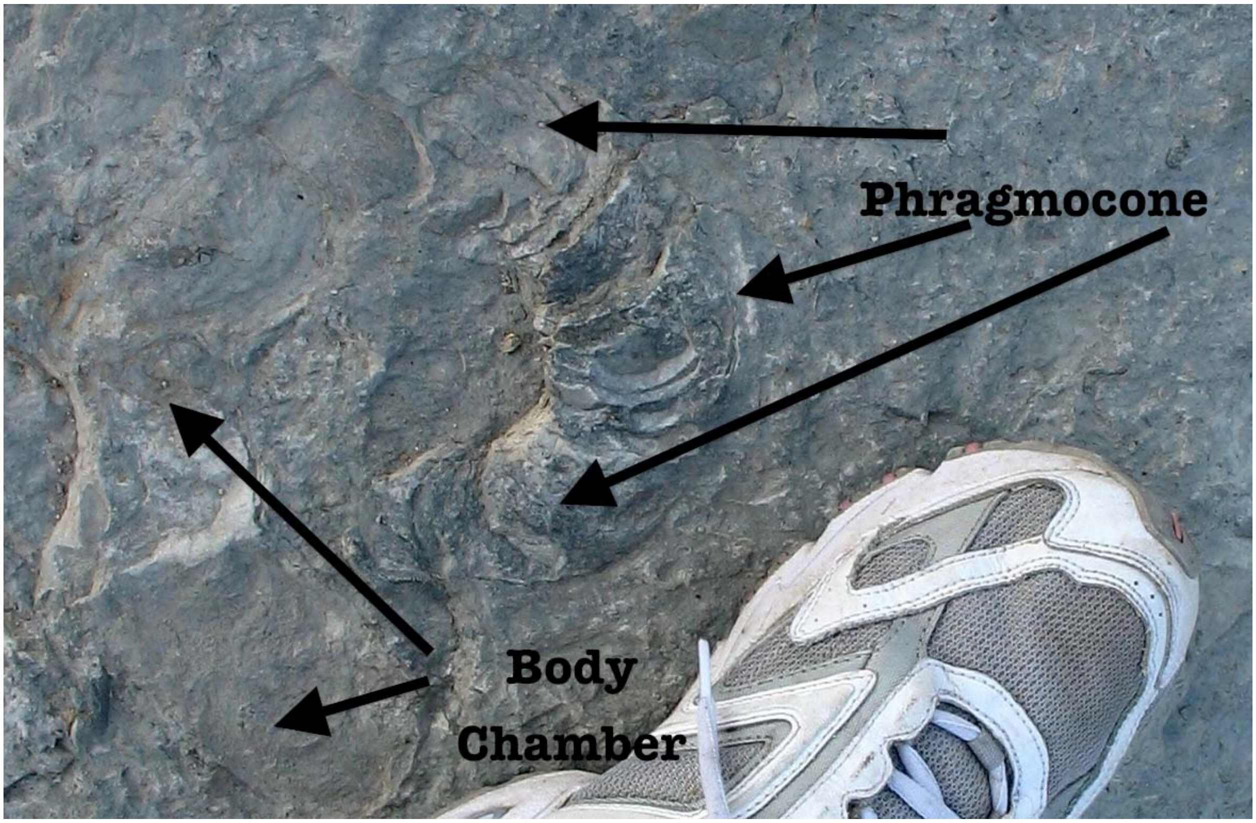


Figure 13: Serpenticonic nautiloid in Middle Rapid Member strata at the Devonian Fossil Gorge, Coralville Lake, IA. Found by Susan Funk of Iowa City and is currently on display at the Coralville Dam's Visitor Center.

Figure 14: Cyrtoconic nautiloid in Middle Rapid Member strata at the Devonian Fossil Gorge, Coralville Lake, IA. Found by J. Preslicka and is currently on display at the Coralville Dam's Visitor Center.

LITTLE CEDAR FORMATION, UPPER RAPID MEMBER: "WATERLOOENSIS ZONE" (STAINBROOK 1941A)

Table 5: Upper Rapid Member cephalopod fauna summary.

Cephalopod Type	Name or Shell Form	Approx. # of species present	Relative Abundance
Nautiloid	Orthocones	~1	Very rare
Nautiloid	Brevicones	~1	Extremely rare
Nautiloid	Serpenticones	1	Extremely rare

Discussion

The cephalopod fauna from the crinoidal beds of the Upper Rapid is extremely sparse. In many years of hunting, the authors have only found a very few specimens of the above listed shell forms. Even the otherwise ubiquitous *Acleistoceras* sp. is not currently known to the authors from this interval.

The Uppermost Rapid preserves banks composed of pulverized echinoderm debris (Curtis Bridge Grainstone unit of Plocher, 1987) deposited in very energetic shallow water (Witzke et al., 1988, p. 233). It would appear that cephalopods did not prefer this sort of habitat, or that the constant wave action pulverized many of their shells prior to burial & preservation.

Figure 15: Serpenticonic nautiloid fossil from the Curtis Bridge Grainstone unit (Plocher, 1987) of the Upper Rapid Member. Found by J. Preslicka in the Mid River Marina Quarry, Johnson County.

Table 6: Lower Cou Falls Member cephalopod fauna summary.

Cephalopod Type	Name or Shell Form	Approx. # of species present	Relative Abundance
Nautiloid	Orthocones	~1	Uncommon
Nautiloid	Brevicones (Includes *Acleistoceras sp.*)	~2	Moderately common in basal beds
Nautiloid	Nautilicones	1	Extremely rare

CORALVILLE FORMATION, COU FALLS MEMBER: "CRANAENA ZONE" (STAINBROOK 1941A)

Discussion

Cephalopods become a bit more abundant and diverse in the basal Coralville Formation, which is the bottom of a transgressive-regressive cycle (Witzke et al., 1988, p. 246, figure 13). *Acleistoceras* sp. (Figure 16) returns, and is the most common component of Cou Falls cephalopod faunas. It is accompanied by a very small (~2" at maturity) Oncocerid nautiloid, as yet unidentified. Nautilicones are extremely rare in this interval, only a single specimen having been encountered by the authors as of yet. As the name Coralville suggests, corals are abundant in this interval, and some of them nucleated around dead cephalopod shells.

Figure 16: Specimen of *Acleistoceras* sp. from the basal Cou Falls Member of the Coralville Formation. Arrow points to last suture. Body chamber is to the right, phragmocone to the left. Note Leatherman pocket tool for scale. Found by J. Preslicka.

CORALVILLE FORMATION, COU FALLS MEMBER: "IDIOSTROMA BEDS" (STAINBROOK 1941A)

No cephalopods have yet been found by the authors in this interval. This portion of the Cou Falls records a shallowing upwards depositional trend, and preserves branching coral and stromatoporoid thickets (Witzke et al., 1988, p. 238). The waters in such environments were very shallow, with lots of wave action due to storms. This was not a habitat preferred by cephalopods, leaving the only opportunity for preservation being drift shells. Some of these likely were brought in from deeper water areas to the southeast during times of storms, but perhaps were pulverized by wave action prior to burial and preservation.

Table 7: Basal Iowa City Member cephalopod fauna summary.

Cephalopod Type	Name or Shell Form	Approx. # of species present	Relative Abundance
Nautiloid	Orthocones	~1	Not known outside the basal"Gastopod/Oncolite Beds"
Nautiloid	Brevicones (Includes *Acleistoceras sp.*)	~1	Not known outside the basal"Gastopod/Oncolite Beds"

CORALVILLE FORMATION, BASAL IOWA CITY MEMBER: "GASTROPOD/ONCOLITE BEDS"

Discussion

Cephalopods make their final appearance in Lower Cedar Valley Group strata in the basal Iowa City Member. This interval in Johnson County locally preserves very shallow lagoonal environments, where shells of *Acleistoceras* sp. (see Figure 17) and indeterminate orthocones are sometimes encountered.

These specimens appear likely to represent cases of post-mortem transport. Modern day Nautilus lives in the southwestern Pacific Ocean and is not known to range north of the Phillipines, yet its shells occasionally are found well to the north on beaches in places such as Japan and China (Moore, 1964, p.p. K88, K90). Sometimes when a *Nautilus* dies, its shell will float to the surface of the sea where it can then be moved about by wind and sea currents, and thus be deposited in an area far from where the animal actually lived. In the case of the Iowa City Member cephalopods, some ancient storm(s) probably blew injured, dead or dying *Acleistoceras* sp. (see Figure 17) into the lagoons present in the Johnson County area at the time the sediments were deposited.

The Iowa City Member nautiloid specimens are also often found encrusted with several layers of algae. This implies that the shells eventually settled to the bottom of the lagoon, and that the algae had enough time to grow on the shells prior to their burial. They are often also found associated with abundant gastropod shells, some of which presumably fed on the prolific amounts of algae that were present in the lagoonal environment.

No cephalopods are currently known by the authors from the Iowa City Member above the Gastropod/Oncolite horizon.

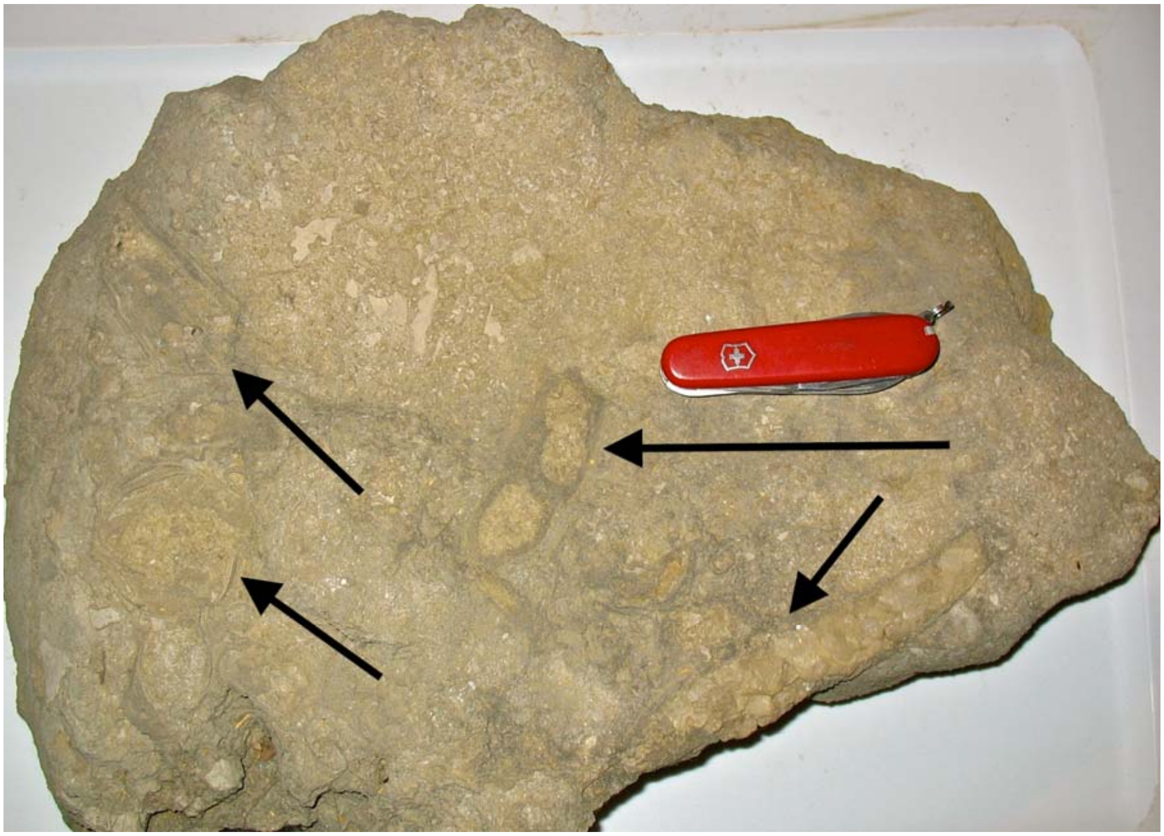


Figure 17: Slab with several *Acleistoceras* sp. (arrows) encrusted with algae. Basal Iowa City Member, Coralville Lake area, Johnson County. Found by J. Preslicka & C. Newsom.

Table 8: Summary of number of cephalopod species present in the units of the Lower Cedar Valley Group: Little Cedar and Coralville Formations in the area of Johnson County. Note overall decline in number of species from the oldest strata (Lower Solon Member) to the youngest (Iowa City Member).

Stratigraphic Interval	Approx. # of species present
Lower Solon Mb. "independensis"	~9
Upper Solon Mb. "profunda"	~6
Lower Rapid Mb. "bellula"	~5
Middle Rapid Mb. "pentamerella"	~5
Upper Rapid Mb. "waterlooensis"	~3
Lower Cou Falls Mb. "Cranaena"	~4
Upper Cou Falls Mb. "Idiostroma"	0 known
Basal Iowa City Mb. "Gastropod-Oncolite"	~2

CONCLUSION

Hopefully this article has helped elucidate that the biodiversity of cephalopods in strata of the Lower Cedar Valley Group is greater than it might appear at first glance. The fact that so many differing forms of cephalopods can be found in these rocks hints at the complexity of the marine ecosystem which was present at the time the sediments were deposited. It would seem likely that cephalopods filled many different ecological niches in the Cedar Valley Sea.

We have begun to compile faunal lists so that the entire fauna of each stratigraphic unit may be documented. However, work remains, beginning with taxonomy--assigning names to the cephalopods and placing them within the phylogenetic framework of cephalopod evolution. After this is accomplished, detailed analysis of the Iowa Devonian cephalopod fauna can be made by tracking the taxa through time and comparing the Iowa fauna with other Devonian cephalopod faunas both continent- and world-wide. Correlating the Iowa fauna with stratigraphically important taxa can result in placement of the fauna within the context of Global Stratigraphic Units. To these ends a large sample of cephalopods has been assembled and additional careful collections are underway, but much work still remains to be done.

ACKNOWLEDGMENTS

Many thanks are due to Mr. John Catalani for his help in the writing and proofreading of this manuscript, as well as providing photos of several of his specimens for us to use within it.

Also many thanks to the River Products Company, Inc. for allowing the Mid America Paleontology Society and Cedar Valley Rocks & Minerals Society access to their quarries for club field trips, which have produced a good many cephalopod specimens over the years!

REFERENCES

Cooper, G.A. and P.E. Cloud, 1938, New Devonian Fossils from Calhoun County, Illinois. Journal of Paleontology 12:444-60.

Davis, R.A., Fraaye, R.H.B., and Holland, C.H., 2001, Trilobites within nautiloid cephalopods. Lethaia, Vol. 34, pp. 37-45. Oslo. ISSN 0024-1164.

Miller, A.K., 1936, Devonic Ammonoids of Iowa, Iowa Academy of Sciences, Fiftieth Meeting, April 3, 1936, pp. 336-338.

Moore, R.C. (editor), 1964, Treatise on Invertebrate Paleontology, Part K: Mollusca 3, Cephalopoda-General Features-Endoceratoidea-Actinoceratoidea-Nautiloidea- Bactritoidea. Copyright 1964 by the University of Kansas Press and the Geological Society of America.

Plocher O.W., 1987, A crossbedded grainstone unit in the Upper Rapid Member, Cedar Valley Formation, Middle Devonian of Johnson County, Iowa (abs.): Proceedings of the Iowa Academy of Science v. 94, Program Abstracts, 99th session, Abs. No. 144.

Stainbrook, M.A., 1941a, Biotic analysis of Owen's Cedar Valley Limestones: Pan-American Geology, v. 75, p. 321-327.

Thompson, I., 1982, The Audubon Society Field Guide to North American Fossils. Published by Alfred A. Knopf, Inc., of New York, 6th printing 1990.

Ward, P.D., 1988, In Search of Nautilus - Three Centuries of Scientific Adventures in the Deep Pacific to Capture a Prehistoric-Living-Fossil. A New York Academy of Sciences book, published by Simon & Schuster Trade Division.

Witzke, B.J., Bunker, B.J., and Rogers, F.S., 1988, Eifelian through Lower Frasnian stratigraphy and deposition in the Iowa area, Midcontinent, U.S.A: *in* N.J. McMillan, A.F. Embry, and D.J. Glass (eds.), Devonian of the World: Canadian Society of Petroleum Geologists, Memoir 14, v.1, p. 221-250.

THE PENNSYLVANIAN STRATA OF JOHNSON COUNTY, IOWA: CHANNEL AND KARST FILLS IN KLEIN AND CONKLIN QUARRIES

Thomas R. Marshall and Brian J. Witzke

Iowa Geological & Water Survey
Iowa Dept. Natural Resources
Iowa City, IA 52242-1319
thomas.marshall@dnr.iowa.gov
brian.witzke@dnr.iowa.gov

INTRODUCTION

In Johnson County, Pennsylvanian strata are present as nonmarine or marine-influenced shales, mudstones, siltstones, sandstones, and conglomerate in incised paleovalleys in Middle Devonian limestone or Upper Devonian shale or as paleokarst fills in Devonian carbonates (Witzke, 1984) (Figures 1a, 1b). While the extensive coals deposits of further west and southwest in Iowa are not present in Johnson County, a few thin coal seams have been found, and most of the strata have at least some carbonaceous material in them (1984).

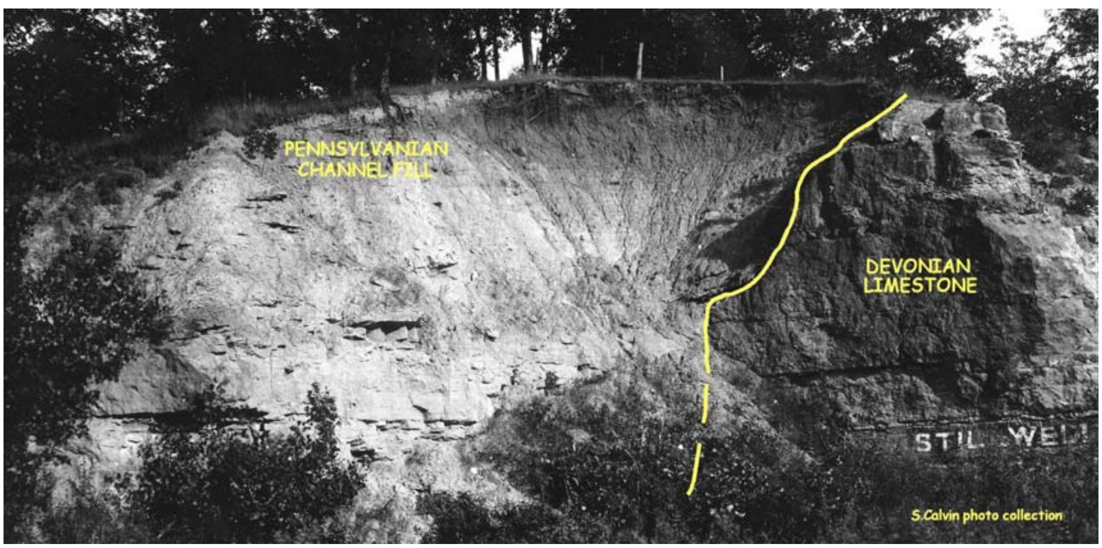


Figure 1a. Pennsylvanian channel fill in Devonian Limestone near present-day location of Mayflower Dormitory, 1858, from Samuel Calvin collection. Line marks channel margin.

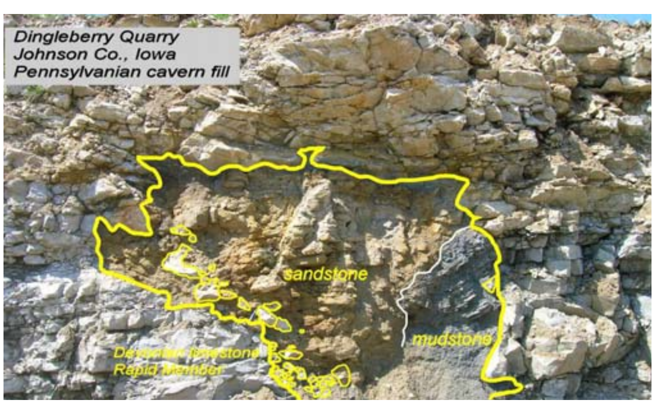


Figure 1b. Pennsylvanian sandstone and mudstone filling a cavern opening in the Devonian Rapid Member of the Little Cedar Formation of the Cedar Valley Group at Dingleberry Quarry, north of Iowa City. Line delineates outer margins of paleokarst fill.

Pyrite and marcasite are very common in Pennsylvanian rocks in Johnson County, some of which have oxidized to limonite. Siderite (iron carbonate) is present as concretions or cement. Some strata are locally calcareous. Fossils include *Lepidodendron* (scale trees), *Calamites* (horsetails), ferns, and spores (1984).

The Pennsylvanian of Johnson County (Figure 2) has been correlated with the Lower Pennsylvanian (Morrowan) "Caseyville" Formation found around Muscatine and further east in the Illinois Basin; however, it is possible that some Middle Pennsylvanian (Desmoinesian) units (such as the Spoon Formation or Cherokee Group) are present in Johnson County as well (Ludvigson and Nations, 1989). Currently, sandstone petrography is used for an informal correlation of units. Fluvial (river) sandstones of the Caseyville are mature quartzarenites while those of the Spoon or Cherokee are immature feldspathic litharenites (Witzke and Kay, 1984, Ludvigson and Nations, 1989). This difference in sandstones may be a result of a change in provenance and/or climate between the Lower and Middle Pennsylvanian.

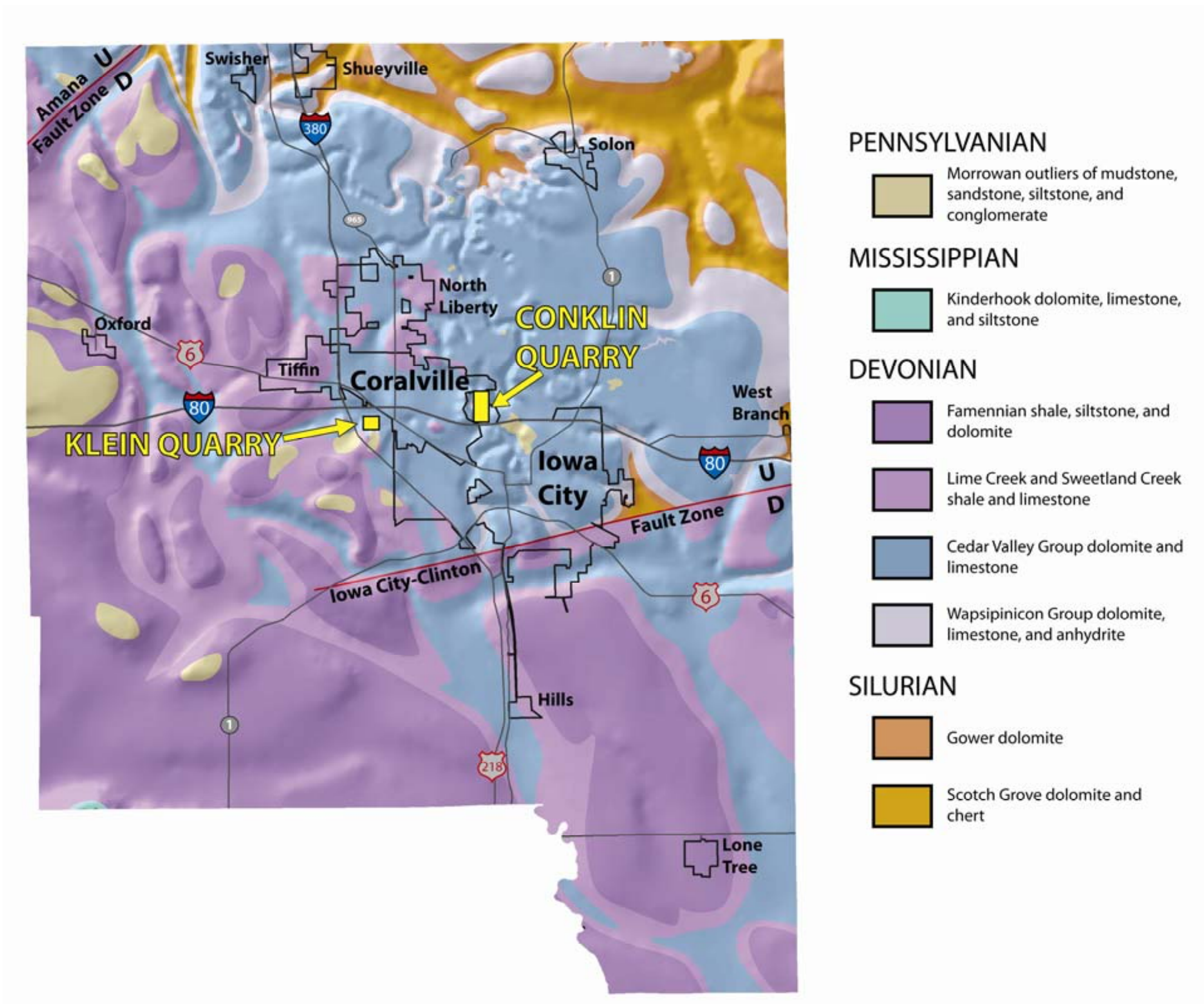


Figure 2. Bedrock geologic map of Johnson County; Pennsylvanian outliers are the scattered tan blobs on the map. Much of the county geology consists of Devonian shales, limestones, and dolomites within Fammenian formations or the Cedar Valley Group (purple and blue regions). Some Mississippian strata are present in the extreme southwestern corner of the county and Silurian strata in the northeast corner. Other significant features include the Iowa City-Clinton Fault Zone and the Amana Fault Zone (**'U'** indicates side of the fault that has moved up relative to other side **'D'**). Shading on map indicates bedrock topography. Please note location of Klein and Conklin quarries. Derived from 2010 bedrock geologic map by the Iowa Geological and Water Survey.

During the Pennsylvanian, Iowa was part of extensive lowland situated in continuously wet equatorial belts. While Iowa was warm, wet, and tropical, areas that occupied the Southern Hemisphere of the time such as India, South Africa, Australia, and Saudi Arabia were covered in continental glaciers. Expansion of these glaciers caused sea level to fall globally leaving low-lying areas such as Iowa as exposed dry land. As these glaciers melted, global sea level rose and Iowa was covered by shallow seas. Periodic expansion and shrinkage of glaciers in the Southern Hemisphere resulted in the deposition of repeated packages of nonmarine and marine sediments in areas such as Iowa, referred to by geologists as cyclothems. The high amount of biomass in swamps and forests that lined ancient shallow seas and rivers contributed to extensive peat deposits which through burial, heat, pressure, and time became coal. Frequent rainfall during this time contributed to increased weathering and erosion of highlands to the north and east of Iowa; during times of low sea level, river systems deposited significant amounts fluvial sand, silt, and clay. When Iowa was covered by shallow seas, lime mud and marine clay were deposited. The sediments deposited by Pennsylvanian seas in Johnson County were eroded away over time leaving behind outliers of nonmarine or marine-influenced deposits (Figure 2). As Pennsylvanian time progressed, Iowa moved north into drier latitude resulting in the deposition of less coal and sandstone and more carbonates and caliche soils.

DESCRIPTIVE GEOLOGY

Klein Quarry

At Klein Quarry, Pennsylvanian strata include gray silty mudstones, siltstones, sandstones, and quartz-granule conglomerates which fill paleovalleys incised into the underlying limestone as well as paleokarst fills in the limestone (Figures 3 and 4). In addition, there is a channel complex with multiple bedform geometries and reactivation surfaces (Figure 5); the youngest channel is filled with a dark gray, almost black, mudstone interlaminated with siltstone. Many channels have significant deposits of pyrite at their base (Figure 6), and pyrite nodules and disseminated pyrite are common in channel deposits as well as pyritized wood (*Cordaites* pith casts). Oxidation of the pyrite upon exposure to air during excavation is responsible for the reddish brown or bright orange stain seen on the highwalls and spoil piles in the quarry (Figure 7). Siderite cement, concretions, and stringers are also found, some yielding carbonized plant debris (Figure 8).

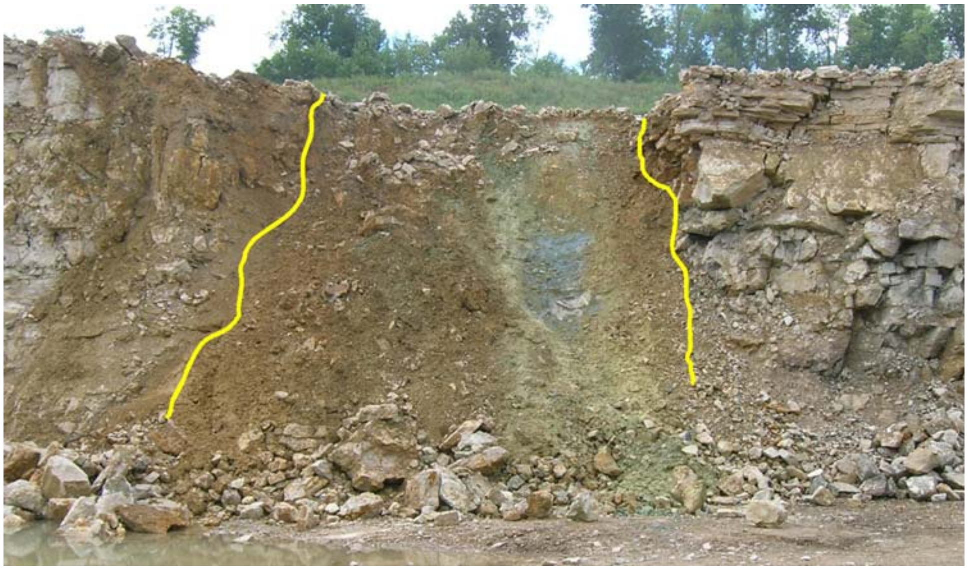
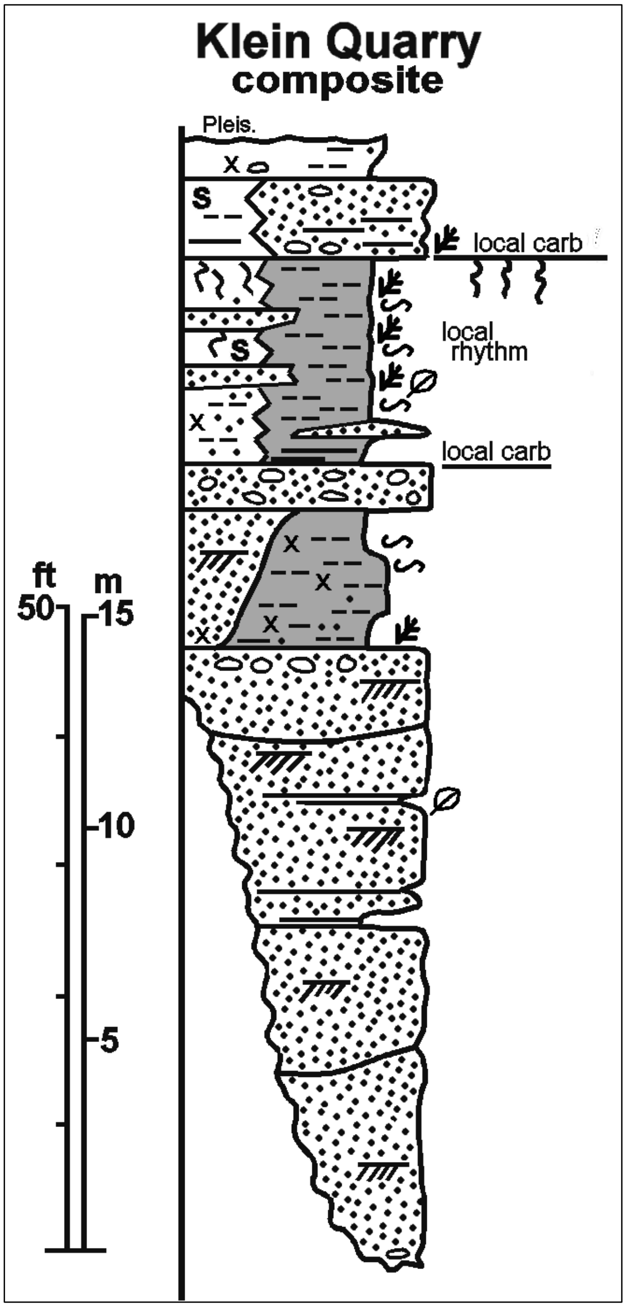


Figure 3. Paleokarst fill in Devonian limestone of greenish-gray to light gray Pennsylvanian mudstone at Klein Quarry, lines mark margins of paleokarst



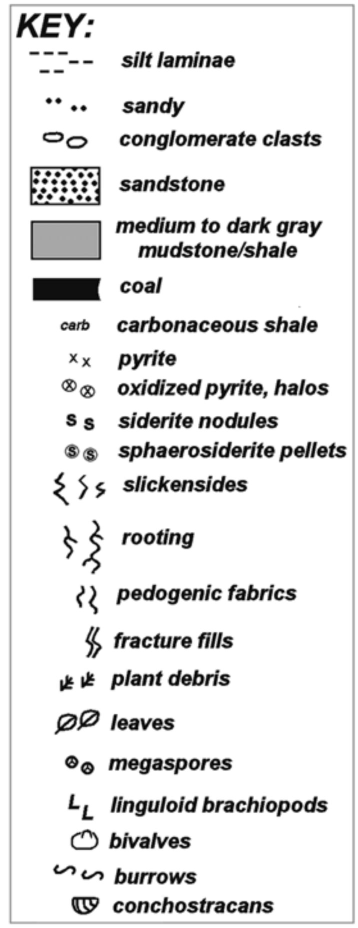


Figure 4. Composite section of Pennsylvanian strata at Klein Quarry, note rhythmites in mudstone and channel-filling nature of some strata

Figure 5 (next page). Photo tracing of multiple channel complex at Klein Quarry, diverse bedforms and channel-filling lithologies along with multiple reactivation surfaces can be seen. Photographs included in figure illustrate field appearance of diagram sections highlighted by red boxes. Note foresets at far left of lower diagram which may be point bar deposits. Star indicates site sampling at base of dark gray mudstone for miospores in southwest corner of pit (KLQ-SWBU). Appendix A lists the taxa collected from this site; some of the more significant miospores are illustrated in Plate 1. From Witzke, 2010.

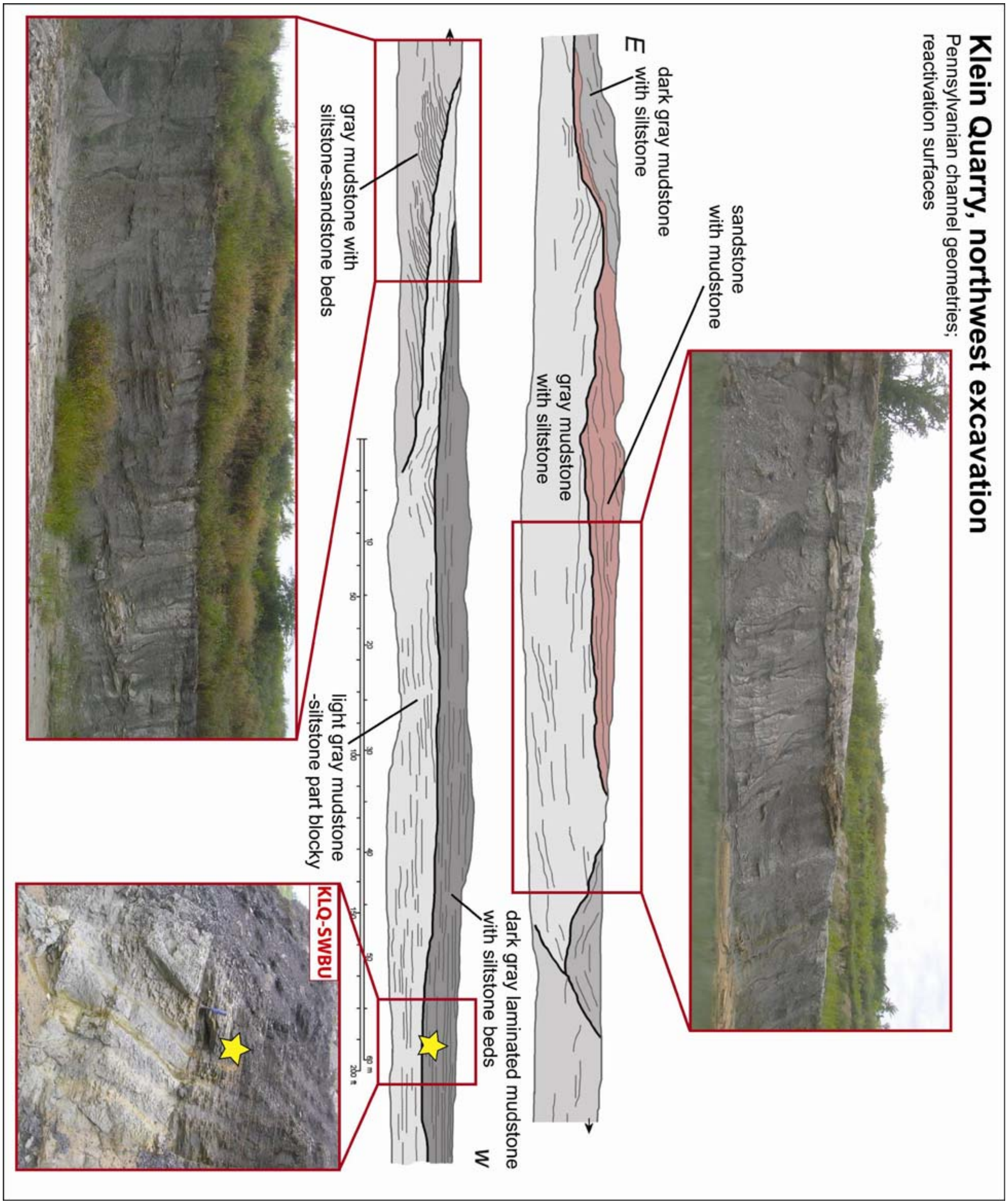


Photo tracing by Brian Witzke

Figure 6. Accumulation of Pennsylvanian pyrite at base of sideritc sandstone or siltstone at Klein, dime for scale

Figure 7. Two examples of the extensive staining from oxidation of pyrite at Klein Quarry

Figure 8. Carbonized plant debris in sideritic sandstone, Klein Quarry, rock hammer for scale

Sandstones are light to yellowish gray, fine to very-coarse-grained, quartzose, pyritic and sideritic, subangular to subrounded, and locally argillaceous. Carbonaceous specks, carbonized logs, and large *Cordaites* leaves are often found in the Pennsylvanian sandstones at Klein. Some sandstones also have carbonaceous stringers or laminations. These units are usually heterolithic with fine laminations of siltstone and mudstone and exhibit various bedforms such as ripples, cross-beds, and foresets. Localized calcareous cement is present in addition to pyrite and siderite cement. Some dark or FeOx Liesegang banding can be seen in fine-grained sandstone. 1 mm to 3 cm mud clasts are also present. The dominant quartz grains indicate that these units may be equivalent to the Lower Pennsylvanian "Caseyville" from elsewhere.

Along with siltstones, mudstones are the dominant lithology at Klein Quarry; they are light to dark gray, strongly-laminated, frequently contain siderite and/or pyrite nodules, and are silty to varying degrees. There are three distinctive dark gray mudstone facies: 1. mudstone with burrows, 2. largely unfossiliferous, featureless mudstone, and 3. carbonaceous, plant-rich mudstones. The mudstone facies with burrows also yields abundant miospores and other carbonaceous debris. The carbonaceous, plant-rich mudstones contain cuticle-rich leaf beds, miospores, and carbonized wood debris. The dark gray mudstones are heterolithic with interlaminations/interbedding of siltstone and sandstone and lenses of very fine-grained sandstone or siltstone (Figure 9). The silt laminations/interbeds vary in thickness with some bundling of similar-sized laminae; convoluted laminae indicate bioturbation (Figure 10). Because of the rhythmic thickening and thinning of laminations grouped in repeating clusters, it is likely these silt laminae are tidal rhythmites (Witzke, 2010). Light gray mudstones have silt laminations, slickensides, pyrite and FeOx nodules, plant debris, *Cordaites* leaves, and are locally sandy. Silt-filled burrows are also present.

Conglomerates or conglomeratic sandstones are usually light to yellowish gray, pyritic, carbonaceous, and locally calcareous. They contain quartz granules or gravels and conglomeratic clasts. Plant debris and carbonaceous/organic laminations are also found.

Figure 9. Heterolithic interbedding of dark gray mudstone and light-colored siltstone/sandstone beds in the Pennsylvanian section at Klein Quarry along southern part of pit. Interbedding or interlamination can be seen at various scales in outcrop. Believed to be tidal rhythmites as discussed in the text. Rock hammer for scale.

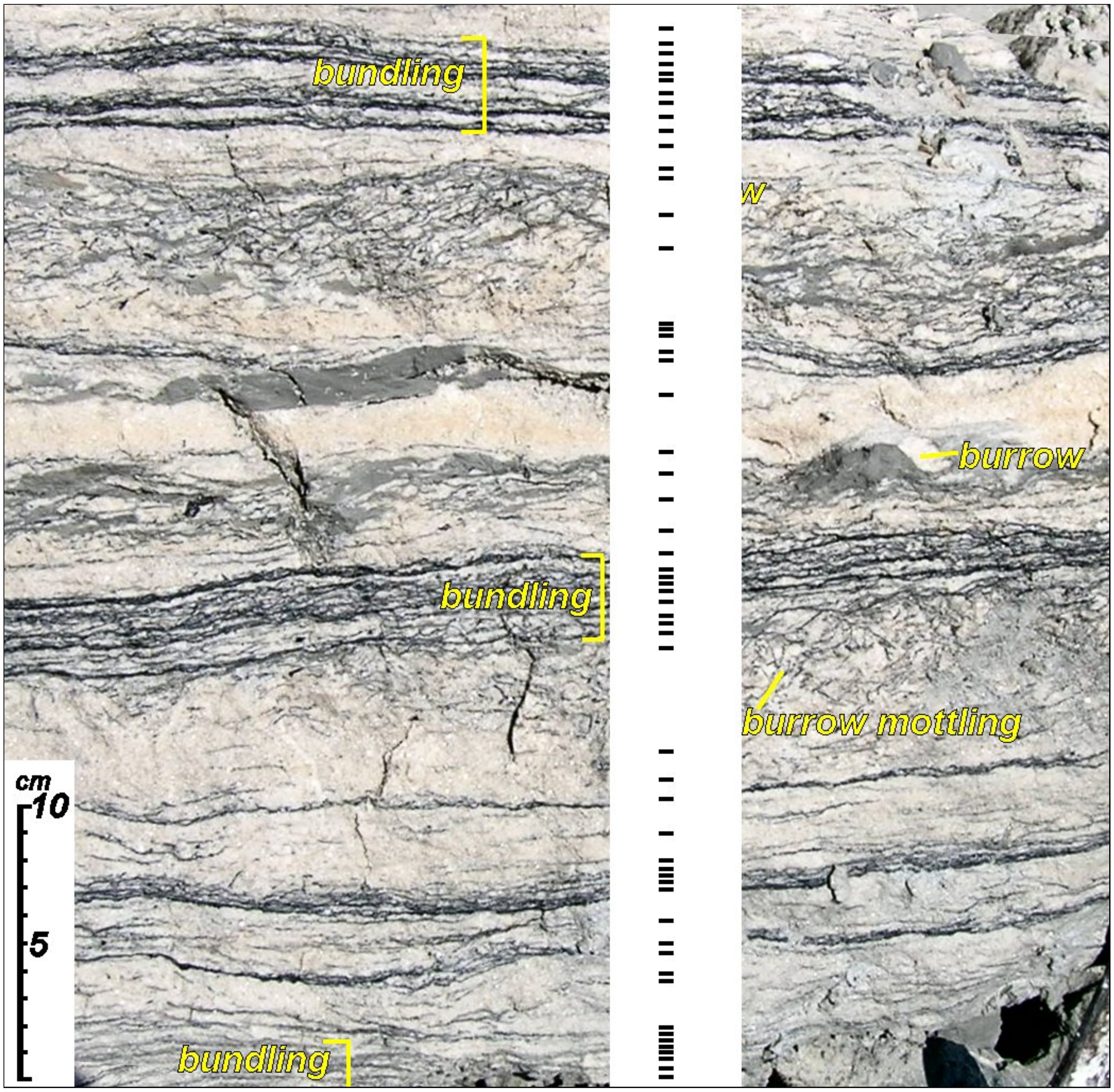


Figure 10. Close up of finer-scale laminations between lighter-colored siltstones and darker mudstones that can be seen in highwall and in rocks in spoil piles. Thickness of laminations appears to increase and decrease cyclically. The thinner, darker shalier laminations are clustered in bundles; the bundles themselves appear to be repeated in a cyclic pattern. These laminations are interpreted to be tidal, and the rhythmic patterns are indicative of tidal cycles. Alteration between mudstone and siltstone likely resulted from patterns in sedimentation due to changes in water energy throughout the tidal cycle. Short hash marks running close middle of figure denote shaly laminations. Convolutions or disruptions in laminae indicate extensive burrowing (bioturbation). The tidal laminations and burrowing provide evidence that some of the Pennsylvanian strata at Klein Quarry and Johnson County were deposited in at least a marine-influenced environment. Please note scale bar in lower left corner.

Conklin Quarry

At Conklin Quarry, Pennsylvanian sandstones, mudstones, and conglomerates can be found in paleovalleys in Devonian limestones as well in paleokarst openings within the Cedar Valley limestones (Witzke, 1984). In some places in the pit, especially along the southeast portion of the main pit, sandstones and mudstones have filled channels that have incised as much as 13 feet (4 meters) into the underlying Coralville Member of the Cedar Valley Formation (Witzke, 1984).

Sandstones are white to gray with some local orange iron oxide staining, fine to medium-grained, and mostly poorly-cemented with minor pyrite or ferric oxide cement. Some sandstone beds are cross-bedded with southeast-trending cross-sets while others are laminated (Witzke, 1984). Some of the sandstones are heterolithic with laminae of gray silty clay or siltstone. In the southeast part of the main pit, plant fossils are common in the sandstones, and burrows up to 2 inches (5 cm) are found on the surface of some of the beds (Witzke, 1984). Plant fossils are usually found in carbonaceous stringers, as scattered carbonized or pyritized woody debris, or as impressions in the sandstone (Witzke, 1984).

The sandstones from the southeast area of the pit resemble quartzarenites with dominant quartz grains and trace feldspar and other grains. In addition they are white with localized orange iron oxide staining, fine to medium-grained, moderately well sorted, and have angular to rounded grains (Witzke, 1984). Euhedral to subhedral quartz overgrowths around grains is common (Witzke, 1984). In the south-central part of Conklin Quarry, Pennsylvanian sandstones are predominantly fine-grained with sparse medium to coarse grains, poorly sorted, locally silty, and argillaceous. Grains are subangular to rounded, most being subrounded. There may be more feldspar present and quartz overgrowths are not common (Witzke, 1984). Based upon their petrographic differences, the sandstones from the southeast portion of the quarry may be equivalent to the Lower Pennsylvanian "Caseyville" while those from the south-central part equivalent to Middle Pennsylvanian Spoon or Cherokee sandstones.

Mudstones and shales are medium to dark gray, partially laminated, and locally sandy or silty. Some of the mudstones are heterolithic with lenses of siltstone or fine-grained sandstone; some of the lenses are cross-bedded and pyrite-cemented. The mudstones are carbonaceous including carbonized wood debris (Witzke, 1984). Conglomeratic sandstones with quartz, chert, and limestone clasts locally occur above Devonian limestones in the old quarry (Witzke, 1984).

INTERPRETATIVE GEOLOGY

Sometime during the Late Mississippian, a significant drop in overall global sea level left the Midwest exposed dry land for around 20 million years. This period of non-deposition due to exposure coupled with broad uplift of the Wisconsin Dome and Arch led to the erosion and removal of large amounts of Ordovician, Silurian, Devonian, and Mississippian strata in eastern Iowa (Witzke, 1984). In Johnson County, this erosion removed much of the Mississippian strata was removed except for a small amount in the extreme southwestern corner of the county. In the northeastern corner and along the northern edge of Johnson County, Devonian strata were removed revealing the underlying Silurian dolomites (Witzke, 1984).

During this time of exposure, the Devonian limestones and dolomites underwent weathering and karstification creating caverns and vugs in the rocks. During the early Pennsylvanian, an overall rise in global sea level rose caused Iowa to be periodically covered by shallow seas. The karst features may have been flooded by the shallow seas resulting in deposition of sediments into them; furthermore, these karstic openings may have been filled by Pennsylvanian streams or stream flooding. Other nonmarine sediments may have filled karst by caving or washing in of surrounding material around the opening.

Falling base level as sea level dropped caused streams draining the Pennsylvanian landscape of Iowa to cut into underlying deposits creating incised channels or valleys. As sea level rose again, the incised valleys flooded shoreward resulting in channel aggradation and deposition of sediments within paleovalleys and floodplains upstream (Witzke, 1984). The cross-bedded sandstones in Klein and Conklin quarries were likely deposited in active channels. Mud, limestone, quartz, and chert clasts in the conglomeratic sandstones were likely ripped up by active stream erosion or collapse of overbank deposits and incorporated into fluvial sediments within the channel. Furthermore, the bedforms seen at Klein Quarry such as the ripples, cross-beds, and foresets are strongly indicative of point bar deposits. The multiple-channel complex at Klein and elsewhere in Johnson County were likely deposited by younger channels incising into older channel deposits either through changes in base level through rising and falling of sea level or migration of river channels within the paleovalley (Witzke and Kay, 1984). Mudstones and siltstones overlying the cross-bedded sandstones or interlaminated with sandstones in the upper part of the channel fill indicate a decrease in water energy during the later part of deposition (Witzke and Kay, 1984). At Conklin Quarry, the northwest-southeast trend of the channels aligns closely with those around the Mayflower Dormitory and northern part of Iowa City indicative of a larger areal channel system (Witzke, 1984; Witzke and Kay, 1984).

Laminated mudstones and siltstones probably resulted from floodplain deposits. Carbonaceous laminations and plant debris were likely buried by sediment on the floodplain; larger logs could have been displaced by higher energy floodwaters and later buried (Figure 11). Well-preserved delicate leaves and other similar plant material (Figure 12) were probably buried rapidly by very fine-grained sediment in very still water farther away from the channel on the floodplain. Laminated mudstones without plant fossils or burrows were probably derived from sediment deposited in areas that underwent inundation and sedimentation frequent enough to prevent the growth of extensive vegetation (Witzke and Kay, 1984).

Figure 11. *Sigillaria* log in Pennsylvanian sandstone, Klein Quarry. Dime for scale

Slickensides and rootings in the light gray mudstones indicate that some sediment underwent pedogenesis becoming ancient soils or paleosols (Figure 13). During times of low sea level, the coeval interfluve surfaces between the incised paleovalleys became well-drained, dropping the water table. Afterwards, over time, soil-forming processes took place, and paleosols developed (Howell and Flint, 2003). Vegetation grew in these ancient soils, and their roots (Figure 14) were preserved in the rock record within the paleosols.

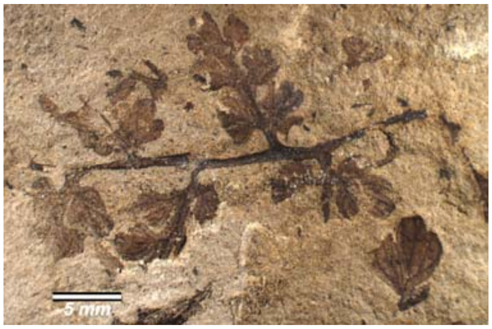


Figure 12. Well-preserved leaves and branch of *Eusphenopteris*, Klein Quarry

Initially, it was believed that the Pennsylvanian deposits in Johnson County were all deposited in a fluvial/nonmarine environment as the marine flooding of incised valleys may have only reached Scott or Muscatine County (Witzke, 2010). However, there is abundant evidence that there was also deposition in a marine-influenced estuarine environment in Johnson County as well.

Figure 13. Quaternary till (small mound on top of knoll) overlying Pennsylvanian paleosol (slopes of knoll), Klein Quarry, note mottling in paleosol. Thomas Marshall standing next to paleosol for scale.

The sulfate for the abundant pyrite found in the Pennsylvanian in both quarries was likely sourced from seawater. Fossils such as linguloids and burrows are also marine indicators (Witzke, 2010). The best indicator of an estuarine environment in Johnson County is the tidal rhythmites in the dark gray mudstones because it reflects the tidal influence on the streams within the paleovalleys (Figure 15). Heterolithic laminations and interbedding of mudstone, siltstone, and sandstone may have resulted from alternating depositional energy during the tidal cycle where tidal currents deposited coarser sand and silt while finer mud settled out of suspension during periods of slack tide (Howell and Flint, 2003). If these are estuaries, they were probably very large, extending over 400 km northwestward from southern Illinois into southeastern Iowa (Witzke, 2010). For a comparison, figure 16 is a block diagram of estuarine facies in an incised valley from the Book Cliffs in Utah.

Figure 14. An example of rooting, Klein Quarry, rock hammer for scale

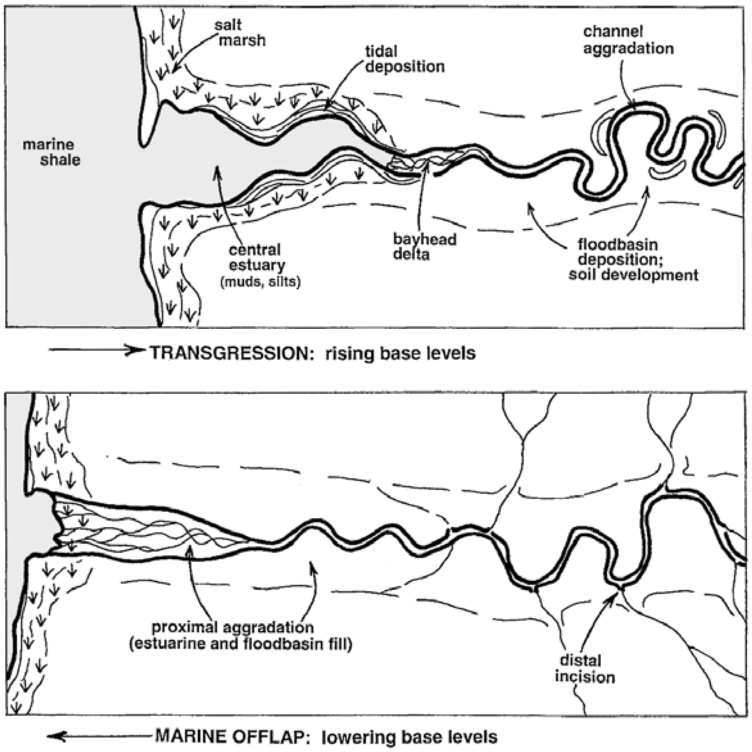


Figure 15. Lower Pennsylvanian estuaries in southeast Iowa during sea level rise (top) and during sea level fall (bottom), note upstream channel aggradation and tidal deposition in top diagram and channel incisement in bottom diagram. Estuaries may have reached over 400 km into Johnson County as evidenced by tidal rhythmites in Klein Quarry (Witzke, 2010).

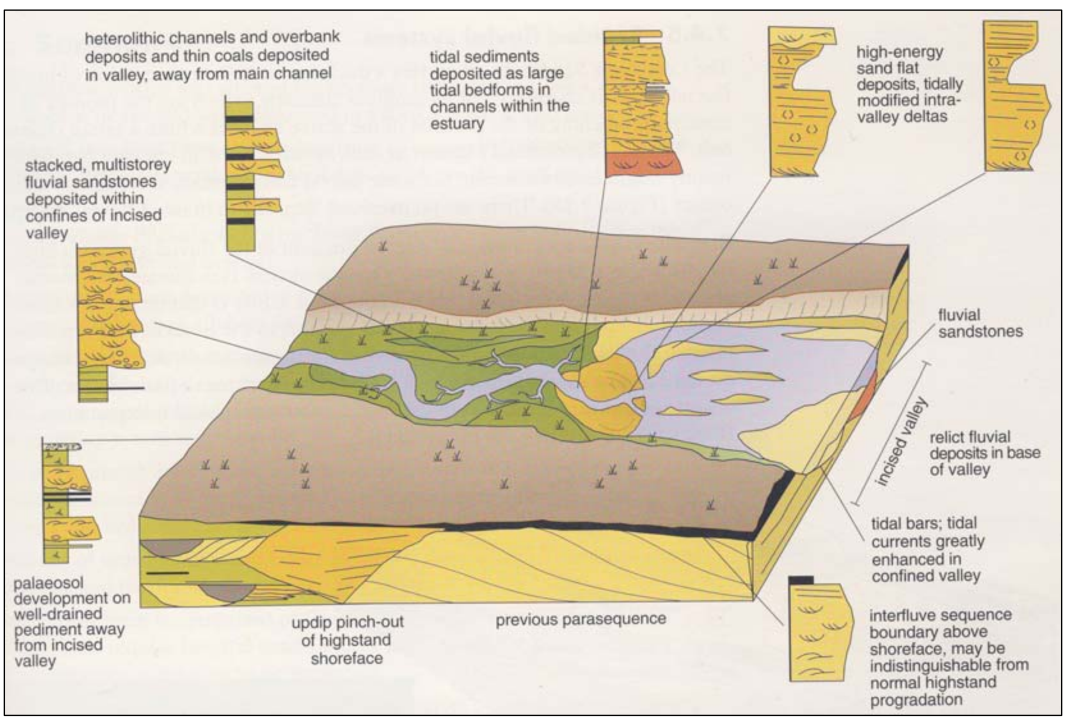


Figure 16. Block diagram of estuarine facies found at Book Cliffs, Utah, compare with above diagrams. Although based on Cretaceous rocks from a different area and greater landscape relief, this diagram is a good visual aid to see the spatial relationships of similar facies found at Klein Quarry such as paleosols, tidally-influenced heterolithic dark gray mudstones, the stacked multi-channel complex, and conglomeratic sandstones which may be indicative of incisement or overbank deposits (Howell and Flint, 2003).

AGE OF PENNSYLVANIAN STRATA IN JOHNSON COUNTY

As previously mentioned, sandstones in Klein and Conklin quarries have been informally correlated with Morrowan "Caseyville" strata further east in Scott and Muscatine counties on the basis of sandstone composition. Furthermore, the presence of sandstones with a higher amount of feldspar (some possibly up to 27%) and other grains in Johnson County seem similar to the immature feldspathic litharenites of Desmoinesian Spoon Formation or Cherokee Group found elsewhere (Ludvigson and Nations, 1989). Therefore, a possibility exists that some Pennsylvanian strata in Johnson County are Desmoinesian. Further petrographic work is needed.

Samples collected from cores and surface exposures in the Pennsylvanian from Klein Quarry (Figures 5, 17, and 18, Appendix A) have yielded miospores identified by Bob Ravn as *Velamisporites radiatus* and *Savitrisporites asperatus* (Plate 1 and Appendix A) which have only been identified from the Wildcat Den Coal further east which is Morrowan (Ravn, personal communication, 2010). However, Ravn noted that, while common Morrowan taxa such as those found at Wyoming Hill in Muscatine County are present in strata from Klein Quarry, definitive Caseyville indicators such as *Schulzospora rara* are absent (personal communication, 2010). He therefore concluded that deposits from Klein Quarry may be younger than other Caseyville exposures such as Wyoming Hill. Klein samples yielded *Densosporites irregularis* (Plate 1 and Appendix A) in some numbers which does range into the Atokan, although rarely (Ravn, personal communication, 2010). Furthermore, palynological distributions from definite Morrowan strata to definite Atokan strata have not been documented to date (Ravn, personal communication, 2010). Because the possibility of Atokan strata cannot be completely ruled out, Ravn has supplied an age range for the Klein Quarry sections of latest Morrowan to basal Atokan (personal communication, 2010). Further palynological work will be needed for a more positive age determination.

CONCLUSION

Outliers of Pennsylvanian are found in Johnson County seem to be mostly Lower Pennsylvanian Morrowan and correlative to "Caseyville" strata further east, although Middle Pennsylvanian Desmoinesian may be present. While mostly fluvial, there is enough evidence to indicate that marine-influenced estuarine deposits do extend at least as far west as Johnson County. Well-preserved Pennsylvanian plant fossils are found at both quarries resulting from the flooding and burial of swamps and forests lining rivers and estuaries. Although only outliers, Pennsylvanian strata are a significant component to the geological story of Johnson County.

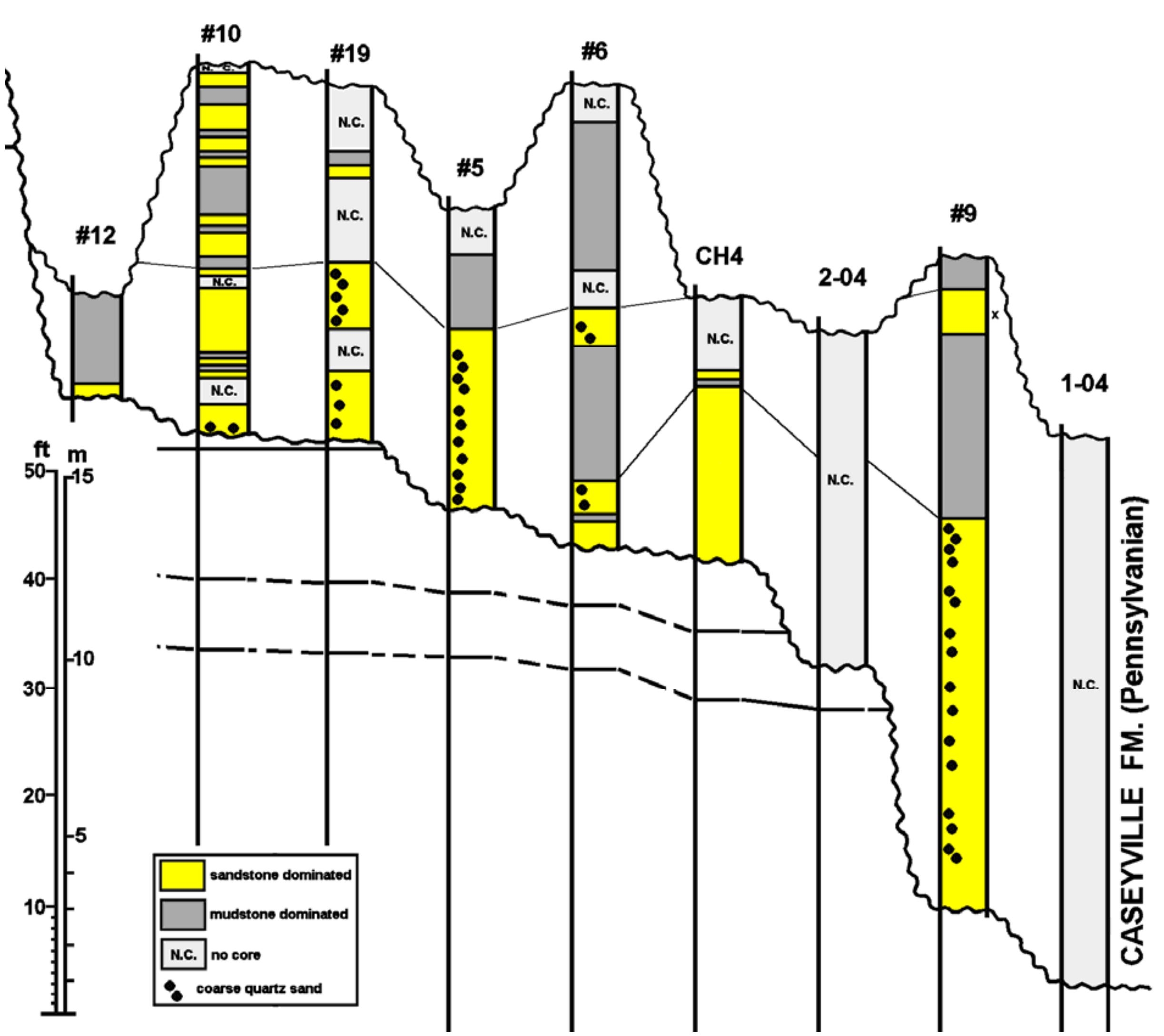


Figure 17. Geologic cross section of the Pennsylvanian of Klein Quarry constructed from cores drilled at the quarry. Core #5 was sampled by Brian Witzke for miospores at 27 feet and Core #6 at 50.7 feet. A listing of the resulting taxa can be found in Appendix A. Some of the more significant taxa are illustrated in Plate 1. Note incisement into underlying Devonian limestone.

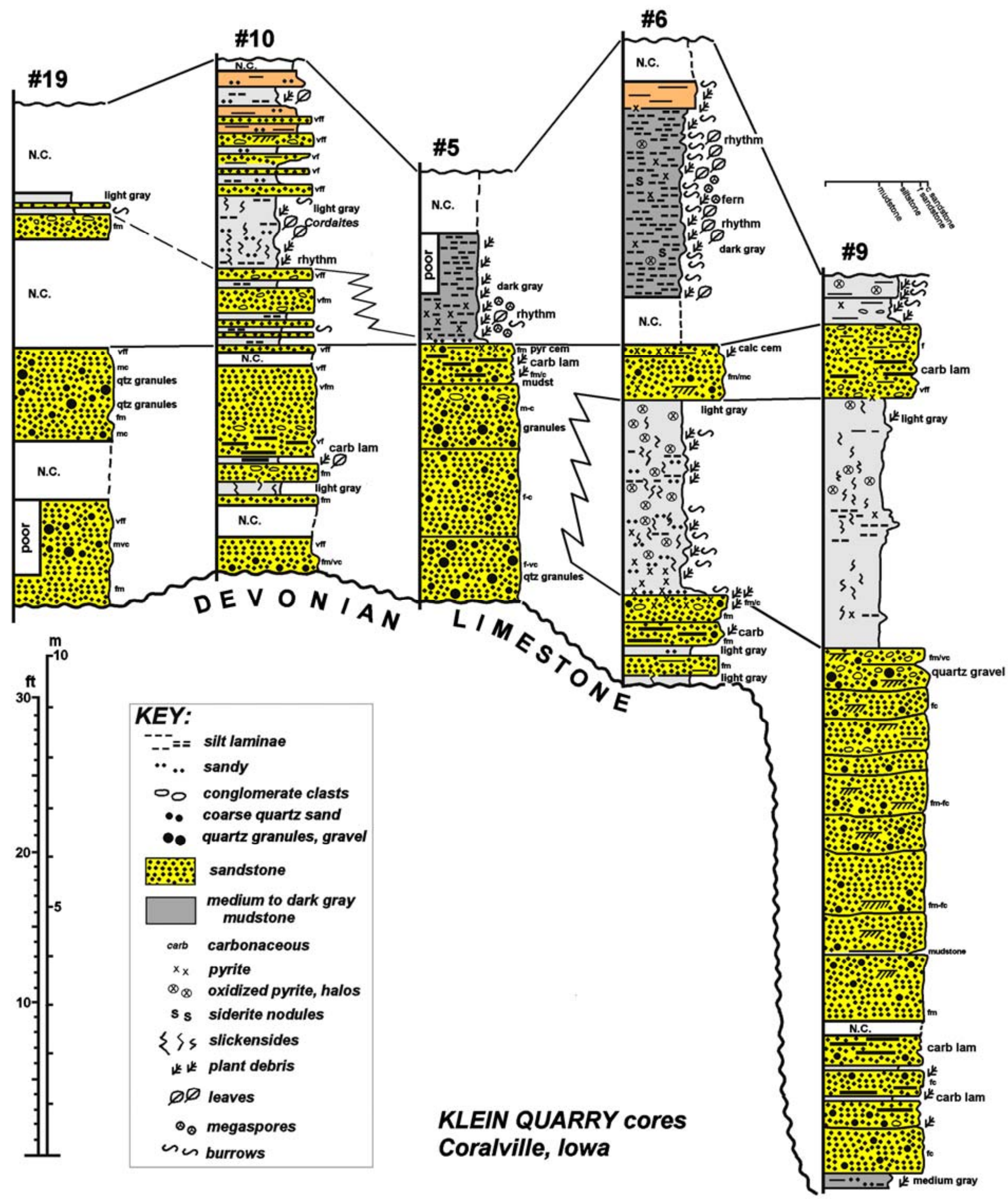
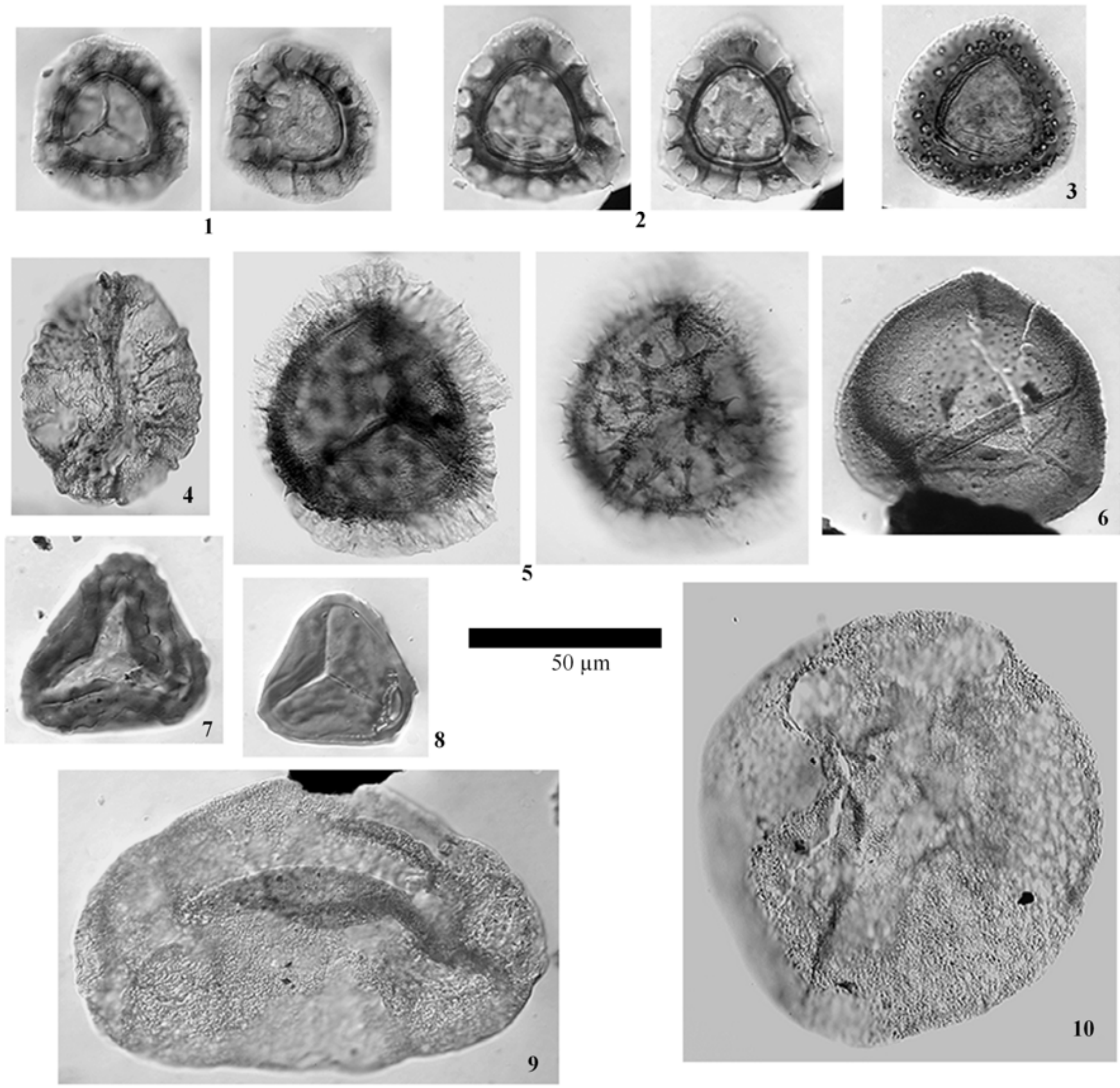


Figure 18. Close up, more detailed view of the geologic cross section in Figure 17. Core #5 was sampled by Brian Witzke for miospores at 27 feet and Core #6 at 50.7 feet. A listing of the resulting taxa can be found in Appendix A. Some are illustrated in Plate 1. Note presence of rhythmites in mudstone and incisement into underlying Devonian limestone.



1 *Densosporites irregularis* Hacquebard & Barss 1957 (proximal and distal views)
2 *Densosporites irregularis* Hacquebard & Barss 1957 (proximal and distal views)
3 *Densosporites sphaerotriangularis* Kosanke 1950
4 *Velamisporites radiatus* (Ravn & Fitzgerald) Ravn 1991
5 *Kraeuselisporites ornatus* (Neves) Owens, Mishell & Marshall 1976
6 *Crassispora kosankei* (Potonie & Kremp) Bhardwaj emend. Smith & Butterworth 1967 (large form of Ravn & Fitzgerald, 1982)
7 *Savitrisporites nux* (Butterworth & Williams) Sullivan 1964
8 *Savitrisporites asperatus* Sullivan 1964
9 indeterminate bisaccate gymnospermous pollen grain
10 *Wilsonites delicatus* (Kosanke) Kosanke 1959

Plate 1. Miospores identified from Klein Quarry by Bob Ravn, 2010

REFERENCES

Howell, J.A., and Flint, S.S., 2003, Part 3 Siliciclastic case study: The Book Cliffs; Tectonic setting, stratigraphy and sedimentology of the Book Cliffs, A.L. Coe, editor: *in* The Sedimentary Record of Sea-Level Change, Cambridge University Press, Cambridge, UK, pp. 135-157

Ludvigson, G.A., and Nations, B.K., 1989, Pennsylvanian rocks in Johnson County, Iowa, O.W. Plocher, editor: *in* Geological Reconnaissance of the Coralville Lake Area, Geological Society of Iowa, Guidebook 51, pp. 87-92

Witzke, B.J., 1984, Summary of the geologic history of the Iowa City area, B.J. Witzke, editor: *in* Geology of the University of Iowa Campus Area, Iowa City, with a walking tour along the Iowa River, Iowa Geological Survey, Guidebook No. 7, pp. 2-12

Witzke, B.J., 1984, History of geological investigations of Devonian and Pennsylvanian strata in Iowa City, B.J. Witzke, editor: *in* Geology of the University of Iowa Campus Area, Iowa City, with a walking tour along the Iowa River, Iowa Geological Survey, Guidebook No. 7, pp. 13-17

Witzke, B.J., 1984, Pennsylvanian strata at Conklin Quarry, B.J. Bunker, and G.R. Hallberg, editors: *in* Underburden-Overburden, an examination of Paleozoic and Quaternary strata at the Conklin Quarry near Iowa City, Geological Society of Iowa, Guidebook No. 41, pp. 21-23

Witzke, B.J., 2010, Early Pennsylvanian estuarine cyclothems in eastern Iowa—discoveries in our backyard: University of Iowa Geoscience seminar series, March 2010

Witzke, B.J., and Kay, R.T., 1984, The Pennsylvanian stratigraphic sequence of Iowa City, B.J. Witzke, editor: *in* Geology of the University of Iowa Campus Area, Iowa City, with a walking tour along the Iowa River, Iowa Geological Survey, Guidebook No. 7, pp. 31-34

APPENDIX A

Lists of miospores identified by Bob Ravn, 2010

The following are lists of miospores identified and prepared by Bob Ravn from core and bulk samples from Klein Quarry. KLQ5 refers to samples from core #5 (refer to cross section in Figures 17 and 18), KLQ6 refers to samples from core #6 (refer to cross section in Figures 17 and 18), and KLQ-SWBU refers to bulk samples from the SW corner of the quarry (refer to Figure #5).

KLQ5-27- Klein Quarry Core #5 (sampled at 27 feet)

Palynomorphs relatively sparse but diverse. Kerogen mixed structured plant material and dark brown to black near-opaque polygonal sharp-edged kg grains.

Florinites mediapudens
Endosporites zonalis
Cyclogranisporites minutus
Densosporites sp. - indet.
Quasillinites diversiformis (?)
Lycospora pusilla
Granulatisporites pallidus
Calamospora hartungiana
Calamospora breviradiata
Florinites visendus
Apiculatasporites sp. - indet.
Florinites similis
Colatisporites decorus
Cirratriradites saturni
Cyclogranisporites cf. *lasius*
Densosporites irregularis
Calamospora liquida

KLQ6-50.7- Klein Quarry Core #6 (sampled at 50.7 feet)

Kerogen similar to above, palynomorphs fairly common.

Wilsonites delicatus
Lycospora pusilla - numerous
Crassispora kosankei
Calamospora breviradiata
Florinites visendus
Raistrickia sp. - indet.
Apiculatasporites sp. - indet.
Punctatisporites cf. *labiatus*
Florinites similis
Savitrisporites nux 129.4/18.3
Colatisporites decorus
Cyclogranisporites sp. - indet.
Cyclogranisporites minutus
Densosporites irregularis
Endosporites plicatus

Deltoidospora sp. - indet.
Granulatisporites pallidus
Cirratriradites saturni
Diaphanospora parvigracila
Densosporites triangularis
Raistrickia? *abdita*
Radiizonates striatus
Savitrisporites asperatus

KLQ-SWBU- Exposures in SW corner area, sampled at base of dark gray mudstone

Kerogen and palynological recovery similar to above.

Florinites visendus - common
Florinites mediapudens
Deltoidospora sp. - indet., large
Lycospora pusilla
Florinites similis
Colatisporites decorus
Densosporites sphaerotriangularis 115.3/17.2
Apiculatasporites sp. - indet.
Endosporites plicatus
Raistrickia saetosa
Calamospora breviradiata
Densosporites irregularis 142.8/17.3 several
Savitrisporites asperatus 135.0/11.7
Calamospora liquida
bisaccate cf. *Phillipsites tenuis* 124.2/13.7
Velamisporites radiatus 143.0/14.0
Wilsonites delicatus 142.0/13.9
Kraeuselisporites ornatus 138.1/12.3
Granasporites medius
Cirratriradites cf. *saturni* sensu Ravn & Fitzgerald 1982
Convolutispora sp. - indet.
Cingulizonates loricatus
Crassispora kosankei – large Morrowan form 144.3/6.9
Stenozonotriletes sp. - 117.3/5.0
Cyclogranisporites sp. - indet.
Radiizonates striatus

KLEIN QUARRY PENNSYLVANIAN PALEOFLORA

Brian J. Witzke and Charles C. Monson
Iowa Geological and Water Survey
Iowa Dept. Natural Resources
Iowa City, IA 52242-1319
brian.witzke@dnr.iowa.gov,
charles.monson@dnr.iowa.gov

INTRODUCTION

Pennsylvanian deposits at Klein Quarry have yielded a variety of plant fossils, including leaves, bark, logs, and root casts. The primary groups represented are fernlike plants and larger arborescent (treelike) flora. The general character of the paleoflora matches the stereotypical Pennsylvanian assortment of massive canopy plants and fernlike ground cover. However, the particular assortment of taxa at Klein is unique and has not lent itself well to correlation with other paleoflora.

FERNS

True ferns were present in the Pennsylvanian, but the fernlike fossil plants commonly found at Klein are seed ferns rather than spore-bearing true ferns. They include *Eusphenopteris*, *Mariopteris*, and cf. *Palmatopteris*. Leaflets are preserved in isolation or with fragments of attached central stem (Figure 1).

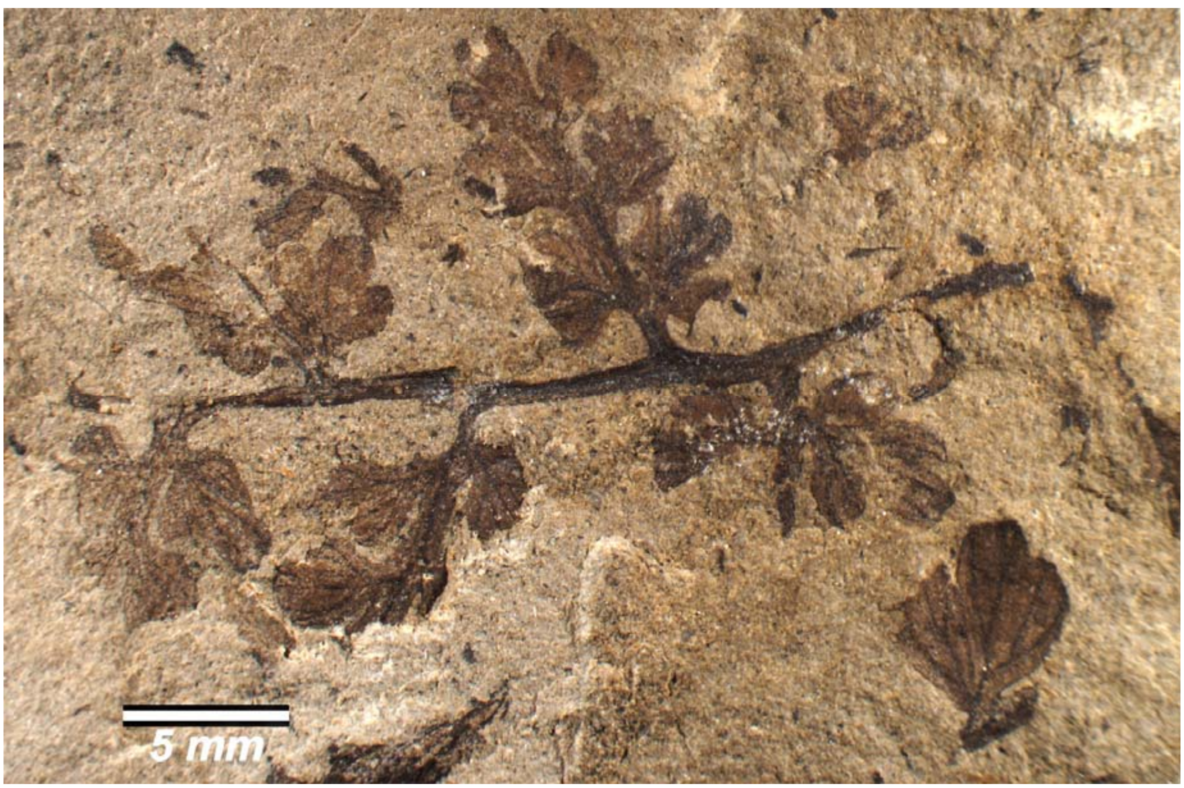


Figure 1. *Eusphenopteris*.

Fern fossils sometimes occur with leaves from large arborescent cordaites. Unusually large examples of these strap-shaped leaves can be found at Klein (Figure 2). *Cordaites* may also be the source of some of the large pieces of wood that are present. (Here, we use the term “cordaite” loosely to refer to indeterminate members of a group of extinct gymnosperms, not necessarily members of the genus *Cordaites* itself.)

LYCOPODS

Logs from the lycopsid trees *Sigillaria* (Figure 3) and *Lepidodendron* (Figure 4) are also present at Klein. *Lepidodendron* logs are easily recognizable thanks to the characteristic diamond-shaped leaf scars on the trunk. Other parts of *Lepidodendron* have been found in the area as well, including the leaves, *Lepidophyllum*. (Early paleobotanical workers who encountered partial remains of large plants gave individual names to features which later turned out to be from the same type of plant.) *Lepidostrobus*, a cone from the same type of tree, was found at Conklin Quarry (Witzke, 1984).

Figure 2. *Cordaites* leaf.

BIOSTRATIGRAPHY

Figure 3. *Sigillaria* log.

The channel-fill flora at Klein may be comparable in age to the relatively well-studied Pennsylvanian "Spencer Farm Flora" from the Caseyville Formation of Illinois (Leary and Pfefferkorn, 1977). Certainly, the lithologic similarities between the Caseyville channel fills and the first-phase channel fills at Klein invite comparison between the two floras. However, some of the most characteristic plants of the Illinois Caseyville paleoflora, including *Megalopteris* and *Lesleya*, have not been found at Klein, making it difficult to assert age-equivalence between the two.

DEPOSTIONAL ENVIRONMENTS

The depositional environment suggested by lithology and plant remains is a well-drained, low-lying area cut by river channels. Many of the channel-fill plant fossils are in excellent condition, suggesting that they underwent little transport before entering the channel, were transported only short distances, and were buried quickly (particularly in the case of the leaves; tree trunks are more durable and may undergo greater transport). The presence of *Stigmaria* (root casts of *Sigillaria* or *Lepidodendron*) indicates that trees were growing in place in the area and that incipient paleosols were present (Figure 5). Carbonized logs (Figure 4, upper right) suggest fire occurrences; the high oxygen levels of the Pennsylvanian probably led to frequent wildfires.

Figure 4. *Lepidodendron* (lower left) and carbonized log (upper right).

Cordaites are thought to have been dominant members of "upland" plant communities growing on relatively dry interfluves, while the horsetail *Calamites* (Figure 6) was a "lowland" plant growing in the basin. Both are present at Klein. Some types of cordaite are thought to have occurred in lowlands, but it is also possible that their co-occurrence here reflects transport of "upland" flora into low-lying areas due to slope failure.

Figure 5. *Stigmaria* root cast.

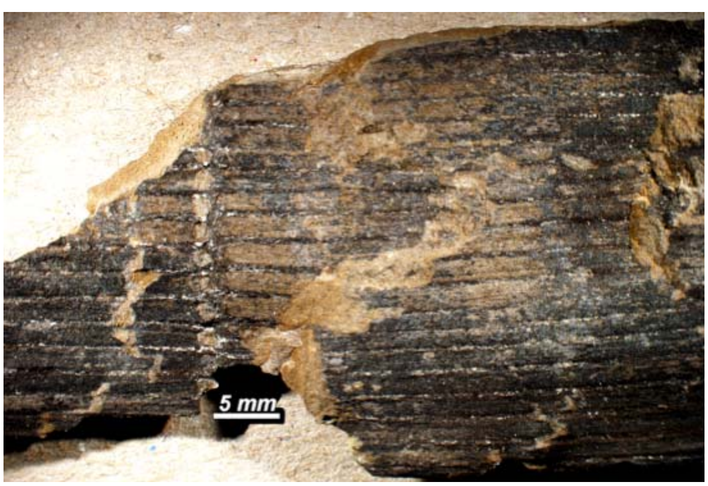


Figure 6. *Calamites*.

Several different modes of preservation occur at Klein. Lycopsid and cordaite leaves are found as compression fossils. Cordaite-rich layers tend to occur in siderite-cemented siltstones, although they are also found in dark mudrocks. Other plants are found in more friable sediments. Some plant fragments have been pyritized.

PARTIAL LIST OF PLANT FOSSILS FROM KLEIN QUARRY

Work on these fossils is ongoing, and some of these identifications are only tentative.

Fern-like foliage:
- *Eusphenopteris*
- *Mariopteris*
- cf. *Palmatopteris*
- other unidentified species

Arborescent plants:
- *Cordaites* (very large leaves)
- *Lepidodendron* log pieces
- *Lepidophyllum* (lycopod leaves)
- Scattered *Mesocalamites*
- *Sigillaria*
- *Stigmaria* (root casts)
- indeterminate large wood

REFERENCES

Anderson, W.I., 1998, Iowa's geological past: three billion years of change. University of Iowa Press, Iowa City, 424 p.

Leary, R.L., and H.W. Pfefferkorn, 1977, An Early Pennsylvanian flora with *Megalopteris* and *Noeggerathiales* from west-central Illinois: Illinois State Geological Survey Circular 500, 77 p.

Witzke, B.J., 1984, Pennsylvanian strata at Conklin Quarry: Geological Society of Iowa Guidebook 41, p. 21–23.

QUATERNARY GEOLOGY OF THE IOWA CITY AREA

E.A. Bettis III
Department of Geoscience,
University of Iowa
Iowa City, Iowa 52242-1319
art-bettis@uiowa.edu

Stephanie Tassier-Surine and Deborah J. Quade
Iowa Geological & Water Survey
Iowa City, Iowa 52242-1319
stephanie.surine@dnr.iowa.gov
deborah.quade@dnr.iowa.gov

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 2.2 million to 500 thousand years before present (Hallberg, 1986; also see contribution by Rovey et al. in this guidebook). Conklin Quarry, one of the localities we will visit on this trip, 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., this guidebook). 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., 1980; 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

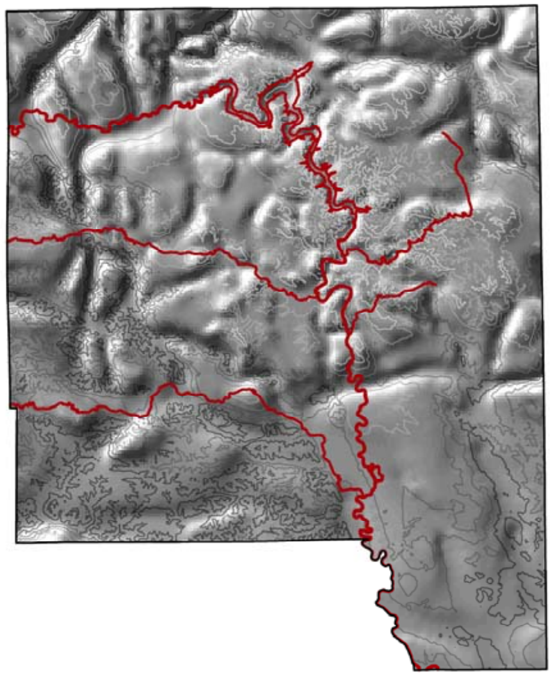


Figure 1. Hillshade and topography of the bedrock surface in Johnson County, Iowa. The lowest elevations on the bedrock surface are in the southwestern part of the county. A complex series of pre-Pleistocene and Pleistocene valleys are cut into the county's bedrock surface. Note that the Iowa River Valley 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). 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.

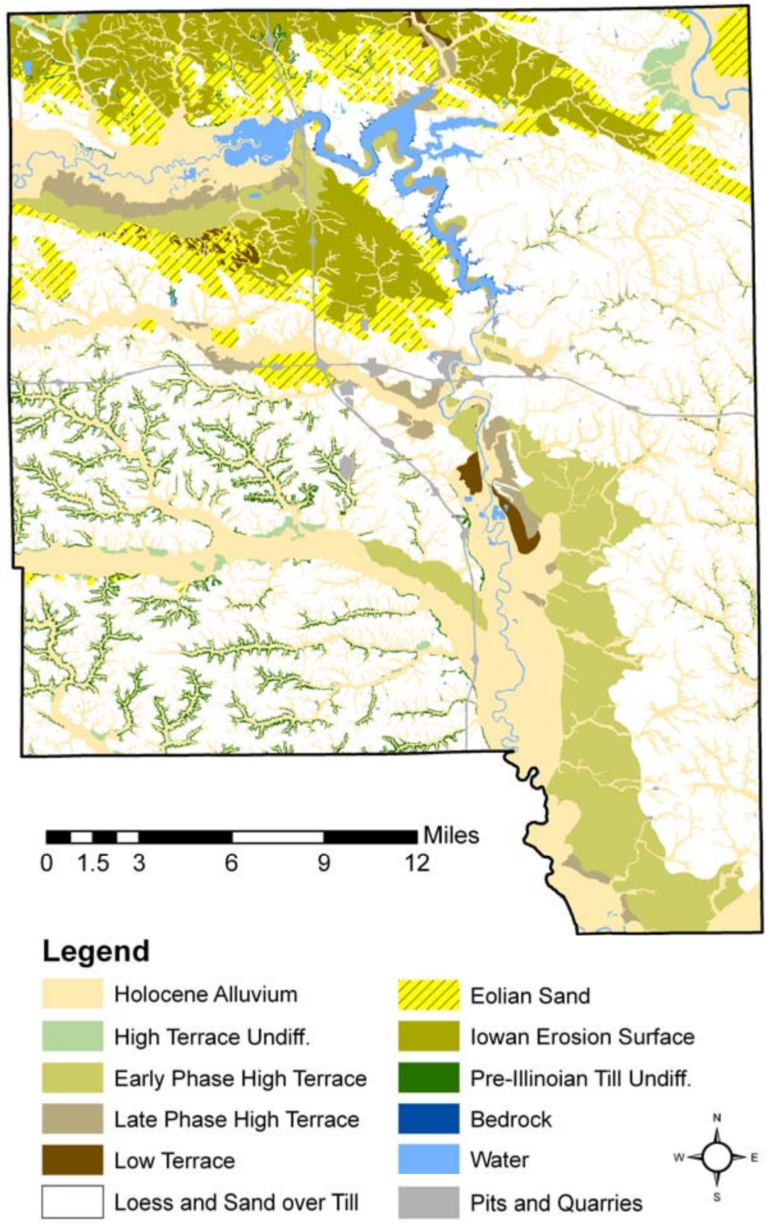


Figure 2. Generalized surficial geology map of Johnson County, Iowa. Areas of wind-blown (eolian) sand mark the margin of the Iowan Erosion Surface in the northern part of the county. Pre-Illinoian glacial deposits are extensively exposed along steep slopes in the southern part of the county where the 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.

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 CONKLIN AND KLEIN QUARRIES

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. The loess is generally poorly exposed except in recently worked faces in Conklin Quarry and in large slump block headwalls in Klein Quarry. 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 was originally formed in the upper part of the Pisgah Formation but was eroded and transported downslope by solifluction 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 (se also contribution by Rover et al. in this guidebook). 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 revered 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., this guidebook).

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.

At both quarries 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 Quaternary sections at both quarries are in less than ideal condition for study at this time. 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

Conklin Quarry

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 Quaternary section we will visit today is located about 300 meters north of the 1975-1976 section. 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 (see paper by Rovey et al. in this guidebook).
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.

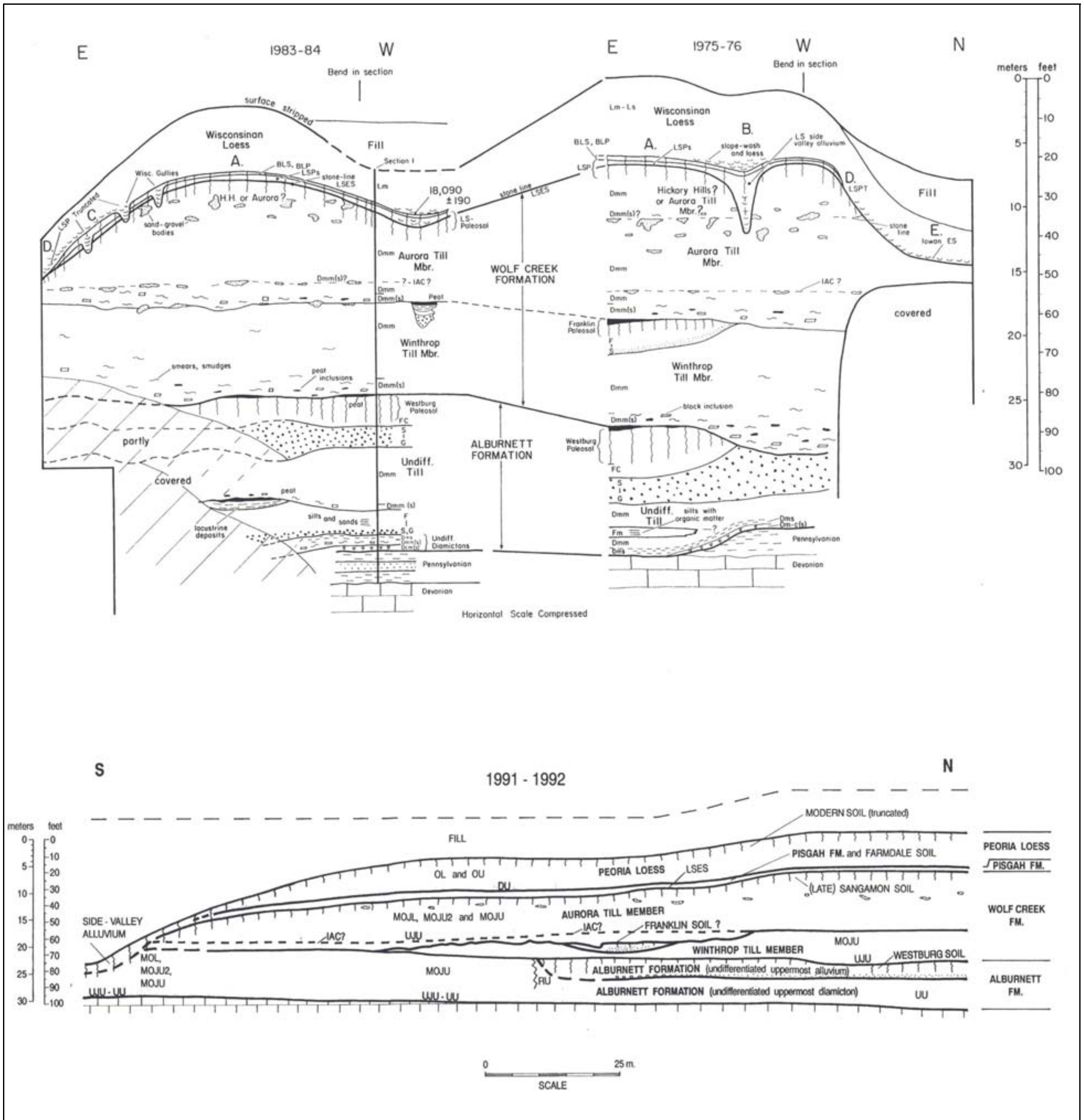


Figure 3. Quaternary sections exposed on the western side of Conklin Quarry in 1975-1984 (top) and 1991-1992 (bottom). Subsequent quarry operations have moved the quarry face several hundred meters west and south of the 1975-1984 section. The present Quaternary exposures in the quarry are located about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

Klein Quarry

The Quaternary section at Klein Quarry has not been studied in as much detail as the Conkin 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 Albunnett 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. 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 has continued to expand to the south the alluvium at the top of the Alburnett Formation has disappeared from most of the exposure, the Lime creek shale is no longer at the bedrock surface and large-scale deformation structures are not present in the Pre-Illinoian till sequence.

Present Quaternary exposures are most accessible 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), along the southwest wall (Late Sangamon paleogeomorphic sequence, upper pre-Illinoian sequence, and lower pre-Illinoian alluvial sequence), and in the southeast corner of the quarry (base of the section and lower pre-Illinoian till 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 a 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 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 occurs between overlying oxidized and underlying unoxidized tills. This is probably a remnant of the extensive alluvial deposit separating the Wolfe Creek and Alburnett formations that we have observed in both Klein and Conklin quarries.

Northeast Corner

1. Unoxidized and unleached (UU) Alburnett Formation till overlies Devonian limestone in this area. The limestone surface has been streamlined by glacial erosion and a small, striated whaleback (a streamlined landform carved into bedrock) is present. Striations on the rock surface in this area 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 4). 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.

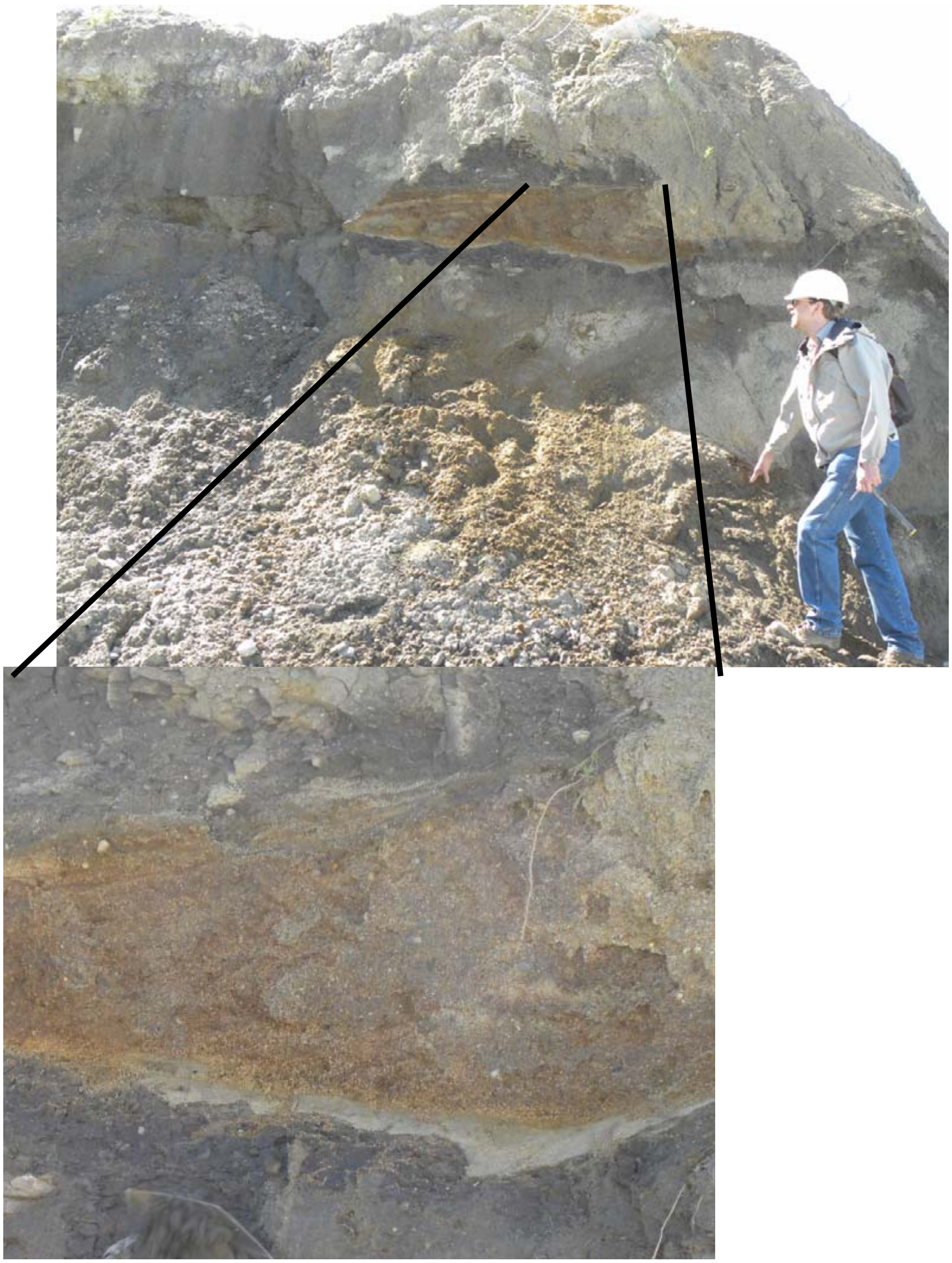


Figure 4. Body of deformed sand at till/till contact near southeast corner of Klein Quarry, August, 2010. Tom Marshall for scale. Photo by Brian Witzke.

REFERENCES

Balco, G. and Rovey, C.W. II, 2010, Absolute chronology for major Pleistocene advances of the Laurentide Ice Sheet. Geology 38: 795-798.

Bettis, E.A. III, 1990, Holocene alluvial stratigraphy of western Iowa, *in* Bettis, E.A., III ed., Holocene alluvial stratigraphy and selected aspects of the Quaternary history of western Iowa: Midwest Friends of the Pleistocene Field Trip Guidebook, p. 1-72.

Bettis, E.A. III, 1998, Subsolum weathering profile characteristics as indicators of the relative rank of stratigraphic breaks in till sequences: Quaternary International, v. 51/52, p. 72-73.

Bettis, E.A. III, Baker, R.G., Green, W.R., Whelan, M.K., and Benn, D.W., 1992, Late Wisconsinan and Holocene alluvial stratigraphy, paleoecology, and archaeological geology of east-central Iowa: Iowa Department of Natural Resources, Geological Survey Bureau, Guidebook Series No. 12, 82 p.

Bettis, E.A. III and T. J. Kemmis. 1992. Effects of the Last Glacial Maximum (21,000-16,500 B.P.) on Iowa's Landscapes. North-Central Section of the Geological Society of America Abstracts with Programs, 24:5.

Bettis, E.A. III, D.R. Muhs, H.M. Roberts, and A.G. Wintle. 2003a. Last Glacial Loess in the Conterminous U.S.A. Quaternary Science Reviews 22: 1907-1946.

Bettis, E.A. III, J.P. Mason, J.B. Swinehart, X. Miao, P.R. Hanson, R.J. Goble, D.P. Loope, P.M. Jacobs, and H.M. Roberts. 2003. Cenozoic eolian sedimentary systems of the USA midcontinent: *in* Easterbrook, D.J. (editor). Quaternary Geology of the United States, INQUA 2003 Field Guide Volume, Desert Research Institute, Reno, NV. pp.195-218.

Boellstorff, J., 1978, North America Pleistocene Stages reconsidered in light of probable Pliocene-Pleistocene continental glaciation: Science, 202: 305-307.

Canfield, H.E., Hallberg, G.R., and Kemmis, T.J., 1984, A unique exposure of Quaternary deposits in Johnson County, Iowa: Proceedings of the Iowa Academy of Science, v. 91, p. 98-111.

Esling, S.P., 1984, Quaternary stratigraphy of the lower Iowa and Cedar River Valleys, southeast Iowa. Unpublished PhD thesis, Geology Department, University of Iowa, Iowa City, 451 p.

Hallberg, G.R., 1980a, Pleistocene stratigraphy in east-central Iowa: Iowa Geological Survey Technical Information Series 10, 168 p.

Hallberg, G.R., 1980b, Illinoian and Pre-Illinoian stratigraphy of southeast Iowa and adjacent Illinois: Iowa Geological Survey Technical Information Series 11, 206 p.

Hallberg, G.R., 1986, Pre-Wisconsin glacial stratigraphy of the central plains region in Iowa, Nebraska, Kansas, and Missouri: in Richmond, G.M. and Fullerton, D.S., eds., Quaternary Glaciations in the United States of America, Report of the International Correlation Programme-Project 24: *in* Sibrava, V., Bowen, D.Q., and Richmond, G.M., eds., Quaternary Science Reviews, Quaternary Glaciations in the Northern Hemisphere, V. 5, p. 11-15.

Hallberg, G.R., Fenton, T.E., and Miller, G.A., 1978, Part 5 Standard weathering zone terminology for the description of Quaternary deposits in Iowa: *in* Hallberg, G.R., ed., Standard procedures for evaluation of Quaternary materials in Iowa: Iowa Geological Survey Technical Information Series 8, p. 75-109.

Hallberg, G.R., Fenton, T.C., Miller, G.A., and Lutenegger, A.J., 1978b, The Iowa erosion surface: an old story, an important lesson, and some new wrinkles: *in* Anderson, R., ed., 42nd Annual Tri-State Geological Field Conference Guidebook, p. 2-1 to 2-94.

Hallberg, G.R., Wollenhaupt, N.C., and Wickham, J.T., 1980, Pre-Wisconsinan stratigraphy in southeast Iowa: *in* Hallberg, G.R., ed., Illinoian and Pre-Illinoian stratigraphy of southeast Iowa and adjacent Illinois: Iowa Geological Survey Technical Information Series 11, p. 1-110.

Hallberg, G.R., Kemmis, T.J., Wollenhaupt, N.C., Esling, S.P., Bettis, E.A. III and Bicki, T.J., 1984, The overburden: Quaternary stratigraphy of the Conklin Quarry: *in* Bunker, B.J. and Hallberg, G.R., eds., Underburden-Overburden, an examination of Paleozoic and Quaternary strata at the Conklin Quarry near Iowa City, Geological Society of Iowa Guidebook 41, p. 25-62.

Johnson, W.H., Hansel, A.K., Bettis, E.A. III, Karrow, P.F., Larson, G.J., Lowell, T.V., and Schneider, A.F., 1997, Late Quaternary temporal and event classifications, Great Lakes Region, North America: Quaternary Research, v. 47, p. 1-12.

Johnson, R.G., 1982, Matuyama-Bruhnes polarity reversal dated at 790,000 B.P. by marine-astronomical correlations: Quaternary Research, v. 17, p. 135-147.

Kay, G.F., and Apfel, E.T., 1929, The pre-Illinoian Pleistocene geology of Iowa: Iowa Geological Survey Annual Report 34, p. 1-304.

Kemmis, T.J., Bettis, E.A. III and Hallberg, G.R., 1992, Quaternary Geology of Conklin Quarry. Guidebook Series No. 13, Iowa Department of Natural Resources, Geological Survey Bureau, Iowa City, 41 p.

North America Commission on Stratigraphic Nomenclature (NACSN), 1983, North American Stratigraphic Code: American Association of Petroleum Geologists Bulletin, v. 67, p. 841-875.

Prior, J.C., 1991, Landforms of Iowa: Iowa City, University of Iowa Press, 154 p.

Ruhe, R.V., 1969, Quaternary landscapes in Iowa: Ames, Iowa State University Press, 255 p.

Ruhe, R.V., Daniels, R.B., and Cady, J.G., 1967, Landscape evolution and soil formation in southwestern Iowa: U.S.D.A. Soil Conservation Service Technical Bulletin 1349, 242 p.

Ruhe, R.V., Dietz, W.P., Fenton, T.E., and Hall, G.F., 1968, Iowan drift problem, northeastern Iowa: Iowa Geological Survey Report of Investigations 7, 40 p.

A PALEOMAGNETIC REVERSAL WITHIN THE PRE-ILLINOIAN ALBURNETT FORMATION, EASTERN IOWA

Charles W. Rovey II
Department of Geography, Geology and Planning,
Southwest Missouri State University,
Springfield, MO 65807
charlesrovey@missouristate.edu

E. Arthur Bettis III
Department of Geoscience,
University of Iowa
Iowa City, Iowa 52242
art-bettis@uiowa.edu

Greg Balco
Berkeley Geochronology Center
Berkeley CA 94799
balcs@bgc.org

William F. Kean
Department of Geosciences
University of Wisconsin-Milwaukee
wkean@csd.uwm.edu

ABSTRACT

The Matuyama-Brunhes reversal (0.78 Ma) is a paleomagnetic datum within the pre-Illinoian stratigraphic sequence of the North American midcontinent that marks the boundary between the Early and Middle Pleistocene. In eastern Iowa this datum separates Wolf Creek Formation deposits with normal remanent polarity from older glacial diamictons of the Alburnett Formation with reversed polarity.

In this study additional magnetic characterization of the Alburnett Formation was accomplished by systematically sampling sediments of various facies exposed in Conklin Quarry, including till, valley-fill alluvium, and valley-slope colluvium. Direct age control on Iowa tills was also obtained from cosmogenic isotope dates of tills at the quarry.

Two Alburnett Formation tills have reversed detrital remanent magnetization. In contrast, younger locally preserved Alburnett Formation valley-fill and valley-slope sediments inset into the reversely magnetized tills and capped by the Westburg Geosol, have normal detrital remanent magnetization. Therefore, a reverse-to-normal polarity change occurred during the latest phase of Alburnett Formation deposition in eastern Iowa. Nevertheless, cosmogenic isotope dates for tills at Conklin Quarry and elsewhere show that the Alburnett Formation and its equivalents are ~1.3 Ma in age. Therefore, the reversal within the Alburnett Formation cannot be the Matuyma/Brunhes transition. Instead, this reversal most likely reflects the Cobb Mountain Normal Polarity Subchron, (c. 1.2 Ma), which is within error limits of cosmogenic isotope dates for the Alburnett tills and their equivalents.

INTRODUCTION

The Matuyama-Brunhes (M/B) paleomagnetic reversal at 0.78 Ma is a regional datum within the pre-Illinoian glacial sequence of the North American midcontinent (Easterbrook and Boellstorff, 1984; Rovey and Kean; 1996, 2001; Roy et al., 2004). Throughout the region three normal-polarity tills and associated sediments overlie multiple tills with reversed remanent polarity (Fig. 1). Based on fission-track dating of tephra in western Iowa and cosmogenic-isotope burial dating in northern Missouri, the normal-polarity tills are younger than the M/B boundary, whereas the reversely magnetized tills are older. Therefore, this paleomagnetic datum is the M/B reversal, which is the new boundary between the Early and Middle Pleistocene (Gibbard et al., 2010). Rovey and Kean (2001) further suggested that this reversal followed shortly after the maximum expansion of the second major pre-Illinoian glaciation that is recorded widely in the midcontinent of North America. Here we present evidence from Conklin Quarry that this second major glaciation actually is significantly older than the M/B reversal, but did occur shortly before a brief reversal of the earth's magnetic field.

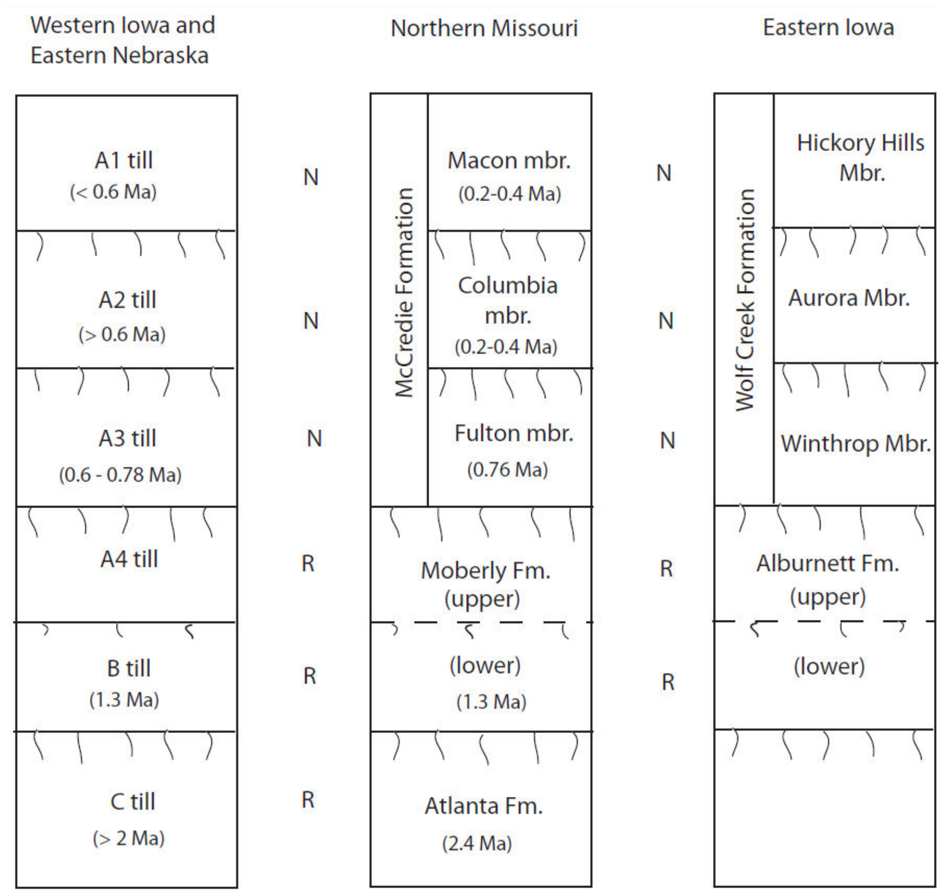


Figure 1. Pre-Illinoian glacial and paleomagnetic sequence, eastern & western Iowa, northeastern Missouri. Stratigraphic units are mostly till. "N" denotes normal magnetic remanence; "R" denotes reversed magnetic remanence. Member divisions in northern Missouri remain informal. Bounding ages for the tills in western Iowa are based on fission-track dates of interbedded tephras (Boellstorff, 1978; Richmond and Fullerton, 1986). Ages in northern Missouri are cosmogenic isotope burial dates; see Balco and Rovey (2008, 2010) for methodology and error limits. The age for the Fulton member is "tuned" to dates for Marine Isotope Stage 18, based on its normal magnetic remanence. The range in ages for the Macon and Columbia members reflects large and overlapping error limits for those units. Stratigraphy for eastern Iowa is from Hallberg (1980).

LOCATION AND STRATIGRAPHY

Conklin 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 (Figure 1). The oldest two tills here are grouped within the Alburnett Formation, which is the oldest formally defined glaciogenic deposit in eastern Iowa. Nevertheless, deposits of at least one Quaternary glaciation which predates the Alburnett are widespread throughout the Midwestern U.S. (Figure 1; Hallberg, 1986; Balco et al., 2005); thus, the Alburnett Formation marks the second major Quaternary glaciation.

Three lithofacies are present within the Alburnett Formation at Conklin Quarry (Figure 2). The lowermost diamicton (till) in the Alburnett Formation directly overlies striated Devonian limestone. This unit is an oxidized, unleached, clast-rich, matrix-supported, sandy loam diamicton. Thin (<30 cm) discontinuous pods of fossiliferous peat and/or organic-rich silt (an A horizon) overlie a 20-30 cm-thick reduced weathering profile developed in the diamicton. Oxidation of the diamicton (below the reduced weathering profile) is probably related to the relatively porous sandy loam texture and position atop fractured carbonate bedrock, rather than to subareal weathering. We interpret the peat and silt to represent a minor stade in the overall main phase of Alburnett glaciation. This interpretation is supported by fossil fauna within the peat indicative of a full glacial environment (Baker et al., 1984), and by low cosmogenic-isotope concentrations within the pedogenically altered silt (Balco and Rovey, 2010). The weathered zone, the silt, and the peat are overlain by a second Alburnett Formation till, an unoxidized, unleached, matrix-supported loam diamicton.

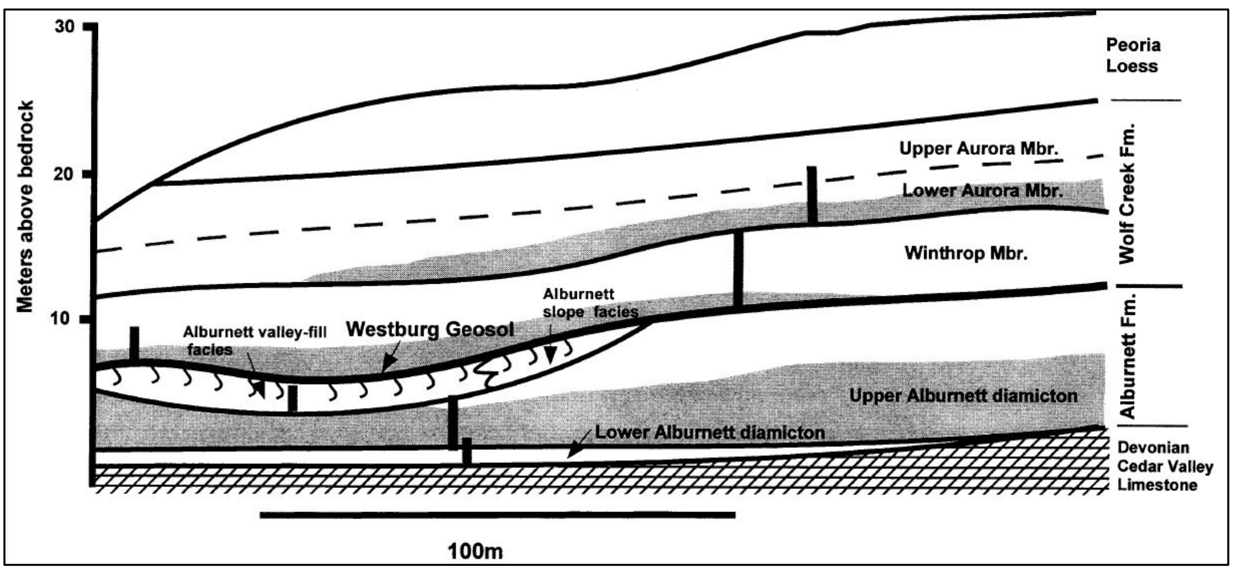


Figure 2. Quaternary section exposed at Conklin Quarry. All units beneath the Peoria Loess are pre-Illinoian in age. Gray shading indicates unoxidized zones. Vertical bars show locations of sampling transects.

A fluvial erosion surface cuts across the upper Alburnett till and defines the southwestern wall of a broad buried paleovalley (Hallberg et al., 1984; Kemmis et al., 1992; Figure 2). This erosion surface is buried by valley-fill (alluvial) and slope (colluvial) deposits of the Alburnett Formation. The valley-fill deposits generally fine upward from basal gravel to sandy clay loam. The Westburg Geosol (an A-Btg-BCg profile at this location) is developed in the upper part of the valley-fill deposits (Hallberg et al., 1984; Kemmis et al., 1992). Slope deposits consist of a basal stone lag that is overlain by loamy diamicton. The lower part of the slope deposits includes zones of weakly graded bedding; in places upper portions are pedogenically altered to a Bt-BC profile of the Westburg Geosol. This soil profile grades downward to a 4 m-thick, oxidized and leached to unleached, weathering profile developed in the underlying slope sediments and glacial diamicton. The slope deposits interfinger with, and grade into, the valley-fill deposits along the paleo-footslope. The presence of well-expressed soil horizons in the valley-fill and slope sediments, and an associated oxidized weathering zone beneath the slope deposits indicate that the Westburg Geosol is of interglacial rank (Follmer, 1983; Bettis, 1998).

The valley-fill and slope sediments in which the Westburg Geosol developed are included in the Alburnett Formation, based on mineral composition and soil stratigraphy (Hallberg, 1980; Hallberg et al. 1984; Kemmis et al. 1992). The weathering profile that developed in the upper Alburnett Formation till beyond the channel margins cuts across the slope and valley-fill sediments without diminution. Moreover, the Westburg Geosol preserved atop the valley-fill sediments is one of the best-expressed and most-mature examples yet encountered and by inference developed during most of the interglacial time between deposition of the Alburnett and Wolf Creek Formation tills. Therefore, the well-expressed Westburg Geosol atop the valley-fill and slope sediments indicates that they are much closer in age to the underlying Alburnett Formation till than to overlying till of the Wolf Creek Formation.

Wolf Creek Formation glacial deposits are also present in the paleovalley incised into Alburnett Formation sediments. Only the two older members of the Wolf Creek Formation were accessible during this study. The Winthrop and Aurora Members (Figures 1and 2) are dominantly massive, matrix-supported, loam glacial diamictons with varying degrees of shear and deformation structures.The Winthrop Member, in particular the lowest meter, is intensely sheared. Distinct block inclusions and debris bands of remobilized Alburnett Formation sediment are also present near the base and locally are deformed into fold structures. In the paleovalley, lower portions of the Winthrop are unoxidized and unleached, and the lower portion of an oxidized weathering profile is developed in the upper part of the unit. Beyond the margin of the paleovalley, the oxidized and unleached weathering zone extends through the entire thickness of the Winthrop Member and into the underlying Alburnett Formation.

A glacial erosion surface separates oxidized Winthrop Member till from overlying unoxidized till of the Aurora Member. The Aurora Member of the Wolf Creek Formation is comprised of two glacial diamictons that are separated by a sharp till-till contact in part of the exposure, and by discontinuous lenses of stratified sediment elsewhere along the outcrop (Figure 2).

PREVIOUS WORK

Conklin Quarry

Baker (1985) and Baker and Stewart (1984) established the polarity sequence of pre-Illinoian tills in eastern Iowa (Figure 1), largely based on samples collected at Conklin Quarry. This work confirmed that the M/B reversal is an important datum in the pre-Illinoian glacial sequence, and it was later helpful in establishing the temporal equivalence between the Alburnett Formation in eastern Iowa and the Moberly Formation in northern Missouri (Rovey and Kean, 1996; 2001).

Baker (1985) isolated the remanent magnetic polarity of a large number of specimens cored from block samples of each pre-Illinoian stratigraphic unit (Table 1). The remanent directions of individual specimens from some blocks are somewhat scattered, but the polarity of each unit is clear. Each till within the Wolf Creek Formation has normal remanent polarity, whereas the older Alburnett Formation tills and intratill silts have reversed polarity. In western Iowa ages of the tills are bracketed by fission-track dates of interbedded tephra, and in northern Missouri a similar till sequence has been dated by the cosmognic-isotope burial dating method (Balco and Rovey, 2008; 2010). The normal-polarity tills are younger than 0.78 Ma and the reversed-polarity tills are older. Based on correlation across these study areas, the change in polarity between the Alburnett (reversed) and the Wolf Creek Formation (normal) must reflect the M/B reversal (Figure 1; Hallberg, 1986).

Table 1

Unit	Sample	n	Inclination	Declination	κ	alpha 95	Polarity
Aurora (upper till)							Normal
	Au4.2	9	+27	342	2.9	33	
	Au3.9	11	+29	345	6.8	19	
	Au3.2	17	+43	260	1.6	45	
	Au2.2	9	+56	295	3.3	34	
Winthrop							Normal
	Wn2.1	13	+43	49	2.5	49	
	Wn0.4*	24	+62	0	2.8	22	
Alburnett (upper till)							Reverse
	Abt2.4	12	-24	137	8.1	22	
	Abt0.9	22	-24	152	6.5	13	
(intratill silt)	Abs	14	-37	180	47	6	Reverse
Moberly (Missouri)		3** Sites	-38	194	7.6	29	Reverse

* Block sample collected from nearby Kline Quarry 5 km south of Conklin Quarry.
** Means are the site averages from 16 individual measurements, each with a highly significant characteristic remanence based on principal component analysis.

Table 1. Summary of previous paleomagnetic measurements. Iowa results are based on specimens from large sample blocks (Baker, 1985). All but one sample block were collected in Conklin Quarry. Missouri results are from Rovey and Kean (2001). Table omits results from a highly sheared and deformed interval at the base of the Winthrop Member having essentially random orientations. “n” is the number of specimens measured, “ κ” is the Fisher precision parameter, and “alpha 95” is the 95% confidence limit (degrees).

Northern Missouri

The Moberly Formation in northern Missouri is laterally continuous with the Alburnett Formation in eastern Iowa (Figure 1, Rovey and Tandarich, 2006). These two units have a similar lithology and both retain a reversed remanent magnetic polarity with shallow inclination (Table 1). Rovey and Kean (2001) interpreted the regionally persistent, shallow, reversed inclinations in the Alburnett Formation and its equivalents as evidence for deposition during the latest part of the Matuyama Reversed Polarity Chron. Shallow, in some cases oscillating, inclinations typify the latest phase of a polarity interval for several thousand years prior to a complete reversal (e.g. Opdyke and Channell, 1996). However, recent cosmogenic-isotope burial dates for the Missouri section, (Table 2, Balco and Rovey 2008; 2010) show that the age of the Moberly Formation (Missouri) is approximately 1.3 Ma. Likewise the lithologically similar “B” till in western Iowa overlies a tephra that is dated at 1.3 Ma in one core (Boellstorff, 1978). We examined this core and found that this tephra is present immediately below the “B” till within an unweathered silt. Thus, the age of the “B” till appears to be close to 1.3 Ma as well, and the shallow inclinations within these tills cannot reflect the onset of the M/B transition at 0.78 Ma.

Table 2

State	Stratigraphic Unit	Age	Number Of Sites
Missouri	Macon	0.21 +/- 0.18 Ma	1*
	Columbia	0.22 +/- 0.16 Ma	2
	Fulton	0.80 +/- 0.06 Ma	3
	Moberly	1.31 +/- 0.09 Ma	2
	Atlanta	2.42 +/- 0.14 Ma	2
Iowa	Winthrop	0.72 +/- 0.37 Ma	1
	Alburnett	0.87 +/- 0.43 Ma	1

* Samples at a second site give an age of < 0.18 +/- 0.5 Ma for the Macon.

Table 2. Cosmogenic-isotope burial ages for tills in northern Missouri and Conklin Quarry, Iowa (Balco and Rovey, 2008 & 2010). See Figure 1 for the rank of stratigraphic units. Ages in Missouri are error-weighted means from multiple sites; the age at each individual site is determined from 2-6 individual isotope-ratio measurements.

PROCEDURES

Paleomagnetics

We collected samples from Conklin Quarry and measured their paleomagnetic remanence in 1997 and 1998. Samples were collected in vertical sequence from fresh exposures by inserting oriented plastic boxes vertically downward on a surface that had been cleaned and leveled by hand in fresh, moist, and undisturbed sediment. All samples from the Alburnett valley-fill and slope sediments were taken from below the upper paleosol that developed in these deposits. Samples were then subjected to stepwise alternating field (AF) demagnetization to clean the magnetic remanence, primarily by removing viscous remanence (VRM) acquired in the current field.

Cosmogenic Isotopes

In 2007 we collected additional samples from the Westburg Geosol developed in the upper Alburnett till and the intra-Alburnett paleosol atop the lower Alburnett till. We sieved the medium-coarse sand from these samples and extracted ^{10}Be and ^{26}Al from the quartz grains following procedures in Balco and Rovey (2008). Near the ground surface (i.e. within a weathering profile) these isotopes are produced in a fixed ratio within quartz grains by bombardment of cosmic radiation. After burial, in this case deposition of an overlying till, production (nearly) stops within the buried profile and the isotope ratio changes systematically with burial time due to differential decay. Thus, the ratio of ^{10}Be:^{26}Al within paleosols/weathering profiles gives the length of time that the paleosol has been buried. In this case isotope ratios within the intra-Alburnett paleosol give the age of the upper Alburnett till, and ratios from the Westburg Geosol date the overlying Winthrop Member.

RESULTS

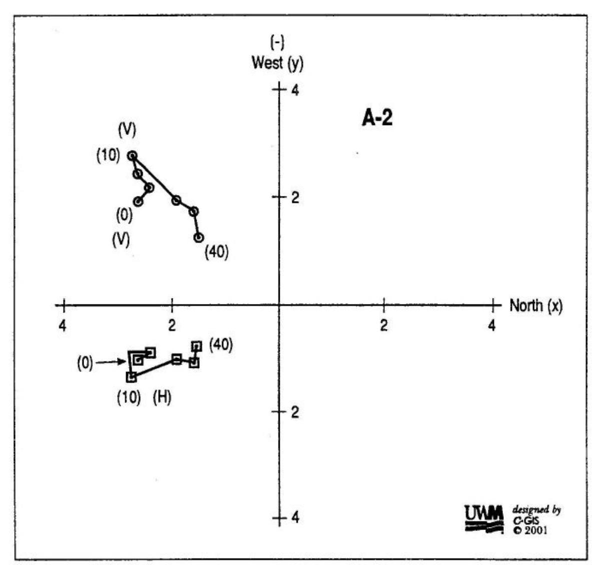
Demagnetization

Alburnett Formation. Samples of Alburnett Formation till had a stable reversed characteristic remanence that is best expressed between 10 and 30 mT of demagnetization (Figure 3a). Alburnett till samples had coercivities ranging generally from 20-40 mT; therefore, the natural remanence should be a detrital remanent magnetization carried by magnetite.

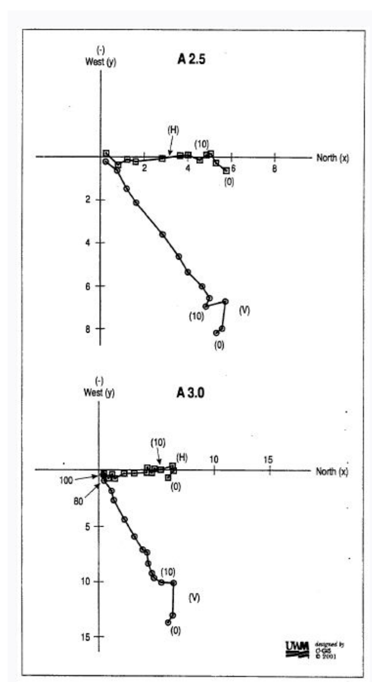
Samples of the upper Alburnett Formation valley-fill silt also had a strong characteristic remanence (Figure 3b), but with normal polarity instead of reversed. Demagnetization of these samples through 100 mT showed a single component of normal magnetization. The Alburnett valley-fill silt samples had coercivities ranging between 25 and 50 mT in most samples, again consistent with a depositional remanence carried by magnetite and inconsistent with any kind of secondary remanence.

Samples from slope deposits of the Alburnett Formation had a weak, in many cases unstable, remanence. Nearly 40% of these samples had intensities which declined to, or closely approached, the magnetometer's lower sensitivity limit (0.05 x 10^{-3} A/m) before reaching the 10 mT demagnetization step (i.e. before any VRM could be removed). Such samples were omitted from further consideration. The remaining slope-deposit samples had normal inclination and mixed declinations.

Figure 3. Vector intensity diagrams, Alburnett Formation. Circles and squares show the vertical and horizontal components, respectively of the magnetic remanence vector upon successive demagnetization steps.



a. Till.



b. Alluvial silt.

Wolf Creek Formation. All Wolf Creek Formation samples had normal inclination, although samples from sheared intervals tended to have scattered declinations. These samples also had lower magnetic intensities and shallower inclinations than other samples within the same respective stratigraphic unit.

The lower intensity is not caused by differences in magnetic mineralogy, because the bulk susceptibility (a measure of total magnetite content) is nearly constant within each respective depositional unit.

Two vertical transects were sampled in the Winthrop Member. The first transect (8 samples) was in an area with minimal shear effects, except near the base. The second transect (4 samples) was in an area exhibiting many shear and deformation structures. Samples from both transects, particularly those from the second, had relatively low NRM, indicating that mechanical stress during or shortly after deposition prevented or disrupted a strongly preferred orientation of magnetic grains.

Polarity and Mean Directions

Alburnett Formation. Optimal "cleaning" or demagnetization levels were obtained for each unit, based on a number of criteria, including the consistency of measured remanence directions in multiple orientations after each demagnetization step. Based on these results, the optimal demagnetization level was approximately 20 mT for Alburnett Formation tills and colluvium, 30 mT for Alburnett silts, and 10 mT for Wolf Creek tills. Declination and inclination values of samples obtained from principal component analysis (PCA) do not deviate significantly or systematically from those obtained at these levels. Therefore, vector-mean values of each stratigraphic unit (Table 3) are calculated from values obtained at optimal demagnetization levels.

Table 3

Unit	n	Inclination	Declination	κ	alpha 95	Polarity	NRM Intensity
Aurora							
Lower Till	3	+65	16			Normal	4.6
Winthrop	12	+71	136	4.5	19	Normal	1.2
Alburnett							
Alluvium	11	+56	350	12.	12	Normal	4.6*
Colluvium	7	+64	213	2.1	37	Normal	1.0**
Upper Till	9	-43	176	2.6	29	Reverse	1.7
Lower Till***	3	-52	172			Reverse	5.5

* omits value from three samples with distinct short-term viscous effects.

** omits value from 5 samples with an unstable remanence.

*** three samples from this unit crumbled during transport to the lab and were discarded.

Table 3. Summary of new paleomagnetic measurements, Conklin Quarry. Table includes results for those units represented by three or more samples. Inclinations and declinations are vector means, "n" is the number of specimens, "κ" is the Fisher precision parameter, and "alpha 95" is the 95% confidence limit (degrees), calculated for units with 7 or more samples. Intensities are median values in 10-3A/m.

Both Alburnett Formation tills have reversed remanent polarity. The vector-mean inclination and declination of the lower till (172º and -52º, respectively) are close to reversed dipole values at this latitude, whereas the upper till has a shallower (-43º) and more erratic inclination. Inclination values in the upper till are consistent with shallow values measured regionally in this unit and its stratigraphic equivalents elsewhere in the midcontinent region (Tables 1 and 3). Baker's (1985) block-mean inclination value of the intratill silt (-37°) is consistent with trends within and between the two Alburnett Formation tills (Figure 4).

In contrast to the reversed polarity of the underlying tills, the alluvial valley-fill silt of the Alburnett Formation has normal polarity. Step demagnetization and PCA analysis isolated no significant reversed components, except for a single suspect sample with a borderline negative inclination. This particular sample was taken from a bioturbated interval and had a weaker magnetization, along with pronounced viscous effects. Overall, declinations and inclinations cluster tightly around normal dipole values (vector means of 350° and +56°, Table 3, Figure 4), albeit with more scatter in the upper 0.6 m. Given that the normal remanence is consistent with a primary detrital magnetization, these results indicate that the alluvial silt in the upper part of the Alburnett Formation was deposited in a normal magnetic field.

Valley-slope sediments (colluvium) from the upper part of the Alburnett Formation also had positive inclinations close to normal dipole values. Declinations, however, were more scattered and tended to be aligned in an east-west orientation, perpendicular to the slope of the paleovalley wall. The fact that these declinations preserved an orientation related to the flow direction is additional evidence that the measured remanence is not merely a secondary post-depositional acquisition. If a secondary magnetic remanence had been acquired through post-depositional processes (e.g. a viscous overprint or a chemical remanence due to growth of authogenic Fe-rich minerals), declinations would consistently align with the dipole field. Therefore, the normal inclinations must have been acquired during deposition and in a normal-polarity magnetic field.

Winthrop Member. Inclinations within Winthrop Member till are also tightly clustered about the normal dipole value (Figure 4), except for samples taken near the base of the second (highly sheared) transect; those inclinations are anomalously low, and the declinations seem to reflect the direction of ice movement during deposition. The vector-mean inclination of +71° (Table 3) for all Winthrop samples is greater than the dipole value of 60°. However, this difference is largely an artifact of the vector-averaging method, because declinations are scattered in both northern and southern orientations. The median value of +58° is a more representative inclination. As was the case with the subjacent Alburnett Formation valley-slope deposits, the fact that

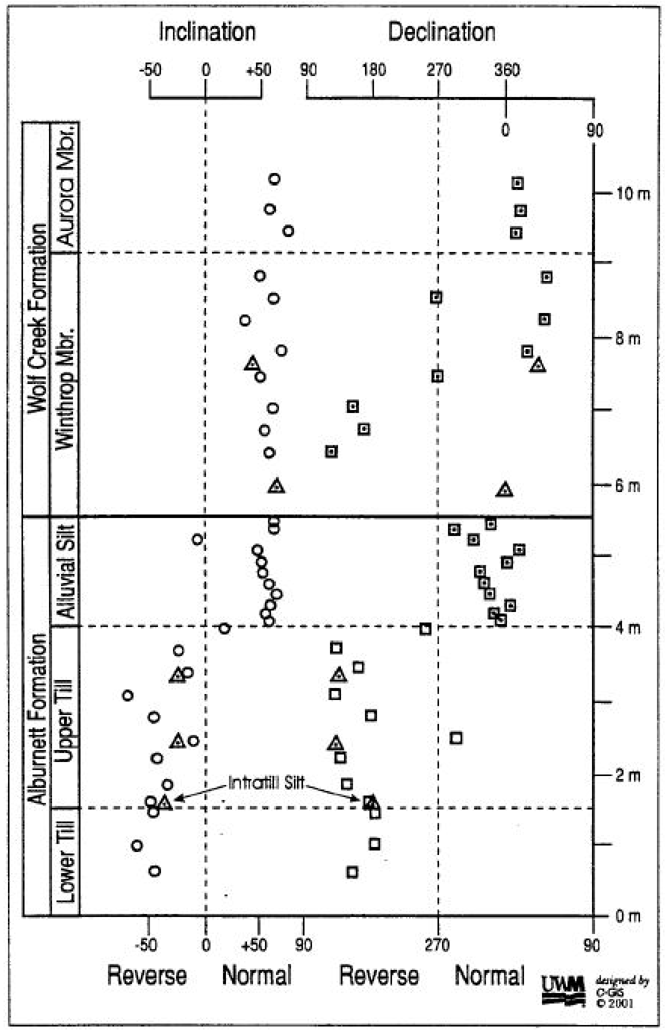


Figure 4. Summary of magnetic polarity measurements, Conklin Quarry. Section shown is a composite of individual transects completed at nearby locations within Conklin Quarry. (see Figure 2). Circles and squares indicate inclination and declination, respectively, measured for this study. Triangle pairs show the average inclination and declination of multiple specimens from large blocks, taken from Baker (1985).

declinations of samples collected from sheared intervals retain an alignment associated with depositional stress implies that the measured remanence is primary.

Aurora Member. The lower till in the Aurora Member had not been sampled prior to this study. Three samples from this till had vector means of 16° declination and +65° inclination (Table 3, Figure 4). Two samples of the upper till within the Aurora Member had magnetic characteristics that are similar to those of the underlying, highly sheared, Winthrop Member. These include low NRM intensities and scattered declinations. Both inclinations, however, were +64°.

Cosmogenic-Isotope Dates

Samples from the intra-Alburnett paleosol give a burial age of 0.87 +/-0.43 Ma (Table 2). The large error limits are due to relatively low isotope concentrations within this profile. Nevertheless, the burial age here is consistent with correlation to both the Moberly Formation in Missouri (cosmogenic isotope date of 1.31 +/- 0.09 Ma) and the "B" till in eastern Iowa, which appears to be close in age to the 1.3 Ma date of the underlying tephra (Figure 1). The low isotope concentrations are due to the soil's weak development (an A/C profile) and indicate that this profile developed over <10 ka (Balco and Rovey, 2010). Thus, the ice advances that deposited the two Alburnett Formation tills (and by correlation the two Moberly and the "B"-"A4" tills reflect short-term fluctuations within the same major glaciation, not successive glacial episodes.

Isotope ratios within the upper Alburnett paleosol (the Westburg Geosol) give a burial age of 0.72 +/- 0.37 Ma, which provides a date for the overlying Winthrop Member. The large error limits again reflect relatively low isotope concentrations within a truncated Bt horizon, but the age is very consistent with Missouri dates for the correlative Fulton member (0.80 +/- 0.04 Ma, Table 2).

DISCUSSION

Glacial tills of the Alburnett Formation have a reversed magnetic remanence whereas those of the Wolf Creek Formation have normal remanence, as previously determined by Baker and Stewart (1984) and Baker (1985). The most surprising and intriguing new results are that the alluvial valley-fill and colluvial slope deposits in the upper part of the Alburnett Formation have normal depositional magnetic remanence. This transition from reversed to normal polarity occurred within a short interval of time between deposition of the upper till of the Alburnett Formation and deposition of the valley-fill and slope deposits within the same formation, confirming that the Alburnett and its equivalents were deposited shortly before a magnetic reversal.

The dates that are now available for the Alburnett tills and their lateral equivalents are inconsistent with the hypothesis that the reversal within the Alburnett Formation is the M/B transition. Which reversal might it be? The short Cobb Mountain "event," (now a normal-polarity subchron within the Matuyama Reversed Chron (Channell et al., 2002; Horng et al., 2002; Gibbard et al., 2005) is variously dated at intervals ranging from 1.17-1.19 Ma to 1.22-1.24 Ma. These dates are just slightly younger than the ~1.3 Ma date for the Alburnett Formation, based on its correlation to the Moberly and "B" tills (Fig.1, Table 2), and the latter range is within 1-σ error limits of the Missouri dates. Alternatively, if the valley-fill sediments within the Alburnett Formation at Conklin Quarry are somewhat younger than the subjacent till facies, this reversal conceivably might be as young as the Jarimillo Normal Polarity Subchron at 0.99-1.07 Ma (Cande and Kent, 1995).

SUMMARY AND CONCLUSIONS

1. This work confirms the general results of Baker and Stewart (1984) and Baker (1985). Tills of the Alburnett Formation are reversely magnetized, whereas younger tills of the Wolf Creek Formation have normal remanent polarity.

2. Based on cosmogenic isotope dates at Conklin Quarry and regional correlation to dated sections in eastern Iowa and northern Missouri, the normal-polarity tills are younger than the M/B boundary at 0.78 Ma, whereas the reversed polarity tills are older. Thus, the boundary between the Early and Middle Pleistocene is present within the pre-Illinoian till sequence throughout eastern Iowa.

3. Cosmogenic isotope dates for tills at Conklin Quarry support correlation of the two Alburnett Formation tills with the "B"-"A4" till sequence in eastern Iowa and with the two Moberly Formation tills in northern Missouri. Likewise, dates for the Winthrop Member at Conklin support correlation of that unit to the Fulton member in northern Missouri.

4. Locally preserved valley-fill and slope sediments, inset into the reversely magnetized Alburnett Formation tills, and capped by the Westburg Geosol at Conklin Quarry, have a normal detrital remanent magnetization. Therefore, a magnetic reversal (reverse to normal) is present within the Alburnett Formation. However, based on cosmogenic isotope dates and correlation to other dated sections, this reversal is too old to be the M/B transition. Instead, the normal remanence within the upper Alburnett alluvial/colluvial facies probably indicates deposition during either the Cobb Mountain or the Jarimillo Normal Polarity Subchron.

REFERENCES

Baker, R.G., Frest, T.J., and Rhodes, R.S. II (1984). Paleoecology of Quaternary sediments at Conklin Quarry. *In* "Underburden-Overburden: An Examination of Paleozoic and Quaternary Strata at the Conklin Quarry Near Iowa City" (B.J. Bunker and G.R. Hallberg Eds.), Guidebook 41, pp. 70-81. Geological Society of Iowa, Iowa City, IA.

Baker, J.L. and Stewart, R.A. (1984). Paleomagnetic study of glacial deposits at Conklin Quarry and other locations in southeast Iowa. *In* "Underburden-Overburden: An Examination of Paleozoic and Quaternary Strata at the Conklin Quarry Near Iowa City" (B.J. Bunker and G.R. Hallberg Eds.), Guidebook 41, pp. 63-69. Geological Society of Iowa, Iowa City, IA

Baker, J.L. (1985). "A paleomagnetic study of Pleistocene glacial sediments in southeast Iowa." Unpublished M.S. Thesis. Iowa State University, Ames Iowa.

Balco, G., Rovey, C.W., and Stone, J. (2005). The first glacial maxium in North America. Science, 307, 222, doi: 10.1126/science.1103406.

Balco, G. and Rovey, C.W. (2008). An isochron method for cosmogenic-nuclide dating of buried soils. American Journal of Science, 308, 1083-1114, doi: 10.2475/10.2008.02.

Balco, G. and Rovey, C.W., (2010). Absolute chronology for major Pleistocene advances of the Laurentide Ice Sheet. Geology, 38(9), 795-798, doi:10.1130/G30946.1

Boellstorff, J. (1978). Chronology of some Late Cenozoic deposits from the central United States and the ice ages. Transactions of the Nebraska Academy of Sciences, 6, 35-49.

Bettis, E.A. III (1998). Subsolum weathering profile characteristics as indicators of the relative rank of stratigraphic breaks in till sequences. Quaternary International, 51/52, 72-73.

Cande, S.C., and Kent, D.V. (1995). Revised calibration of the geomagnetic polarity timescale for the Late Cretaceous and Cenozoic. Journal of Geophysical Research, 100(B4), 6093-6095.

Channell, J.E.T., Mazaud, A., Sullivan, P., Turner, S., and Raymo, M.E. (2002). Geomagnetic excursions and paleointensities in the Matuyama Chron at Ocian Driling Program Sites 983 and 984 (Iceland Basin). Journal of Geophysical Research, 107(B6), 2114, doi:10.1029/2001JB000491.

Easterbrook, D.J. and Boellstorff, J. (1984). Paleomagnetism and chronology of early Pleistocene tills in the central United States. *In* "Correlation of Quaternary Chronologies" (W.C. Mahaney Ed.) pp. 73-90. GeoBooks, Norwich, England.

Follmer, L.R. (1983). Sangamon and Wisconsinan pedogenesis in the midwestern United States. *In* "Late-Quaternary Environments of the Unites States, Volume 1: The Late Pleistocene" (H.E. Wright Jr., Ed.), pp. 138-144. Minneapolis, University of Minnesota Press.

Gibbard, P.L., Boreham, S., Cohen, K.M. and Moscariello,A. (2005). Global chronostratigraphic correlation table for the last 2.7 million years. Boreas, 34(1), unpaginated.

Gibbard, P.L., Head, M.J., and Walker, M.J.C. (2010). Formal ratification of the Quaternary System/Period and the Pleistocene Series/Epoch with a base at 2.58 Ma. Journal of Quaternary Science, 25(2), 96-102, doi: 10.1002/jqs.1338.

Hallberg, G.R., (1980). "Pleistocene Stratigraphy in East-Central Iowa." Iowa Geological Survey Technical Information series No. 10, Iowa City. 168 pp.

Hallberg, G.R. (1986). Pre-Wisconsinan glacial stratigraphy of the central plains region in Iowa, Nebraska, Kansas and Missouri. *In* "Quaternary Glaciations in the United States of America" (G.M. Richmond and D.S. Fullerton, Eds.), Quaternary Science Reviews 5, pp. 11-15.

Hallberg, G.R., Kemmis, T.J., Wollenhaupt, N.C, Esling, S.P, Bettis, E.A. III, and Bicki, T.J. (1984). The overburden: Quaternary stratigraphy of the Conklin Quarry. *In* "Underburden-Overburden: An Examination of Paleozoic and Quaternary Strata at the Conklin Quarry Near Iowa City" (B.J. Bunker and G.R. Hallberg Eds.), Guidebook 41, pp. 25-62. Geological Society of Iowa, Iowa City, IA

Horng, C., Lee, M., Palike, H. , Wei, K, Lian, W, Iizuka, Y., and Torii, M. (2001). Astronomicallly calibrated ages for geomagnetic reversals within the Matuyama chron. Earth Planets Space, 54, 679-690.

Kemmis, T.J., Bettis, E.A. III and Hallberg, G.R. (1992). "Quaternary Geology of Conklin Quarry." Guidebook Series No. 13, Geological Survey Bureau, Iowa Department of Natural Resources, 41 pp.

Opdyke, N.D. and Channell, J.E.T. (1996). Magnetic Stratigraphy. 336 pp. Adacemic Press, San Diego

Richmond, G.M. and Fullerton, D.S. (1986). Summation of Quaternary Glaciations in the United States of America" *In* "Quaternary Glaciations in the United States of America" (G.M. Richmond and D.S. Fullerton, Eds.), Quaternary Science Reviews 5, pp. 183-196.

Rovey, C.W. II and Kean, W.F. (1996). Pre-Illinoian glacial stratigraphy in north-Central Missouri. Quaternary Research 45, 17-29, doi: 10.1006/qres.1996.0002.

Rovey, C.W. II and Kean, W.F. (2001). Palaeomagnetism of the Moberly formation, northern Missouri, confirms a regional magnetic datum within the pre-Illinoian glacial sequence of the midcontinental USA. Boreas 30, 53-60, doi:10.1111/j.1502- 3885.2001.tb00988x.

Rovey, C.W. II and Tandarich, J. (2006). Lithostratigraphy of glacigenic sediments in north-central Missouri, *In* "Guidebook of the 18th biennial meeing of the American Quaternary Association" (R. Mandel Ed.) Kansas Geological Survey Technical Series 21, p. 3- A-1 - 3-A-12.

Roy, M., Clark, P.U., Barendregt, R.W., Glasmann, J.R. and Enkin, R.J. (2004). Glacial stratigraphy and paleomagnetim of late Cenozoic deposits of the north-central United States. Geological Society of America Bulletin, 116, 30-41, doi: 10.1130/B25325.1.

Geological Society of Iowa
109 Trowbridge Hall
Iowa City, Iowa 52242-1319
www.iowageology.org


N
2010 Aerial Photograph of Klein Quarry


N
RIVER
IOWA
2010 Aerial Photograph of Conklin Quarry