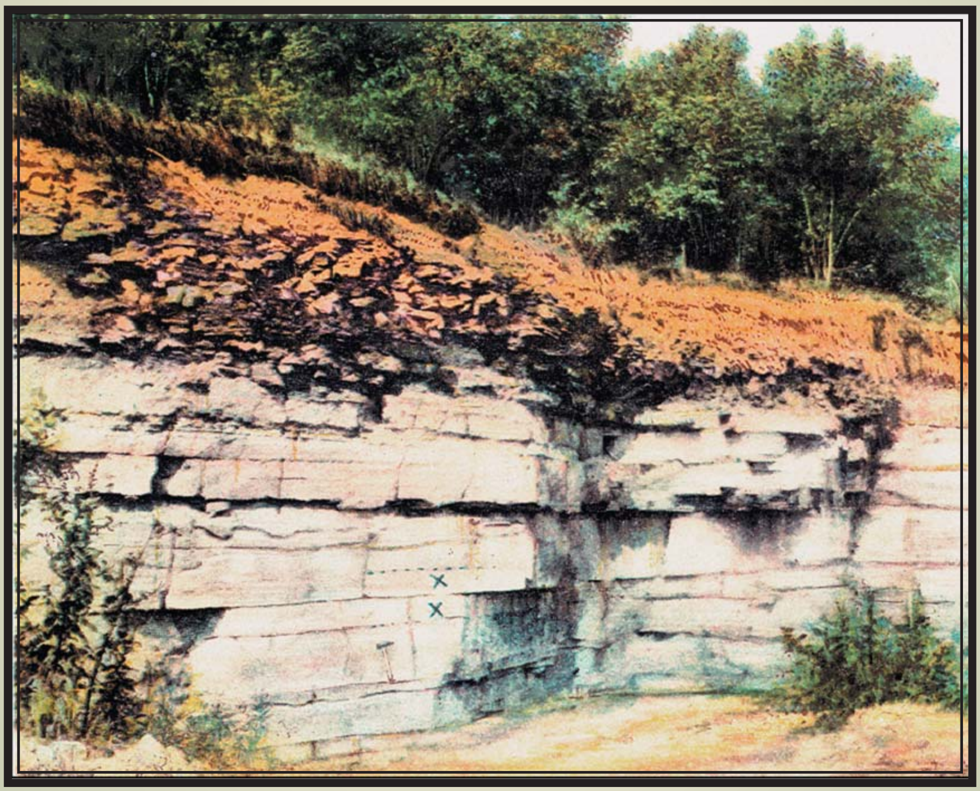
CARBONATE PLATFORM FACIES AND FAUNAS OF THE MIDDLE AND UPPER DEVONIAN CEDAR VALLEY GROUP AND LIME CREEK FORMATION, NORTHERN IOWA

Iowa Geological and Water Survey
Guidebook Series No. 28



Iowa Department of Natural Resources
Richard Leopold, Director
October 2008

COVER

Lithographic plate of Idlewild Member of Lithograph City Formation at Lewis Quarry, immediately south of Osage, Mitchell County, Iowa. Beds marked “X” are those determined by A. Hoen & Co. of Baltimore to be suitable for use in lithography. Reproduced from Plate VIII in Iowa Geological Survey Annual Report for 1902.

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Iowa Geological and Water Survey
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Prepared for the

69th Annual Tri-State and Great Lakes Section – SEPM Fall Field Conference
Co-hosted by the Department of Earth Science, University of Northern Iowa
and the Iowa Geological and Water Survey

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OVERVIEW OF THE LITHOGRAPH CITY FORMATION

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LITHOSTRATIGRAPHY

The Lithograph City Formation was named by Witzke et al. (1988) for the package of strata lying disconformably above the Coralville Formation and disconformably below the Shell Rock Formation or Sweetland Creek Shale (Fig. 1). The type section of the Lithograph City Formation was designated as the old quarry adjacent to the abandoned town of Lithograph City in Floyd County, Iowa. A new quarry (**Saturday Stop #2**) is operating now immediately east of the old one. Prior to 1988 these strata were assigned by most workers to the Coralville Formation, but they do not correlate with any part of the Coralville in its type area. Recognition of the distinctness of the Lithograph City interval occurred in connection with detailed studies of Devonian aquifers in northern Iowa (Witzke and Bunker, 1984, 1985). Further information on the newly recognized Lithograph City Formation was presented in Bunker et al. (1986) and Bunker, ed. (1995).

Inner shelf facies of the Lithograph City Formation in northern Iowa are subdivided into the Osage Springs, Thunder Woman Shale and Idlewild members (ascending order). In east-central and southeastern Iowa the same interval comprises distal inner shelf and middle shelf facies subdivided into the State Quarry, Andalusia and Buffalo Heights members (Fig. 1). Only the inner shelf facies are considered here.

The Osage Springs Member is the basal unit of the Lithograph City Formation in northern Iowa and neighboring Minnesota. At its type section a few miles south of the town of Osage in Mitchell County (**Saturday Stop #1**) it consists of dolomite and dolomitic limestone with calcite-filled vugs. Fossils and ghost fabrics of precursor limestone lithologies are detectable in certain layers. The member becomes increasingly dominated by fossiliferous limestone southward in the northern Iowa outcrop belt where stromatoporoids are very abundant locally. Accordingly to Witzke et al. (1988), the Osage Springs Member in northern Iowa varies in thickness from 3.4 to 7.5 m and it is similar in thickness and lithology to the underlying Iowa City Member of the Coralville Formation. It is distinguished from the latter on stratigraphic position and faunal criteria. It is overlain conformably throughout most of its distribution by the Idlewild Member, although in northwestern Black Hawk County (and presumably also in neighboring parts of Bremer and Butler counties) the Osage Springs and Idlewild members are separated by the Thunder Woman Shale Member.

The type section of the Thunder Woman Shale Member was designated at Yokum Quarry in northwestern Black Hawk County, approximately 1.4 km east of Thunder Woman County Park (Witzke et al., 1988). Yokum Quarry has since been abandoned and the site is now known as the Turkey Ridge Wildlife Area, managed by the Black Hawk County Conservation Board. A complete section of the Thunder Woman Shale Member is exposed in the currently operating Messerly Quarry (**Saturday Stop #4**) where the unit is 2.5 to 3 m thick. The Thunder Woman Shale Member is light grey to buff, slightly dolomitic, unfossiliferous, silty shale. It is much less resistant than underlying and overlying carbonates of the Osage Springs and Idlewild members, but dolomitic intervals are relatively well indurated. The surface distribution of the member is limited to the southern part of the northern Iowa outcrop belt. It is present also in the subsurface of central Iowa, but to the north it grades laterally into the Idlewild Member and to the south it is erosionally truncated (Bunker et al., 1986; Witzke et al., 1988).

The Idlewild Member conformably overlies

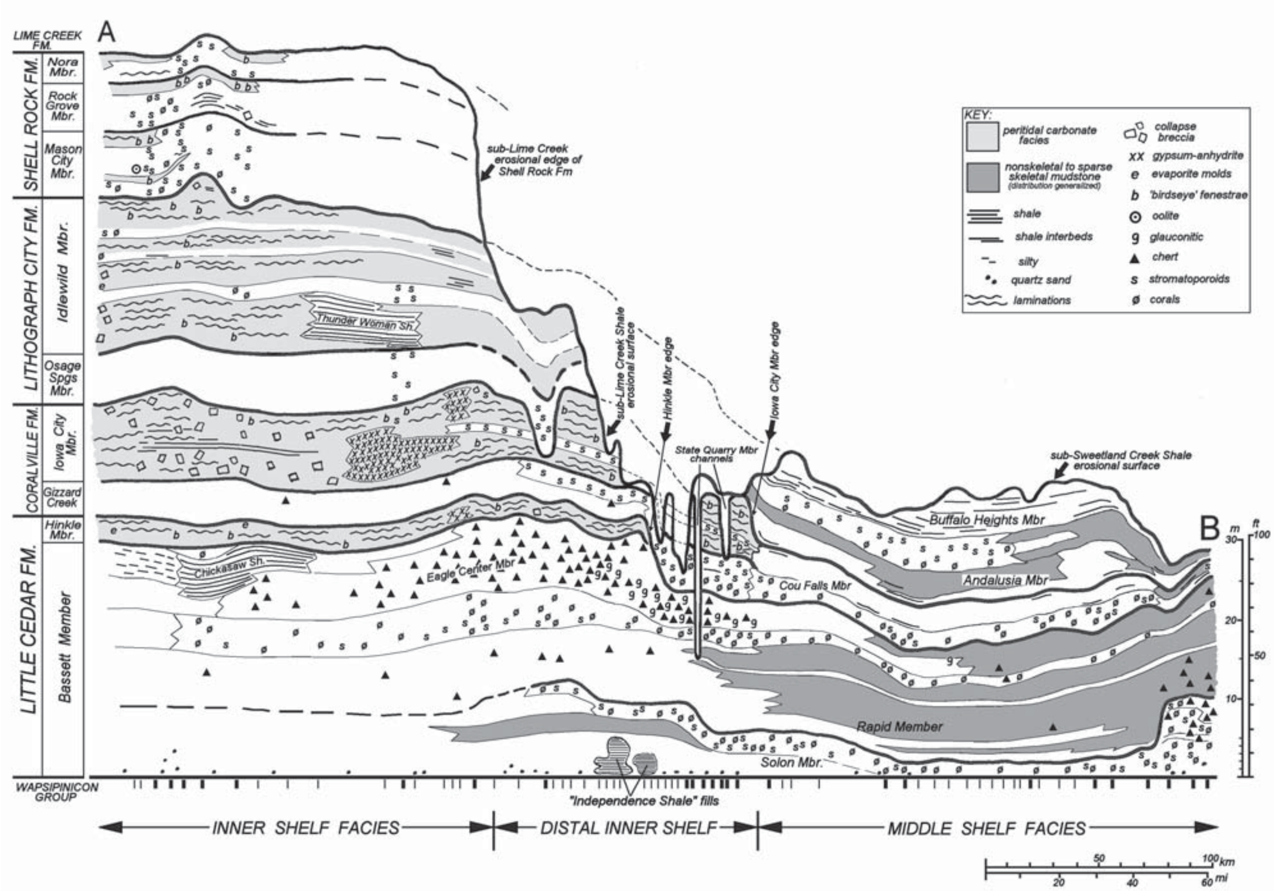

Figure 1. Cross section of Cedar Valley Group strata from north-central Iowa (A) to extreme southeastern Iowa (B). Exposures of the Lithograph City Formation visited on this trip represent the inner shelf facies on left side of diagram. Figure prepared and provided by B. J. Witzke.

the Osage Springs Member throughout most of northern Iowa. Locally it overlies or grades laterally into the Thunder Woman Shale Member. It grades laterally into fossiliferous carbonates of the Andalusia Member in southeastern Iowa. The type section of the Idlewild Member was designated at Floyd Quarry in northern Floyd County, approximately 2.3 km downstream on the Cedar River from Idlewild State Park (Witzke et al., 1988). The Idlewild Member comprises a heterogeneous assortment of lithologies ranging from laminated lithographic limestone and dolomite to calcareous shale to variably fossiliferous limestone. Mudcracks, birdseyes and fenestral fabrics, evaporite molds and intraclasts are present locally, especially in northern areas, signifying a peritidal origin. In the southern part of the northern Iowa outcrop belt the unit becomes more fossiliferous and peritidal features become somewhat less common. The unit ranges in thickness from 16 to 24 m where it is overlain by the Shell Rock Formation (Witzke et al., 1988). Its thickness is appreciably less where truncated beneath Pleistocene glacial deposits, as at **Saturday Stops 2, 3 and 4**.

The contact between the Idelwild Member and the overlying Shell Rock Formation exhibits erosional relief locally. Lithologies of the basal Mason City Member of the latter unit are variably argillaceous, skeletal and dolomitic lime-

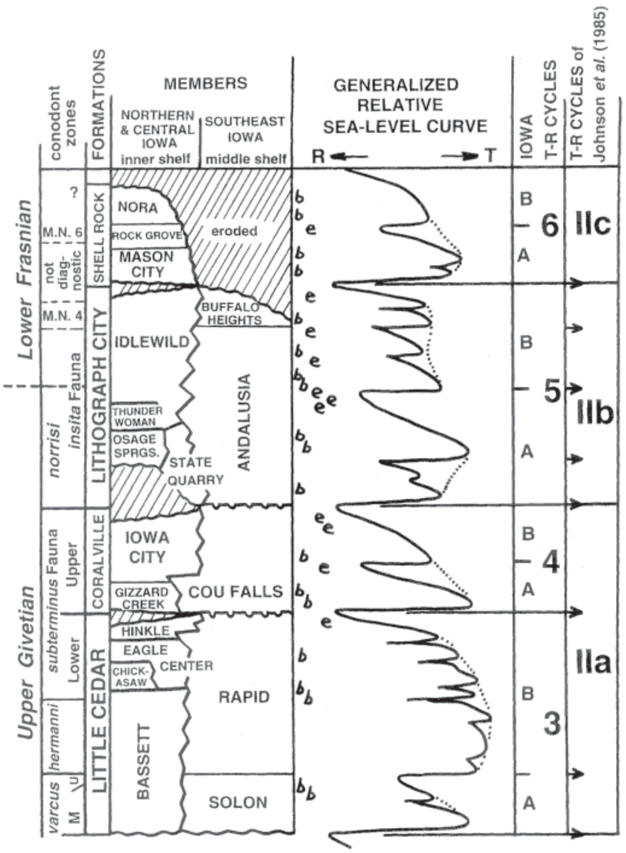

Figure 2. Relative sea-level curve for upper Givetian and lower Frasnian rocks in Iowa and relationship to T-R cycles of Johnson et al. (1985). Figure prepared and provided by B. J. Witzke.

stone, in contrast to the fine-grained limestone of the uppermost Idelwild. Moreover, the Mason City Member contains prominent stromatoporoid biostromes at all known localities (Witzke et al., 1988).

LITHOFACIES TRENDS IN NORTHERN IOWA

All of the Lithograph City Formation localities to be visited in the course of this field conference are assignable to inner shelf facies. Nevertheless, dramatic facies changes are evident in the roughly north-to-south transect encompassed by Saturday's stops. For example, the Osage Springs Member is entirely dolomite and sparsely fossiliferous at its type section in Mitchell County, whereas in Black Hawk County it is highly fossiliferous (biostromal, in part) and only partly dolomitic. Facies changes within the Idlewild Member are equally well developed. At its northern exposures the Idlewild comprises sparsely fossiliferous, pelletal, intraclast- and birdseye-bearing, variably laminated, fine-grained limestones. To the south it is more coarsely bioclastic with only minor beds of sublithographic limestone. North-to-south changes in both the Osage Springs and Idlewild members reflect the differences between highly restricted, peritidal environments and less restricted, inner neritic environments, respectively.

BIOSTRATIGRAPHY

Fossils from the Lithograph City Formation have received considerable attention and form the basis for establishing the age of the unit. Details of brachiopod and stromatoporoid biostratigraphy are given elsewhere in this volume, and so only a brief summary is provided here.

Witzke et al. (1988) reported the conodont *Pandorinellina insita* from the basal Osage Springs Member. Those authors noted that the *insita* Fauna correlates in part with the Lowermost *asymmetricus* Zone of the standard conodont zonation (Ziegler, 1962, 1971). Brachiopods from the Osage Springs Member are dominated by species of *Allenella*, *Athyris*, *Independatrypa* and *Strophodonta* (Day, 1988). The Osage Springs fossil association is indicative of late Givetian age.

The Thunder Woman Shale Member is generally barren of shelly invertebrates, although Witzke et al. (1988) noted the presence of burrow mottles and subsurface occurrences of conodont fragments and fish debris. The late Givetian age of the unit is inferred principally on stratigraphic position relative to the better-dated subjacent and superjacent members of the Lithograph City Formation.

The Idlewild Member has yielded the conodonts *P. insita* and *Polygnathus angustidiscus*, both assignable to the *insita* Fauna (Witzke et al., 1988). Brachiopods include *Allanella*, *Athyris*, *Strophodonta* and *Eleutherokomma*. Joint occurrences of *Allanella allani* and *Eleutherokomma jasperensis* in the upper Idlewild Member suggest equivalency with the Lower *asymmetricus* Zone of Frasnian age (Day, 1986). Accordingly, the Givetian-Frasnian boundary is thought to fall within the Idlewild Member.

Conodonts and brachiopods from the Shell Rock have been correlated with the Middle *asymmetricus* Zone (Day, 1988; Witzke et al., 1988), an interpretation that is consistent with physical evidence for a disconformity separating it from the Lithograph City Formation.

The Lithograph City Formation is regarded as the depositional product of a single transgressive-regressive cycle: Iowa T-R cycle 5 of Witzke et al. (1988) or T-R cycle IIb of Johnson et al. (1985) (Fig. 2). The regressive, upper portions of T-R cycles typically are characterized by the progradation of mudflat facies, with or without evaporites. Pelletal, lithographic and sublithographic facies of the Idlewild Member certainly conform with this generalization. Such facies in the middle and upper part of the member may have been produced by a T-R subcycle (Witzke et al., 1988).

COMMERCIAL STONE PRODUCTION

Commercial interest in rocks now assigned to the Lithograph City Formation dates back to before the turn of the 20th Century when the so-called Devonian "lithographic zone" in Mitchell County was quarried for building stone, aggregate and cement. Calvin (1903, p. 333) noted that most beds of the lithographic zone lack the uniformly fine-grained texture that would make them suitable for lithographic printing, but "the upper eight or nine inches of [bed] No. 3 of the Lewis Quarry section is remarkably fine-grained and homogeneous…" Samples from bed No. 3 were sent to A. Hoen & Co. lithographers in Baltimore where they were tested and found to be "quite satisfactory for the finer process of lithographic engraving..." A copy of A. Hoen & Co.'s report was reproduced in the Iowa Geological Survey Annual Report for 1902. A photograph of the Lewis Quarry, immediately south of Osage, and a color lithographic print of the same image also appeared in the Annual Report for 1902, and both are reproduced here in Figure 3. Calvin (*ibid*.) further noted that although the upper part of bed No. 3 and the lower part of bed No. 5 seem suitable for fine lithographic work, "the beds are badly checked [i.e., fractured or jointed]… making it difficult to get slabs of useful size." He concluded that with additional excavation these beds somewhere might be found with fewer fractures, and that "Mitchell County may add to its industries the production of a high grade lithographic stone."

Perhaps not coincidentally, at about this time a local geologist, Clement L. Webster, began promoting the production and sale of lithographic stone from northern Iowa. A colorful account of Webster, his attempts to extract and sell lithographic stone, and the history of Lithograph City itself was presented by Bunker and Witzke (1995). In brief, Webster achieved limited success between approximately 1906 and the outbreak of World War I. During this time he secured financial backers, founded the town of Lithograph City as a base for quarry workers and their families, and purchased thousands of dollars in quarrying and stone processing equipment. According to Bunker and Witzke (1995, p. 44), by 1915 "Lithograph City included 15 houses, had several more foundations, a hotel, blacksmith shop, stone polishing plant, museum, lumber yard, general store and dance hall." Soon thereafter, amid accusations that directors of Webster's *Interstate Investment and Development Company* had embezzled funds, the financial backers splintered and the company collapsed. Moreover, newer and more efficient methods of printing emerged at about this time, resulting in a greatly reduced market for lithographic stone.

A new firm, the *Devonian Products Company*, was formed to produce aggregate and related materials from the quarry near Lithograph City. The town's name was changed to Devonia, but as the new company failed to achieve commercial success, the town's fortunes did not improve. Ac-

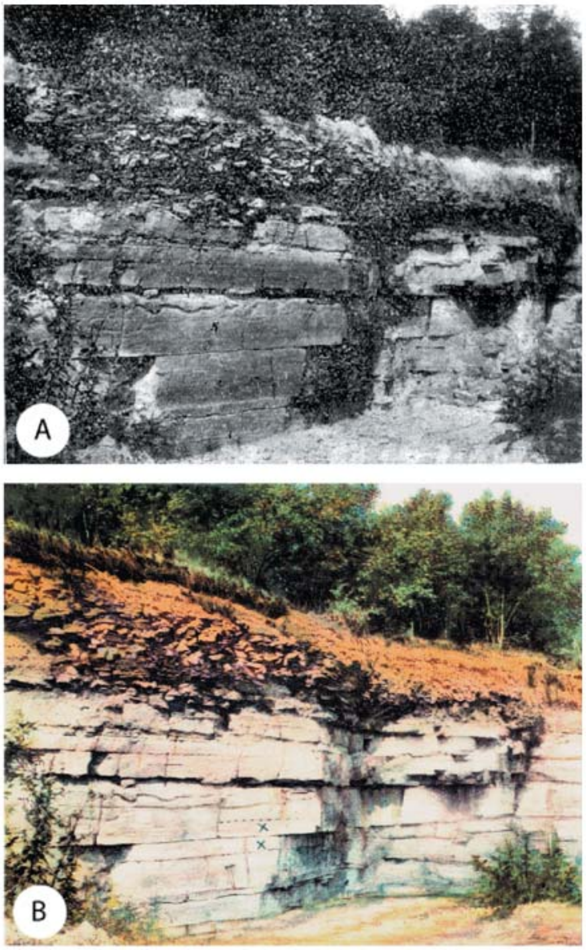

Figure 3. Lewis Quarry, immediately south of Osage (Mitchell County) as it appeared near the turn of the 20th Century. A, photograph taken from Fig. 48 in Calvin (1903). B, color plate of same image, produced on lithographic limestone from bed No. 3 at Lewis Quarry (originally published as Pl. VIII in Iowa Geological Survey, Annual Report for 1902).

cording to Bunker and Witzke (1995), by 1938 the town had been plowed under so that all that remains is a pasture with remnants of sidewalks, cellar holes and a deteriorating obelisk at what once was the corner of 3rd Avenue and Lithograph Street.

Today Croell Redi-Mix, Inc. operates the Jones Quarry on a site immediately east of the original Lithograph City quarry. The Lithograph City Formation is quarried at many sites elsewhere in northern Iowa for a variety of uses. As recently as 2007, large slabs of lithographic stone were extracted from the Jones Quarry, shipped to Solon, Iowa, for processing and then to Chicago where experimental prints were made by lithographer Greg Zinselmeier. It remains to be seen if Iowa will become a commercially viable source of lithographic stone.

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QUATERNARY GEOLOGY OF THE FIELD TRIP AREA

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INTRODUCTION

Our field trip route is confined to the landform region known as the Iowan Surface. Located in northeast Iowa, this landform region is bordered by the late-Wisconsinan age Des Moines Lobe to the west, the Paleozoic Plateau on the east, and a very irregular boundary with the Southern Iowa Drift Plain on the south (Fig. 1). It actually continues a short distance beyond the state border to the north into Minnesota as the Iowan Surface of southeastern Minnesota (Zanner, 1999).

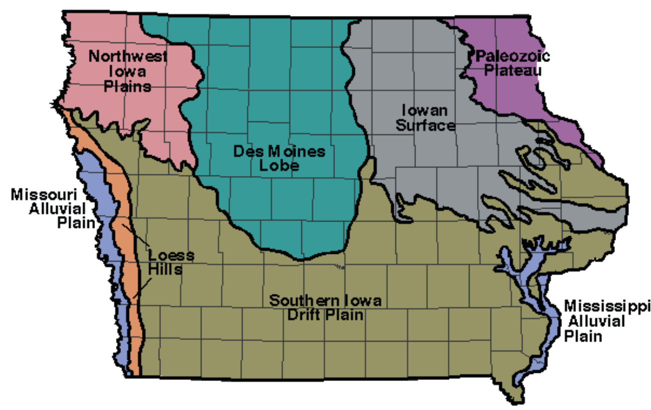

Figure 1. Landform regions of Iowa (Prior, 1991), showing approximate transect of the 2008 Tri-State/GLS-SEPM field trip.

THE IOWAN SURFACE

The Iowan Surface is characterized by a gently rolling topography and broad open vistas (Prior, 1991). Early workers during the late 1800s and early 1900s thought the origin of this landscape region was due to an "Iowan Glacier" that invaded this part of the State sometime between the Illinoian and Wisconsinan glacial periods. Later, the "Iowan" was assigned to the earliest substage of the Wisconsinan (Leighton, 1931, 1933; Kay and Graham, 1943). Because of lack of exposures in this area, the age and origin of this supposed glacial drift was debated for many years. Finally, in the late 1960s, Robert Ruhe and colleagues undertook a detailed investigation of these sediments using drilling and radiocarbon dating. They determined that the so-called Iowan drift did not exist; there had been no Iowan Glacier (Ruhe, 1969). Instead, they showed that the landscape and sediments of this part of the state were actually a result of severe erosion. The Iowan Erosion Surface, or simply Iowan Surface as it came to be called, is an extensive erosion surface cut into Pre-Illinoian glacial deposits (Hallberg, et al., 1978).

The Iowan Surface is described as a multi-level erosion surface with a stepped topography cut into Pre-Illinoian till. These stepped surfaces occur in a subdued and gradual progression from upland drainage divides down to the major stream valleys (Prior, 1991). The formation of the steps or levels took place during periods of accelerated erosion involving stream action, slope wash, and wind deflation. Studies have shown that one of the more recent and one of the most severe of these episodes took place between 21,000 and 16,500 years ago during the coldest part of the Wisconsinan. Analyses of fossil pollen, plant macrofossils, small mammals, insects, and mollusks at various sites in Iowa and adjacent states provide evidence that this region had a cold climate with open tundra conditions (Baker et al., 1986, 1989, 1991).

PERIGLACIAL FEATURES OF THE IOWAN SURFACE

Evidence of tundra conditions and information from additional investigations have led us to

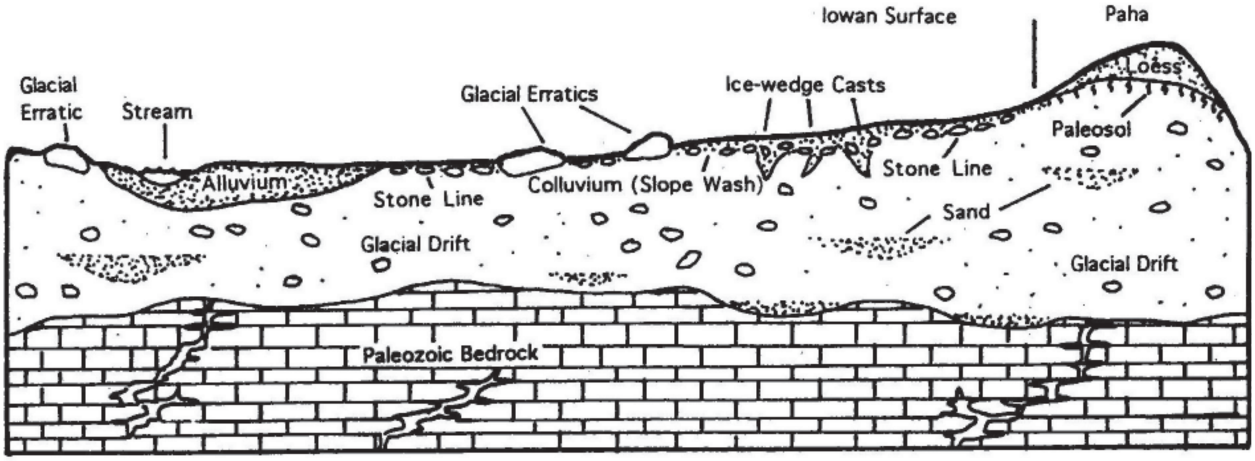

Figure 2. A schematic cross-sectional view of the Iowan Surface showing its characteristic features (from Anderson, 1998, p. 335 [adapted from Prior, 1991 and Walters, 1994].

conclude that a periglacial environment existed in northeast Iowa during this period of time, 21,000 to 16,500 years ago. Intensive freeze-thaw activity, solifluction, strong winds, and other periglacial processes must have taken place. Among other things, this resulted in the formation of an erosion surface on the Pre-Illinoian deposits of the area and the development of a residual lag deposit or stone line as the finer sediments were removed. Along drainage divides, scattered uneroded remnants of the original Pre-Illinoian topography remained above the stepped surfaces. These elongate ridges and scattered elliptical hills were capped with loess and eolian sands as the surrounding landscape was being severely eroded. Paha, as these hills are now called, have a northwest-southeast orientation and consist of a core of Pre-Illinoian till, with a paleosol instead of the stone line of the surrounding erosion surface and overlying eolian sediments. Permafrost, or permanently frozen ground, must have also existed during this period of intense cold, and ice-wedge polygons formed in the Pre-Illinoian tills. Relict polygonal patterned ground and ice-wedge casts, fillings of the former ice wedges, are common features of the Iowan surface (Walters, 1994). Figure 2 shows the characteristic geomorphic features of the Iowan Surface. Field trip participants will have the opportunity to see some of these features in the Quaternary section exposed at the Messerly Quarry.

PRE-ILLINOIAN TILLS

The Pre-Illinoian tills of northeast Iowa are a result of a complex geologic history over a long period of time. At least seven periods of glacial activity occurred between 2.2 million and 500,000 years ago. Although Pre-Illinoian tills are typically uniform and massive with loamy to clay loam textures in the southern part of the state in the Southern Iowa Drift Plain, on the Iowan Surface the Pre-Illinoian tills, have a somewhat different character due to the intense periglacial conditions that existed between 21,000 and 16,500 years ago. Severe weathering and colluvial activity resulted in much less consoliated materials at the surface (Tassier-Surine and Quade, 2008). Surface materials on the Iowan Surface tend to be loams and sandy loams, containing appreciable interbedded gravelly and/or pebbly loam units. These materials are typically up to 20 feet thick, although they may be even thicker on slopes near stream valleys where solifluction processes evidently occurred. Thin loess deposits typically 2 to 3 feet thick, but sometimes thicker immediately east of river valleys, are found covering the pre-Illinoian tills of northeast Iowa.

At the Messerly Quarry, STOP 4 on Saturday, although the deposits are poorly exposed and have been highly eroded, one can see approximately 18 to 22 feet of Pre-Illinoian till overlain by about 2 to 3 feet of loamy sediment. The lower portion of the till is unoxidized and unleached, grayish-brown in color, and rests on the Devonian bedrock. During excavation of this site several years ago, as the till was pushed out of the way, the upper surface of the bedrock showed glacial striations and polishing. The striations showed an azimuth of 290-294° degrees, indicating that the earliest Pre-Illinoian ice sheet in this area came from the west-northwest. The upper 8 to 10 feet of till is oxidized and leached and shows a strong yellowish-brown color. Although the contact between the upper surface of the till and overlying loamy sediments is mostly disturbed due to the berming process that occurred as a part of developing the quarry, one can still make out a stone line in places (or at least the remnants of the stone line). Occasional ventifacts, wind-faceted stones, can be found in the stone line, attesting to the strong winds that must have existed in this area during the latter stages of formation of the Iowan Surface, and before the loamy (mostly eolian) sediments covered the surface. Ice-wedge casts also can be found in the Pre-Illinoian till at this site, and they are most often seen as erosional niches, where the more easily eroded sand infilling has been preferentially removed. Also notable are the large glacial erratics, some over 6 feet in diameter that have been pushed to the edge of the quarry during quarry development. Several of these exotic boulders show faceting and striations from having been dragged along the base of the ice sheet.

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THE FLOYD KARST AREA

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INTRODUCTION

Floyd County displays some of the best karst topography, mostly sinkholes, in the state of Iowa. Development of solutional features in this area probably began by Cretaceous time or earlier (Anderson, 1984). The karst in this area is referred to as mantled karst, because the solutional features have been covered or mantled with glacial drift. Currently, these features are being resurrected or exhumed and they are slowly enlarging. The area just north of the town of Floyd, northeast of the Cedar River, displays the greatest density of sinkholes (Figs. 1 and 2.). Devonian bedrock here is close to the surface and the Cedar River is entrenched, thus providing ideal conditions for the development of karst topography. Torney (1979) carried out an investigation of the Floyd karst area and provided the following general conclusions:

1. The main part of the karst area has no perennial surface drainage, although intermittent streams and gullies ending in sinkholes are common.
2. An examination of 100 sinkholes shows that most of the sinkholes are funnel shaped, with a circular or oval outline.
3. Coalesced sinkholes with obvious connection of two or three original sinkholes are common.
4. A few sinkholes have teardrop shapes or eye shapes because of the entry of a gully along the perimeter.
5. Most sinkholes are vegetated with grass, trees, or brush and appear to be plugged.
6. About half of the sinkholes studied reveal bedrock along their inner perimeters or in their bottoms.
7. Range of depth for the sinkholes studied was 1 to 26 feet, with an average of about 8 feet.
8. Diameter of the circular sinkholes ranged from 6 to 215 feet, with an average of about 60 feet.
9. Many small (less than 2 feet deep and 3 feet in diameter) sinkholes exist in the area.

Beginning in 1972, Grant et al. (1977) conducted a photogrammetric mapping project of this same area and prepared contour maps using a 1-foot contour interval. From aerial photographs taken in 1972 and 1974, they were able to measure changes in the size of sinkholes. A final series of photos was taken in 1976. Unfortunately, this investigation was discontinued and the final results were never published.

A study of sinkholes in this area by Berends (1997) utilized topographic maps, aerial photographs, and field observations in an effort further understand their characteristics. She conducted a nearest neighbor analysis (NNA) to determine if the distribution of sinkholes was random or clustered. The *R* value of 0.02, indicates a clustered distribution. Or, in other words, sinkholes are spaced about 98% closer than they would be for a random distribution. She found sinkholes to be preferentially clustered on the northeast side of the Cedar River, and concluded that northeast of the Cedar River in this area, all of the conditions are met for significant karst topography.

On the northeast side of the Cedar River, the bedrock is near the surface and both bedrock and the surface topography slope to the southwest, toward the river. Southwest of the river, the surface and the bedrock slope in opposite directions and the depth to bedrock increases away from the river. So, northeast of the Cedar River, surface water easily enters the shallow bedrock and then drains down dip to the base level of the entrenched Cedar River. This allows for solutional activity to take place in the bedrock between the point of entry of surface water into the subsurface and the point of exit into the Cedar River.

Figure 1. Aerial photograph of sinkholes approximately 3 miles north of Floyd, Iowa. Note that bedrock is exposed in some of the sinkholes. North is to the top. U.S. Highway 218 is along the right side of the photo. From Iowa Geographic Map Server, Iowa State University, 2006 Orthophoto, USDA National Agriculture Imagery Program, http://ortho.gis.iastate.edu/.

Figure 2. Pasture with numerous sinkholes north of Floyd, Iowa. Note that some sinkholes are dry and bedrock is exposed in the bottoms and walls of some of them, whereas others are plugged and filled with water (photo by Jim Walters).

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OVERVIEW OF MIDDLE AND UPPER DEVONIAN CEDAR VALLEY GROUP AND LIME CREEK FORMATION CARBONATE PLATFORM FACIES, FAUNAS, AND EVENT STRATIGRAPHY OF NORTHERN IOWA

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INTRODUCTION

In this study we provide an overview of the key aspects of the Upper Devonian stratigraphy, sequence stratigraphy, paleontology-biostratigraphy, and sea level event history of the northern part of the Iowa Devonian outcrop-subcrop belt that is the focus of the 2008 combined Tri-State and Great Lakes Section-Society for Sedimentary Geology field conference (Fig. 1). The richly fossiliferous Cedar Valley Group epeiric carbonate platform deposits of the Iowa Basin (Figs. 1-4) accumulated during the interval of the middle Givetian (Middle *varcus* Zone) to middle Frasnian (Montagne Noire Zone 10?) and provide a record of four 3rd order and up to four additional 4th order relative sea level changes (Transgressive-Regressive (T-R) cycles) outlined in studies by Witzke et al. (1989), Witzke and Bunker (1992, 1996, 1997, 2006a), Day (1996, 2004, 2006), and Day et al. (1996). Recent stratigraphic and faunal studies provide evidence that Late Frasnian middle shelf ramp platform deposits of the Lime Creek Formation comprise two late Frasnian T-R cycles (Fig. 4). T-R sequences recognized in the Cedar Valley Group and late Frasnian and early Famennian epeiric basin deposits can be correlated across North America and Eurasia, suggesting that large-scale eustatic (global) changes in sea level were ultimately responsible for the development and cyclic expression of these stratigraphic intervals coinciding in part with Devonian T-R cycles IIa to IIe of Johnson et al. (1985,1996), and subdivisions proposed by Day et al. (1996), Day (1998), Day and Whalen (2003), Whalen et al. (2006), Whalen and Day (2007).

In Northern Iowa (Figs. 1-4) quarry and outcrop exposures of upper Cedar Valley Group

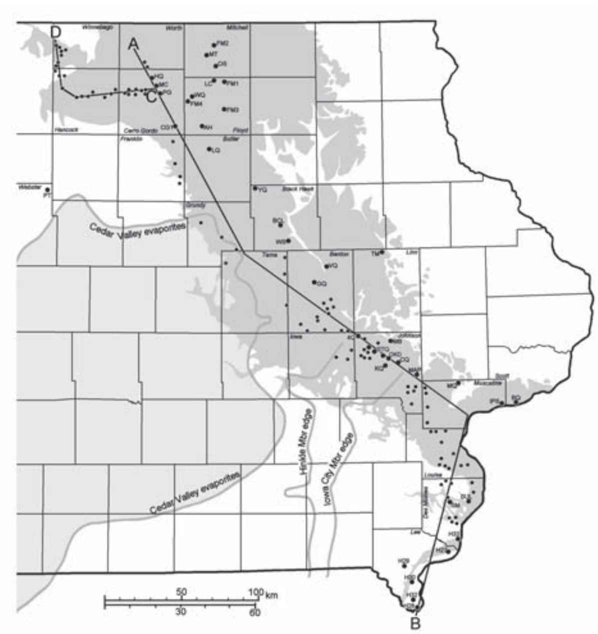

Figure 1. Map of eastern and northern Iowa showing the location of cross-sections lines AB of Figure 2. Darker shading depicts the Devonian outcrop belt, and lighter shading shows the extent of evaporites within the Cedar Valley Group (after Witzke et al., 1988). The distal margins of the Hinkle and Iowa City members (labeled lines) mark the general southeastward extent of inner-shelf facies within the Cedar Valley Group. Black dots show the location of surface and subsurface stratigraphic sections used in the construction of the cross sections. Labeled dots show the location of core and outcrop sections (see Witzke et al., 1989; Bunker et al., 1986; Witzke and Bunker, 1997a; Witzke, 1998 for descriptions and precise locations); smaller dots correspond to well sections (based on well cuttings only) available on Iowa Geological Survey's Geosam database (http://gsbdata.igsb.uiowa.edu/geosam/). County boundaries are outlined, relevant counties are labeled. After Fig. 1 of Witzke and Bunker (2006).

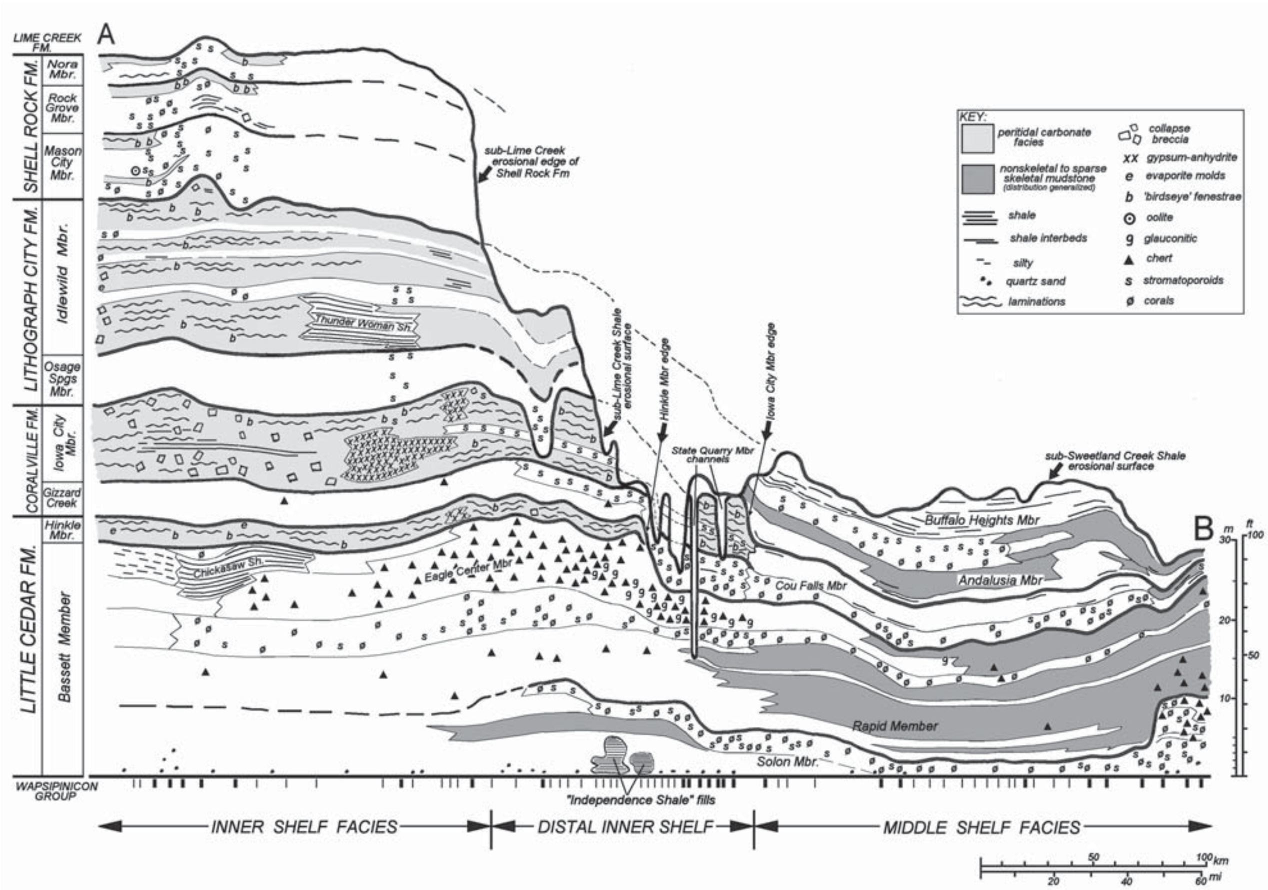

Figure 2. Northwest-southeast stratigraphic cross section of the Cedar Valley Group in eastern Iowa. Significant sub-Lime Creek/Sweetland Creek erosion has truncated Cedar Valley strata, especially in the distal inner-shelf area. "Independence Shale" fills represent stratigraphic leaks of the late Frasnian Lime Creek Shale within Cedar Valley karst networks and openings. See Figure 1 for location of cross-section line (AB) and data points used in the construction. Modified from Fig. 2 of Witzke and Bunker (2006).

strata (upper Coralville, Lithograph City, and Shell Rock formations) of Late-Givetian to Middle Frasnian consist of cyclic sequences of middle and inner shelf facies including open and restricted-marine carbonates, evaporites and shales. These strata were deposited during parts of four major 3rd order relative sea level fluctuations recognized as Iowa Devonian transgressive-regressive (T-R) cycles 4 (upper part) to 7 (Figs. 2 and 3). Middle-Upper Devonian cratonic T-R cycles are bounded regionally by disconformities, and regressive portions of these cycles are typically marked by progradation of peritidal or marginal-marine facies bounded by subaerial exposure and erosional surfaces in inner shelf facies tracts of northern Iowa (Fig. 2). They are developed entirely in subtidal deposits across the middle shelf facies tract in southeastern Iowa and western Illinois (Figs. 2 and 3). Initiation and development of T-R cycles resulted from repeated abrupt deepening events, followed by intervals of depositional progradation.

All of the upper Cedar Valley Group late Givetian-Middle Frasnian age 3rd order T-R cycles are traceable across central and western North America. Additional widely traceable deepening events expressed as 4th order T-R cycles in Iowa (see Figs. 2 and 3) represent intra- Iowa Devonain T-R cycle 5 to 6 events that provide the basis for subdivision of North American Devonian T-R cycles IIb-2 of Day et al. (1996), and confirm development of the two late Frasnian deepening

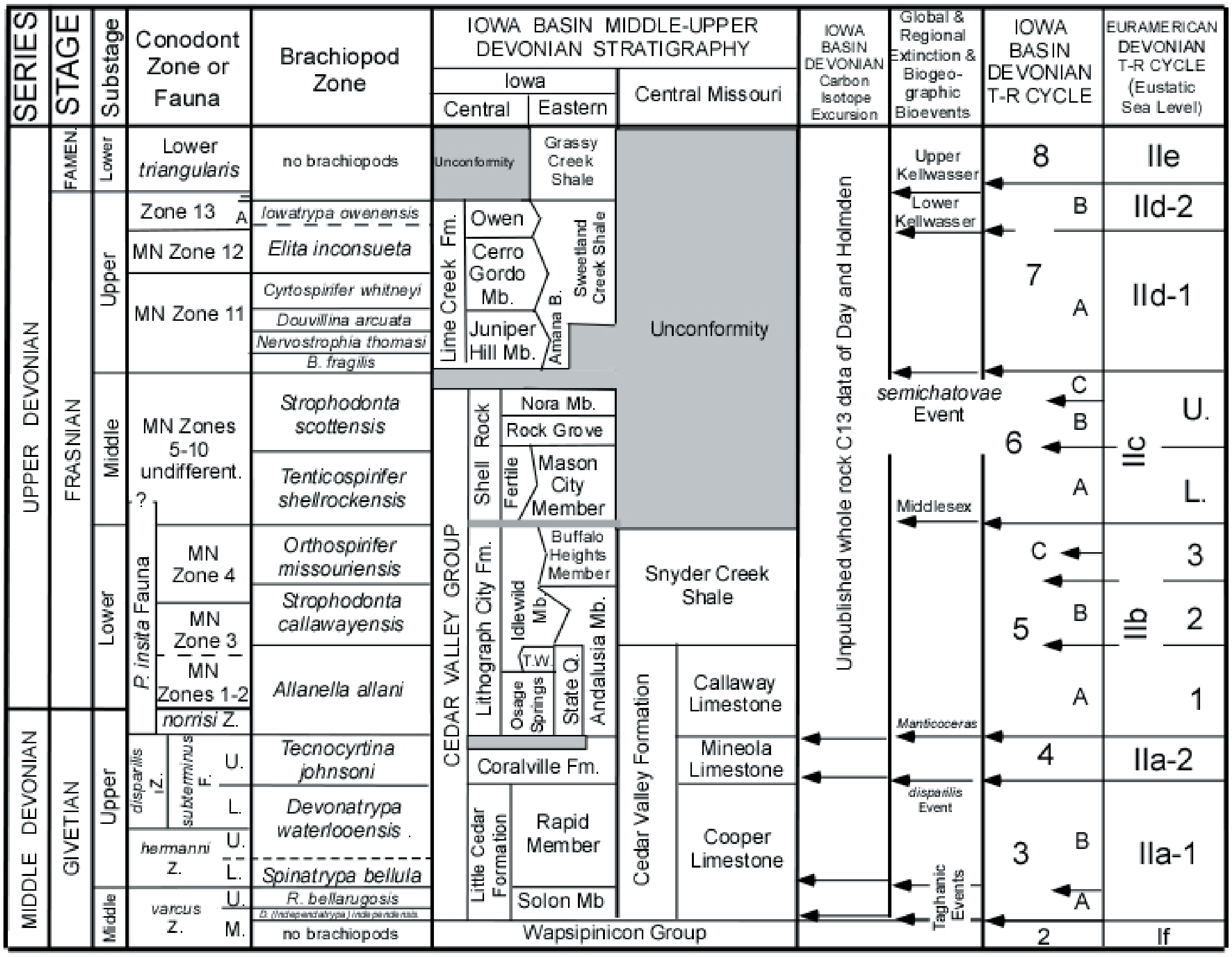

Figure 3. Time-rock correlation chart outlining the stratigraphic and biostratigraphic framework for the Middle-Late Devonian (Middle Givetian to Early Famennian) Cedar Valley Group and Lime Creek Formation and equivalents of the Iowa Basin showing relationships between: the qualitative eustatic T-R cycles of Johnson et al. 1985), Johnson and Klapper (1992), Day et al. (1996), Day (1998, 2006) and Iowa Basin Devonian T-R cycles of Witzke et al. (1989), Bunker and Witzke (1992), and Witzke and Bunker (1996). Iowa Devonian conodont biostratigraphy follows Witzke et al. (1985, 1989), Day (1990), Klapper in Johnson and Klapper (1992), Bunker & Witzke (1992), Witzke & Bunker (1996), Over (2002, 2006). Devonian brachiopod biostratigraphy from Day (1989, 1992, 1996, 1997). Iowa Basin Devonian stratigraphy after Witzke et al. (1989), Witzke and Bunker (1992, 1996), and Day (1995, 1997). Modified from Day (2006, Fig. 3). Abbreviations: *P. = Panderinellina;* State Q. = State Quarry Member; T. W. = Thunder Woman Shale Member.

events within the interval of Euramerican Devonian T-R cycle IId of Johnson et al. (1985), locally recorded by the lithologic and faunal succession within the Lime Creek Formation.

Significant sea level low-stand events led to Cedar Valley platform emergence and erosional incision and/or karst formation in platform carbonates of the Cedar Valley Group in the very late Middle Devonian (within the Upper Givetian) and terminated Cedar Valley Group deposition during the Middle Frasnian. The first lowstand incised into older inner and middle shelf deposits of the Little Cedar and Coralville formations in eastern Iowa, and the Coralville Formation (Iowa

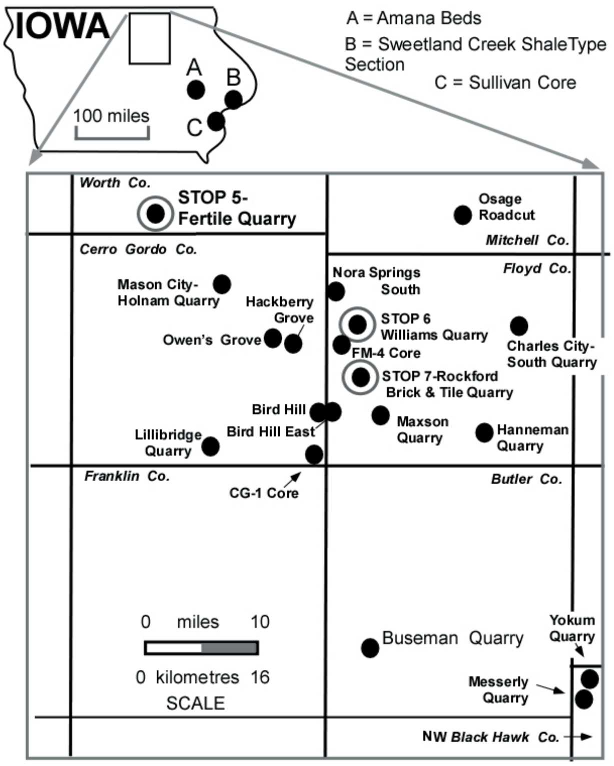

Figure 4. Map of north-central Iowa showing locations of important quarry and subsurface well core sections discussed and or illustrated in this study. Locations of Sunday's field conference stops 5 to 7 are circled.

City Member) across the inner shelf areas of northern and western Iowa (Day et al., 1996; Witzke and Bunker, 1992, 2006; Day, 2006; Witzke et al., 2007). In northern and eastern Iowa, this erosional surface is onlapped by subtidal marine deposits of the Lithograph City Formation and will be examined at four of the seven field conference stops. Minimal estimates of sea level fall of 35 m terminated Coralville Formation deposition during the very late Givetian (very late part of *disparilis* Zone-lowest *norrisi* Zone?). A second and profound low-stand estimated at 90-125 m terminated Cedar Valley Group (Shell Rock Formation) carbonate platform development during the late part of the middle Frasnian (M.N. Zone 10?). Late Frasnian or early Famennian platform emergence eroded platform deposits spanning the Frasnian-Famennian boundary interval in northern Iowa, although a conformable to disconformable F-F boundary is recognized in offshore positions of southeastern Iowa, in the lower part of the Grassy Creek Shale at the type locality of the Sweetland Creek Shale (Klapper and Johnson, 1992) recently documented by Over (2002, 2006).

UPPER DEVONIAN STRATIGRAPHY AND PALEONTOLOGY OF NORTHERN IOWA

Epeiric carbonate platform deposits of the upper Cedar Valley Group and Lime Creek Formation make up the surface bedrock and subcrop across northern (Figs. 1 and 4). Field conference stops will focus attention on important quarry and road-cut exposures of the upper Cedar Valley Group units (Lithograph City and Shell Rock formations as defined in the Iowa Devonian stratigraphic revision of Witzke et al. (1989), and the Lime Creek Formation (Figs. 1 to 4). As defined by Witzke et al. (1989) the Cedar Valley Group consists of four formations, each corresponding to a large-scale 3rd order transgressive-regressive (T-R) cycles (depositional sequence) and each deposited during a cyclic rise and fall of sea level. In ascending order, these include the Little Cedar, Coralville, Lithograph City, and Shell Rock formations (Figs. 2 and 3). The Lime Creek Formation of northern Iowa onlaps and overlays the complex erosional surface developed on older Frasnian Cedar Valley Group carbonate platform deposits and comprises another major 3rd order T-R cycle in the Iowa Basin (Fig. 3). Each Cedar Valley Group major 3rd order depositional sequence, termed T-R cycles, include a number of smaller scale 4th order cycles recognized within all four Cedar Valley Group formations, as well as the Lime Creek (see Iowa Devonian T-R cycles in Fig. 3).

Witzke and Bunker (1996, 1997, 2006) recognize two major lithofacies groupings within the Cedar Valley Group, each geographically constrained and marked by different suites of lithofacies and significant contrasts in the nature of bounding surfaces within individual sequences. These groupings characterize two general regions (Fig. 2) of Cedar Valley deposition: 1) a geographically expansive-immense "inner-shelf" region (which includes much of Iowa and adjoining areas of Minnesota, Nebraska, and Missouri), and 2) a "middle-shelf" region (restricted to southeastern Iowa and adjoining areas of western Illinois and northeastern Missouri). These regions are clearly separated at a sharp break located at the outer margin of the inner shelf, which marks the maximum distal progradation of peritidal facies in the region (shelf breaks for two of the Cedar Valley sequences are marked at the Hinkle Member and Iowa City Member edges shown on Figure 2). Cedar Valley Group carbonates and shales in northern Iowa represent the inner-shelf region.

The Inner-Shelf Region

These facies (Fig. 2) of the Cedar Valley Group sequence packages includes shallow-marine, peritidal, and mudflat/evaporite lithofacies. Peritidal and evaporitic facies are developed in the regressive (progradational) parts of each sequence, but such facies are completely absent across the middle-shelf area of eastern and southeastern Iowa. Each sequence within the Cedar Valley Group is bounded by erosional subaerial exposure and/or erosional surfaces across the inner shelf (Fig. 2).

The Middle-Shelf Region

Middle Shelf facies of the Cedar Valley Group are found seaward of the inner shelf edges of individual T-R cycle packages in eastern and southeastern Iowa and are entirely represented by subtidal marine carbonate and argillaceous to shaly carbonate lithofacies (Figs. 1 to 3). This area represents a more offshore and deeper-water region of deposition compared to that developed across the inner shelf. Peritidal and evaporite facies are entirely absent across this region.

The thickness of individual sequences is notably thinner across the middle shelf than seen across the inner shelf, and, by comparison, the middle-shelf sequences are relatively condensed (i.e., slower rates of sediment accumulation in offshore subtidal settings). The middle shelf facies in eastern Iowa includes evidence for starved and condensed sedimentation, particularly displayed by the development of phosphatic units and numerous subtidal hardground surfaces. The development of sparsely skeletal to non-skeletal argillaceous lime mudstones is largely restricted to the middle-shelf area in Iowa (Fig. 2), and these facies are interpreted to represent the deepest-water depositional facies developed within the Cedar Valley Group and transition into deeper water outer shelf basinal facies in the central and southern part of the Illinois Basin to the east and southeast.

LITHOGRAPH CITY FORMATION

The Lithograph City Formation was proposed (Bunker et al., 1986; Witzke et al., 1989) for upper Givetian and lower Frasnian strata positioned disconformably between the Coralville Formation (mudflat facies of the Iowa City Member) below and the Shell Rock Formation or Sweetland Creek Shale above (Fig. 3). The type locality of the formation was designated in the Jones Quarry near the abandoned town of Lithograph City in Floyd County, Iowa (Groves and Hubscher, 2008, Stop 2), where high quality stone for lithographic engraving was quarried in the early 1900s (see Bunker et al., 1986). The Lithograph City Formation in northern Iowa includes limestone, shale, and dolomite, variably fossiliferous, laminated, or brecciated; evaporites are present in central Iowa. The formation is dominated by fossiliferous limestone, dolomite, and shale in southeastern Iowa. Three members of the formation are recognized in northern Iowa (Osage Springs, Thunder Woman Shale, and Idlewild). Two distinctive facies south of the northern outcrop belt are assigned member status within the Lithograph City Formation. These are the State Quarry Member in eastern Iowa and the Andalusia Member in southeastern Iowa and adjacent areas of northeastern Missouri and western Illinois (Figs. 2 and 3). Where capped by younger

Devonian strata, the formation ranges from about 20 to 36 m in thickness in northern and central Iowa. It is thinner to the southeast where it ranges from 0 to 12 m in thickness (Fig. 2).

Conodont samples from the Osage Springs and the Idlewild members of the Lithograph City in northern Iowa yield low diversity assemblages of the *Pandorinellina insita* Fauna associated with species of the brachiopod genera *Allanella* and *Radiatrypa* that are widespread in very late Givetian and early Frasnian faunas in western North America (see Day, in Witzke et al. 1986; Day, 1989, 1996, 1998; Day et al., 1996; Day and Copper, 1998). As originally defined by Klapper et al. (1971) the *insita* Fauna consisted of the interval of strata with conodont faunas dominated by *P. insita* below strata containing the lowest occurrence of *Ancyrodella rotundiloba.* The lower limit of the *insita* Fauna has biostratigraphic significance (Fig. 3), but its upper limit is not well defined; noted to range as high as the Middle *asymmetrica* Zone (Montagne Noire Zone 5, Klapper, 1989) in the Waterways Formation of Alberta (Uyeno, 1974). Strata with the first occurrence of *Skeletognathus norrisi* (Uyeno,v1967) define the base of the uppermost Middle Devonian (Givetian) conodont zone (Fig. 3, *norrisi* Zone) that occupy the stratigraphic position above the *disparilis* Zone of Ziegler and Klapper (1982). In offshore sections in western North America and Eurasia, the first occurrence of *Ancyrodella rotundiloba* defines the base of the lowest Frasnian Montagne Noire Zone 1 (Klapper, 1989). This interval has formerly been correlated with the Lowermost *asymmetrica* Zone, originally defined on the range of *Mesotaxis asymmetrica* below the lowest occurrence of *A. rotundiloba* early form (Ziegler, 1971). The oldest part of the *insita* Fauna, characterized by the association of *Pandorinellina insita* and *Skeletognathus norrisi* is assigned to the norrisi Zone (Fig. 3).

Osage Springs Member

The Osage Springs Member is characterized by fossiliferous dolomite and dolomitic limestone, in part slightly argillaceous, in the type area (Fig. 3; see type section in Groves and Hubscher, 2008, Stop 1). Calcite-filled vugs and stylolites are common, and poikilotopic calcite cements are present locally in the upper part of the member. Thin intervals containing faintly laminated to intraclastic fabrics have been noted at some localities. The Osage Springs Member becomes limestone-dominated (skeletal calcilutite and calcarenite) southward in the northern Iowa outcrop belt, and stromatoporoids (locally biostromal) also become increasingly common in that direction as seen in the Yokum (Fig. 4; Witzke et al., 1986, Stop 1, unit 16) and nearby Messerly (Figs. 4 and 5; Groves and Hubscher, 2008, Stop 4) quarries in northwestern Black Hawk County. Fossiliferous and locally oolitic limestones and dolomites have been noted in central Iowa (Klug, 1982). The member is conformably overlain by laminated carbonates of the Idlewild Member in the northern outcrop belt, and is conformably overlain by the Thunder Woman Shale in the southern outcrop belt as in the Messerly Quarry section as shown in Figure 5, and in the subsurface of central Iowa. The Osage Springs Member varies from 3.4 to 7.5 m in thickness (Fig. 2).

Paleontology of the Osage Springs Member

The conodont *Pandorinellina insita* first occurs in north-central Iowa in the basal Osage Springs Member (Bunker et al., 1986). Based upon the first occurrence of P. insita within the basal Osage Springs Member, the Osage Springs has been correlated with the *norrisi* Zone (Witzke et al., 1985; Bunker et al., 1986; Witzke et al., 1988), although it may be somewhat younger (as young as Montagne Zone 1, Fig. 3, early Frasnian) across northern Iowa (Fig. 3).

Macrofauna of the Osage Springs Member is dominated by brachiopods in northern outcrops. In its type section at the Osage Roadcut (Fig. 4, Groves and Hubscher, 2008, Stop 1) moldic fossils of *Athyris vitatta* and *Allanella allani* occur in the dolomites throughout the lower part of the Osage Springs. In the southern outcrop belt in Black Hawk County *Allanella alani, Athyris*

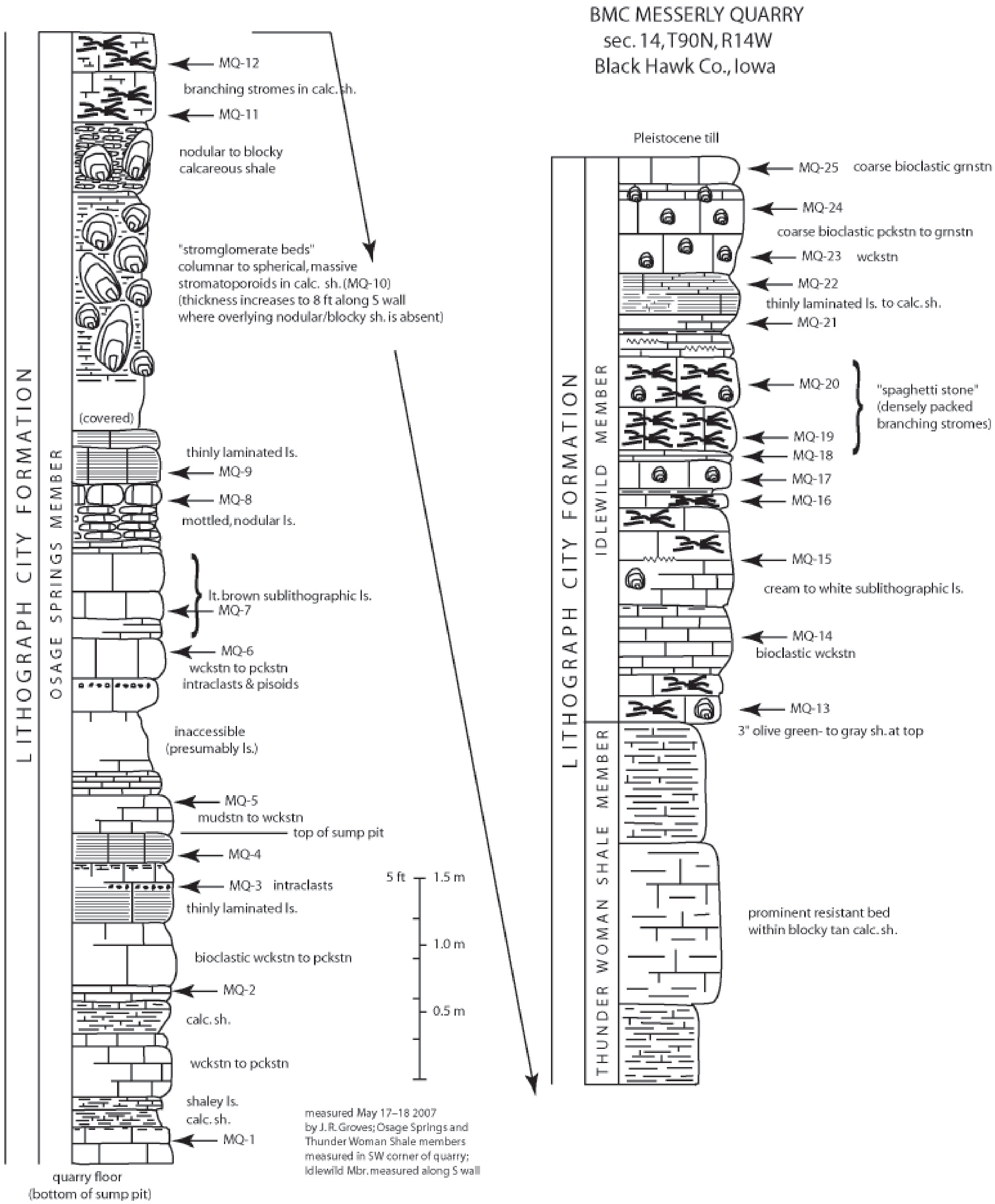

Figure 5. Middle and Upper Devonian strata of the Iowa City Member of the Coralville Formation and Osage Springs, Thunder Woman, and Idlewild members of the Lithograph City Formation exposed in the Messerly Quarry in northwestern Black Hawk County, Iowa (Figs. 2 and 4). Older version of section of Groves and Hubscher (2008, Stop 4).

vitatta, Desquamatia (Independatrypa) scutiformis, Pseudoatrypa sp. and *Strophodonta (S.) iowensis* weather from shaley matrix of the biostromal units in the upper part of the Osage Springs at the Yokum Quarry and nearby Messerly Quarry (Figs. 4 and 5; Groves and Hubscher, 2008, Stop 4; Day, 1989, 1992). Stromatoporoids become abundant to the south and include both massive and branching forms in the Messerly and Yolum Quarry sections. Echinoderm debris is present in all sections, and bryozoans, gastropods, corals, and burrows have been noted locally.

Thunder Woman Shale Member

The Thunder Woman Shale Member (Figs. 3 and 5) is characterized by light to medium gray, slightly dolomitic and silty shale; argillaceous dolomite is present locally, in part laminated and with crystallotopic gypsum molds. Shelly fossils are absent in the member, but horizontal and sub-horizontal burrow mottles are common in the upper half. Conodont fragments and fish debris have been noted in the subsurface of north-central Iowa (Klug, 1982b). The Thunder Woman Shale is present in the southern part of the northern outcrop belt of the Lithograph City Formation, and extends into the subsurface of central Iowa in Butler and southern Floyd counties (Bunker et al., 1986). Its type section is in the Yokum Quarry (Witzke et al., 1986, 1989) that is now inactive and flooded. An important reference section is in the nearby Messerly Quarry (Figs. 4 and 5). It is erosionally truncated to the south within the Devonian outcrop of eastern Iowa. The member is replaced northward in the outcrop belt of northernmost Iowa and adjacent Minnesota by carbonate dominated strata of the lower Idlewild Member (Fig. 3). The Thunder Woman Shale ranges from 3 to 6 m in thickness.

Idlewild Member

The Idlewild Member (Fig. 3) is characterized by an interbedded sequence of contrasting lithologic groupings: 1) laminated and pelleted lithographic and "sublithographic" limestones and their dolomitized equivalents, in part with mudcracks, "birdseye," or evaporite molds (see lower Idlewild Member in Fig 6); 2) non-laminated dolomite and limestone, in part "sublithographic," pelleted, oncolitic, intraclastic, brecciated, and/or sandy, and locally containing mudcracks and "birdseye"; 3) calcareous shale, in part brecciated to intraclastic; and 4) fossiliferous dolomite and limestone (mudstone-wackstones, and occasional grainstones), with scattered to abundant brachiopods and/or stromatoporoids (locally biostromal; see upper Idlewild Member Fig. 6). Lithologic groupings 1 and 2 dominate the sequence at most localities, but group 4 lithologies are well developed in the middle Idlewild at the Hanneman and Charles City South quarries (Fig. 6). They are rhythmically interbedded with lithologic group 2 in most of the upper Idlewild in the Maxson Quarry near the town of Marble Rock in Floyd County (Figs. 4 and 7) comprising small-scale 5th order T-R cycles. Fossiliferous skeletal mudstone and wackstones of group 4 are seen near the top of the Idlewild Member at in the Maxson Quarry and at the Nora Springs South locality (Figs. 4 and 7) on the south bank of the Shell Rock River.

Certain fossiliferous to biostromal carbonates of group 4 with a distinctive and diverse brachiopod fauna can be correlated from section to section in Floyd County. At both the Hanneman and Charles City South quarries, fossiliferous group 4 strata in the middle part of the member abruptly overly mudflat facies of lithologic group 1 of the lower Idlewild Member (Figs. 4 and 6). This abrupt facies change records the second major Lithograph City T-R cycle marine flooding event in the inner shelf region of Iowa Devonian T-R cycle 5B (Fig. 3), coinciding with Devonian T-R cycle IIb-2 of Day et al. (1996).

The Idlewild Member contains gypsum and anhydrite in the subsurface of central Iowa (Fig. 5), primarily in the lower part of the member. The member is replaced by fossiliferous carbonates of the middle and upper Andalusia Member in southeastern Iowa (Fig. 2). Where capped by the Shell Rock Formation, the Idlewild Member ranges from 16 to 24 m in thickness.

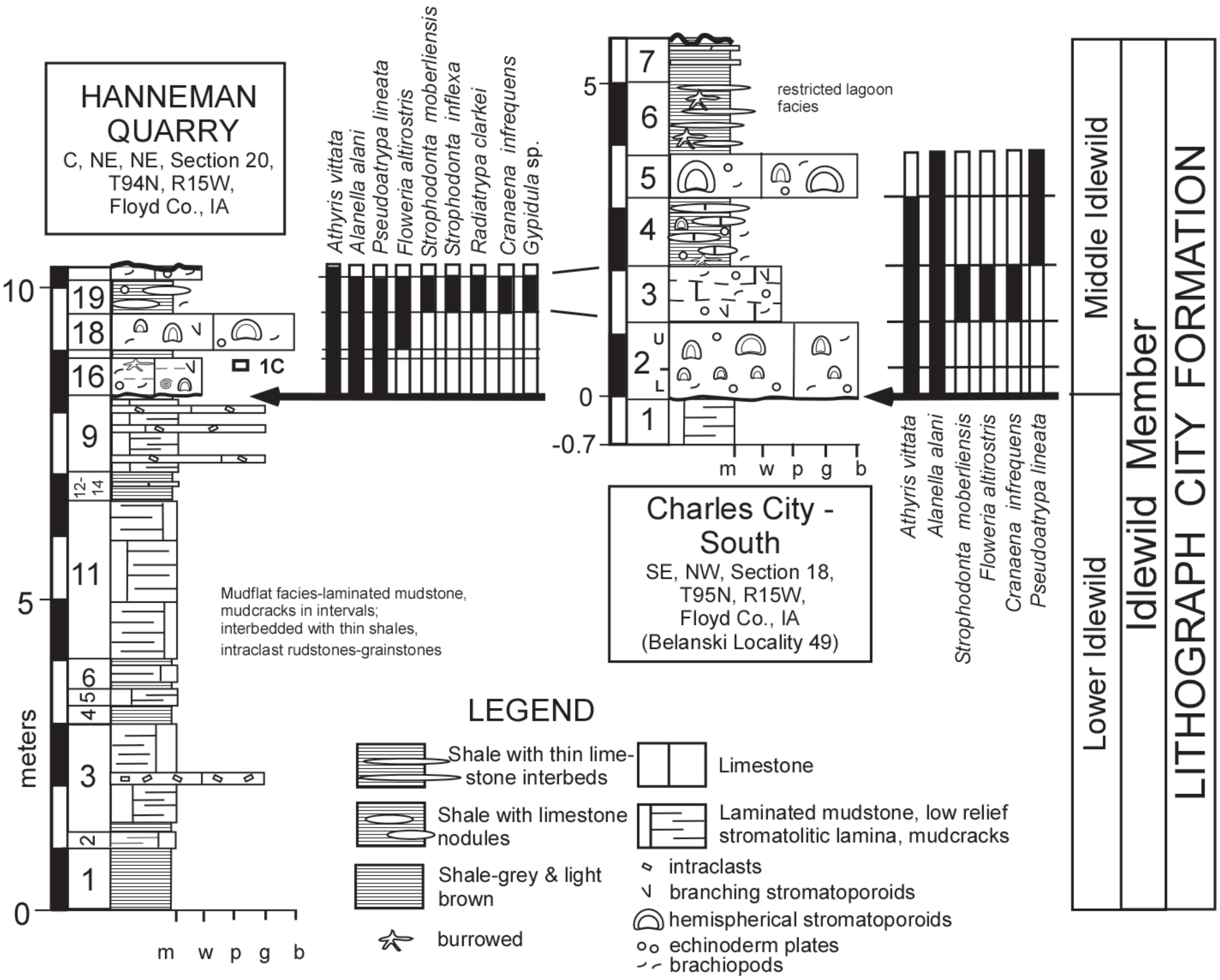

Figure 6. Upper Devonian (Lower Frasnian) stratigraphy of lower and middle parts of the Idlewild Member of the Lithograph City Formation exposed in the Hanneman and Charles City South quarries in central and northeastern Floyd County, Iowa (Figs. 2 and 4). Hanneman Quarry section modified from figure 14 of Day (1992, see p. 77). The Charles City South Quarry section is adapted from the description of C. H. Belanski (Belanski Station/Locality 49, Belanski Register) Stop 4). The symbols at base of section columns signify carbonate depositional textures as in Figure 5.

Paleontology of the Idlewild Member

Conodonts from fossiliferous beds in the Idlewild Member (Bunker in Witzke et al., 1986; Witzke et al., 1989) include *Pandorinellina insita* and *Polygnathus angustidiscus*; these are assigned to the *insita* Fauna as discussed above (Fig. 3). Given its position above the Osage Springs Member, it is likely that the Idlewild is entirely Early Frasnian, likely spanning parts of Montagne Noire Zones 1 to 4 (Fig. 3). Lithologic groupings 1 and 2 commonly contain ostracodes and are burrowed in part; stromatolites and gastropods have been noted locally.

Fossiliferous beds of the Idlewild throughout the member contain brachiopods (Day, 1986, 1989, 1992, 1998; Day and Copper, 1998). Echinoderm debris is common in some beds, and bryozoans, gastropods, and ostracodes also occur. Small-scale cycles consisting of lithologic

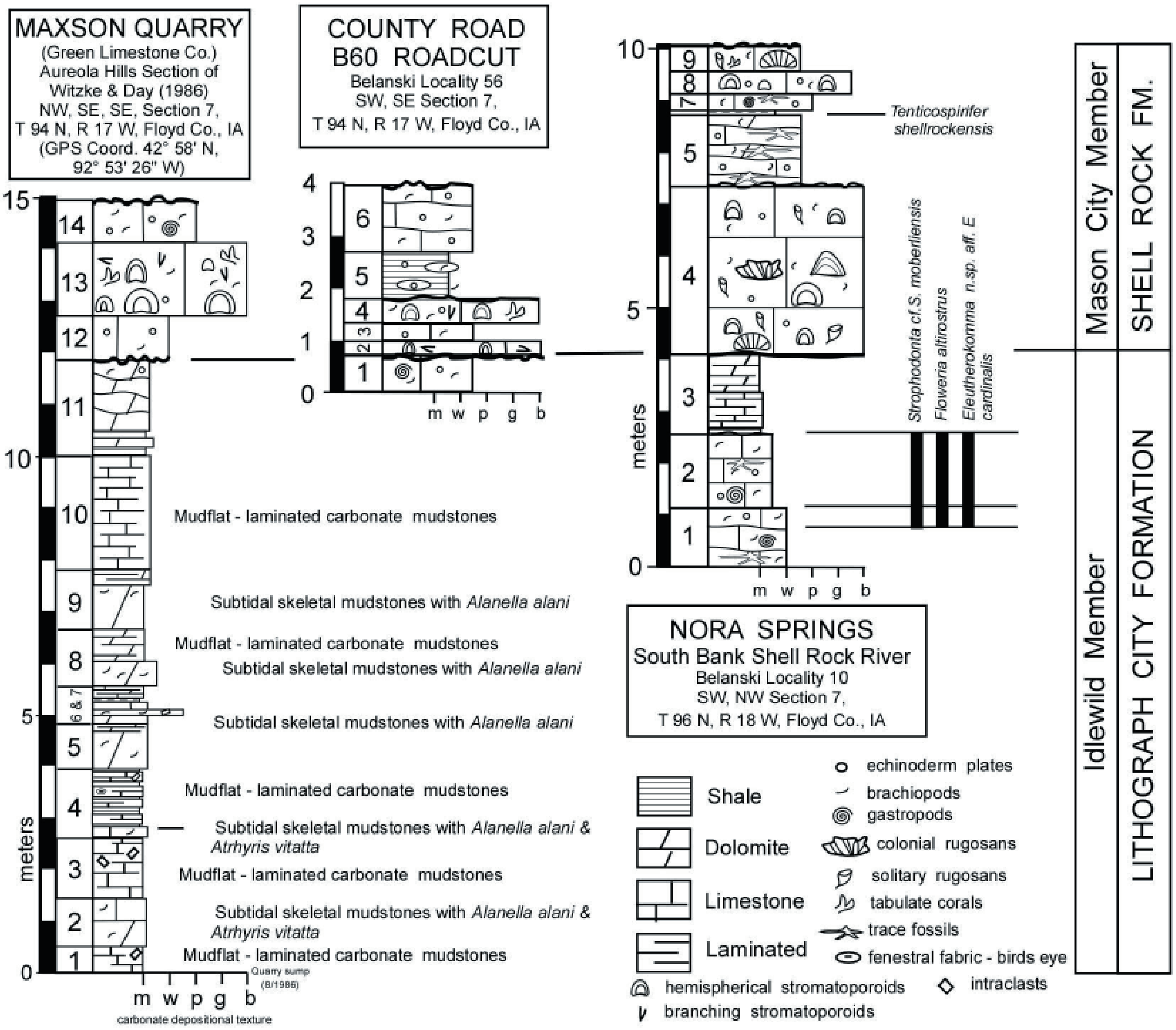

Figure 7. Upper Devonian stratigraphy of the upper Idlewild Member (Lower Frasnian) of the Lithograph City Formation and Mason City Member (Middle Frasnian) of the Shell Rock Formation exposed in the Maxson Quarry (Greene Limestone Company), the roadcut (now covered) on Floyd County Road B60 just outside of Maxson Quarry, and Nora Springs on south bank of the Shell Rock River in western Floyd County, Iowa (Figs. 2 and 4). Maxson Quarry section measured by Day and Witzke in 1986 (Witzke et al., 1986). The B60 Road-cut and Nora Springs South sections are adapted from the descriptions of C. H. Belanski (Belanski Station/Locality 10 and 56, Belanski Register). The symbols at base of section columns signify carbonate depositional textures as in Figure 5.

groups 1 to 3 interbedded with fossiliferous group 4 skeletal carbonates contain monospecific or low diversity assemblages that include *Allanella allani*, *Athyris vitatta*, or *Pseudotrypa lineata*. At the Maxon Quarry in Floyd County (Figs. 4 and 7) assemblages in the upper Idlewild contain the first two taxa, and at the Lubben Quarry in Butler County such assemblages may feature all three taxa (Wtizke et al., 1986, Stop 2). Fossiliferous skeletal carbonates (some biostromal) in the middle part of the Idlewild at the Hanneman and Charles City South quarries yield a diverse fauna including: *Athyris vittata, Eleutherokomma* sp. aff. *E. cardinalis*, *Floweria altirostis*, *Pseudoatrypa lineata*, *Productella* sp. cf. *P. fragilis*, *Strophodonta* (*S.*) *moberliensis*, *Cranaena infrequens*, and *Gypidula* sp. The skeletal mudstone and wackestones in the upper 2 to 3 meters of the Idlewild Member Maxson Quarry, Floyd County Road B-60 roadcut, and Nora Springs South sections (Figs. 4 and 7) yield a brachiopod fauna named the "*Eleutherokomma* Fauna" by Day (1989). These units yield *E.* n. sp. aff. *E. cardinalis,* the highest occurrences of *Allanella Allani* in the Frasnian of North America, with *Athryis vitatta*, *Pseudoatrypa lineata*, *Floweria altirostrum.*

Stromatoporoids are abundant in some beds, and locally form biostromes (domal or branching forms variably dominate). The regionally traceable interval of biostromal development within the Idlewild is seen in both the northern and southern outcrop areas in northern Iowa. In the southern outcrop belt in Black Hawk County, prominent Idlewild biostromal carbonates and associated brachiopod faunas occur just above the Thunder Woman Shale in the Yokum and Messerly quarries (Figs. 4 and 5; Groves and Hubscher, 2008, Stop 4). The equivalent biostromal interval to the north are seen at Hanneman and Charles City South quarries in Floyd County as discussed above. This signifies a seaway major deepening and platform backstepping event in the inner shelf region of the Lithograph City platform.

The biostromal carbonates of the Idlewild in northern Iowa yield diverse stromatoporoid fauna documented in studies by Smith (1994) and Turner and Stock (2006). As discussed by Stock (2008) the Idlewild fauna is one of the most diverse in the Frasnian of Iowa and includes: *Hammatostroma albertense, Atelodictyon fallax A.* cf. *A. fallax, A. masoncityense*, *Petridiostroma*? *vesiculosum, Pseudoactinodictyon trautscholdi Bullulodictyon*? *patokense*, *Actinostroma clathratum*, *Clathrocoilona involuta*, *C.* cf. *C. abeona*, *C.* cf. *C. solidula, Stictostroma maclareni, Trupetostroma bassleri, T.* cf. *T. bassleri, Hermatostroma insulatum, H. hayensis, Arctostroma dartingtonense, Parallelopora catenaria, Habrostroma turbinatum, Stachyodes* cf. *S. costulata, S.* cf. *S. spongiosa, and Amphipora* cf. *A. ramose.* According to Stock (2008), six of Smith's species also occur in the overlying Mason City Member of the Shell Rock Formation (*Hammatostroma albertense*, *Atelodictyon masoncityense*, *Actinostroma clathratum*, *Clathrocoilona involuta*, *Trupetostroma bassleri*, *Hermatoporella hayensis*) indicating that the disconformity separating the two formations is of short duration, although erosional truncation of mudflat carbonates capping the Idlewild Member in the Nora Springs area are observed below its disconformable contact with the basal Shell Rock Formation in the northern outcrop area of the Cedar Valley Group in northern Iowa.

SHELL ROCK FORMATION

Belanski (1927) named the "Shellrock stage" (formation) for a limestone-dominated interval exposed along the Shell Rock River in northern Iowa, and subdivided it into three "substages" (members), in ascending order, the Mason City, Rock Grove, and Nora. Type sections of all three members are located in natural outcrops along the Shell Rock River and abandoned quarries in the vicinity of the town of Nora Springs in northwestern Floyd County The most complete and accessible exposure of the Shell Rock Formation is the important reference section at the Williams Quarry (Figs. 4 and 8; Day and Witzke, 2008, Stop 6), with a closely similar section in the subsurface in the nearby Floyd-Mitchell # 4 well core (Figs. 2 and 4, locality FM 4; Fig. 9). The Shell Rock Formation is now included in the upper Cedar Valley Group (Witzke et al., 1988; Fig. 3). A comprehensive summary of the stratigraphy of the formation in the type area is given by Koch (1970) and Witzke et al. (1988). The Shell Rock Formation is characterized by fossiliferous carbonates with some shale in the type area (Figs. 4, 8 and 9). It disconformably overlies the Idlewild Member of the Lithograph City Formation, and erosional relief has been noted locally (see Figs.

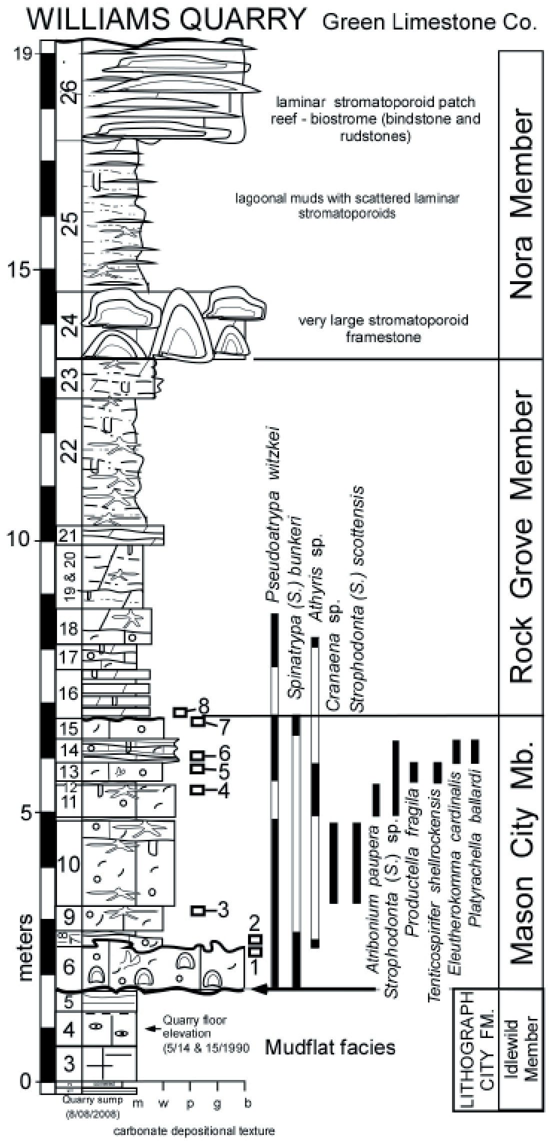

Figure 8. Upper Devonian stratigraphy of the upper Idlewild Member (Lower Frasnian) of the Lithograph City Formation and Shell Rock Formation exposed in the Williams Quarry (Greene Limestone Company), south of Nora Springs in northwestern Floyd County. Measured by J. Day, 1990 and 2008, modified from Day and Witzke (2008, Stop 6). The symbols at base of section columns signify carbonate depositional textures as in Figure 5. This is Locality 7 of Koch (1970) and the location of the famous hardground (top of unit 6) with attached rhombiferan and edrioasteroid echinoderms described by Koch and Strimple (1968).

7, 8, 9, 11). Where capped by younger Devonian strata, the Shell Rock Formation ranges from about 17 to 24 m in thickness over its known geographic extent in northern and central Iowa. The eroded upper surface of the formation is buried by the Lime Creek Formation. We do not include detailed discussion of the three members of Shell Rock Formation in the type area in northern Floyd County since these are featured in a variety of earlier publications (Belanski, 1927, 1928a; Koch, 1970; Sorauf, 1998). We do draw attention below to important facies changes that occur to the west of the type area as observed in quarry exposures and cores in Cerro Cordo and Worth counties that we believe warrant designation of a new member of the Shell Rock Formation to include dolomite facies that replace the lower Shell Rock that are known to be equivalents of the Mason City Member.

Significant facies changes within the lower part of the Shell Rock occur to the west of the type area where equivalents of the Mason City Member become progressively dolomitized, thicker, and dominated by biostromal and patch reef and lagoonal carbonates up to 12 meters in thickness, versus approximately 5 to 7 meters of Mason City limestones in the type area. This facies change was initiall commented on in the important investigation of the Devonian of northern Iowa by Witzke and Bunker (1984) where they re-interpreted Devonian units in northern Iowa. They initially used a deep rock-core penetration of the Devonian sequence at Mason City as a primary reference section for the region (Mason City core, Fig. 1, stored at Iowa Geological Survey Oakdale facility). They suggested that the upper interval in the Mason City core (their "Unit E of the Cedar Valley) represents a more dolomitic facies of the typical Shell Rock section exposed at Nora Springs. Other associated lithologic changes noted are significantly larger proportions of shallow-water deposits in the upper Nora Member with laminated, "birdseye"-bearing, brecciated, and intraclastic facies in the western outcrop and subsurface.

The westward facies change in the lower Shell Rock is noted at the Holnam Quarry in Mason

City area. In the Holnam Quarry (Fig. 10, Witzke, 1998, Fig. 2) nearly 12 meters of the "Mason City Member" consists of biostromal and stromatoporoid-rich lagoonal facies, nearly twice in thickness as in the Nora Springs area in Floyd County, with the upper 4 to 5 meters of lagoonal carbonates consisting of dolomite. The lower reefal (patch reef) facies become entirely dolomitized further west, where dolomites with relict patch reef fabrics locally exceed 10-12 meters in thickness, and form clinoform wedges that prograde from east-to-west in exposures in the north pit of the Fertile Quarry (Figs. 4 and 10; Day and Witzke, 2008, Stop 5). Unlike in sections around the Mason City area, the upper Rock Grove and Nora members are readily identifiable in the exposures and cores at the Fertile Quarry.

Very unusual facies relationships between the thick patch reef dolomites and the Rock Grove Member are observed in north pit of the Fertile Quarry. Rhythmically bedded argillaceous skeletal dolomites of the Rock Grove Member are observed to onlap, and eventually toplap, prograding clinoform wedges of dolomitized patch reef dolomites in the north pit highwall exposure (see Day and Witzke, 2008, Stop 8).

Fertile Member (new) of the Shell Rock Formation

Given the distinctive lithologies in the interval equivalent to the Mason City Member in its type area to the southeast, we propose the name Fertile Member to encompass the 10 to 12 meters of dolomitized carbonate bank/patch reef units making up the lower part of the Shell Rock section as exposed in the active south and inactive north pits of the Fertile Quarry. This member also includes the lower eight meters of the Shell Rock in the IDOT C2002 Core (Fig. 11) section that was drilled in the south pit area and subsequently removed by quarry operations since that time. The upper three units (11 to 13 in the Holnam Quarry, Fig. 10) could also be assigned to the Fertile Member.

In the Holnam (Figs. 4 & 10; Witzke, 1998, Fig.2) and Fertile (Figs. 4 and 11; Day, 2008, Stop

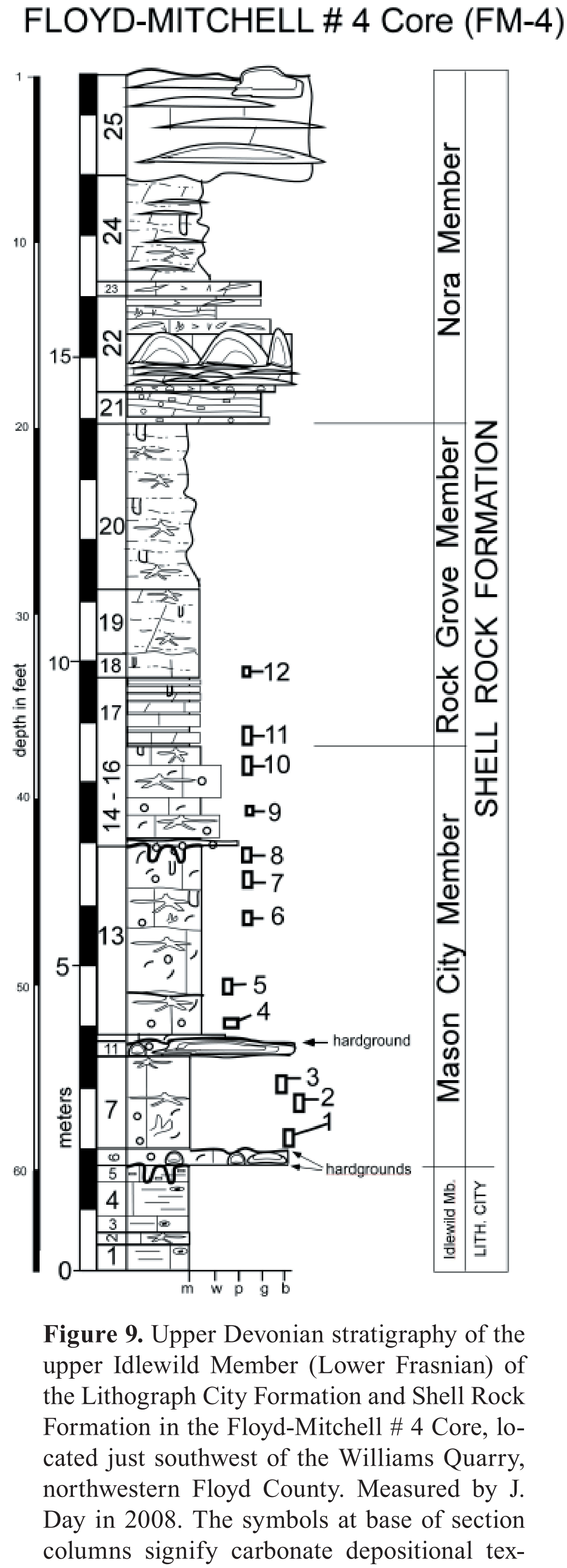

Figure 9. Upper Devonian stratigraphy of the upper Idlewild Member (Lower Frasnian) of the Lithograph City Formation and Shell Rock Formation in the Floyd-Mitchell # 4 Core, located just southwest of the Williams Quarry, northwestern Floyd County. Measured by J. Day in 2008. The symbols at base of section columns signify carbonate depositional textures as in Figure 5.

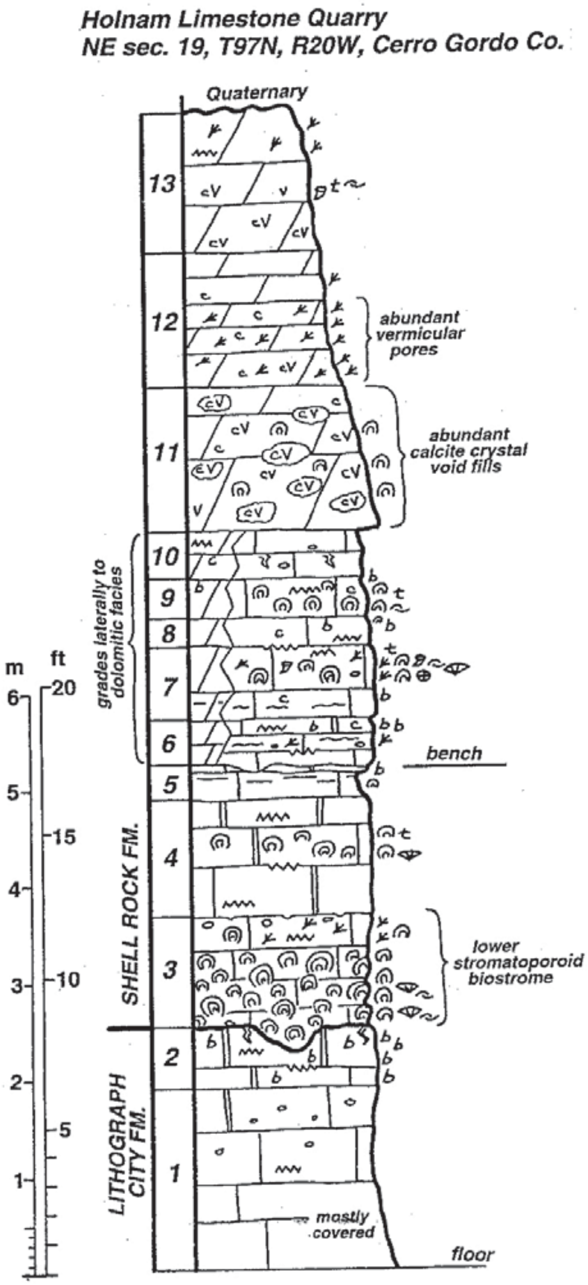

Figure 10. Upper Devonian stratigraphy of the upper Idlewild Member (Lower Frasnian) of the Lithograph City Formation and Shell Rock Formation Holnam Quarry in the Mason City area, Cerro Gordo County, Iowa. After Figure 2 of Witzke (1998), see that article for legend.

5) quarries the lower part of the Shell Rock features biostromal and stromatoporoid patch reef facies (largely dolomitized). Lateral variation between stratigraphically-equivalent limestone and dolomite facies occurs over short distances in the Mason City Holnam Quarry as well as the Fertile Quarry (Figs. 10 and 11).

Paleontology of the Shell Rock Formation

The Shell Rock Formation is richly fossiliferous, and its fossils have been the focus of a variety of studies dating the early part of the later part of the nineteenth century. Conodonts of the Shell Rock Formation, which include *Ancyrodella gigas, Polygnathus asymmetricus,* and others (Anderson, 1964, 1966; Witzke et al., 1989), indicate correlation with the Middle Frasnian. Brachiopod faunas (Day, 1989, 1996) of the Shell Rock are correlated with Great Basin Devonian Faunal Interval 30 of Johnson (1990) and indicate correlation of the Mason City Member fauna with Montagne Noire Zones 5-6 of Klapper (1989). Brachiopods and echinoderm debris are present in all members, and articulated specimens of crinoids, disarticulated echinoids are known from the Mason City Member (Belanski, 1928; Koch and Strimple, 1968; Strimple, 1970). Shell Rock Formation yields a diverse and locally abundant Middle Frasnian brachiopod fauna, largely restricted to the Mason City and Rock Grove Members. Stromatoporoids are the most conspicuous fossils forming patch reef and biostromal units in the Mason City and Rock Grove members of the Shell Rock Formation and domal to subspherical and stick-like branching forms commonly form dense accumulations in some beds. Stromatoporid-dominated reefal units of the Mason City also yield a diverse rugose coral fauna recently described by Sorauf (1998). These accumulations are termed "biostromes," reef-like tabular bodies of coralline fossils.

Most of the Shell Rock brachiopod fauna was described in a series of papers by Belanski (1928a, 1928b, 1928c, 1928d). Day (1989, 1996) summarized and updated the diverse brachiopod fauna (32 species) of the Shell Rock Formation, based to a large extent on Belanski's collections. He used these faunas to define the *Tenticospirifer shellrockensis* and *Strophodonta cicatricosa* Zones. Day and Copper (1998) described the atrypid brachiopod fauna of the Shell Rock that includes *Pseudoatrypa witzkei* and *Spinatrypa* (*S.*) *bunkeri*. Ma and Day (2000) revised and re-described the cyrtospiriferid brachiopod genera and species known from the Frasnian of Iowa, including *Tenticospirifer shellrockensis* that occurs in the Mason City and Rock Grove members of the Shell Rock. Additional fossils in the Shell Rock Formation include ostracodes, spirorbids (worm tubes), conularids, calcareous algae, calcispheres, charophytes, and fish debris (Koch, 1970). Molluscs are common locally and include bivalves, gastropods, nautiloids, and scaphopods. Biostromal beds in the Mason City and Nora members are dominated by stromatoporoids, and massive (tabular to subspherical) and branching forms are present (see taxonomic studies by Stock, 1982, 1984a, b). Corals (solitary and colonial rugosans, and tabulates) occur in some beds. Additional fossils include ostracodes, spirorbids, conularids, calcispheres, calcareous algae, charophytes, and fish debris (Koch, 1970).

Mason City Member

The Mason City Member yields a diverse Middle Frasnian marine invertebrate fauna from subtidal biostromal and patch reef, and shelf carbonates. Koch and strimple (1968) described articulated specimens of the rhombiferans *Adecetocystites williamsi, Strobilocystites calvini* and the edrioasteroid *Agelacrinites hanoveri* attached to the spectacular hardground surface at the top of unit 6 of the Williams Quarry section shown in Figure 9.

Stromatoporoids recovered from biostromal units in the lower and upper Mason City Member were first described by Hall and Whitfield (1873). The diverse stromatoporoids fauna of the Shell Rock Formation has been summarized in several reports by Carl Stock (1973, 1982, 1984a, 1984b, and 2008). The Mason City stromatoporoid fauna occurs in biostromal units, patch reef

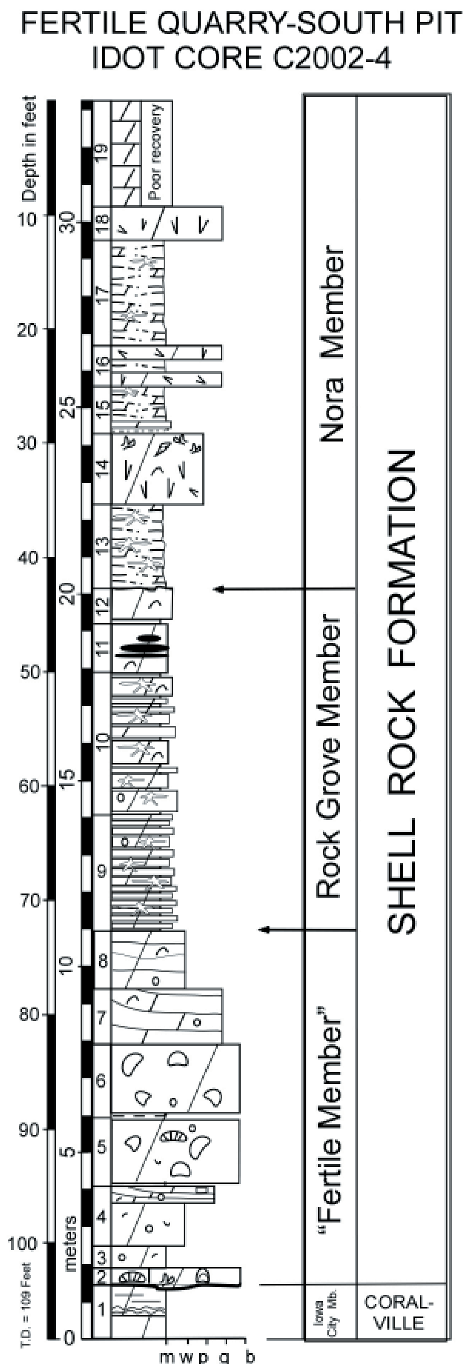

Figure 11. Upper Devonian stratigraphy of the upper Idlewild Member (Lower Frasnian) of the Lithograph City Formation and Shell Rock Formation in the IDOT C2002 Core from the active south pit of the Fertile Quarry, southern Worth County, Iowa. Measured by J. Day, 2008. Modified from Fig. 2 of Day and Witzke (2008, Stop 5).

buildups, and associated lagoonal facies. The fauna discussed by Stock (2008) includes: *Hammatostroma albertense*, *Ateoldictyon masoncityense*, *Actinostroma clathratum*, *Clathrocoilona involuta, Stictostroma ordinarium*, *Trupetostroma bassleri*, *Hermatostroma polymorphum, H. hayensis, Stachyodes costulata, S.*? *conferta* , and *Amphipora pervesiculata.*

Sorauf (1998) described the rugose coral fauna of the Mason City Member, with *Smithiphyllum belanskii* and *Pachyphyllum websteri* in the lower biostromal units (Figs. 7 and 8), and a more diverse fauna with *Tabulophyllum mutabile*; *T. curtum*; *Disphyllum floydensis*; *D. iowense*; *Pachyphyllum minutissimum*; and *Trapezophyllum* sp. A in the upper biostromal units of the member in the Nora Springs and Mason City area (Holnam Quarry, Figs. 4 and 10).

Twenty-Four brachiopod species first appear in the Mason City Member (Day, 1989, 1996), and most of these range into the Rock Grove and Nora (lower part) members. Occurrences of brachiopods in the lower Shell Rock at the Williams Quarry are shown in Figure 10. The ranges of *Cranaena parvirostra, C. maculata, Cariniferella* sp., *Strophodonta* (*S.*) scottensis, and *Nervostrophia* n.sp. are restricted to *Tenticospirifer shellrockensis* Zone of Day (1989) the Mason City Member in the Iowa Basin (Fig. 3). Important species with their first occurrences in the lowest Mason City are *Eleutherolomma cardinalis, Platyrachella ballardi*, and *Tenticospirifer shellrockensis*. These species also occur in the dolomite (patch reef –carbonate bank) facies of the Fertile Member (discussed above) in the lower Shell Rock Formation at the Fertile Quarry (Fig. 10; Day and Witzke, Stop 5). Other important species with first occurrences in the Mason City are *Pseudoatrypa witzkei*, *Spinatrypa* (*S.*) *bunkeri*, *Lorangerella Gregaria, Hypothyridina magiste, Cyrtina* n.sp., *Nervostrophia* n.sp., *Productella fragila* and *Strophodonta* (*S.*) *Scottensis*, all of which range upward into the Rock Grove Member. A number of species first appear in the upper 30 to 40 centimeters of the Mason City Member and serve to define and characterize the *Strophodonta cicatricosa* Zone of Day (1989). These include the nominal species and *Atribonium paupera*, *Gypidula papyracea*, and *Cariniferella* n. sp. *Cariniferella* n. sp. appears to be restricted to the basal unit of this zone. In the Shell Rock type area, *Schizophoria floydensis* first appears in the Nora Member, although its its lowest occurrence is now known to low in the Fertile Member (at a position equivalent to the lower Mason City).

Rock Grove Member

The Rock Grove Member fauna is similar in many respects to that of the underlying Mason City Member, although it most notably lacks a substantial stomatoporoid and rugose coral fauna. Rock Grove Member rugose corals do occur and are described by Sorauf (1998). The sparse stromatoporoid fauna reported by Stock (2008) includes *Actinostroma* sp., *Clathrocoilona* sp., *Hermatoporella* sp., *Stachyodes* sp., and *S.*? sp. The brachiopod fauna of the Nora Member consists of 16 species (Day, 1989, 1996) and all have their first appearances within and range up from the Mason City Member. Most Rock Grove brachiopods are known to range into the Nora Member, but assemblages in the Nora are dominated by large stromatoporoids in the Nora biostromes at the base and top of the Member in the Shell Rock type area.

Nora Member

The fauna of the Nora is dominated by large stromatoporoids and associated corals in the two major biostrome-patch reefs in the lower and upper parts of the member (Figs. 8 and 9). The fauna described from the Nora includes stromatoporoids (Stock, 2008), rugose corals (Sorauf, 1998) and brachiopods (Day, 1989, 1996). The dominant elements of the Nora fauna are the truly gigantic-whopper stromatoporoids in the lower and upper biostromes that are well developed in the Williams Quarry section (Figs. 4 and 8) and elsewhere in Floyd (subsurface, FM-4 core, Figs. 4 and 9) and Cerro Gordo County. Stock (2008, and older studies) has described this fauna, and lists the following taxa from the Nora: *Anostylostroma*? sp., *Actinostroma expansum*, *Clathrocoilona* sp., *Stictostroma* sp. *Trupetostroma* sp., *Hermatostroma iowense*, *Hermatoporella* cf. *H. pycnostylota*, *Arctostroma* sp., *Stachyodes*? sp., *S.*? *conferta,* and *Amphipora* sp. He describes extremely large (30 m) specimens of *A. expansum* as well as *H. iowense.*

LIME CREEK FORMATION

The Late Frasnian age Lime Creek Formation of northern Iowa was named after natural exposures along the south bank of Lime Creek (later re-named the Winnebago River) in eastern Cerro Gordo County. The type section of the Juniper and Cerro Gordo members is approximately 3 miles northwest of Stop 7 at the Cerro Gordo County Clay Banks Nature Preserve (formerly Hackberry Grove, Anderson and Furnish, 1987). In the late 1800s and early part of the twentieth century these strata were termed the "Hackberry Stage" (or Hackberry beds) after this locality in several early reports, and the term "Rockford Shales" were also used (named after characteristic exposures a few miles to the southeast at Rockford). An early history of the nomenclature of these beds is outlined in the important study of stratigraphy and fauna of the "Hackberry Stage" by Fenton and Fenton (1924), and in the summary by Anderson and Furnish (1987). These strata have long been known as the "Lime Creek shales" by Iowa Geological Survey geologists following Calvin's (1897) recommendation. In its type area the Lime Creek Formation is up to 43 meters thick. Its overlies the Nora Member of the Shell Rock Formation above a pronounced erosional disconformity, and in Iowa and Johnson counties the Amana Beds Member and North Liberty Beds (Lime Creek equivalents), respectively, overlie older Coralville or Lithograph City strata above a complex erosional unconformity in eastern Iowa. It comprises the surface bedrock unit in the type area and a Holocene erosional surface current forming in Cerro Gordo and adjacent parts Floyd County east of the Lime Creek erosional edge.

In its type area, the Lime Creek Formation is divided into three members, in ascending order, the Juniper Hill Shale, Cerro Gordo Member, and the Owen. (Figs. 3 and 12). The interval now included in the Juniper Hill Shale was excluded from the "Hackberry Stage" by the Fentons (1924) who erroneously assigned it to the Sheffield Formation know to be of Middle Famennian age. Calvin (1897) clearly included this shale-dominated within the Lime Creek Formation.

Juniper Hill Member

The Juniper Hill Member is dominated by green-gray to gray calcareous shale, with calcareous nodules in certain intervals (Fig. 12). The Juniper Hill is 18.1 meters in thickness in the CG-1 core, and is 10.5 meters thick at its type section along the south bank of Winnebago River. A thickness 11.8 meters of Juniper Hill shales was described by C.H. Belanksi in the old pits of the Rockford Quarry on the northern side of the quarry property (see Belanski Register, Locality 4 = Rockford Quarry).

The member lacks significant megafossils in most surface exposures but does yield conodonts (Anderson, 1966) and other microfossils. Fossils have been reported in earlier reports by Webster (1908), Thomas (1922), and In contrast, fossils are common in the Juniper Hill Shale in the CG-1 core in the subsurface of southeastern Cerro Gordo County (Figs. 4 and 12) where it has yielded a relatively diverse brachiopod fauna (see Day, 1989, 1995, 1996) along with crinoid debris and other fossils. Body fossils (small brachiopods, carbonized logs and branches, hexactinellid sponges, and conularids) were reported from and recovered from the lower and middle part of the Juniper Hill in older exposures in the 1920s and 1930s in the Rockford Brick and Tile Quarry (see Day, 2008, Stop 7, Fig. 3). Those exposures were destroyed by quarry operations later in the first half of twentieth century. Those fossils are stored in the University of Iowa's fossil repository in Iowa City (Belanski Collection). The basal 10 to 15 centimeters of the Juniper Hill in the CG-1 core and at the Clay Banks section (Figs. 4

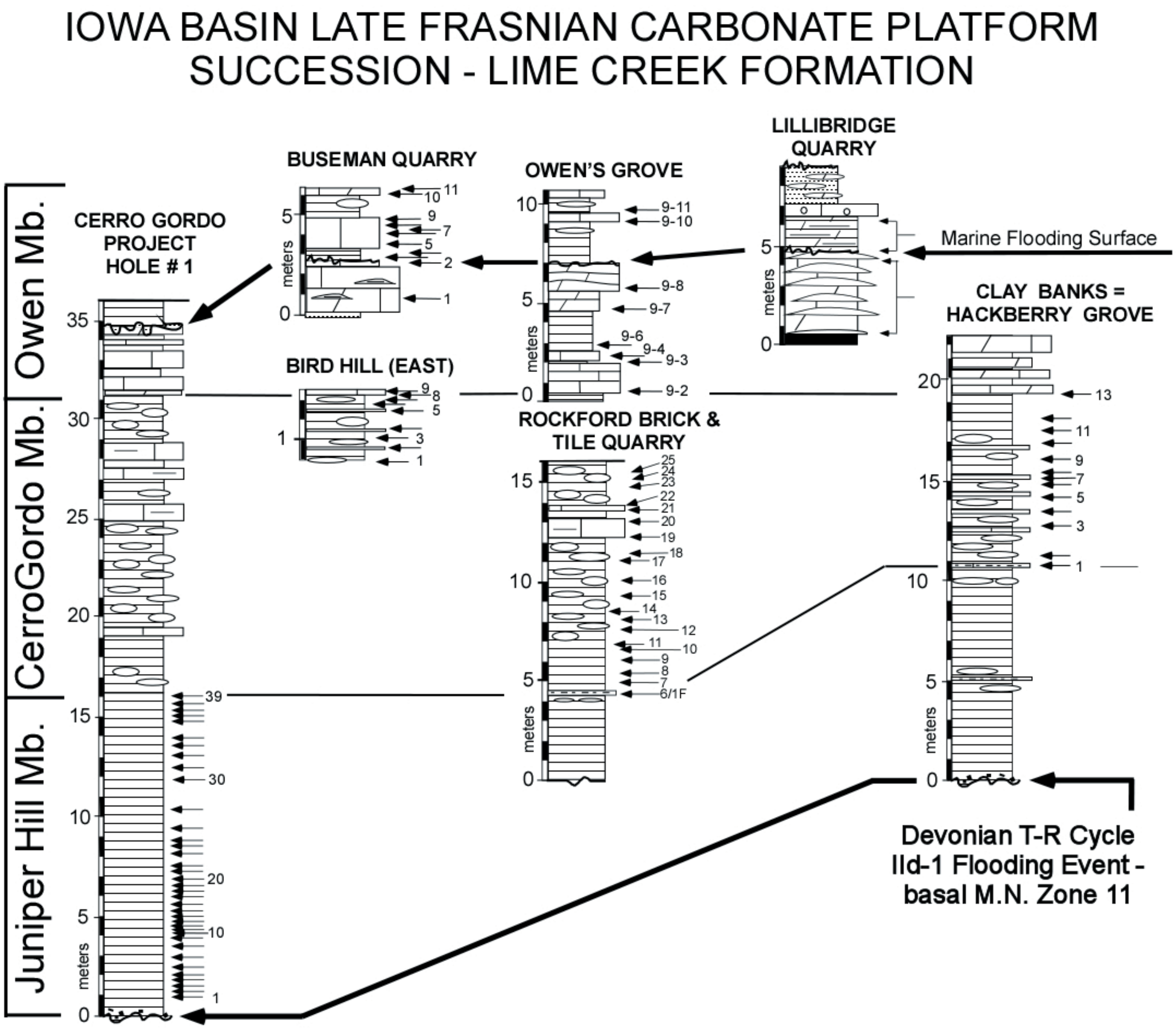

Figure 12. Stratigraphy of the Lime Creek Formation at key surface and subsurface reference sections in its type area in eastern Floyd and western Cerro Gordo counties (Figs. 2 and 4) in north-central Iowa sampled for conodonts by Day (1990) and brachiopods (Day, 1989, 1995). Sample positions of brachiopod samples only are shown. Positions of conodont samples are shown and listed for the CG-1, Rockford Quarry, and Clay Banks sections in Day (1990). Positions of the marine flooding events that initiated Iowa Devonian T-R Cycles 7A and 7B coincide with positions of Euramerican Devonian T-R cycles IId-1 and IId-2 of Day (1998), respectively. The position of the Late Frasnian Lower Kellwasser Extinction bioevent horizon coincides with the T-R cycle IId-2 flooding surface (Fig. 3).

Table 1. Distribution of Late Frasnian brachiopod species in the Juniper Hill Member samples 1 to 39 collected from the CG-1 core (Figs. 4 and 12). Modified after fig. 9 of Day (1989), with corrections to genus name of the cyrtospiriferid *(Conispirifer)* from Ma and Day (2000).

CERRO GORDO PROJECT HOLE #1 CORE SEQUENCE																																			
Sample Interval	**1**	**3**	**4**	**5**	**6**	**9**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**
"Lingula" fragila	X												X							X															
Nervostrophia thomasi		X	X	X	X	X																													
Pseudoatrypa devoniana							X					X										X							X		X	X	X		X
Vincalaria sp.								X													X						X	X		X					
Petrocrania sp.								X																											
Conispirifer cyrtinaformis									X																										
Devonoproductus walcotti									X	X		X					X					X		X											
Schizophoria iowensis									X	X	X	X		X		X	X					X	X		X										
Nervostrophia rockfordensis										X					X	X	X	X				X									X				
Ambocoelia n.sp.											X						X		X					X											
Douvillina arcuata											X								X			X													
Productella cf. *P. thomasi*											X																					X			
Retichonetes brandonensis											X															X									
Rhipidomella n.sp.											X																								X
Stainbrookia infera																						X													
Thomasaria altumbonata																						X													
Cyrtina inulta																								X											
Rigauxia orestes																								X											
"Theodossia" hungerfordi																								X											
Cranaena navicella																															X				
Platyrachella macbridei																																		X	

and 12) consist of an indurated shaly phosphatic lag deposit with abundant placoderm fish plates, conodonts (see Day, 1990), and millions of fossils of the green algal structure (*Tasmanites*).

As mentioned above, the Juniper Hill Member does yield a brachiopod fauna in the subsurface in the CG-1 core section (Figs. 2, 4 and 12) and is discussed by Day (1989, 1995, 1995). The brachiopod fauna (21 species) and sequence in the CG-1 core is shown in Table 1, and was first documented by Day (1989) who defined the "*Lingula*" *fragila*, *Nervostrophia thomasi*, and *Douvillina arcuata* zones (Fig. 3) based on their first (lowest occurrence datums=LADs) in the core section.

Cerro Gordo Member

The Cerro Gordo Member consists of fossiliferous calcareous shales with intervals of nodular shaley limestone and beds of argillaceous limestone. It ranges in thickness from 7.3 meters at its type section at Clay Banks Nature Preserve, to up to 16 meters based on a composite thickness determined from exposures at the Rockford Quarry and the nearby Bird Hill localities (Figs. 4 and 12). The member is best known for its remarkable brachiopod fauna described in studies dating to the late 1850s that includes at least 40 species identified (Day, 1989, 1995), also discussed by Anderson (1995b) and Witzke (1998). The composition and distribution of brachiopod species in the Cerro Gordo Member in the Rockford Quarry section (Figs. 4 and 12) are shown in figure 3 of Day (2008, Stop 7). Additional fossils include green algae (*Tasmanites*), algal reproductive structures (charophyte spores), foraminifera (Cushman and Stainbrook, 1943), sponges, stromatoporoids (Stock, 1984, 2008), tabulate corals, solitary and colonial rugose corals described by Sorauf (1998), bryozoans (cyclostomes, cryptostomes, trepostomes), bivalves (largely undescribed fauna, one of the most diverse Devonian bivalve faunas in North America), gastropods, cephalopods (nautiloids, the ammonoid *Man-*

ticoceras, see Baker et al., 1986), tentaculites, calcareous worm tubes, annelid worm jaws (scolecodonts), echinoderms (crinoids, echinoids), ostracodes (Gibson, 1955), conodonts (Anderson, 1966, Metzger, 1989; Day, 1990), and fish material (placoderm, shark) (see also Fenton and Fenton, 1924; Wilson and McNamee, 1984, for further references on the remarkable Cerro Gordo fauna). Further discussion of the Cerro Gordo Member fauna is featured in Day (2008, Stop 7).

Owen Member

The upper member of the Lime Creek Formation, the Owen Member, is the least shaly interval of the formation, and is characterized by fossiliferous limestone, dolomitic limestone, and dolomite, interbedded with calcareous shale. Beds of oolitic limestone are known to occur in eastern Cerro Gordo County (Lynn, 1978). The Owen Member in the field trip area was subdivided into three intervals by Fenton and Fenton (1924): 1) a basal bed containing abundant branches of the digitate stromatoporoid *Amphipora* (called the *"Idiostroma* Zone"); 2) a thick interval of fossiliferous dolomitic limestones and shales above their *"Floydia* Zone", this characteristic Lime Creek gastropod was re-studied by Day (1987), who noted its original spelling, *Floyda* (*F. gigantea*), named after Floyd County); and 3) an upper interval characterized by an abundance of corals and stromatoporoids (the so-called *"Acervularia [=Hexagonaria]* Zone" of Fenton and Fenton (1924; see Stock, 1984 and 2008, for a listing of stromatoporoids from this interval). These latter two intervals likely share a partial lateral facies relationship across the outcrop belt of Cerro Gordo, Franklin, and Butler counties.

Lime Creek Deposition

The classic area of Lime Creek exposure in Floyd and Cerro Gordo counties marks an interesting transitional belt between coeval carbonate-dominated facies to the west (subsurface) and shale-dominated facies to the southeast. This classic area lies in the outer portions of a broad carbonate-dominated inner shelf environment, where it interfingers with more offshore shale facies along the marginal region of this inner shelf (Witzke, 1987; Witzke and Bunker, 1996). Benthic fossils become increasingly rarer in the offshore direction, probably due to bottom oxygen stresses across the middle shelf region. Seaway depths were sufficient to maintain a stratified water column across the middle shelf area of southeastern Iowa, typified by a thin interval of dysoxic to anoxic shale facies of the coeval North Liberty Beds (see Witzke and Bunker, 2004) in Johnson County in eastern, and the Sweetland Creek Shale and lower Grassy Shale in Scott and Muscatine counties in southeastern Iowa. By contrast, the Lime Creek Formation of northern and western Iowa includes carbonate facies deposited in oxygenated shallower-water settings. The Cerro Gordo and Owen members of the Lime Creek Formation in the field trip area, with their rich and diverse benthic faunas, must have been deposited in well-oxygenated environments. Most of the Lime Creek Formation (Juniper Hill, Cerro Gordo, and lower half of the Owen members) records a Late Frasnian transgressive-regressive (T-R, deepening-shallowing) cycle of deposition. The shallowest facies in the field trip area are seen in the lower half of the Owen Member, which includes oolitic and biosromal units. The deepest depositional environment of the sequence is represented in the Juniper Hill Shale, which includes dysoxic to oxic shale facies deposited when low-oxygen waters impinged along the margins of the inner shelf. A basal transgressive lag of phosphatic clasts and fish bone is found at its base. The Cerro Gordo Member represents an intermediate facies tract, not quite shallow enough for the development of stromatoporoid-rich and oolitic facies. The Lime Creek transgressive-regressive cycle is well displayed farther onto the inner shelf in the subsurface of central and western Iowa. There the formation records, in ascending order, a shallowing-upward sequence: 1) lower open-marine fossiliferous limestones, 2) a middle interval rich in stromatoporoid biostromes (similar to the upper Owen Member), and 3) an upper peritidal to supratidal facies, evaporitic in part (Witzke and Bunker, 1996). This latter facies is not seen in the type Lime Creek area, and was deposited in shallow restricted-marine to mudflat environments.

The main Lime Creek depositional cycle was initiated as seas encroached across the continental interior during the late Frasnian following a prolonged period of erosion across Iowa. The basal erosional unconformity is developed on the upper Shell Rock Formation in the type Lime Creek area, but erosion locally truncated lower units of the Cedar Valley Group farther to the southeast. Likewise, a period of subaerial exposure and erosion followed the last Lime Creek depositional cycle (see discussion below of Iowa Devonian T-R Cycle 7B) in Iowa, and deposition did not resume in northern Iowa until much later in the Late Devonian (middle Famennian shales of the Sheffield Fm.).

UPPER CEDAR VALLEY GROUP AND LIME CREEK FORMATION LEVEL EVENT HISTORY

Deposition of Upper Cedar Valley Group and Lime Creek Formation T-R cycles during the late Givetian to late Frasnian was marked by significant expansion of the subtropical seaways during transgressive and sea level high-stand intervals. At these time open-marine facies spread across most of Iowa and adjacent areas of Missouri and eastern Nebraska (Witzke et al., 1989; Day et al., 1996; Bunker and Witzke, 1992; Witzke and Bunker, 1996, 2006; Day, 2006), and the influx of largely cosmopolitan benthic marine faunas in the late Givetian (Taghanic Onlap of Johnson, 1970; T-R cycle IIa of Johnson et al., 1989) through the late Frasnian (Day, 1989, 1992, 1996).

At present, stratigraphic and biostratigraphic studies have identified five significant 3rd order, and three additional 4rth order sea level rises that controlled the timing of upper Cedar Valley Group and Lime Creek T-R cycles in northern Iowa that can be identified in most basins in North America and in Devonian basins in Eurasia, and represent epeiric records of global sea level signals (Fig. 3).

Iowa Devonian T-R Cycle 4 (Coralville Formation)

The second Cedar Valley Group T-R cycle 4 (Fig. 3) is represented by strata of the Coralville Formation which is placed in the upper part of Johnson et al. (1985) T-R cycle IIa (Witzke et al., 1989; Bunker and Witzke, 1992; Johnson and Klapper, 1992, Witzke and Bunker, 1997, 2006; Day, 2006), now designated as Euramerican Devonian T-R cycle IIa-2 (Day et al., 1996). As such, the Coralville Formation represents last intra-T-R cycle IIa deepening event recorded in the Iowa Basin (Fig. 3). Transgressive facies of lower Cou Falls Member of the Coralville yield conodonts of the Upper *subterminus* Fauna (Fig. 3; Table 1; Witzke et al., 1985; Witzke et al., 1989; Bunker and Witzke, 1992), and brachiopod faunas assigned to the *Tecnocyrtina johnsoni* Zone (Day, 1997). During the in the inner-self area of northern and eastern Iowa, peritidal mudflat carbonates of the Iowa City Member prograded from the north to southeast in the Johnson County area prior to the sea level lowstand event that terminated Coralville Formation deposition.

Post-Coralville Formation Late Givetian Sea Level Lowstand

Significant erosional relief characterizes the sub-Lithograph City Formation surface along portions of the distal inner shelf, where the State Quarry Member of the basal Lithograph City Formation infills deep erosional channels cut into underlying Coralville and Little Cedar strata (Figs. 2 and 3). These channels are known to incise up to 25 m in Johnson County, Iowa (Witzke and Bunker, 1994), and, when the northward thickening of underlying strata is considered, an erosional incision of 32 to 35 m is displayed across the distal inner-shelf. These values provide minimum estimates of the magnitude of sea-level fall that occurred between deposition of the Coralville and Lithograph City formations on the inner shelf of northern Iowa associated with this depositional cycle. This event occurred during the interval of the Upper *subterminus* Fauna (Upper *disparilis* Zone) as shown in (Fig. 3), and also affected the Elk Point Basin and western Canadian Sedimentary Basin of Manitoba and northern Alberta, respectively (see Day et al., 1996).

Iowa Devonian T-R Cycle 5 (Lithograph City Formation)

Iowa Devonian T-R cycle 5 coincides to Devonian T-R Cycle IIb of Johnson et al. (1985) and subdivisions designated as Tr-R cycles IIa-1 and IIb-2 by Day et al. (1996). Three significant marine flooding events controlled the development of very late Givetian and early Frasnian carbonate platform and mixed carbonate-clastic facies of the Lithograph City Formation in the Iowa Basin defining Iowa Devonian T-R cycles 5A to 5C (Figs. 2 and 4).

The initial late Givetian marine flooding of Devonian T-R cycle IIb of Johnson et al. (1985, 1989), and T-R cycle IIb-1 of Day et al. (1996) occurred during the *norrisi* conodont zone (*Allanella allani* brachiopod Zone) and coincides directly to Iowa Devonian T-R cycle 5A. In eastern Iowa this event is recorded by the State Quarry Member and lower Andalusia Member (Day, 2006; Figs 2 and 3). At the Yokum (Fig. 1, locality YQ) and Messerly (Stop 4) quarries in northwestern Blackhawk County, the Osage Springs and, Thunder Woman Shale member comprises a single T-R cycle representing most of Iowa Devonian T-R cycle 5A. North of Black Hawk and southern Butler counties (Stops 1-3) the Thunder Woman Shale has pinched out, and is replaced by peritidal facies of the lower Idlewild Member. In most of northern Iowa T-R cycle 5A is comprised of the dolomitized subtidal carbonates of the Osage Springs and peritidal facies of the lower Idelwild as seen at the type locality of the Osage Springs member section (Stop 1) in northern Floyd County.

Iowa T-R cycle 5B (Figs. 2 and 3) records renewed marine flooding across North American platforms during early Frasnian Montagne Noir (M.N.) Zone 3 (Iowa Basin *Strophodonta callawayensis* Zone). In eastern Iowa, deposits recording Devonian T-R cycle 5B include the upper Andalusia Member of the Lithograph City Formation, and the Snyder Creek Shale in central Missouri (Fig. 3). This flooding coincides with Devonian T-R cycle IIb-2 of Day et al. (1996). In quarry sections (Fig. Y, Hanneman and Charles City South quarries) in Floyd County in northern Iowa two to three meters of open marine subtidal skeletal carbonates are abruptly juxtaposed over inter-tidal mudflat deposits in the middle part of the Idlewild Member that provide a inner shelf record of the significant marine flooding event of T-R cycle 5B.

The Iowa Devonian T-R cycle 5C flooding event in southeastern Iowa coincides with the base of the Buffalo Heights Member of the Lithograph City Formation above the pyritic hardground discontinuity developed on top of the Andalusia Member. Brachiopods of the *Orthospirifer missouriensis* Zone have their first occurrences in the Buffalo Heights Member with conodonts of M.N. Zone 4 (Fig. 3; Day 2006). In a number of locations in Floyd County in northern Iowa (Figs. 3 and Z) , T-R cycle 5C deepening is recorded by open marine subtidal skeletal carbonates with a large new species of the brachiopod *Eleutherokomma* are abruptly juxtaposed over inter-tidal mudflat deposits in the upper few meters of Idlewild Member, where they have not been removed by pre-shell Rock emergence and erosion. This significant early Frasnian flooding event can correlated with continental margin successions in western Canada (Alberta Rocky Mountain Devonian depositional sequence 4 of Whalen and Day, 2008) and provides a regional record of a potential global event permitting subdivision of Devonian T-R cycle IIb-2 of Day et al. (1996). This flooding event is coincident with the Timan event of House (1985).

Iowa Devonian T-R Cycle 6 (Shell Rock Formation)

Iowa Devonian T-R cycle 6 (Fig. 3) coincides with most of Devonian T-R Cycle IIc of Johnson et al. (1985). Three shallowing up carbonate T-R cycles are recognized within the middle Frasnian Shell Rock Formation across northern Iowa in surface and subsurface localities designated as subcycles 6A to 6C (Fig. 3). Iowa Devonian T-R cycle 6A includes strata of the Mason City and lowermost Nora members with brachiopods of the *Tenticospirifer shellrockensis* Zone. Iowa Devonian T-R cycle 6B is comprised by the most of the Nora Member and lower biostrome of the Rock Grove Member in its type area, upper Nora and lowest biostrome faces in areas to the northwest (Fertile Quarry-Stop 5), with brachiopods of the *Strophodonta scottensis* Zone (Fig. 3.) The initial flooding event of T-R cycle 6A is aligned here low in M.N. Zone 5 (within lower part of *punctata* Zone). The precise timing of the marine flooding event initiating deposition of Iowa Devonian T-R cycles 6B cannot established with any degree of precision at present, other than it is likely within M.N. Zone 7 or 8 based on the known upper range limit of *T. shellrockensis* within Zone 8 in the southern NWT of western Canada (Ma and Day, 2000). Iowa Devonian T-R cycle 6C is comprised of the lagoonal facies capped by the upper stromatoporoid patch reef (biostrome) of the Nora Member as seen at the main Shell Rock reference section in the Williams Quarry (Fig. 12 and Stop 6, Fig. 2, units 25 and 26).

Upper Middle Frasnian Sea Level Lowstand

The upper surface of the Cedar Valley Group is deeply eroded beneath overlying strata of the Lime Creek-Sweetland Creek formations (upper Frasnian), and karst is developed in older Wapsipinicon Group and Silurian units and infilled by stratigraphic leaks of late Frasnian Lime Creek shales referred to a the "Independence Shale" (see Fig. 2). This surface developed during an episode of subaerial erosion during the latter part of the middle Frasnian. The mid Frasnian erosional episode beveled and truncated units within the upper Cedar Valley Group across Iowa, and the Shell Rock Formation is sharply truncated across the distal inner-shelf area (Figs. 3B & 4), and entirely absent across the middle-shelf region of southeastern Iowa, northeastern to central Missouri, or central Illinois (Figs. 3B) and appear to have been removed by subaerial erosion.

When the full regional truncation of Cedar Valley strata across the inner-shelf region of Iowa is considered, an erosional truncation of 65 m of stratigraphic thickness is evident. "Independence Shale" stratigraphic leaks) into caverns and other karstic openings developed in the Little Cedar Formation (see Fig. 2), up to 90 m stratigraphically below the highest parts of the regional sub-Lime Creek erosional surface across the inner shelf. Additional fillings of Late Frasnian Lime Creek sediments and microfossils have also been identified in karstic openings and fractures developed within Silurian dolomite strata at a number of localities in eastern Iowa (Bunker et al., 1985, p. 53). It appears that sub-Lime Creek erosional base levels may have been lowered enough to develop karst systems through the entire thickness of the Cedar Valley, Wapsipinicon, and upper Silurian strata in eastern Iowa during the mid Frasnian (in excess of 125 m).

Iowa Devonian T-R Cycle 7 (Lime Creek Fm.-Sweetland Creek Shale-lower Grassy Creek Shale)

Two late Frasnian sequence packages can now be identified in the carbonate platform succession of the Lime Creek Formation in northern Iowa (Figs. 3 and X). These coincide with subdivisions of Devonian T-R cycle IId proposed by Day (1998) designated as Devonian T-R cycles IId-1 and IId-2. Sequence packages representing both of these subdivisions are widely recognizable in western North American study sites in New Mexico, the Alberta Rocky Mountains, and the southern NWT (Day and Whalen 2003, 2006; Whalen and Day, 2005, 2007-in press) as well as the Iowa Basin.

The initial late Frasnian marine deepening event began at or near the base of M.N. Zone 11 (*semichatovae* transgression), coinciding exactly with the marine flooding of T-R cycle IId-1 as proposed by Day (1998). Iowa Devonian T-R cycle 7A (Fig. 3) comprises the local record of this event in the Iowa and western Illinois basins. In the platform succession of northern Iowa, this is comprised of the Juniper Hill, Cerro Gordo, and lower part of the Owen Member (Fig. 12).

In western North American sections in western Alberta (Whalen and Day, 2008) an abrupt deepening event at or near the base of M.N. Zone 13 is signified by carbonate platform back-stepping marking the initiation of Devonian T-R cycle IId-2 (Fig. 3). The same event is recorded by an abrupt deepening event recently recognized within the middle Owen Member at the Buseman Quarry and other sections if Cerro Gordo and Butler County (Figs. 3, 4, and 12) where a prominent discontinuity surface on top of inner platform carbonates can be widely traced in surface sections, with deeper water facies juxtaposed above shallow-water deposits above this surface (Fig. 12). The Owen Member above this position features middle shelf taxa such as *Iowatrypa owenensis* and *Palmatolepis sp.*

Latest Frasnian-Middle Famennian Platform Emergence in Northern-Continuous Basinal Deposition Across F-F Boundary in Southeastern Iowa

The late Frasnian Lime Creek platform in the Iowa Basin experienced a prolonged period of emergence that stripped latest Frasnian and early Famennian deposits across most of the Iowa region. Deposition continued during the latest Frasnian and Famennian in the basinal region of southeastern Iowa recorded by the Grassy Creek Shale where we can recognize the F-F boundary in a number of surface and subsurface localities (Fig. 1). In those locations strata across the boundary appear conformable.

CONCLUDING REMARKS

The Upper Devonian strata and faunas of the Cedar Valley Group and the Lime Creek Formation of Northern Iowa provide the best documented records of epeiric subtropical carbonate platform development and evolution and faunal records that record key events during the Frasnian in North America. We encourage others to continue investigations of these fascinating rocks to add to the knowledge of global environmental change and bioevents recorded in the Iowa Basin Devonian.

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STROMATOPOROID BIOSTRATIGRAPHY OF THE IOWA FRASNIAN

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INTRODUCTION

Iowa is the only place on the North American craton where stromatoporoids are found throughout most of the Frasnian. Two occurrences of only lower Frasnian stromatoporoids are two species from the Snyder Creek Formation of central Missouri (Birkhead, 1967), and seven species from part of the Souris River Formation of Manitoba—six from the Point Wilkins Member, and one from the overlying Sagemace Member (Stearn, 1996). Only Iowa has middle-upper Frasnian stromatoporoids. All other Frasnian stromatoporoid occurrences in North America are near the margin of the continent, in the western US (e.g., Nevada, Utah), western Canada (e.g., Alberta), and arctic Canada (e.g., Banks Island).

STRATIGRAPHIC DISTRIBUTION WITHIN IOWA

The distribution of stromatoporoid genera in the Frasnian of Iowa was presented by Stock and Turner (2006). In this paper I discuss species distributions (Fig. 1). Publication on the Frasnian stromatoporoids of Iowa began with the description of four species by Hall and Whitfield (1873). In subsequent years other workers (e.g., Fenton, 1919) recorded the occurrences of those species, and Stock (1984) redescribed their type specimens along with new topotype specimens. Two additional species were added by Parks (1936). Stock's (1973) master's thesis includes stromatoporoids from the Shell Rock and Lime Creek Formations. Stromatoporoids from the Mason City Member of the Shell Rock Formation were described by Stock (1982), including two new species. In her master's thesis, Smith (1994) described the stromatoporoids of the Idlewild Member of the Lithograph City Formation.

Andalusia Member (Lithograph City Formation)

The Andalusia Member of eastern Iowa spans the Middle-Upper Devonian boundary (Day, 2006). There is a stromatoporoid biostrome in the upper part of the Member (Witzke and Bunker, 2006, Fig. 11). I have thin sectioned only one specimen from the Andalusia Member, which appears to be a species of *Clathrocoilona*; therefore, no attempt has been made to correlate this specimen within and outside Iowa.

Idlewild Member (Lithograph City Formation)

The most diverse assemblage of stromatoporoids in the Frasnian of Iowa occurs in the Idlewild Member. Smith (1994) described 22 species in 13 genera. A slightly updated list of her species constitutes Table 1. Six of her species also occur in the overlying Mason City Member of the Shell Rock Formation (Table 2) (*Hammatostroma albertense*, *Atelodictyon masoncityense*, *Actinostroma clathratum*, *Clathrocoilona involuta*, *Trupetostroma bassleri*, *Hermatoporella hayensis*), suggesting any unconformity between the two Members represents a relatively brief hiatus in deposition.

Mason City Member (Shell Rock Formation)

Stock (1982) described 11 species in 10 genera from the Mason City Member. Table 2 contains an updated list of these species. He further divided the fauna into two biofacies, two species from the upper part of the Member (*Stictostroma ordinarium*; *Stachyodes*? *confertum*), and all other species, plus one specimen of "*S.*"

confertum, restricted to the lower part of the Member.

Sorauf (1998) noted a similar dichotomy in the rugose coral fauna of the Mason City Member, but with a reversal of species diversity. The lower biofacies contains *Smithiphyllum belanskii* and *Pachyphyllum websteri*, whereas the upper biofacies has six species: *Tabulophyllum mutabile*; *T. curtum*; *Disphyllum floydensis*; *D. iowense*; *Pachyphyllum minutissimum*; and *Trapezophyllum* sp. A. The most likely explanation for the opposite trends in species diversity is that the lower Mason City Member was deposited in shallower water than was the upper biofacies.

Rock Grove Member (Shell Rock Formation)

Stromatoporoids are unknown from the Rock Grove Member in outcrop; however, a small fauna has been recovered from a drill core (CG-1) from a well (W30839) in southeastern Cerro Gordo County. The species are listed in Table 3. I have just begun study of this small fauna, so species, and to some extent genus, identifications are not now conclusive. Most of the specimens in the core are small, representing either *Stachyodes* or juveniles of typically larger species. The presence of *Stachyodes* sp. and *Stachyodes*? sp. indicates a similarity with the upper biofacies of the Mason City Member, whereas *Actinostroma* sp., *Clathrocoilona* sp. and *Hermatoporella* sp. show affinities with the lower biofacies of the Mason City Member and/or the Nora Member.

Nora Member (Shell Rock Formation)

Much of the Nora Member is characterized by biostromes of exceptionally large stromatoporoids that form the top and bottom of the Member (Koch, 1970). The largest of these is *Actinostroma expansum*, which can achieve a width of over 30 m and a thickness of over 1 m, but *Hermatostroma iowense* can also reach large size. There are 11 species in the Nora member (Table 4).

Cerro Gordo Member (Lime Creek Formation)

Only two species occur in the Cerro Gordo Member (Table 5). These species also occur in the southern biofacies of the Owen Member. Mistiaen (1985) moved the somewhat problematic species *Stromatopora incrustans* (see Stock, 1984) to *Habrostroma*. Although I believe Mistiaen's reassignment of the species to *Habrostroma* is a step in the right direction, it overextends the variation within the genus.

Owen Member (Lime Creek Formation)

Stromatoporoids from the Owen Member are listed in Table 6. There are two stromatoporoid biofacies present, a southern biofacies in Butler County that shares some species with the Cerro Gordo Member, and a northern biofacies in Floyd, Cerro Gordo and Franklin Counties with a unique fauna.

The southern biofacies is dominated by *Clathrocoilona solidula*, with some specimens of "*Habrostroma*" *incrustans*. At several localities of the northern biofacies, the base of the Owen Member is marked by thin biostromes of *Amphipora* sp., known in the older literature as the "*Idiostroma* zone" (Fenton, 1919). In addition to *Amphipora*, the northern biofacies contains six other species.

The distribution of rugose corals in the Owen Member (Sorauf, 1998) does not reflect the discrimination between the northern and southern biofacies. According to Sorauf, only *Pachyphyllum dumonti* is restricted to the southern biofacies, and the extremely rare *Tabulophyllum expansum* is found in only the northern biofacies. Rugose coral species of the Cerro Gordo Member are absent from the Owen Member.

CORRELATIONS WITH STRATA OUTSIDE OF IOWA

The Frasnian was a time when global sea level was high enough to breach any paleobiogeographic barrier, resulting in a cosmopolitan distribution of many stromatoporoids (Stock, 2005). Few species are endemic to Iowa.

Stearn (2001) provided a great service to those studying Devonian stromatoporoids, by giving the ranges of 61 species within a succession of 10 assemblages. The upper half of his Assemblage 7, plus the entirety of Assemblages 8 and 9 constitute the Frasnian part of his biostratigraphic framework. He also showed how his assemblages relate to conodont zones. Another extremely useful aspect of Stearn's paper is an appendix that contains synonymies and updated genus identifications of many misnamed Devonian species. Several Iowa species also occur in Canada.

Because there are so many species present in the Iowa Frasnian, correlations of all species will not be given, especially for unpublished faunas. In order to avoid redundancy, the stage to which all formations mentioned below belong, is indicated in Table 7. For similar reasons, reference citations are not given for occurrences of species outside North America; however, occurrences in Belgium are attributed to Lecompte (1951; 1952), those in Belgium to Kazmierczak (1971), and those in Czech Republic to Zukalova (1971)

Idlewild Member (Lithograph City Formation)

The six stromatoporoid species that co-occur in the Idlewild Member and Mason City Member of the Shell Rock Formation will be dealt with under the latter. Of the remaining species, five (*Petridiostroma*? *vesiculosum*, *Hermatostroma insulatum*, *Arctostroma dartingtonense*, *Parallelopora catenaria*, *Habrostroma turbinatum*) occur in the Callaway Formation of Missouri. *Petridiostroma*? *vesiculosum* also occurs in Alberta (Cairn, Southesk, Flume, and Beaverhill Lake Formations). *Arctostroma dartingtonense* also occurs in the Givetian of England and Belgium, and in the Frasnian of Poland and Alberta (Cairn [as *Ferestromatopora dubia*] and Mikkwa [as *Stromatopora mikkwaensis*] Formations). *Atelodictyon fallax* is found in the Givetian of Belgium. *Pseudoactinodictyon trautscholdi* occurs in the Frasnian of Belgium (as *Stromatoporella bifida*), Poland, and Russia. *Stictostroma maclareni* is known from the Kakisa Formation of Northwest Territories.

Mason City Member (Shell Rock Formation)

In the upper biofacies, *Stictostroma ordinarium* is known from the Callaway Formation of Missouri. Stearn (2001, p. 223) said that "*Syringostroma*" *confertum* is a "diagenetic structure;" however, Mistiaen (1991) believed the skeletal structure was similar to that of the twiglike stromatoporoid *Stachyodes*, and included such nonbranching forms in *Stachyodes australe*. The name *Stachyodes*? *conferta* is used here. This species has been reported from the Waterways Formation of Alberta (Stearn, 1962), the Beaverhill Lake Formation of Alberta (Stearn, 1963), the Leduc Formation of Alberta (Klovan, 1966), the Mikkwa Formation of Alberta (Stearn, 1966), the Escarpment Member of the Hay River Formation, Northwest Territories (Stearn, 1966), the Cairn and Southesk Formations of Alberta, and Divisions II to VI of the Swan Hills Formation of Alberta.

The lower biofacies contains a more diverse fauna. Of the species co-occurring with the Idlewild Member, *Hammatostroma albertense* also occurs in the Duperow Formation of Saskatchewan (Stearn and Shah, 1990), the Cairn and Southesk Formations of Alberta (Stearn, 1961), the Leduc Formation of Alberta (Klovan, 1966), and the upper Givetian—Frasnian of Poland. *Atelodictyon masoncityense* is found in only Iowa, and *Clathrocoilona involuta* also occurs in the Callaway and Snyder Creek Formations of Missouri (as *C. subclathrata*) (Birkhead, 1967). *Actinostroma clathratum* is widespread in the Givetian and Frasnian, with occurrences in the Dawson Bay and Duperow Formations of Saskatchewan (Stearn and Shah, 1990), the Leduc (Klovan, 1966), Mikkwa (Stearn, 1966), Cairn, and Peechee (Stearn, 1975) Formations of Alberta, the Hay River and Twin Falls Formations of Northwest Territories (Stearn, 1966), the Givetian of England, Germany, Austria, Czech

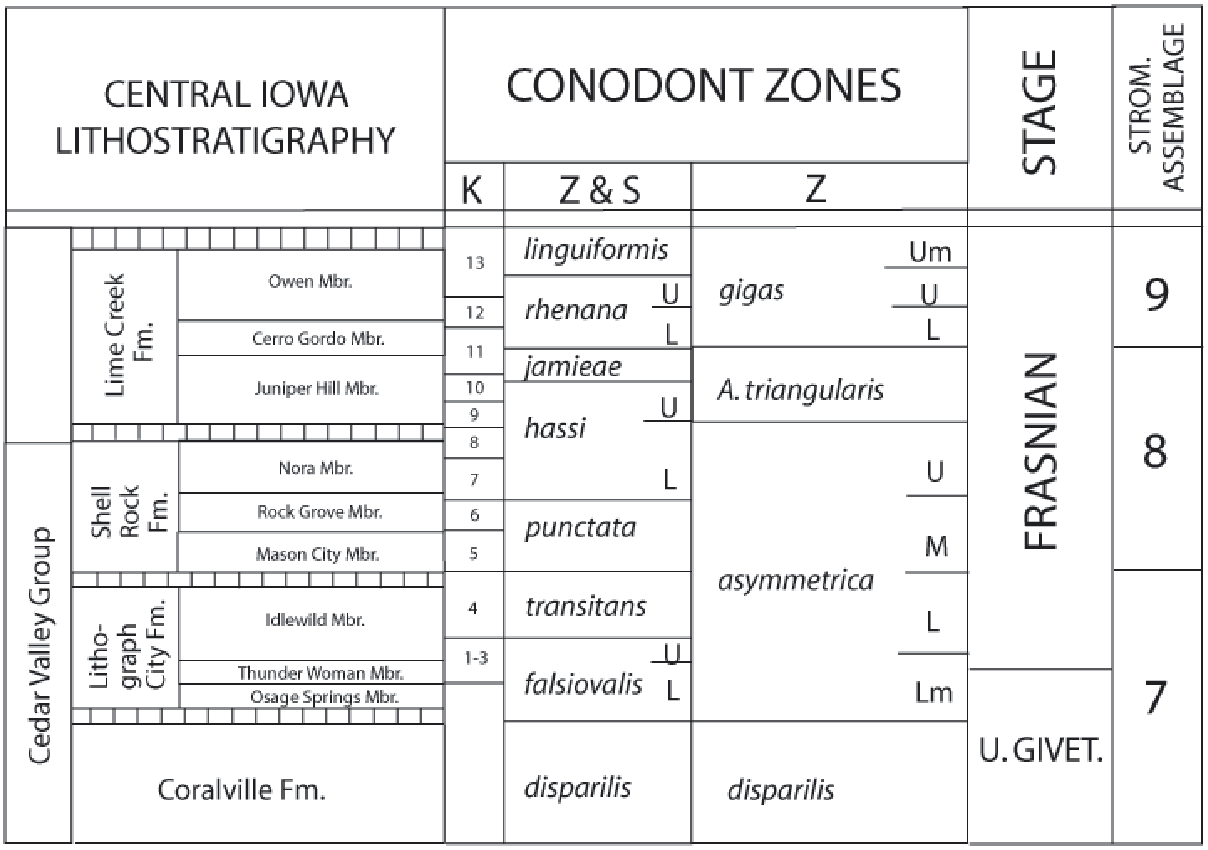

Figure 1. The Iowa upper Givetian and Frasnian stratigraphy correlated with Stearn's (2001) stromatoporoid assemblages and three conodont zonations; SA = Stearn's assemblages; K = Klapper (1988); Z&S = Ziegler and Sandberg (1990); Z = Ziegler (1962, 1971). Equivalence of Z and Z&S from Ziegler and Sandberg (1990); equivalence of K and Z&S from Klapper and Becker (1999).

Republic, Italy, Russia, Uzbekistan, China, and Australia, and the Frasnian of Czech Republic and Russia. *Trupetostroma bassleri* is found in the Givetian and Frasnian of Belgium, and the Frasnian of Russia. *Hermatoporella hayensis* occurs in several formations in North America, including the Callaway Formation of Missouri (as *Trupetostroma ideali*) (Birkhead, 1967), the Mikkwa Formation of Alberta, and the Twin Falls, Tathlina, Redknife, and Kakisa Formations of Northwest Territories (Stearn, 1966).

Of the remaining species, *Stictostroma ordinarium* is known from the Callaway Formation of Missouri, and *Hermatostroma polymorphum* occurs in the Frasnian of Belgium and Czech Republic. *Stachyodes costulata* is widespread, being known from the Souris River and Duperow Formations of Saskatchewan (Stearn and Shah, 1990), the Leduc (Klovan, 1966), Peechee, and Beaverhill Lake (Stearn, 1975) Formations of Alberta, the Givetian of Belgium, Poland, and Russia, and the Frasnian of Belgium, Poland, Czech Republic, and Russia.

Rock Grove Member (Shell Rock Formation)

Incomplete knowledge of the species in the Rock Grove member precludes any meaningful biostratigraphic correlation with areas outside Iowa.

Nora Member (Shell Rock Formation)

Four of the species in the Nora Member have been identified with any degree of certainty. *Hermatostroma iowense* is found in only Iowa. *Actinostroma expansum* occurs in the Dawson Bay and Souris River (Frasnian part) Formations of Manitoba (Stearn, 1996), the Slave Point Formation of British Columbia (Qi and Stearn, 1993), and the Givetian-Frasnian of Poland. A species in the Nora Member is referred to *Hermatoporella pycnostylota*, which is found in the Dawson Bay and Duperow Formations of Saskatchewan (Stearn and Shah, 1990), and the Waterways Formation of Alberta (Stearn, 1962). The distribution of *Stachyodes*? *conferta* is discussed under the Mason City Member.

Cerro Gordo Member (Lime Creek Formation)

Clathrocoilona solidula is restricted to Iowa; however, "*Habrostroma*" *incrustans* has also been found in the upper Givetian of France and Afghanistan.

Owen Member (Lime Creek Formation)

As with the Nora Member, few species in the Owen Member, aside from those also occurring in the Cerro Gordo Member, have been identified with certainty. *Stictostroma kayi* and *Clathrocoilona solidula* are found in only Iowa. *Arctostroma contextum* has been reported from the Point Wilkins Member of the Souris River Formation of Manitoba (Stearn, 1996). A species in the Owen Member is referred to *Hermatoporella papulosa*, which is found in the Waterways Formation of Alberta (Stearn, 1962). The distribution of "*Habrostroma*" *incrustans* is discussed under the Cerro Gordo Member.

CORRELATIONS WITH STEARN'S STROMATOPOROID ASSEMBLAGES

Six stromatoporoid species found in the Iowa Frasnian are also diagnostic species used by Stearn (2001) in his biostratigraphy of the Devonian stromatoporoids of arctic and western Canada. His Assemblage 6 is middle Givetian, Assemblage 7 spans the Givetian-Frasnian boundary, Assemblage 8 is lower-middle Frasnian, and Assemblage 9 is upper Frasnian.

Hammatostroma albertense and *Hermatoporella hayensis* co-occur in the Idlewild Member of the Lithograph City Formation (Table 1), and the Mason City Member of the Shell Rock Formation (Table 2)—these species characterize Stearn's Assemblages 7-9. *Actinostroma expansum*, a prominent component of the Nora Member of the Shell Rock Formation, is diagnostic of Stearn's Assemblages 6-7. Some Nora specimens are referred to *Hermatoporella pycnostylota*, representing Stearn's Assemblage 7. Of two species diagnostic of Stearn's Assemblages 7-8, *Arctostroma contextum* and *Hermatoporella papulosa*, the first has been identified in the Owen Member of the Lime Creek Formation, and the second is referred to an Owen species.

SUMMARY

Stromatoporoids are a prominent component of the fossil fauna of Frasnian-age strata in Iowa. There is an overall upward decrease in species diversity per member, with a high of 22 in the Idlewild Member of the Lithograph City Formation, 11 each in the Mason City and Nora Members of the Shell Rock Formation, and nine in the Owen Member of the Lime Creek Formation. The small sample from the Rock Grove Member of the Shell Rock Formation precludes a fair comparison with other members, and the Cerro Gordo Member of the Lime Creek Formation appears to represent an environment of deposition that was not favorable for most stromatoporoids.

Many of the species in the Iowa Frasnian are known from outside the state, especially with western Canada, which was connected with

Iowa by a continuous seaway. The large number of publications on western Canadian stromatoporoids is no doubt a byproduct of the large petroleum reserves in their Frasnian rocks. Few of the stromatoporoid species used by Stearn (2001) to characterize his time-based assemblages also occur in Iowa. Future study of the Iowa fauna should yield more details on correlations outside the state.

A good number of species have also been reported from western and central Europe, a correlation made possible in large part due to important monographic publications on the Devonian stromatoporoids of Belgium, Poland, and Czech Republic. The widespread distribution of these species is characteristic of the overall cosmopolitan distribution of Frasnian stromatoporoids.

Many genera, and possibly species, of Frasnian stromatoporoids found in Iowa, occur in the western U. S. (e.g., Guilmette Formation of Nevada and Utah; Devils Gate Formation of Nevada). Studies of these faunas are just now beginning.

Table 1. Stromatoporoids of the Idlewild Member of the Lithograph City Formation.

Hammatostroma albertense Stearn
Atelodictyon fallax Lecompte
Atelodictyon cf. *A. fallax* Lecompte
Atelodictyon masoncityense Stock
Petridiostroma? *vesiculosum* (Stearn)
Pseudoactinodictyon trautscholdi (Riabinin)
Bullulodictyon? *patokense* Yavorsky
Actinostroma clathratum Nicholson
Clathrocoilona involuta Stock
Clathrocoilona cf. *C. abeona* Yavorsky
Clathrocoilona cf. *C. solidula* (Hall & Whitfield)
Stictostroma maclareni Stearn
Trupetostroma bassleri Lecompte
Trupetostroma cf. *T. bassleri* Lecompte
Hermatostroma insulatum Birkhead
Hermatoporella hayensis (Stearn)
Arctostroma dartingtonense (Carter)
Parallelopora catenaria Birkhead
Habrostroma turbinatum (Birkhead)
Stachyodes cf. *S. costulata* Lecompte
Stachyodes cf. *S. spongiosa* Stearn
Amphipora cf. *A. ramosa* (Phillips)

Table 2. Stromatoporoids of the Mason City Member of the Shell Rock Formation.

Hammatostroma albertense Stearn
Ateoldictyon masoncityense Stock
Actinostroma clathratum Nicholson
Clathrocoilona involuta Stock
Stictostroma ordinarium Birkhead
Trupetostroma bassleri Lecompte
Hermatostroma polymorphum Lecompte
Hermatoporella hayensis (Stearn)
Stachyodes costulata Lecompte
Stachyodes? conferta (Stearn)
Amphipora pervesiculata Lecompte

Table 3. Stromatoporoids of the Rock Grove Member of the Shell Rock Formation.

Actinostroma sp.
Clathrocoilona sp.
Hermatoporella sp.
Stachyodes sp.
Stachyodes? sp.

Table 4. Stromatoporoids of the Nora Member of the Shell Rock Formation.

Anostylostroma? sp.
Actinostroma expansum (Hall & Whitfield)
Clathrocoilona sp.
Stictostroma sp.
Trupetostroma sp.
Hermatostroma iowense (Parks)
Hermatoporella cf. H. pycnostylota (Stearn)
Arctostroma sp.
Stachyodes? sp.
Stachyodes? conferta (Stearn)
Amphipora sp.

Table 5. Stromatoporoids of the Cerro Gordo Member of the Lime Creek Formation.

Clathrocoilona solidula (Hall & Whitfield)
"Habrostroma" incrustans (Hall & Whitfield)

Table 6. Stromatoporoids of the Owen Member of the Lime Creek Formation.

Gerronostroma sp.
Clathrocoilona solidula (Hall & Whitfield)
Stictostroma kayi (Parks)
Hermatostroma sp.
Hermatoporella cf. H. papulosa (Stearn)
Arctostroma contextum (Stearn)
"Habrostroma" incrustans (Hall & Whitfield)
New genus & species
Amphipora sp.

Table 7. North American formations mentioned in this paper, in alphabetical order, by stage.

Frasnian	
	Beaverhill Lake
	Cairn
	Duperow
	Flume
	Hay River
	Kakisa
	Leduc
	Mikkwa
	Peechee
	Redknife
	Snyder Creek
	Souris River (part)
	Southesk
	Tathlina
	Twin Falls
	Waterways
Givetian	
	Callaway
	Dawson Bay
	Slave Point
	Souris River (part)

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A BRIEF DESCRIPTION OF LITHOGRAPHY

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INTRODUCTION

Lithography was invented in 1796, and as such it was the first new printmaking technique to emerge in about 300 years. It became very popular by the 1830s because it was the first printmaking technique to allow the artist to naturally "paint" or "draw" an image onto a medium. The basic idea is simple, and it works because of the affinity of oil for oil and the repulsion between oil and water. A simplified version of the process is as follows: 1) The artist draws or paints on lithographic stone with a greasy substance such as a waxy or greasy crayon. The stone picks up this greasy substance and holds it. 2) The stone is moistened with water. Parts of the stone not protected by the grease soak up the water. 3) Oil-based ink is rolled onto the stone. The greasy parts of the stone pick up the ink, while the wet parts do not. 4) A piece of paper is pressed onto the stone, and the ink transfers from the stone to the paper.

A fascinating account of the invention of lithography was given by the inventor himself, Alois Senefelder (1771–1834), in his book *Vollständiges Lehrbuch der Steindruckerey* (1818). An English translation of the book was published in 1819 under the title *A Complete Course of Lithography*. The 1977 paperback reprinting of the English version includes an introduction by A. H. Mayor, Curator Emeritus of Prints, Metropolitan Museum of Art, who observed that: "*Lithography is the only major print process whose invention was described by its inventor. We know more about its origins in the 1790's than we know about the appearance — where? how? — of silk screen in the 1920's. There is nothing to add to Senefelder's dramatic story of his invention, nor to his clear explanation of the process.*"

Figure 1. Lithographic print of sea anemones from Ernst Haeckel's (1904) *Kunstformen der Natur (Artforms of Nature).*

HISTORY AND DESCRIPTION OF THE ORIGINAL PROCESS

Senefelder invented lithography while experimenting with printing techniques for sheet music. His original intent was to print using copper plates, a process that required him to use a steel pen for engraving reversed (or mirror image) characters on copper. An impression then taken from the engraved plates would yield the desired positive image of the music. The greatest difficulties in this process were writing in an inverted sense and correcting inevitable errors without starting a new plate from scratch. The need to correct engraving errors led Senefelder to develop a covering varnish that consisted of "*three parts wax, with one part common soap, melted together over the fire, mixed with a small quantity of lampblack, and dissolved in rain-water*" to produce a black ink "*with which I could with great ease correct the faults I accidentally made*." It then occurred to Senefelder that he could practice writing backwards by drawing with this waxy ink on a polished slab of fine Kellheim stone, and he soon discovered that he could write better and more distinctly on the stone than on the copper plates. Upon learning from a stone mason that stone plates from one to eight inches thick could be acquired inexpensively, Senefelder began to conceive the possibility of using stone plates, rather than copper plates, for printmaking.

The first lithographic print was a "bill" [list] written by Senefelder for his mother's washerwoman. Lacking "even the smallest slip of paper" and ordinary ink in his inkstand, Senefelder wrote the bill backwards on a piece of polished stone using the wax, soap and lampblack mixture, with the idea that he could later copy it onto paper. "*Some time after this I was just going to wipe this writing from the stone, when the idea all at once struck me, to try what would be the effect of such a writing with my prepared ink, if I were to bite in the stone with aqua-fortis* [nitric acid]*; and whether, perhaps, it might not be possible to apply printing ink to it, in the same way as to wood engravings, and so take impressions from it.*" Senefelder combined one part nitric acid with ten parts water and allowed the caustic mixture to stand on the lettered stone for five minutes. When he examined the results of this experiment he found that the letters stood about $1/120^{th}$ of an inch above the unlettered part of the stone: in effect, the hydrophobic waxy ink repelled the acid and prevented etching of the stone immediately beneath the letters. A clear and neat print was made when Senefelder applied a thin film of printer's ink on the raised letters and then pressed paper onto the stone.

Senefelder enjoyed immediate but short-lived financial success when he printed twelve songs by the musician and composer Gleissner. Using an old copper-plate press, and with assistance from a printer, the music was written on stone and printed in 120 copies in less than two weeks. The prints were sold for 100 florins, whereas expenses for stones, paper and printing amounted to just 30 florins, leaving a clear profit of 70 florins. According to Senefelder: *"...in the exultation of my hopes, I already saw myself richer than Crœsus.*" Unfortunately, owing to labor problems and difficulties with presses, Senefelder spent the next two years failing to meet contractual printing obligations, with things going so badly that he ended the period in debt. He experimented with a variety of presses, including dead-weight and falling-weight types, once nearly killing himself with the latter while dropping a 300 pound stone from a height of ten feet. He was able to produce consistently clear, high quality prints only after designing a new press in which stone plates were passed through upper and lower revolving cylinders.

A persistent obstacle to high volume production of prints was the need to write music or text as reversed characters on the polished stones. In his initial effort for Gleissner, Senefelder expedited the writing process by tracing a page of music with black lead pencil on paper, then wetting the paper, placing it face down on a stone, and passing it through a strong press. In this way a faint outline of the music, in reverse, was transferred to the stone and it was then a straightforward matter to complete the image with the waxy ink mixture. Senefelder soon wondered if it might not be possible to compose drawings or text with specially prepared ink and paper so that a complete positive image could be transferred in reverse to stone. In the process of experimenting with ink and paper Senefelder discovered the final principle of chemical lithography: "*The art of transferring from the paper to the stone, rested principally on the greater or less affinity of one* *ingredient to another; for instance, I observed that every liquid, especially a viscous liquid, such as a solution of gum, prevented the ink from attaching itself to the stone. I drew some lines with soap on a newly polished stone, moistened the surface with gum-water, and then touched it with oil colour, which adhered only to the places covered with soap*." Modern lithography employs many subtle refinements, but the basic technique has not changed since the beginning of the Nineteenth Century.

SOURCE, PROPERTIES AND PREPARATION OF LITHOGRAPHIC LIMESTONE

The stone first used by Senefelder was described as "*calcareous slate*," extracted from quarries near the town of Kellheim, Bavaria, along the banks of the Danube. The quarries at Kellheim were exhausted by the time Senefelder's book was published, however, and so the village of Solnhofen became the main producer of lithographic limestone. In a bit of an overstatement, Senefelder described Solnhofen as a place where "*…all the inhabitants are stone-masons. The country there abounds in this species of stone, so that for centuries to come no want of stones is to be feared. When the ground is uncovered to the depth from ten to fifteen feet, these stone-plates appear in horizontal strata, which at first are of very inconsiderable thickness, often not thicker than paper; and for that reason, and their want of consistency, cannot be used for any lithographic purpose*." Presumably better stone was encountered deeper down.

Senefelder demonstrated that the Solnhofen stone was exceptionally pure calcium carbonate: when dissolved in nitric, muriatic or other acids it left no insoluble residue. He described the following properties of ideal stone: 1) thickness of two to two and a half inches; 2) harder stone is better than softer stone, because pen strokes and etching needles will gouge deeply into soft stone; 3) compositional uniformity—isolated soft spots become hollows during the polishing process; and 4) textural uniformity—small holes, veins and fissures must be avoided, whereas very small veins, discolored areas, and "*impressions of fish, plants, etc., are not essential defects*."

It is essential to compose images on a perfectly flat stone. Senefelder flattened and polished his stones with fine quartz sand. A thin layer of sand was sprinkled on the upper surface of one stone and this was covered by a second stone of similar size and shape. The upper stone was then moved in a circular motion, causing the sand to grind and flatten the lower stone. Periodically the pair of stone slabs was inverted, so that the lower stone became the upper stone, to prevent the stones from developing concave and convex surfaces.

REFINEMENTS

(EXCERPTED FROM WIKIPEDIA)

Senefelder experimented in the early 1800's with multicolor lithography, and in his book he predicted that the process would eventually be perfected and used to reproduce paintings. Multicolor printing was introduced through a new process developed by Godefroy Engelmann in 1837 known as chromolithography. A separate stone was used for each color, and a print went through the press separately for each stone. The main challenge was of course to keep the images aligned. This method lent itself to images consisting of large areas of flat color, and led to the characteristic poster designs of the period.

Modern lithography can be used to produce posters, maps, books, newspapers, and packaging—just about any smooth, mass-produced item with print on it. In modern lithography an image is drawn or transferred to the surface of a stone plate with an oil-based medium. The range of oil-based media is endless, but the fidelity of the image relies on the lipid content of the material being used: i.e., its ability to withstand water and acid. Following the placement of the image, an acid emulsified with gum arabic is applied. The function of this emulsion is to create a salt layer directly around the image area. The salt layer seeps into the pores of the stone, completely enveloping the original image. Using lithographic turpentine, the printer then removes the oily drawing medium, leaving only the salt layer. It is this salt layer that holds the skeleton of the image's original form. When printing, the stone plate is kept wet with water. The water is attracted to the layer of salt created by the acid wash. Ink with a high lipid content is then rolled over the surface. The water repels the grease in the ink and the only place for the ink to go is the cavity left by the original drawing material. When the cavity is sufficiently full, the stone and paper are run through a press, transferring the ink from the stone to the paper.

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FIELD TRIP STOPS – SATURDAY

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STOP 1 – OSAGE ROADCUT

Roadcut on west side of County Road T38, approximately 1.5 miles south of Osage and immediately north of the Cedar River bridge (SE SE SE sec. 35, T98N, R17W, Mitchell County, Iowa).

CAUTION!

This is a potentially dangerous locality.
Please be mindful of the sometimes heavy traffic along T38.
Also, be careful along the steep rock faces of the roadcut
and in deep ditches on either side of the road.

FIELD DESCRIPTION

This locality was designated by Witzke et al. (1988) as the type section for the Osage Springs Member of the Lithograph City Formation. A separate locality description was presented by Witzke and Bunker (1995a). The Osage Springs Member here is ~24 feet (~7 m) thick, but only the upper 15 feet are safely accessible along the west side of road (Figs. 1, 2). The lower beds of the member and the contact with the underlying Coralville Formation are well exposed, but less easily accessible, in the deep ditch on the east side of the road. The contact with the overlying Idlewild Member of the Lithograph City Formation is present near the top of the exposure on both sides of the road.

The Osage Springs Member here comprises tan to creamy white dolomite with abundant calcite-filled vugs. Beds in the lower part of the exposure are very thick to thick, becoming thinner toward the top of the unit. Fine horizontal laminations are preserved near the top of the member. Dolomite beds are finely to coarsely crystalline, commonly containing calcite-filled molds of brachiopods and other skeletal grains. Slabs and thin sections reveal that certain layers are distinctly mottled, suggesting bioturbation of the precursor limestone lithology.

The lower part of the Idlewild Member is represented by interbedded finely crystalline dolomite and limestone. Very large, zoned dolomite rhombs in micritic and microcrystalline dolomite matrix are present locally in the unit ~2 feet below the top of our measured section (spl. OS-6). Beds at the top of our section are tan to creamy, sublithographic to lithographic limestone.

PETROGRAPHIC DESCRIPTIONS

OS-7 Alternating laminae, each ~0.5 to 1.0 cm thick, of pelsparite, pelmicrite (Fig. 3F) and micrite. Micritic laminae might have originated as densely packed peloids in which the individual peloids are no longer recognizable.

OS-6 Micrite and microcrystalline dolomite. Large, zoned dolomite rhombs scattered throughout fine matrix (Fig. 3E). Small ostracods abundant; calcite-filled skeletal molds also present. Isolated patches of pelsparite suggest that rock originally might have been peloidal throughout.

OS-5 Medium dolomite with calcite-filled vugs and calcite-filled skeletal molds. Apparent intraclasts of microcrystalline dolomite fairly common (Fig. 3D). Fabric is distinctly mottled, suggesting bioturbation of precursor limestone lithology.

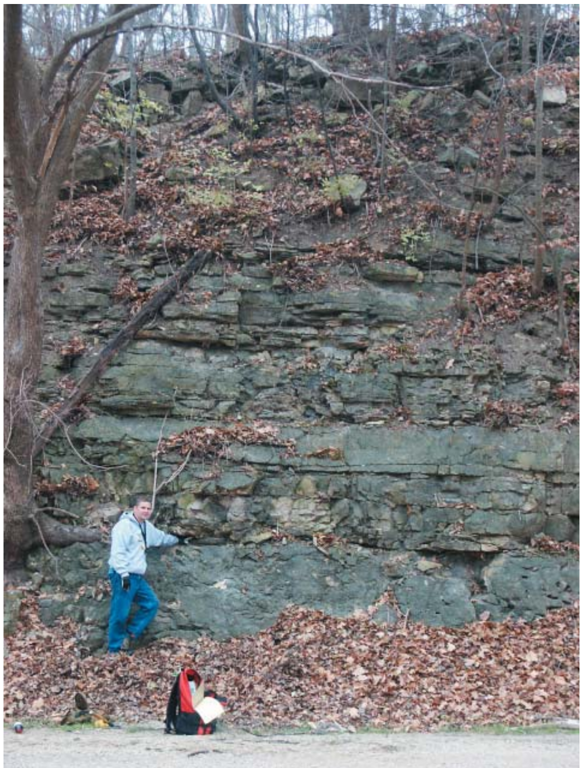


Figure 1. Upper Osage Springs Member and lower Idlewild Member exposure along west side of T38 (Saturday Stop 1).

OS-4	Not examined.
OS-3	Thinly laminated microcrystalline dolomite with calcite-filled vugs interpreted as possible birdseyes (Fig. 3C).
OS-2	Medium- to coarse-grained dolomite with scattered larger rhombs (Fig. 3B). Calcite-filled vugs and skeletal molds present in patches. Fabric is mottled, suggestion bioturbation of precursor limestone lithology.
OS-1	Medium dolomite with abundant calcite-filled vugs and skeletal molds (Fig. 3A).

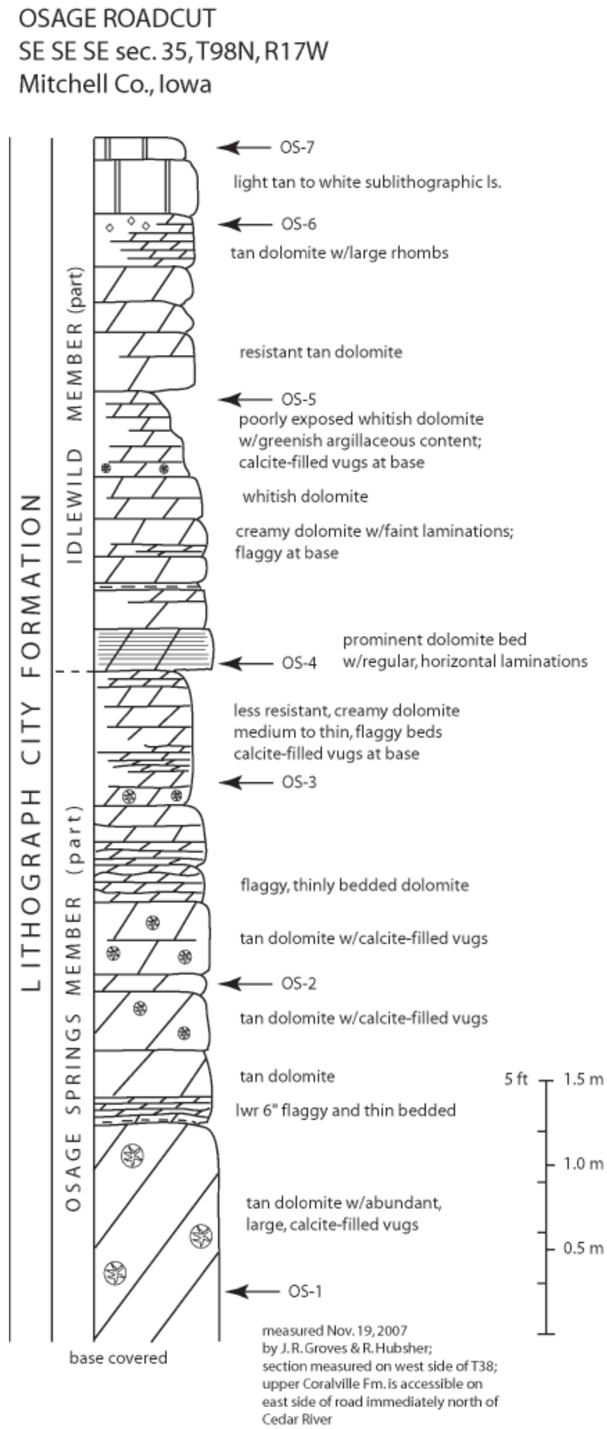
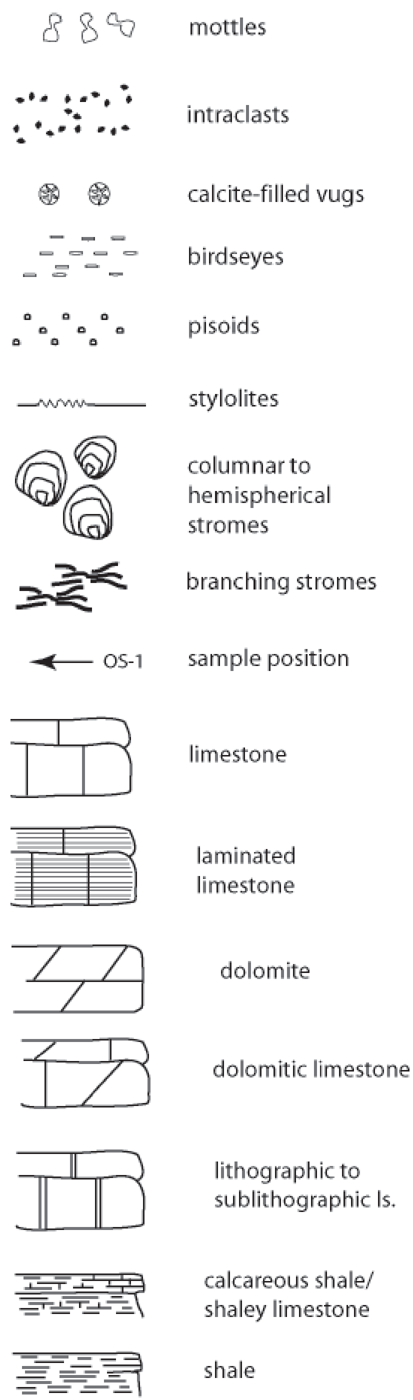


Figure 2. Columnar stratigraphic section of upper type Osage Springs Member and basal Idlewild Member at Osage roadcut.

KEY TO SYMBOLS

These symbols are used in columnar stratigraphic sections for all Saturday stops.



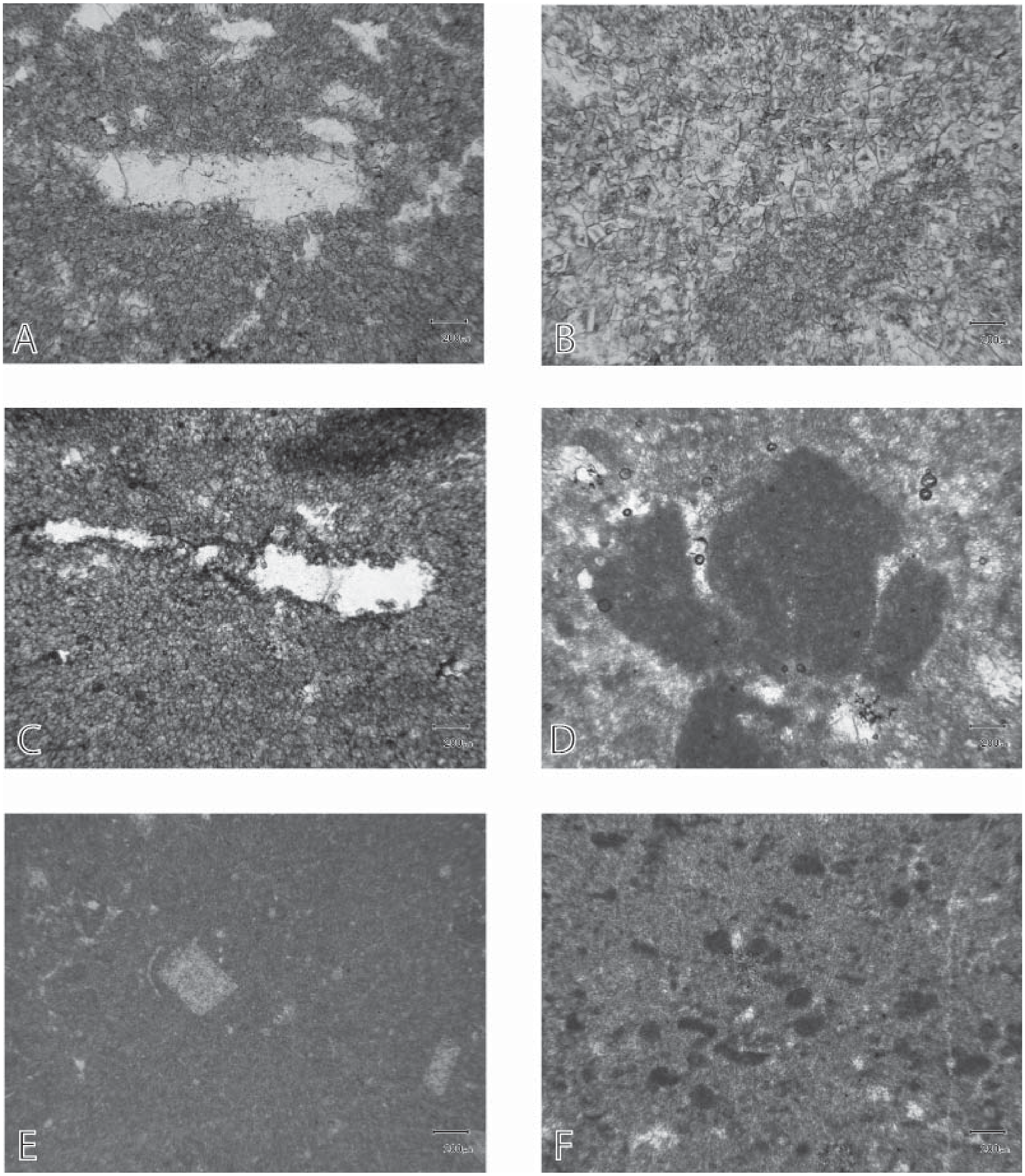


Figure 3. Thin section photomicrographs from Stop 1. A) Calcite-filled skeletal mold in dolomite matrix (spl. OS-1); B) Coarsely crystalline dolomite of mottled fabric (spl. OS-2); C) Calcite-filled vug, possibly a birdseye, in microcrystalline dolomite matrix (spl. OS-3); D) Microcrystalline dolomite intraclast embedded in coarser dolomitic matrix with scattered calcite-filled vugs (spl. OS-5); E) Large dolomite rhomb embedded in peloidal and micritic matrix (spl. OS-6); F) Pelmicrite lamina (spl. OS-7). Scale bar in lower right corner of each image = 200µm.

STOP 2 – JONES QUARRY

Quarry operated by Croell Redi-Mix, Inc., and informally known as the east pit of the Lithograph City quarries. This locality is immediately east of the abandoned quarry from which lithographic stone was extracted in the early part of the 20th Century (approximately six miles south of Osage on County Road T38; sec. 26, T97N, R17W, Floyd County, Iowa).

CAUTION!

This is a potentially dangerous locality.
Access to the east face of the quarry, where the section was measured and described, requires climbing on large blocks of loose limestone. All but the lowest beds can be examined more safely outside the pit along the quarry road leading from T38.

FIELD DESCRIPTION

This locality was designated by Witzke et al. (1988) as the type section of the Lithograph City Formation. A detailed locality description was presented by Witzke and Bunker (1995b). Rocks exposed along the east face of the quarry are assigned to the Idlewild Member of the Lithograph City Formation. They are ~27 feet (7.7 m) thick and capped by Pleistocene till (Figs. 1, 3).

Beds at the quarry floor are brownish, finely crystalline dolomite with scattered vugs. Dolomitic lithologies give way to limestones approximately six to seven feet above the quarry floor. Limestones of the Idlewild Member record numerous, small-scale, shallowing-upward cycles. The very shallow subtidal to peritidal origin of the cycles is indicated by multiple occurrences of thinly laminated mudstone with intraclasts, birdseyes and fenestral fabrics. The laminated lithologies are probably tidal laminites, although a stromatolitic origin cannot be ruled out.

Very good lithographic limestone is present in the lower part of the section (spls. LC-6 and LC-7) (Fig. 2). The stone is light tan to white, dense and micritic with scattered birdseyes. This interval of lithographic rock comprises two thicker beds (~1 ft each) separated by a single thin (~1") bed, which itself is bounded by prominent stylolites. These layers very likely correspond to so-called "bed No. 3" of Calvin (1903), the bed tested for its suitability in lithographic printing by A. Hoen & Co. of Baltimore. Petrographically, the lithographic stone consists of densely packed pellets in micritic matrix. Additional intervals of sublithographic to lithographic limestone occur higher in the section, especially near the top of the quarry face. The higher layers are thinner than those of "bed No. 3," and thus are not as suitable for lithography.

PETROGRAPHIC DESCRIPTIONS

LC-20 Pelmicrite with clotted fabric suggesting birdseyes; very large dolomite rhombs scattered in matrix.

LC-19 Dismicrite to pelmicrite; calcite-filled voids suggestive of birdseyes; minor dolomite rhombs and indeterminate skeletal silt scattered in matrix.

LC-18 Pelmicrite with dolomite rhombs scattered in matrix; ostracodes and calcispheres common.

LC-17 Bioclastic pelmicrite; bioclasts include abundant crinozoans along with ostracodes, calcispheres and indeterminate skeletal silt.

LC-16 Bioclastic pelmicrite to pelsparite; bioclasts mostly disarticulated small ostracodes.

LC-15 Intraclast-bearing, pelletal biomicrite to biosparite; bioclasts include brachiopods, crinozoans and paleoberesellid algal fragments; dolomite rhombs scattered in micritic matrix.

LC-14 Bioclastic pelsparite with scattered pelmicritic intraclasts (Fig. 4F); bioclasts include disarticulated ostracodes and brachiopods.

LC-13	Bioclastic pelmicrite to pelsparite (Fig. 4E); bioclasts include disarticulated ostracodes and brachiopods.
LC-12	Pelmicrite to pelsparite; clotted fabric suggests birdseyes; calcispheres very abundant.
LC-11	Pelmicrite with isolated, small patches of pelsparite; clotted fabric suggestive of birdseyes.
LC-10	Intraclast-bearing, bioclastic pelsparite; bioclasts include crinozoans, brachiopods and disarticulated ostracodes.
LC-9	Alternating laminae of micrite, pelmicrite and pelsparite (Fig. 4D); small birdseyes and dolomite rhombs scattered throughout matrix.
LC-8	Pelmicrite with scattered ostracodes and large dolomite rhombs.
LC-7	Dismicrite to pelmicrite (Fig. 4C); clotted fabric suggestive of birdseyes.
LC-6	Intraclast-bearing pelmicrite with isolated patches of pelsparite; disarticulated ostracodes present.
LC-5	Biomicrite to pelbiomicrite (Fig. 4B); allochems include abundant ostracodes, calcispheres, algal fragments, indeterminate skeletal silt and possible intraclasts.
LC-4	Microcrystalline dolomite; small, calcite-filled voids suggestive of birdseyes.
LC-3	Alternating thin laminae of medium- and coarsely crystalline dolomite.
LC-2	Alternating laminae of finely- crystalline to medium dolomite (Fig. 4A).
LC-1	Finely crystalline dolomite.

Figure 1. Idlewild Member of Lithograph City Formation along east face of Jones Quarry (type section of Lithograph City Formation; Saturday Stop 2).

Figure 2. Lithographic and thinly laminated lithologies of the Idlewild Member at Jones Quarry (Saturday Stop 2). Hammer head rests on top of lithographic limestone (sample position LC-7). Two laterally continuous stylolites in the center of this unit (= "bed No. 3" of Calvin, 1903) separate it into thicker upper and lower layers and a thin central layer. Overlying two beds are thinly laminated limestones, tidal laminites or stromatolites.

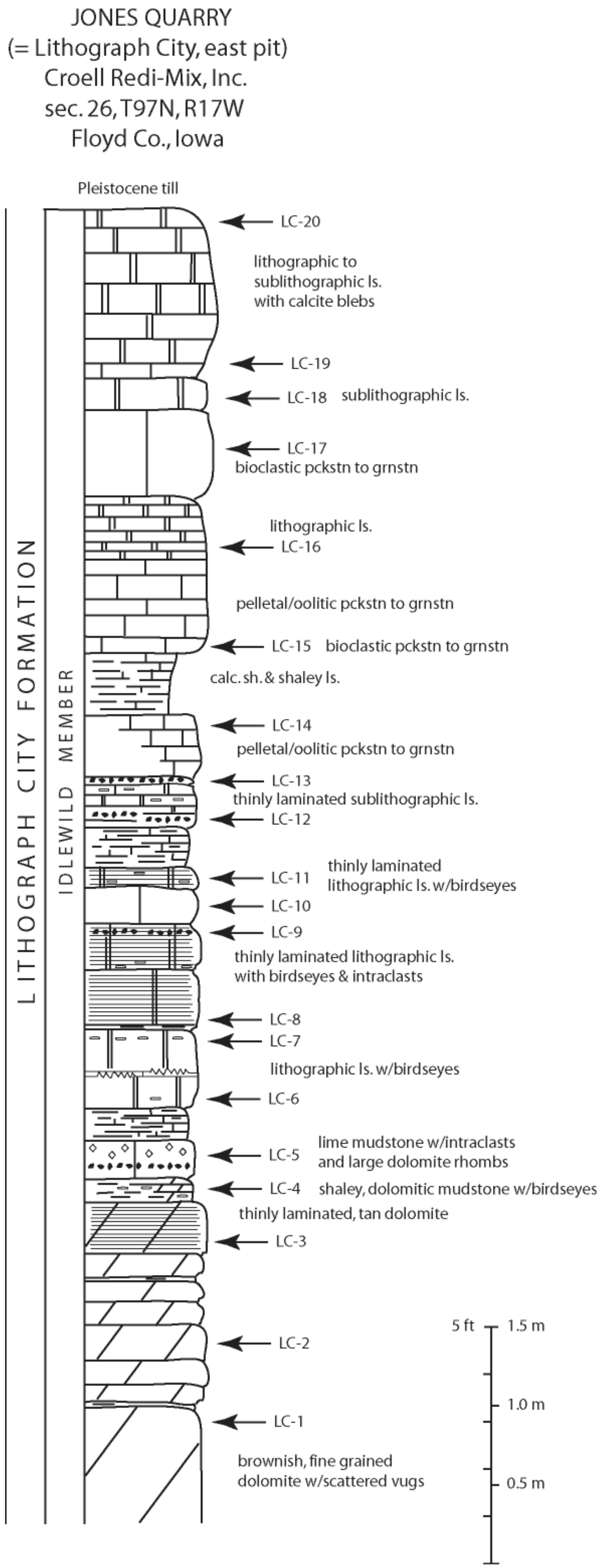


Figure 3. Columnar stratigraphic section of Idlewild Member at Jones Quarry.

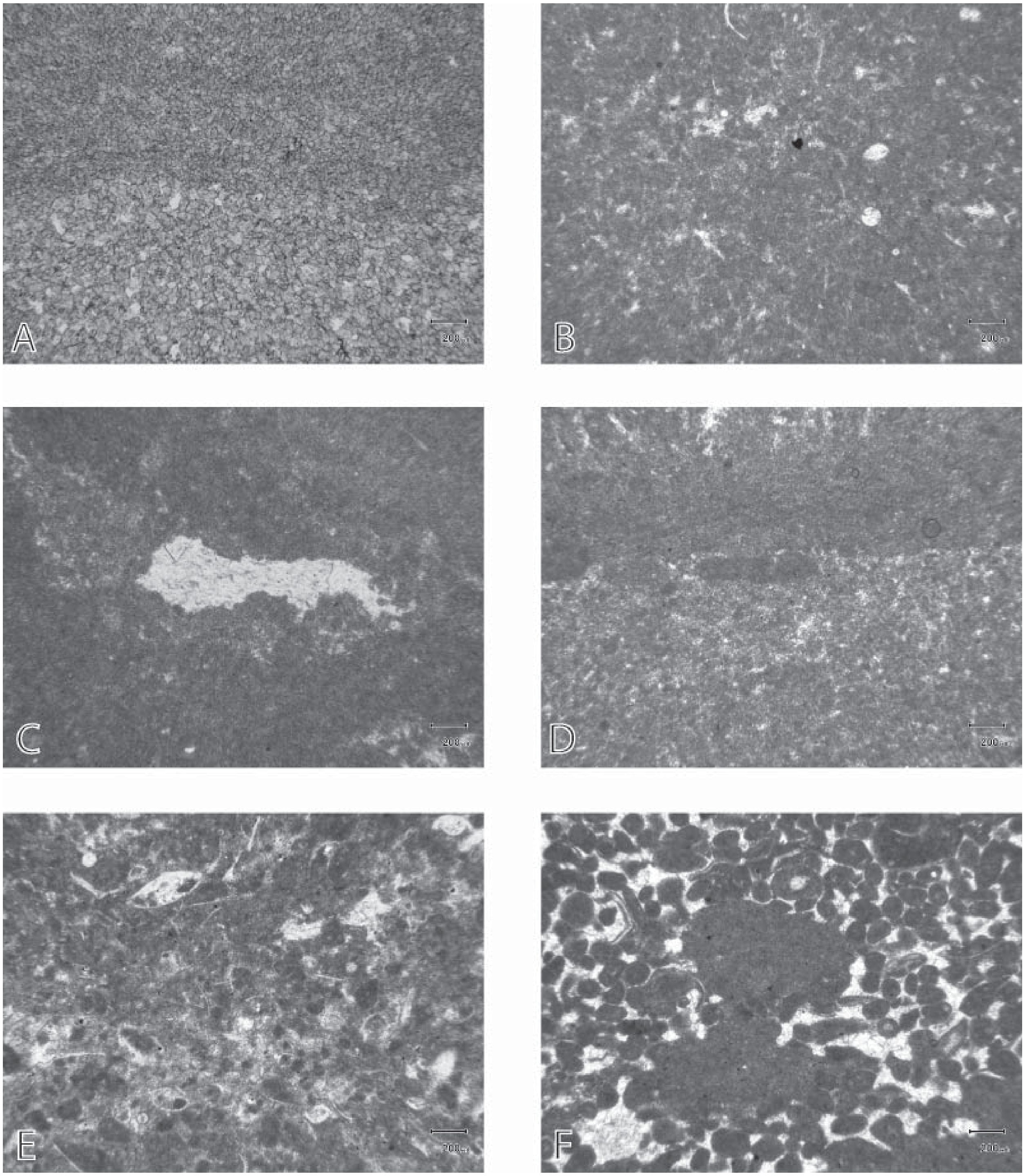


Figure 4. Thin section photomicrographs from Stop 2. A) Alternating laminae of medium- and finely crystalline dolomite (spl. LC-2); B) bioclastic pelmicrite with abundant disarticulated ostracodes (spl. LC-5); C) small birsdeye in pelmicrite matrix (spl. LC-7); D) alternating laminae of fine pelsparite and pelmicrite (spl. LC-9); E) bioclastic pelmicrite to pelsparite with abundant ostracodes (spl. LC-13); F) intraclast-bearing pelsparite (spl. LC-14). Scale bar in lower right corner of each image = 200µm.

STOP 3 – STEERE QUARRY

Quarry operated by Greene Limestone Co., formerly known as the Florry Quarry.
This locality is approximately four miles west of Greene,
~ ¼ mile south of County Road C13 (center sec. 8, T93N, R17W, Butler Co.).

FIELD DESCRIPTION

A good section of the Idlewild Member, similar in many details to the Idelwild Member at the Jones Quarry, is exposed here. The Idlewild Member at Steere Quarry comprises approximately 33 feet of strata which can be accessed safely along the east wall of the pit (Fig. 1).

Beds at the quarry floor are medium- to coarsely crystalline dolomite. Above the dolomite is a succession of mostly sublithographic to lithographic limestone beds with coarser lithologies being much subordinate (Fig. 3). The fine-grained carbonates are dominated by pelletal fabrics, in places with birsdeyes and/or small, micritic intraclasts. Multiple small-scale cycles are evident here, as at Jones Quarry. The cycles are two- to two and one-half feet thick and typically consist of alternating pelmicrite and pelsparite laminae at their bases, grading upward into more uniform micrite to pelmicrite (i.e., pure lithographic limestone) at their tops. Exceptions to the pelletal fabrics include a distinctive crinozoan biomicrite bed that occurs ~eight feet above the base of the section (Fig. 2), and a highly mottled, dolomitic, micrite bed that occurs ~12 feet above the base of the section. Bioclastic material is limited mainly to calcispheres, disarticulated ostracodes, calcite-filled molds of small brachiopods and very rare paleoberesellid algae. The restricted biota and distinctive lithofacies point to a peritidal environment of deposition.

PETROGRAPHIC DESCRIPTIONS

SQ-12 Alternating laminae, each ~0.5 cm thick, of intrapelmicrite and birdseye-bearing, clotted, pelsparite (Fig. 5F) . No bioclasts present.

SQ-11 Intraclast- and birdseye-bearing, alternating pelmicrite and pelsparite with rare ostracodes and calcispheres (Fig. 5E).

SQ-10 Dismicrite to pelmicrite with clotted fabric (possible small birdseyes; Fig. 5D); large dolomite rhombs and very rare ostracodes and calcispheres are scattered in micritic matrix.

SQ-9 Pelsparite with subordinate laminae of pelmicrite (Fig. 5C); ostracodes and calcispheres common; crinozoan fragments and skeletal algae present.

SQ-8 Intraclast-bearing pelmicrite and pelsparite with common disarticulated ostracodes (Fig. 5B); crinozoan debris and calcite-filled shell molds rare.

SQ-7 Mottled, dolomitic pelmicrite with scattered calcispheres and indeterminate skeletal silt (Fig. 5A).

SQ-6 Crinozoan biomicrite with patches of crinozoan biosparite (Fig. 4F); accessory bioclasts include small brachiopods, ostracodes and indeterminate skeletal silt.

SQ-5 Intraclast- and birdseye-bearing pelmicrite to pelsparite (Fig. 4E) with rare dolomite rhombs, calcispheres, ostracodes, paleoberesellid algae and calcite-filled shell molds.

SQ-4 Micrite to pelmicrite with isolated patches of pelsparite (Fig. 4D); rare dolomite rhombs, calcite-filled shell molds; very rare quartz fine sand and silt.

SQ-3 Alternating medium laminae of micrite, pelmicrite and clotted pelsparite (Fig. 4C) with possible intraclasts; calcispheres common; large dolomite rhombs scattered in micritic matrix.

SQ-2 Micrite to pelmicrite with scattered, large dolomite rhombs (Fig. 4B); disarticulated ostracode shells common.

SQ-1 Medium- to coarsely crystalline, zoned, dolomite rhombs embedded in micrite or microcrystalline dolomite matrix (Fig. 4A).

Figure 1. Idlewild Member of Lithograph City Formation along east face of Steere Quarry (Saturday Stop 3).

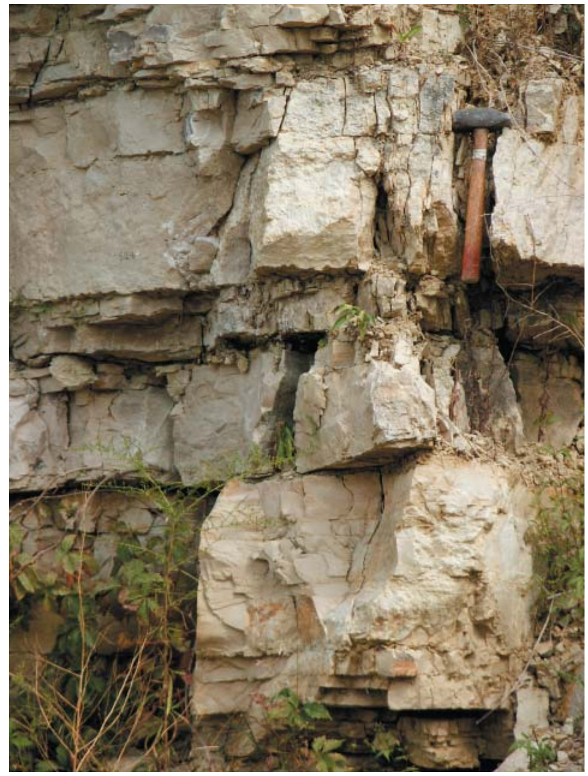


Figure 2. Lower part of section at Steere Quarry. Hammer is positioned at crinozoan biomicrite bed (spl. SQ-6). Thick bed at bottom of photo is lithographic limestone between spls. SQ-3 and SQ-4.

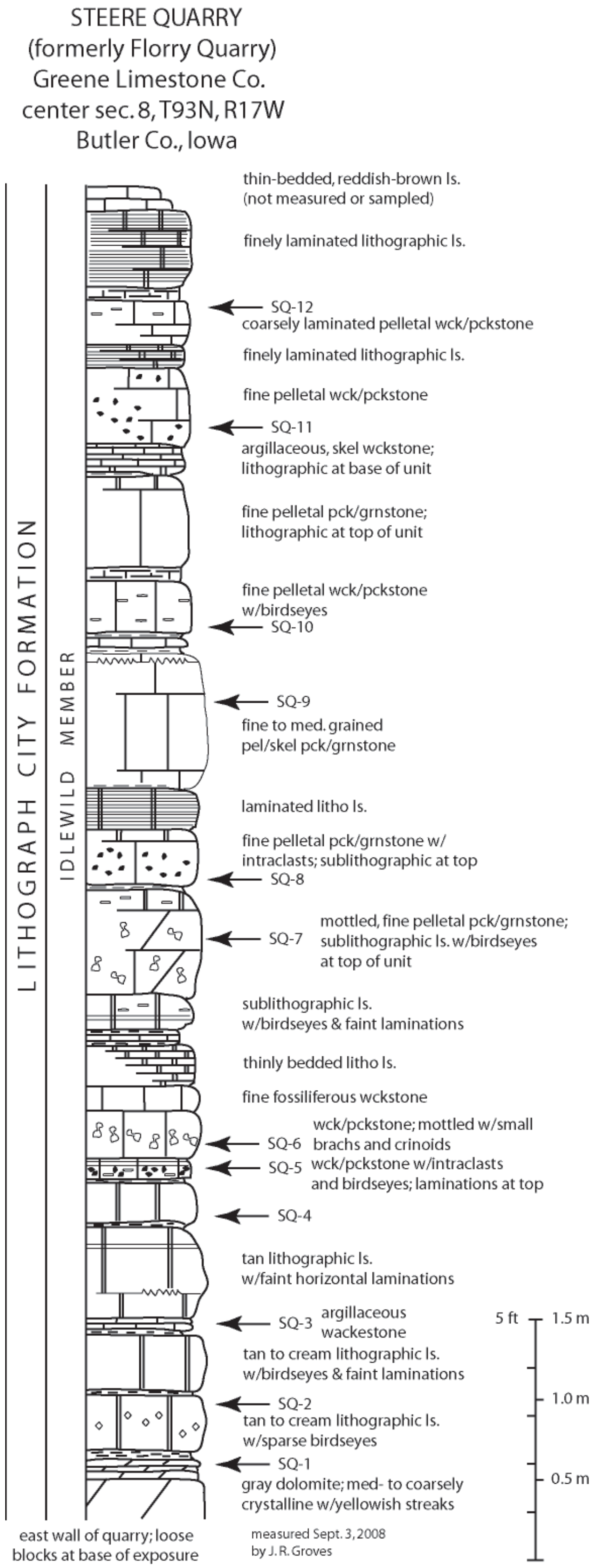


Figure 3. Columnar stratigraphic section of Idlewild Member at Steere Quarry.

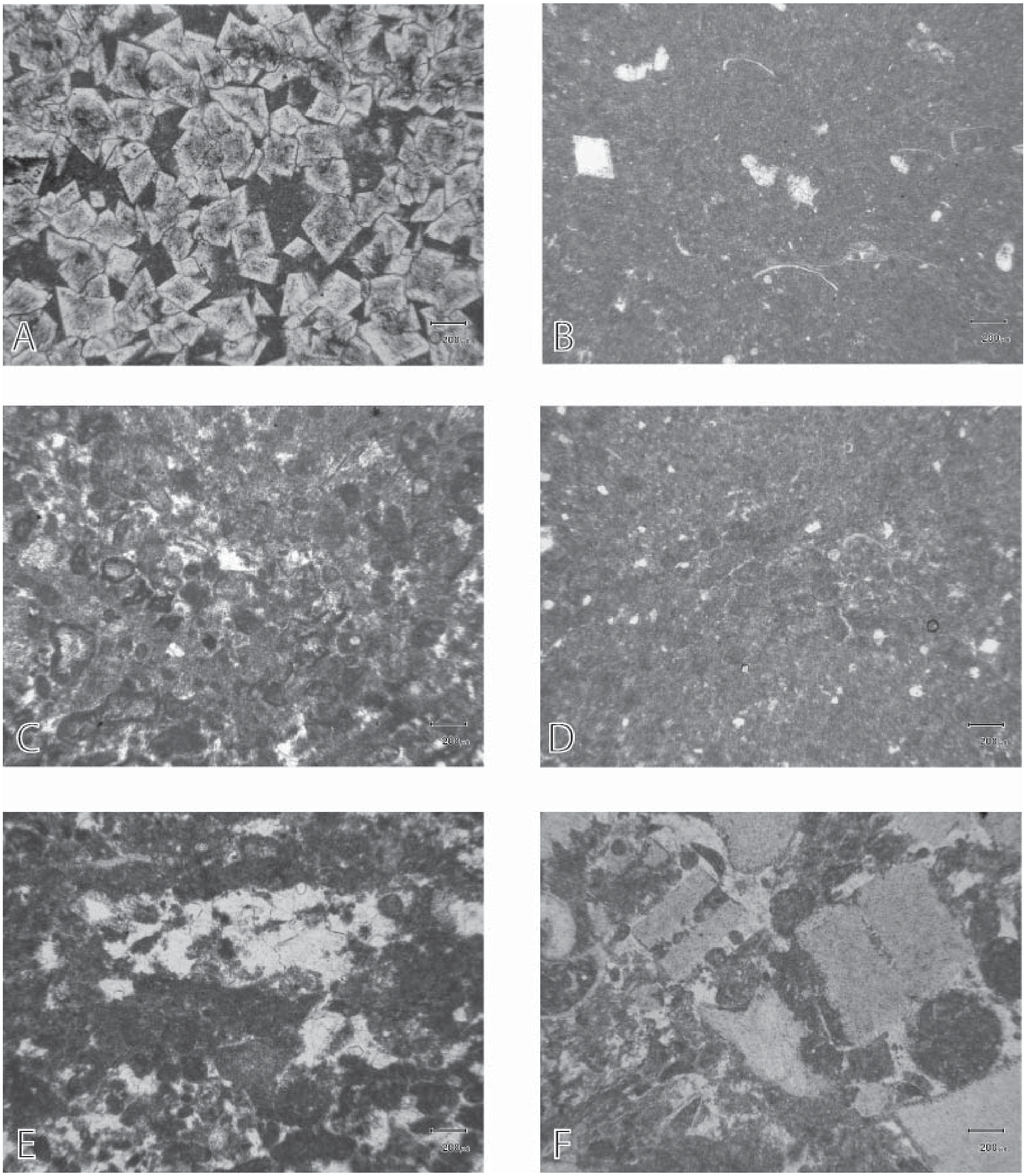


Figure 4. Thin section photomicrographs from Stop 3. A, dolomite rhombs in micrite or microcrystalline dolomite matrix (spl. SQ-1); B, dolomite rhombs and ostracodes scattered in micrite matrix (spl. SQ-2); C, clotted pelsparite fabric (spl. SQ-3); D, alternating micrite and pelmicrite laminae with quartz silt (spl. SQ-4), E, possible birdseye in pelsparite to pelmicrite fabric (spl. SQ-5); F, crinozoan biomicrite (spl. SQ-6). Scale bar in lower right corner of each image = 200µm.

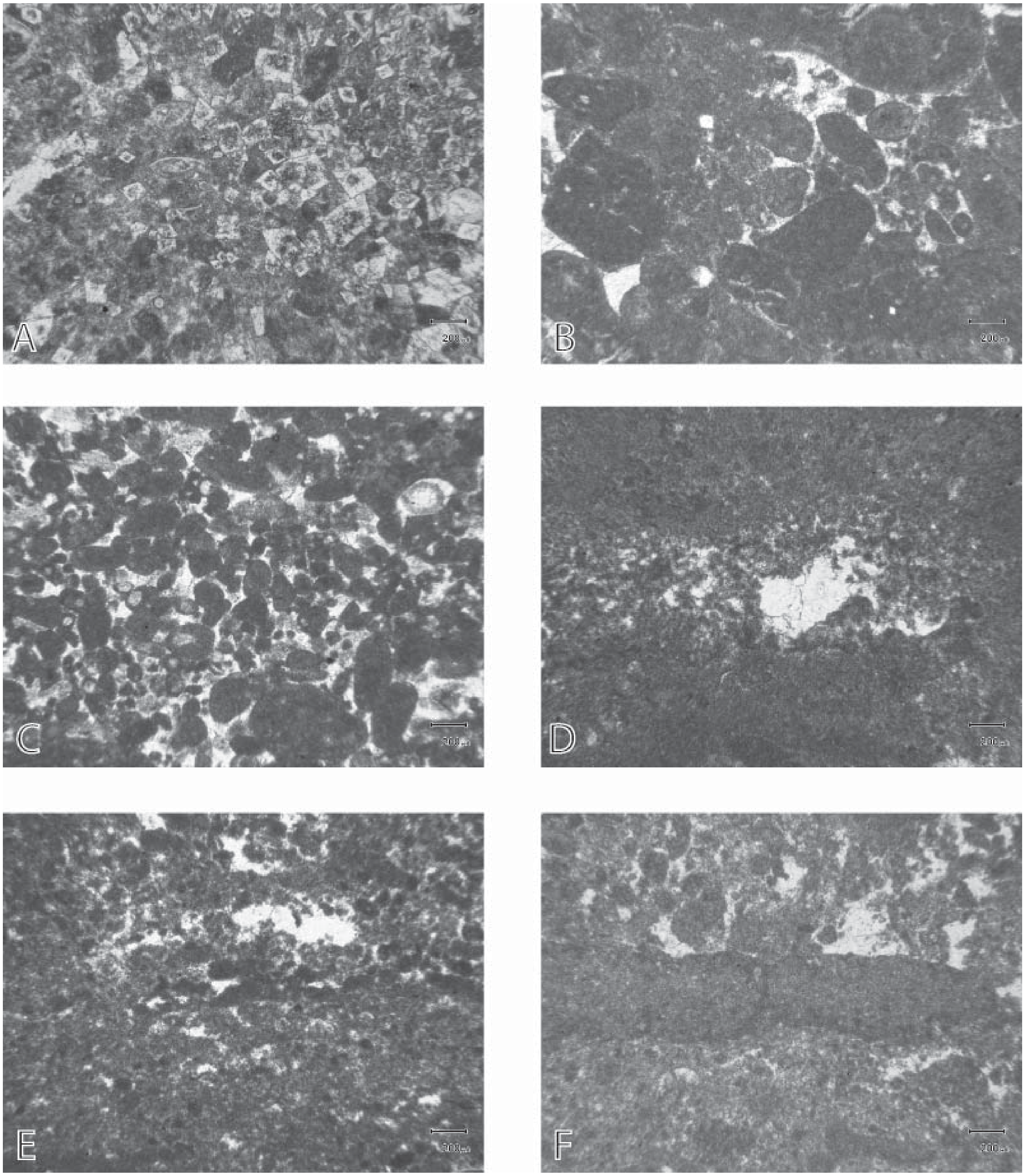


Figure 5. Thin section photomicrographs from Stop 3 (continued). A, dolomite rhombs in dolomitic pelmicrite matrix with scattered calcispheres (spl. SQ-7); B, intrasparite in which clasts are pelmicrite (spl. SQ-8); C, calcisphere-bearing pelsparite (spl. SQ-9); D, birdseye-bearing pelsparite lamina bracketed by pelmicrite laminae (spl. SQ-10), E, clotted pelsparite and pelmicrite (spl. SQ-11); F, micritic intraclast in palsparite to pelmicrite matrix (spl. SQ-12). Scale bar in lower right corner of each image = 200µm.

STOP 4 – MESSERLY QUARRY

Quarry operated by BMC, Inc. This locality is just south of County Road C55, approximately one mile west of Union Road and one mile east of the small town of Finchford (sec. 14, T90N, R14W; Black Hawk Co.).

FIELD DESCRIPTION

Messerly Quarry is a relatively new quarry in the Lithograph City Formation. The exposed section is quite similar to that in the abandoned Yokum Quarry, just one mile to the east. The Messerly Quarry section was first described by Walters et al. (2004). It was measured and described along the west and south walls of the pit.

The Lithograph City Formation at Messerly Quarry is nearly 50 feet thick and includes complete sections of the Osage Springs, Thunder Woman Shale and Idlewild members (Figs. 1, 4). The Osage Springs Member here is dominated by inner neritic, variably dolomitic limestone, including some features suggestive of peritidal origin such as possible tidal laminites, intraclasts and pisoids, but it does not include bedded dolomite as seen at its type section (**Stop 1**). The upper part of the Osage Springs Member is a spectacular stromatoporoid biostrome, up to 10 feet thick, in which small to very large, columnar to spherical stromatoporoids are encased in argillaceous limestone and calcareous shale matrix (Fig. 2). Along the west wall of the quarry the biostrome is overlain by two feet of limestone with densely packed branching stromatoporoids.

The Thunder Woman Shale is ~eight feet thick and consists of light tan, generally nonresistant shale. A slightly more indurated layer of calcareous shale occupies the middle two and one-half to three feet of the unit.

About 15 feet of the Idlewild Member are exposed locally, although the unit is truncated to the west so that it is only three or four feet thick along the west wall of the pit. In contrast to exposures farther north, the Idlewild at Messerly Quarry contains only a few, thin beds of lithographic to sublithographic limestone. Rather, it is dominated by coarser, bioclastic lithologies, with massive and branching stromatoporoids being most conspicuous. Branching stromatoporoids are especially abundant in two beds in the middle part of the unit termed informally "spaghetti stone" (Fig. 3). Quartz sand and silt are present in the upper part of the Idlewild at this site.

The Lithograph City Formation is overlain locally by a fairly thick deposit of Pleistocene till with oxidized and unoxidized horizons and ice-wedge casts. The Pleistocene section here is the subject of a separate discussion (see Walters, this guidebook).

PETROGRAPHIC DESCRIPTIONS

MQ-25 Biointrasparite to biointramicrite (Fig. 5F); small intraclasts in sparry calcite or micritic matrix; bioclasts include stromatoporoids, crinozoans, brachiopods and calcispheres; fine sand- and silt-sized quartz present.

MQ-24 Biomicrite; abraded stromatoporoids and brachiopods embedded in micritic matrix; other bioclasts include ostracodes, calcispheres and crinozoans; coarse sand- to silt-sized quartz present.

MQ-23 Biopelmicrite to biopeldismicrite, clotted in patches; bioclasts include stromatoporoids, calcispheres, crinozoans, brachiopods, ostracodes and umbellids; coarse sand- to silt-sized quartz present.

MQ-22 Intramicrite to intrasparite; small to large intraclasts embedded in micritic matrix or sparry calcite; bioclasts include calcispheres and ostracodes with subordinate brachiopods; coarse sand- to silt-sized quartz present.

MQ-21 Biopelmicrite (Fig. 5E); clotted fabric with some intraclasts and skeletal fragments including stromatoporoids, paleoberesellid algae and calcispheres; fine sand- and silt-sized quartz present.

MQ-19&20 Biomicrite; branching stromatoporoid boundstone with scattered, fine debris from brachiopods, ostracodes and calcispheres.

MQ-18 Biomicrite to biopelmicrite; branching stromatoporoid boundstone in part; other bioclasts include very abundant calcispheres, ostracodes, paleoberesellid algae and subordinate crinozoans.

MQ-17 Intrabiomicrite; faintly clotted fabric with possible birdseyes; bioclasts include calcispheres, paleoberesellid algae and rare gastropods.

MQ-16 Intraclast-bearing, pelletal biomicrite; bioclasts include branching stromatoporoids with accessory ostracodes, calcispheres and paleoberesellid algae.

MQ-15 Biopelmicrite; fabric consists of very fine pellets with scattered fragments of stromatoporoids, brachiopods, ostracodes and indeterminate skeletal silt.

MQ-14 Dolomitic biomicrite; bioclasts include very abundant calcispheres with subordinate ostracodes.

MQ-13 Dolomitic biomicrite; bioclasts are dominated by branching stromatoporoids with accessory brachiopods; dolomitic micrite matrix highly ferruginous with apparent pseudomorphs after pyrite.

MQ-12 Not examined.

MQ-11 Dolomitic biomicrite (Fig. 5D); branching stromatoporoids encased in dolomitic micrite matrix; accessory bioclasts include ostracodes, calcispheres and paleoberesellid algae with subordinate crinozoans and brachiopods.

MQ-10 Not examined.

MQ-9 Micrite; faint clotted fabric suggests pelletal origin, but discrete pellets not evident; ostracodes rare; quartz silt rare.

MQ-8 Dolomitic biomicrite (Fig. 5C); bioclasts include fragmentary paleoberesellid algae, umbellids, brachiopods, ostracodes and indeterminate skeletal silt.

MQ-7 Biomicrite, very fine-grained; bioclasts include indeterminate skeletal silt, crinozoans and ostracodes; matrix appears finely pelletal in patches; quartz silt present.

MQ-6 Biomicrite (Fig. 5B); abundant bioclasts include brachiopods, crinozoans and paleoberesellid algae with subordinate ostracodes and branching stromatoporoids; quartz silt common.

MQ-5 Biopelmicrite to biopelsparite; bioclasts include very abundant disarticulated ostracodes, paleoberesellid algae, calcispheres and calcite-filled skeletal molds.

MQ-4 Alternating laminae of biomicrite, biopelmicrite and minor biopelsparite (Fig. 5A); bioclasts mainly calcispheres and ostracodes.

MQ-3 Alternating laminae of dolomitic micrite and sparsely dolomitic biopelmicrite to biopelsparite; bioclasts include ostracodes and calcispheres.

MQ-2 Dolomitic, intraclast-bearing biopelsparite to biopelmicrite; bioclasts include disarticulated ostracodes and rare calcispheres.

MQ-1 Biomicrite; thinly laminated; bioclasts include disarticulated, thin-shelled ostracodes; quartz silt present.

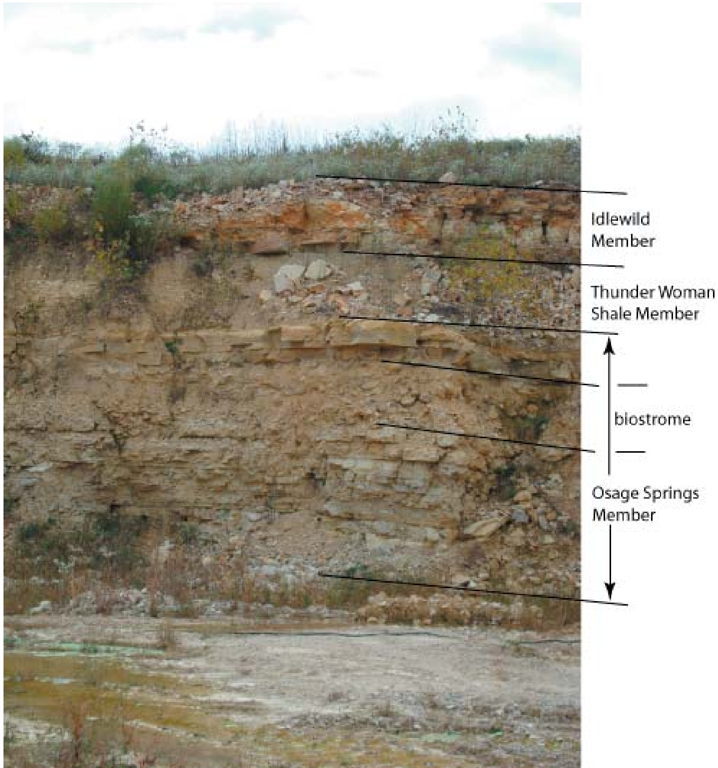
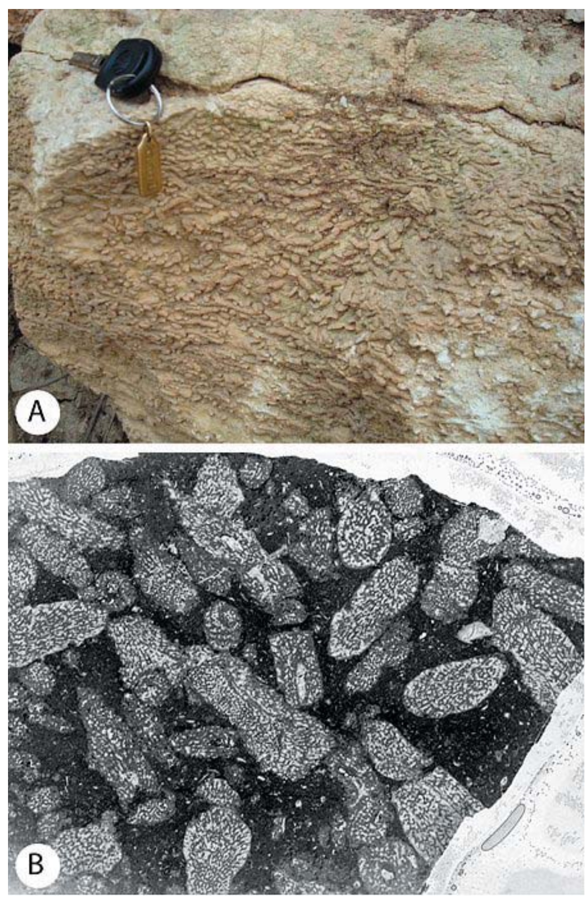


Figure 1. (Left) Lithograph City Formation exposed along west side of Messerly Quarry. Idlewild Member is anomalously thin because of local truncation; it reaches ~15 feet along the south side of the pit.

Figure 2. (Lower left) Stromatoporoid biostrome in upper part of Osage Springs Member at Messerly Quarry.

Figure 3. (Below) A, Densely packed branching stromatoporoids – the so-called "spaghetti stone" – in the middle part of the Idlewild Member, Messerly Quarry; B, branching stromatoporoid boundstone as seen in thin section (spl. MQ-19; magnification ~ ×2).



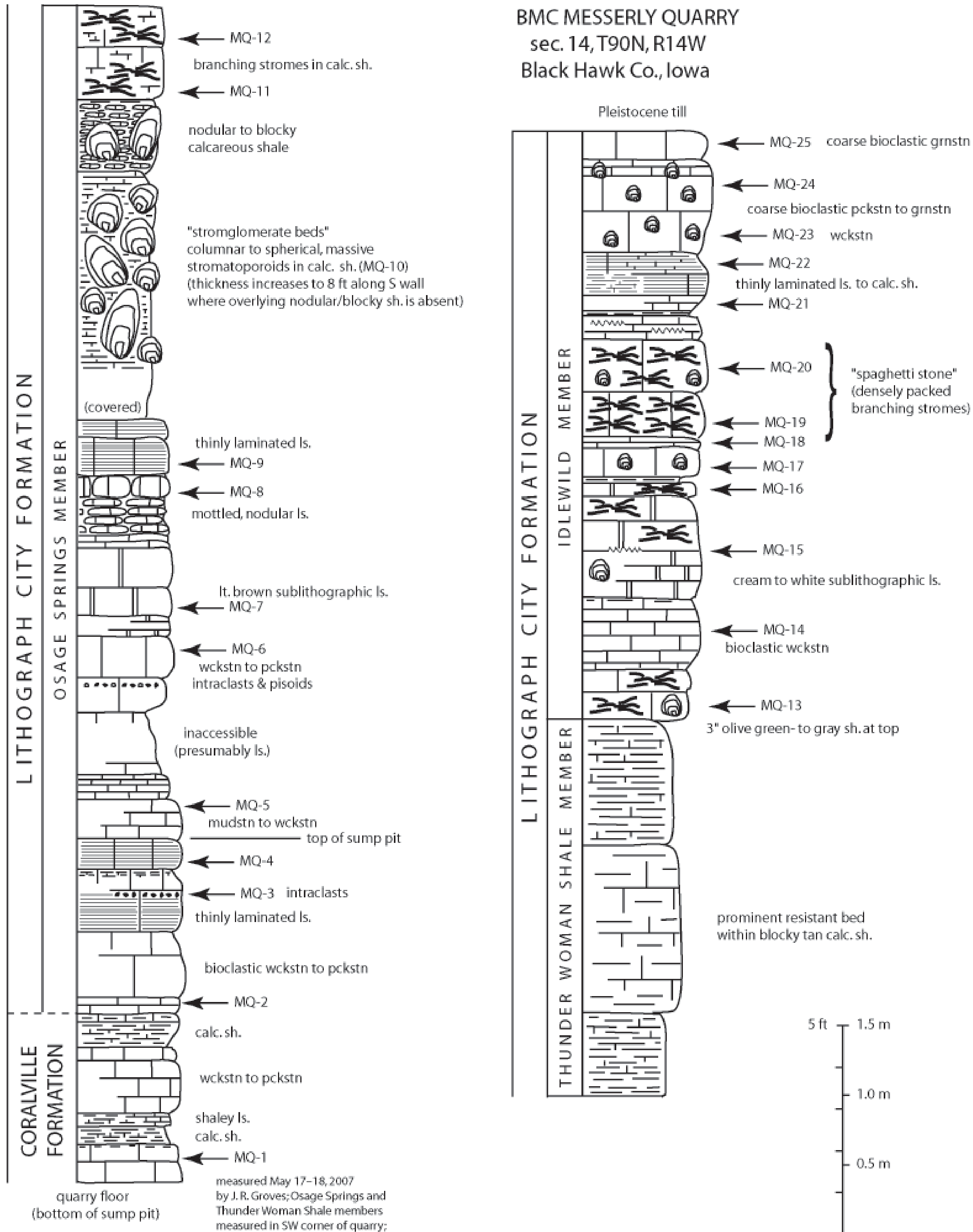


Figure 4. Columnar stratigraphic section of the Lithograph City Formation at Messerly Quarry (Stop 4).

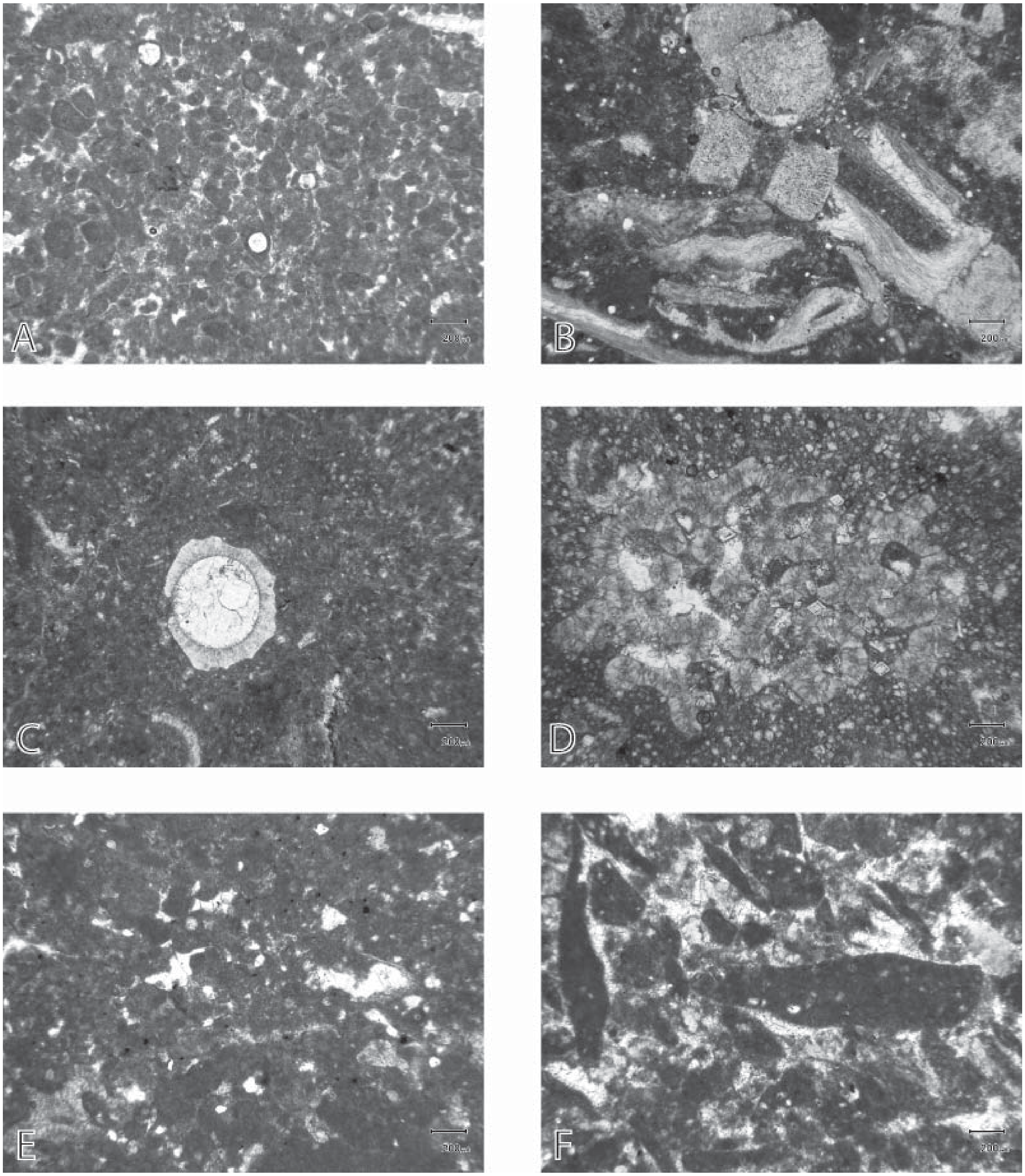


Figure 5. Thin section photomicrographs from Stop 4. A, biopelsparite lamina with scattered calcispheres (spl. MQ-4); B, biomicrite with scattered quartz silt (spl. MQ-6); C, dolomitic biomicrite with large umbellid in center of image (spl. MQ-8); D, branching stromatoporoid embedded in dolomitic micrite matrix (spl. MQ-11), E, clotted, intraclast-bearing biopelmicrite with scattered quartz sand and silt (spl. MQ-21); F, micritic, quartz-silty intraclasts in sparry calcite cement (spl. MQ-25). Scale bar in lower right corner of each image = 200µm.

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Walters, J. C., J. R. Groves, and S. Lundy (with contributions by B. J. Bunker and B. J. Witzke). 2004. From ocean to ice: an examination of the Devonian bedrock and overlying Pleistocene sediments at Messerly and Morgan quarries, Black Hawk County, Iowa. Geological Society of Iowa Guidebook 75, 41 p.

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FIELD TRIP STOPS – SUNDAY

STOP 5 – FERTILE QUARRY (Basic Materials Corporation)

Section 36, T 98 N, R 22 W
(GPS for center north pit high wall = 43° 15' 56.44" N, 93° 23'46.13" W)
Worth County, Iowa

Unusual Facies Relationships Within the Middle Frasnian Shell Rock Formation Recording Reefal Carbonate Bank Aggradation and Progradation & Offbank Facies Onlap

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Upper Devonian strata exposed in the Fertile Quarry include the upper part of Idlewild Member of the Lithograph City Formation, and the Shell Rock Formation (Figs. 1 and 2). Exposures in the north pit consist of a nearly complete section of dolomites representing most of the Shell Rock Formation as it is developed in the western outcrop area in Worth County. The lower Shell Rock Formation exposed in the high wall of the north pit of the Fertile Quarry displays spectacular lateral facies variations recording initiation and evolution of a stromatoporoid patch reef or bank buildup (Figs. 1 and 2, Fertile Member), that displays increasing depositional relief and lateral bank progradation of sinusoidal clinoform wedges of dolomitized bank carbonates (Fig. 1, labeled A to F) from east to west with the confines of the north pit. The patch reef margin clinoforms prograded westward into what was presumably a deeper off-bank channel or lagoon (Fig. 1) in this part of the Shell Rock platform during the sea level high-stand phase of Iowa Devonian Transgressive-Regressive (T-R) cycle 6A of Bunker and Witzke (1992) and Day et al. (2008, fig. 3). Rhythmically bedded dolomitized skeletal mudstones and shales of the Rock Grove Member (Figs. 1 to 3) onlap, and eventually toplap the bank margin as seen in the central part of the high wall exposure (Figs. 1 and 4). Most of the Shell Rock along the central and western high wall exposure consist of Nora Member facies (Fig. 3). The dolomitized stromatoporoids patch-reef and bank facies of the Fertile Member (see discussion in Day et al., 2008) are equivalents of Mason City Member limstones in the type area of the Shell Rock to the southeast in northwestern Floyd County (see Stop 6). Within the quarry property the Fertile Member ranges from two to over ten meters (patch reef interior and margin) in thickness as seen in the north pit at Stop 5.

Recognition of the three members of the Shell Rock outside of its type area has been problematic in the western outcrop belt because of the facies change from predominately limestone-dominated platform carbonates to dolomites, with increasing proportions of shallow platform peritidal carbonates, especially in the upper part of the Shell Rock (Fig. 2). Significant dolomitization of biostromal limestones in the lower Shell Rock is observed in the upper part of the Shell Rock at the Holnam Quarry in central Cerro Gordo County (Day et al., 2008, Fig. 10; Witzke, 1998, Fig. 2), and the entire Shell Rock is dolomitized at Fertile Quarry (Fig. 2). In the Holnam (Witzke, 1998, Fig.2) and Fertile (Figs. 1 to 4) quarries the lower part of the Shell Rock features biostromal and stromatoporoid patch reef facies (largely dolomitized). Lateral variation between stratigraphically-equivalent limestone and dolomite facies occurs over short distances in the Mason City Holnam Quarry (Witzke, 1998) as well as the Fertile Quarry (Figs. 1, 3 and 4). The dolomites of the aggrading prograding carbonate bank/patch reef clinoform beds A to F of Fertile

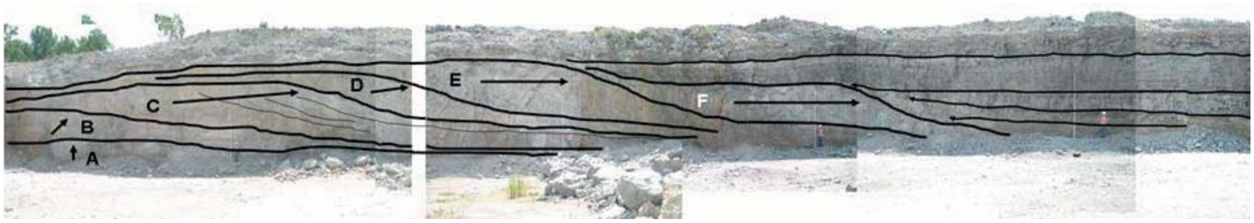

Figure 1. Photo mosaic of exposures of the Shell Rock Formation along southern high-wall of the inactive north quarry pit at the Basic Materials Corporations' Fertile Quarry. Heavy dark lines outline major facies packages on the highwall exposure. Carbonate bank facies of the Fertile Member (equivalents of the type Mason City Member) aggrade (packages labeled A and B) then clinoform wedges (packages labeled C to F) prograde to the west. Fertile Member clinoform wedges of dolomitized stromatoporoid-brachiopod floatstone bank facies are onlapped from west to east by interbedded thin-bedded dolomitized skeletal mudstones and thin shales of the Rock Grove Member. T. Marshall (Iowa Geological and Water Survey) is shown holding 5 meter stadia rod at base of the highwall in photographs used for the mosaic.

Member exposed on the eastern side of the north pit at Stop 5 (Figs. 1 and 3) consist of 10 to 12 meters of thick dolomites featuring large open and spar-lined solution vugs (presumably stromatoporoids and colonial corals). They also feature recognizable skeletal molds of stromatoporoids, with brachiopods *(Tenticospirifer shellrockensis, Platyrachella ulsterensis, Schizophoria floydensis),* corals, and echinoderms (Fig. 1, prograding clinoforms A to F; Fig. 2, units 2 to 6).

Above and laterally adjacent to the thick dolomites of the Fertile Member, original carbonate depositional textures and fabrics are well preserved and permit recognition of the Rock Grove Member (Fig. 2). The Rock Grove Member dolomitic facies (Figs. 3 and 4) are similar to lower Rock Grove limestones in the type area (see Stop 6, Fig. 2) and consist of thin to medium beds of intensely burrowed skeletal mudstones (now dolomites) interbedded thin shales (Figs. 1 to 4). Brachiopods observed along bedding surfaces and shale partings that include *Strophodonta scottensis, Floweria* n. sp., *Pseudoatrypa witzkei, and Spinatrypa bunkeri.* Conularids are also noted on some bedding surfaces of dolomites of the Rock Grove on block piles in the north pit. Rhythmically bedded shales and argillaceous skeletal dolomites of the Rock Grove Member are observed to onlap, and eventually toplap, prograding clinoform wedges of dolomitized patch reef dolomites in the north pit exposure (Figs. 1, 3 and 4).

The Nora Member can be recognized in the Fertile Quarry (Fig. 2, units 14 to 19) and is exposed on the upper bench above the north pit at Stop 5. Lower and upper biostromal intervals (Fig. 2, units 14 and 18) are well developed in the Fertile Quarry exposures and cores, although they are usually dominated by branching stromatoporoids *(Amphipora)* with solitary rugose, branching tabulate corals (thamnoporids). The lower and upper biostromes of the Nora are also separated by lagoonal shales and dolomitic mudstones as seen in the type area to the southeast in Floyd County (see Stop 6).

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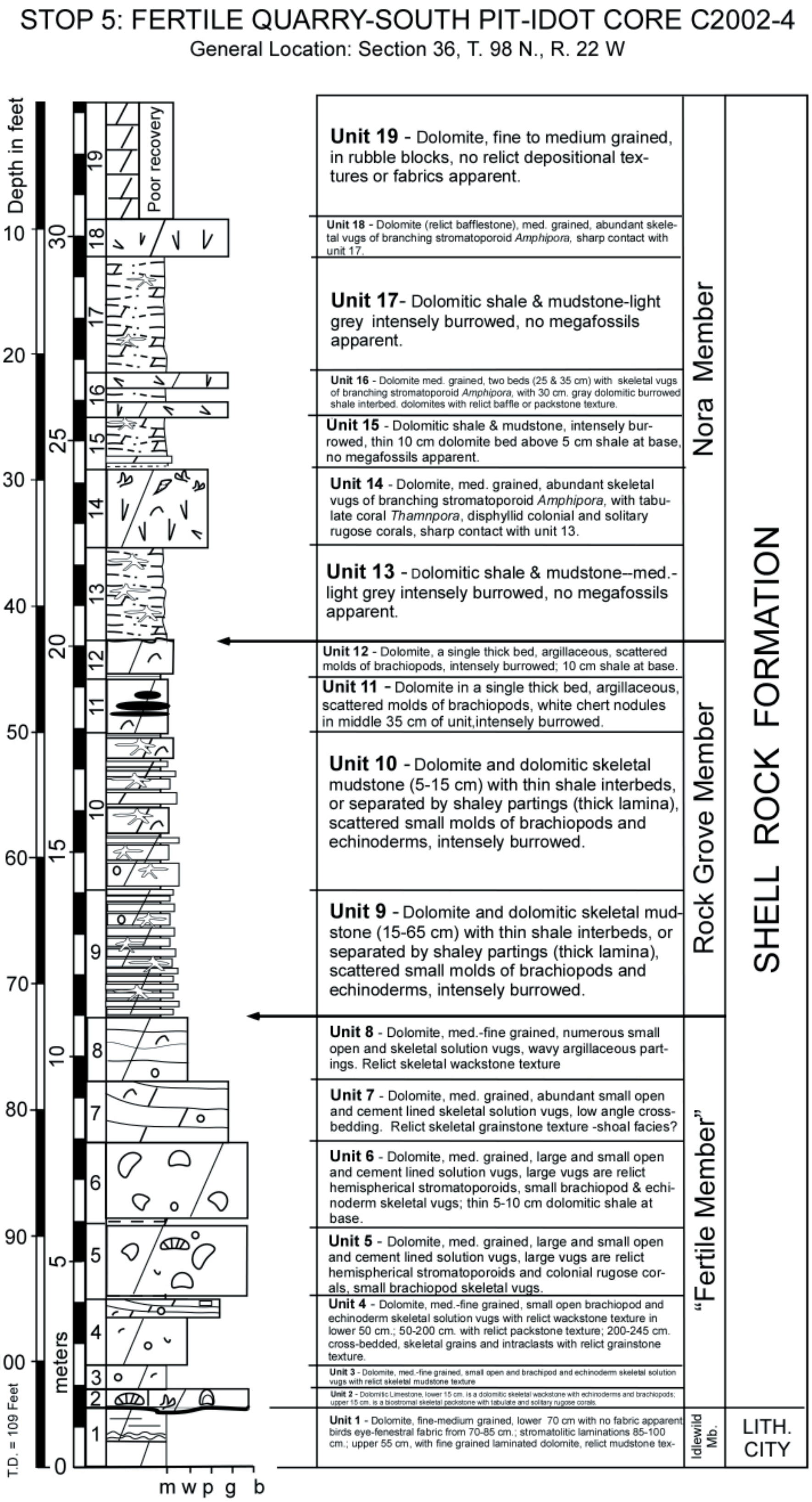

Figure 2. Stratigraphic section of the Upper Devonian Cedar Valley Group strata in the Basic Materials Corporation C2002-4 core drilled in the active south pit area of the Fertile Quarry. Dolomitized tidal flat facies (unit 1) of the Idlewild Member of the Lithograph City Formation underlie a thin biostromal dolomitic limestone (unit 2) of the basal Fertile Member (new) of the Shell Rock (units 2 to 8). The Fertile Member is defined to include the dolomites (exceeding 10 meters in thickness in the North Pit) representing dolomitized carbonate shelf and carbonate bank-patch reef stomatoporoid-rich skeletal floatstones.

Figure 3. Photograph of the Rock Grove Member facies of the Shell Rock along the eastern side of the high wall exposure of the north pit. The white line is the contact of the Fertile Member dolomites, and thin dolomites and shales of the overlying Rock Grove Member. T. Marshall with five meter stadia rod for scale.

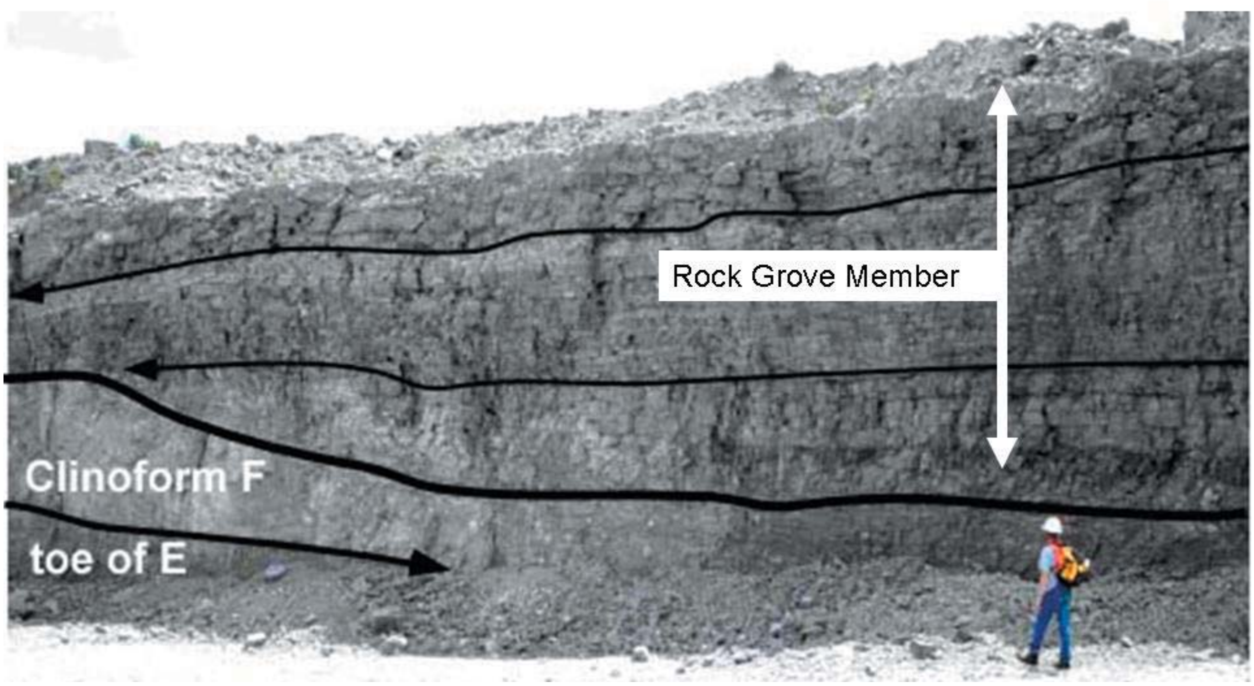

Figure 4. Photograph of the central part of the south highwall face of the north pit in the Fertile Quarry showing the toe of the prograding clinoform wedge E, and most of clinoform F, onlapped by rhythmically bedded dolomites and shales of the Rock Grove Member. T. Marshall of the Iowa Geological and Water Survey is shown for scale.

STOP 6. WILLIAMS QUARRY (Green Limestone Co.)

Upper Devonian (Middle Frasnian) Stratigraphy of the Shell Rock Formation in its type area

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Exposures of Upper Devonian Cedar Valley Group strata in the Greene Limestone Company's Williams Quarry (Figs. 1 and 2) include mud-flat carbonates of the Early Frasnian age upper Idlewild Member of the Lithograph City Formation (Figs. 2 and 3) and a complete section of the Middle Frasnian Shell Rock Formation (Figs. 1 to 5). This is the most complete exposure of the Shell Rock Formation at any single locality in the type area of the Shell Rock in northwestern Floyd County. Consequently it serves as the principle surface reference section for the Shell Rock in the area south of Nora Springs because all three members are fully exposed and accessible for study. The key subsurface reference section is in the nearby Floyd-Mitchell # 4 core, where a closely similar section is known (Witzke, 1998, Figs. 1; Day et al., 2008, Figs. 4 and 9). Prior to and during the 1990s the Williams Quarry was much smaller, and the highwall exposures described or illustrated in older studies by Koch (1970, locality 7), Witzke (1998, Fig. 1), Sorauf (1998, Fig. 6) were positioned in what is now the west side of the quarry pit, that has now been extended over one hundred meters to the east.

Previously, exposures of the upper lithograph City Formation were not known in the Williams Quarry. Expansion of the east pit of the quarry in the late 1990s has exposed the upper 2.0 meters of the Idlewild Member of the Lithograph City Formation (Figs. 2 and 3). A small anticlinal structure is present within the confines of the quarry property and the flank is breached in the by quarry operations and the limb dips eastward up to 20 degrees (Fig. 4). Stripping of the Rock Grove shales on the upper bench has exposed the upper four meters of the Nora Member above the lower Nora biostrome. The upper part of the Nora exposed consists of dolomitic burrowed shales with numerous platy stromatoporoids (unit 24, Figs. 2 and 5) and the upper stromatoproid biostrome (unit 25, Figs. 2 and 5). The both of the Nora biostromes positioned at the bottom and top of the Member are well exposed in the bluffs along the banks of the Shell Rock River to the north and northwest, although these are difficult to access because of the steep slopes or sheer faces of those outcrops (see localities and discussions in Koch, 1970, and Sorauf, 1998).

LITHOGRAPH CITY FORMATION

In August of 2008 J. Day and T. Marshall (Iowa Geological and Water Survey) observed and described up to 2.0 meters of limestones and a thin shale of the upper Idlewild Member below the discon-formable contact of the Lithograph City and Shell Rock formations (Figs. 2 and 3). There is a complex bored hardground that developed during a prolonged period of sediment starvation after the initial Shell Rock transgression over the erosional surface on the upper Idlewild, with 10-15 cm of relief on the surface below the basal Mason City biostromal skeletal carbonates of unit 6 (Figs. 2 and 3).

Idlewild Member

Units 1 to 5 of the Williams Quarry section shown in Figure 2 are included in the Idlewild Member and are interpreted to represent intertidal mudflat facies. These consist of a thin light gray dolomitic shale in the quarry sump (unit 1), overlain by laminated and fenestral (birds eye structure) mudstones of units 3 to 5 above a thin covered interval (Fig. 2, unit 2). Two miles

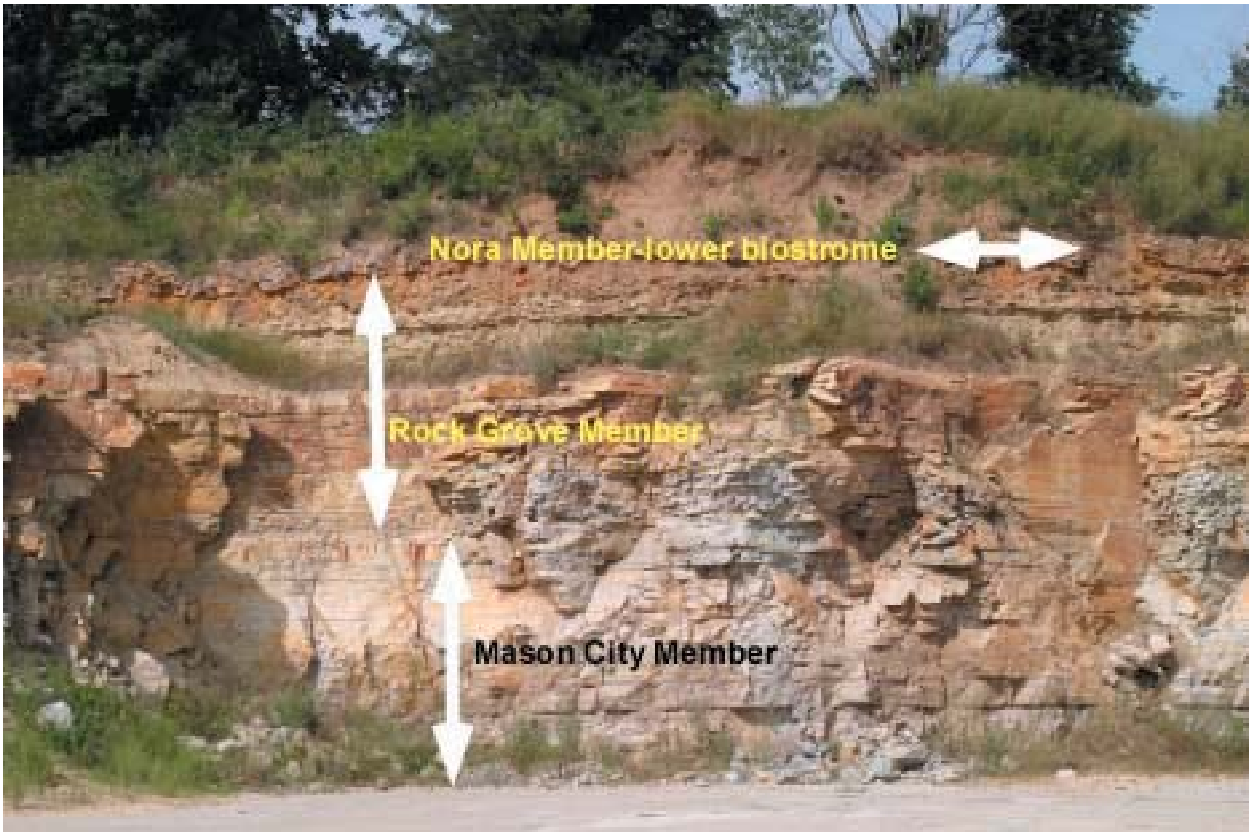

Figure 1. Photograph of the northern high-wall of the active pit of the Williams Quarry consisting of most of the three members of the Middle Frasnian (Upper Devonian) Shell Rock Formation. The upper 3 meters of the Nora are not exposed along this face, but can be seen on top of the working bench on the southern wall of the active pit.

to north at the Nora Spring South section on the south bank of the Shell Rock River subtidal skeletal limestones of the upper Idlewild are in contact with the Mason City across the disconformity (Day et al., 2008, Figs. 4 and 7, Belanski Locality 10), indicating erosional relief measured in meters regionally on the pre-Shell Rock exposure surface on the upper Idlewild Member.

SHELL ROCK FORMATION

A complete section of the Shell Rock Formation is featured in the Williams Quarry (Fig. 2, units 6 to 25) illustrating typical lithologies of all three members (Mason City, Rock Grove, and Nora). The Mason City member displays the most lithologic variability in the Shell Rocks' type area in the northern part of Floyd County in terms of the thickness, number and position of biostromal intervals. In the type Mason City Member on the east bank of the Shell Rock just north of Nora Springs, Iowa (Koch, 1970, section 1, p. 62-63; Sorauf, 1998, text-Fig. 2).

Mason City Member

At the Williams Quarry (Fig. 2, units 6 to 15) the Mason City is comprised of a 100 cm thick stromatoproid-coral biostromal skeletal packstone – floatstone (Fig. 2, unit 6) capped by a prominent sculpted hardground. Koch and Strimple (1968) described the echinoderm fauna attached to the hardground (Fig. 2, top of unit 6),

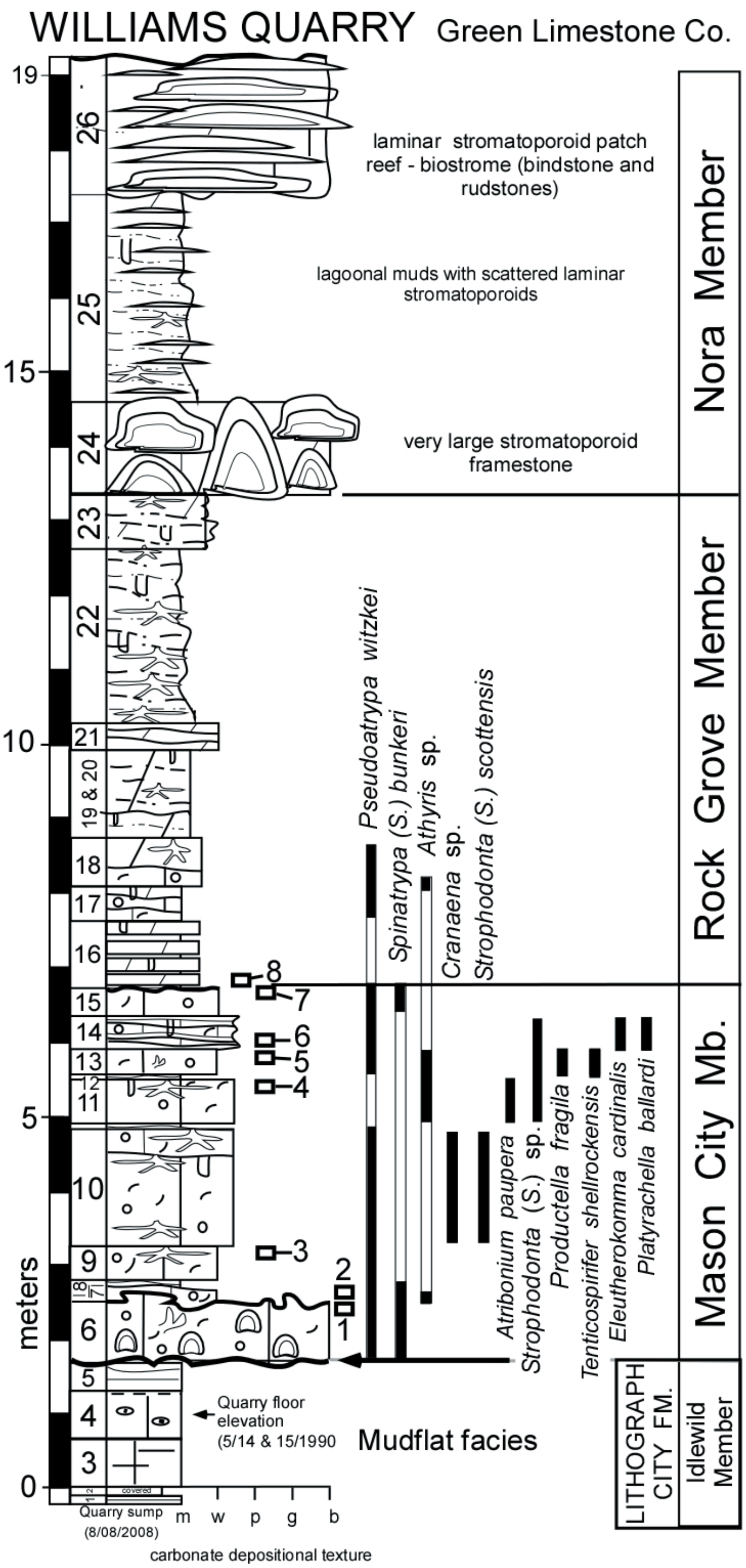

Figure 2. Composite section of the Upper Devonian strata at the Williams Quarry. The upper 2 meters of the Idlewild Member of the Lithograph City Formation were exposed by eastward quarry expansion along the south high-wall as of 8/2008. The upper 3 meters of the Nora Member were exposed by bench stripping in 2004-2005. Occurrences of Shell Rock Formation brachiopod taxa of the *Tenticospirifer shellrockensis* Zone (Day, 1989, 1996) are shown left of section column. Conodont sample positions are shown by numbered black rectangles. This is locality 7 of Koch (1970) and the location of the famous hardground (top of unit 6) with attached rhombiferan and edrioasteroid echinoderms described by Koch and Strimple (1968).

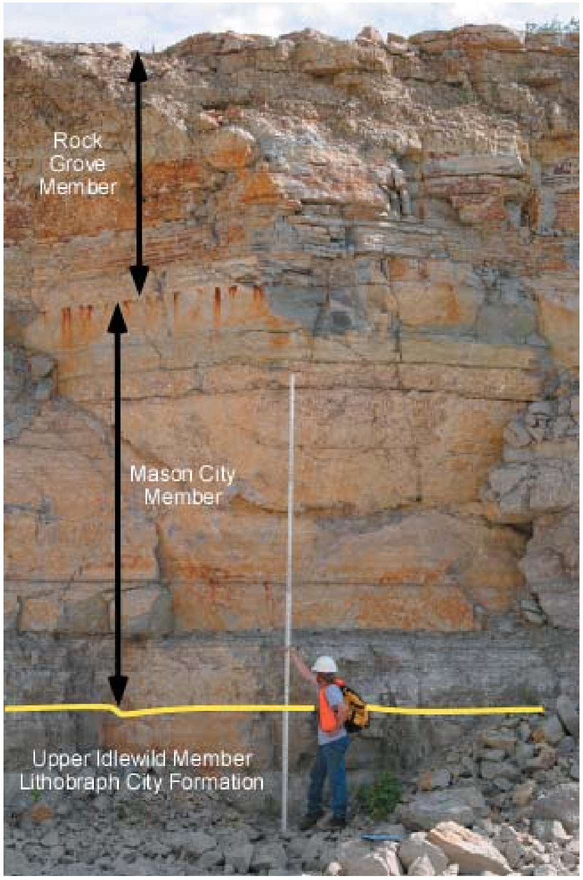

Figure 3. Photograph of the western high wall of the active pit at the Williams Quarry showing the Mason City and lower Rock Grove members of the Shell Rock, and its contact with the underlying mudflat facies of the upper Idlewild Member of the Lithograph City Formation. Exposure includes the lower 10 meters of the stratigraphic section in Figure 2 (units 3 to 21). Iowa Geological and Water Survey geologist T. Marshall is with 5 meter stadia rod for scale.

dominated by the edrioasteroid *Agelacrinites hanoveri* with intact rhombiferan cystoids *Adecetocystites williamsi* and *Strobilocystites calvini.* Sorauf (1998) The thickness of the lower biostromal unit of the Mason City varies significantly in the type area, from 1.8 meters at its type section (Koch, 1970, section 1, unit 4), 2.2 meters thick at the nearby Nora Springs South section of Day et al.(2008, Figs. 4 and 7). The remainder of the Mason City consists of bioturbated fossiliferous skeletal mudstones and wackestones. Sorauf (1998). The Mason City features a diverse and abundant invertebrate (with skeletal grains dominated by echinoderms and brachiopods, with mollusks, solitary and colonial rugose corals, and scattered spherical of hemispherical stromatoporoids. See discussion of the Mason City Member stromatoporoids in Stock (2008) and Day et al. (2008), corals by Sorauf (1998). The distribution of brachiopods in the lower Shell Rock (from Day's 1990 collections) is shown in Figure 2.

Rock Grove Member

In the Williams Quarry (Fig. 2, units 16-23), the Rock Grove is 6.7 meters thick, and is 6.86 meters at it type section (Koch, 1970, section 2, p. 64-65) on the south side of the town of Nora Springs just north of Stop 6. The contact with the Mason City is a pronounced hard ground surface interpreted to represent a second significant marine flooding surface of Iowa Devonian T-R cycle 6B (Day et al., 2008, Fig. 3). The lower Rock Grove (Figs. 2, 3, and 4) is carbonate-dominated consisting of a lower series of thin argillaceous dolomitic skeletal mudstones interbedded with thin shales (Fig. 2, unit 16), similar to the thicker succession of similar rhythmically bedded off-bank Rock Grove beds seen at the Fertile Quarry at Stop 5). These are overlain by thicker beds of burrowed skeletal mudstones (Fig. 2, units 16 to 21). The upper Rock Grove consists of burrowed dolomitic shales and mudstones, capped by thin argillaceous dolomites (Fig. 22 and 23) that are widespread in the Shell Rock outcrop area in Floyd and Cerro Gordo counties, as well as in Worth County (see Day and Witzke, 2008, Stop 5, Fig. 2).

The lower carbonates of the Rock Grove are locally very fossiliferous and contains a diverse middle Frasnian age brachiopod fauna similar to that of the Mason City Member, (Day, 1989, 1996; Day et al., 2008) and sparse stromatoporoids (see Stock, 2008), and coral fauna (Sorauf, 1998). Koch (1970, section 1, unit 11) lists the occurrence of *Platyrachella ulsterensis* and *Schizo-*

phoria floydensis in the upper dolomites in the upper Rock Grove (Fig. 2, unit 23, Figs. 1 and 3).

Nora Member

The Williams Quarry features a complete exposure of the Nora Member (Fig. 2, units 24 to 26) with both the lower and upper stromatoporoid biostromes, and intervening skeletal dolomitic lagoonal shales (Figs. 2 and 5), typical of the Nora in the type area of the Shell Rock (see type and reference sections of the Nora Member in Koch, 1970, sections 3 and 4, p. 66-67). Both of the biostromes (Figs. 1-5) feature a diverse stromatoporoid fauna described in papers by Stock (2008). Stock (2008, and older studies) has described this fauna, and lists the following taxa from the Nora: *Anostylostroma*? sp., *Actinostroma expansum, Clathrocoilona* sp., *Stictostroma* sp. *Trupetostroma* sp., *Hermatostroma iowense*, *Hermatoporella* cf. *H. pycnostylota, Arctostroma* sp., *Stachyodes*? sp., *S.*? *conferta*, and *Amphipora* sp. He describes extremely large (30 meters in length and as thick as unit 24 in Fig. 2) specimens of *A. expansum* as well as *H. iowense* from the lower biostrome well exposed along the access road to the upper bench of the quarry. The shales of unit 25 and upper biostrome (Fig. 2, unit 26) is well exposed along strip bench above the main quarry pit (Fig. 5).

WILLIAMS QUARRY SECTION DESCRIPTION

The stratigraphic section at Williams Quarry (Figures 1 to 5) is a composite of three sections measured and described in 1990, and in 2008 after major expansion of the quarry. units 1-5 (Fig. 1) of the Idlewild and basal Mason City members were described on the south face of the south high-wall in the active pit on 8-8-08 by J. Day and T. Marshall (Iowa Geological and Water Survey); units 6 to 22 (Fig. 1) was described by J. Day in 1990 on the east high-wall face of what is now the inactive northeast sector of quarry in E 1/2, NW, SW, Section 28; units 23-27 were described by J. Day in 2008 on upper bench in SE, NW, SW Section 28, 96N, 18W, Floyd County, IA. Units 1 to 16 see Koch (1970, section 7) and Witzke (1998, fig. 1).

Quarry Floor

A bladed surface in eastern pit below highwall on August 8, 2008, exposed a thin shale/mudstone of the upper Idlewild Member of the Lithograph City Formation.

LITHOGRAPH CITY FORMATION
Idlewild Member

Unit 1 (-0.20- to -0.1 m): Mudstone-light-medium grey, calcareous, silty mudstone.

Unit 2 (-0.1-0.0 m): Covered Interval.

Unit 3 (0.0-0.6 m): Laminated Mudstone-laminated micrite, with shale parting at top of unit.

Unit 4 (0.6-1.3 m): Fenestral Mudstone-laminated to thin-bedded micrite, with irregular spar-filled fenestrae (bird's eye structure), with 2 cm shale at top of unit.

Unit 5 (1.3-1.7 m): Mudstone-laminated micrite, with disconformity capping unit.

SHELL ROCK FORMATION
Mason City Member

The basal contact with the Lithograph City Formation is a disconformity with low erosional relief in the quarry exposures.

Unit 6 (1.7-2.1 to 2.4 m): Skeletal Mudstone-Floatstone-varies from 40 to 70 cm in thickness within the quarry property, with scattered hemispherical stromatoporoids, brachiopods (*Pseudoatrypa witzkei*), echinoderms, gastropods, intensely burrowed, with complex sculpted phosphatized hardground surface with up to 15 cm of local relief, local pyrite patches coating hardground, with attached rhombiferan (*Adece-*

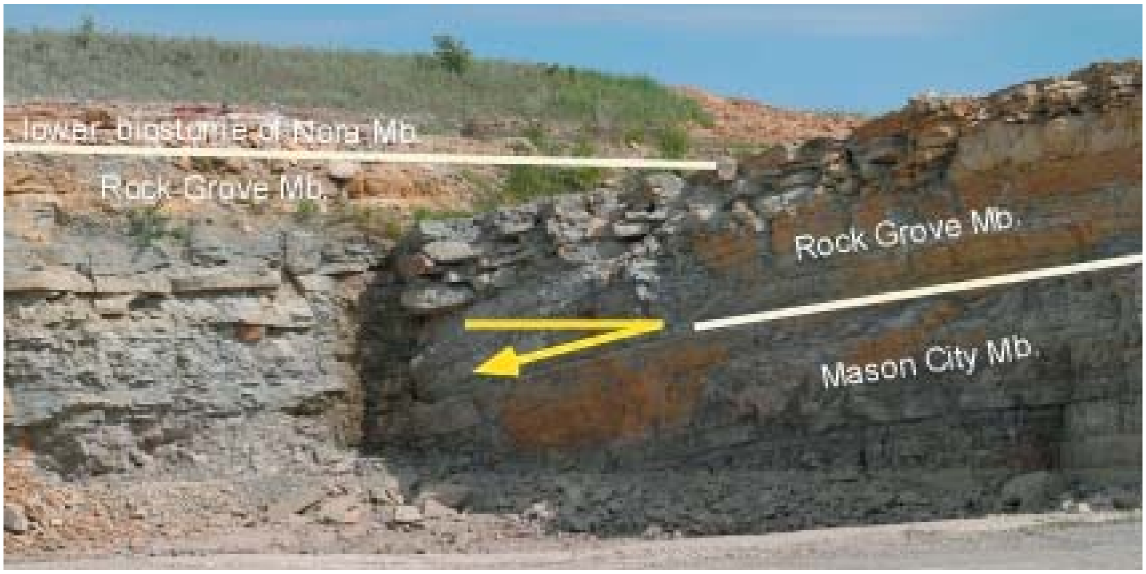

Figure 4. Photograph of the southwestern corner of the active pit at the Williams Quarry showing the Mason City, Rock Grove, and lower biostrome of the Nora Member of the Shell Rock Formation. The breached anticline in the quarry property is evident from dip angles up to 20 degrees to the west, with more subdued low angle dips to the west.

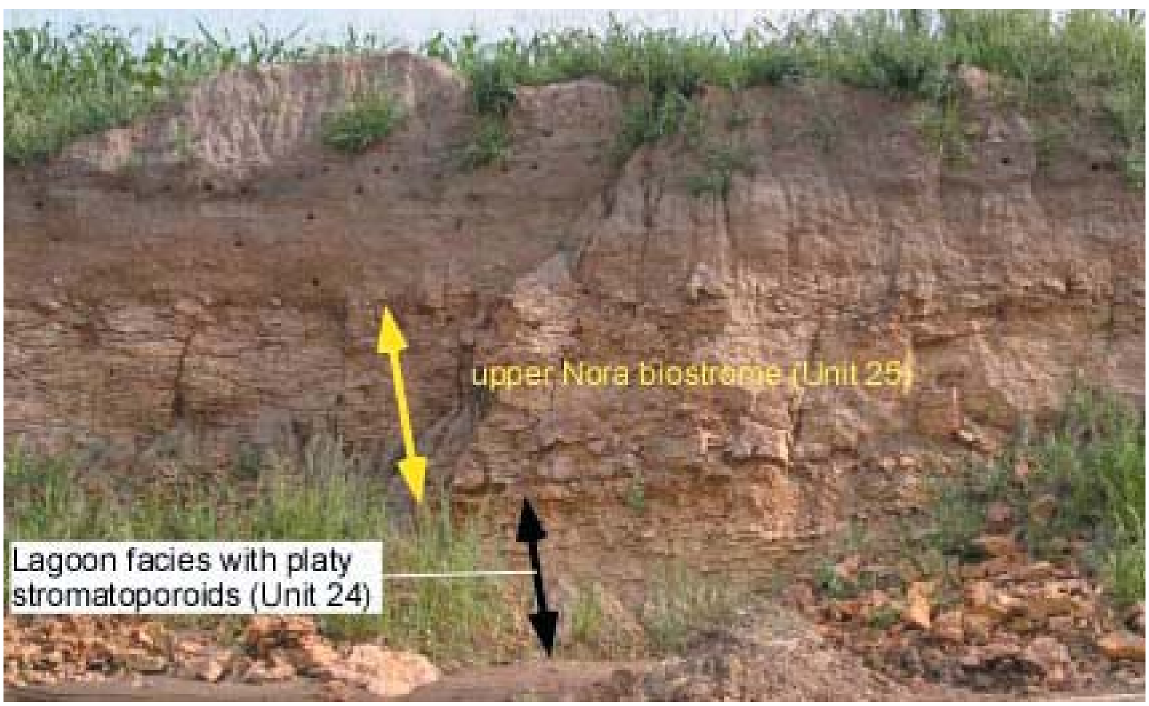

Figure 5. Photograph of the upper Nora Member (Fig. 2, units 24 and 25) recently exposed along the south high wall on the upper strip bench at the Williams Quarry. In older descriptions of the Williams Quarry section by Koch (1970, Section 7, p. 70-71), and Sorauf (1998, text-figs. 1, 6, appendix, locality 16) the middle dolomitic lagoonal shales (Fig. 2, unit 24) and upper biostrome (unit 25) were not exposed in the pre-2000 high wall sections.

tocystites williamsi Koch & Strimple, 1968; and *Strobilocystites calvini* White, 1876) and the edrioasteroid *Agelacrinites hanoveri* (see Koch & Strimple, 1968). Conodont sample WQ-1C in upper 15 cm.

Unit 7 (2.4-2.5 m): Skeletal Wackstone (local patches of packstone)-echinoderms, brachiopods (*Pseudoatrypa witzkei, Spinatrypa bunkeri, Eleutherokomma cardinalis, Athryis* sp.) with phosphatic granules above hard ground contact, some large P. witzkei with geopetal fabrics, intensely bioturbated, with thin platy mudstone at top of unit. Conodont sample WQ-2C from 2.6-2.7 m.

Unit 8 (2.5-2.6 m): Skeletal Mudstone-thin platy argillaceous, dolomitic.

Unit 9 (2.6-3.15 m): Skeletal Wackstone-intensely bioturbated, brachiopods, echinoderms, with packstone skeletal lag and shale parting at upper contact. Conodont sample WQ-3C from 3.45-3.55 m.

Unit 10 (3.15-4.75 m): Skeletal Wackstone-single very thick bed, intensely bioturbated, brachiopods (*Pseudoatrypa witzkei*, *Strophodonta scottensis, Cranaena* sp. & echinoderms.

Unit 11 (4.75-5.4 m): Skeletal Wackstone-thick bed, intensely bioturbated, brachiopods (*Pseudoatrypa witzkei, Spinatrypa bunkeri, Strophodonta scottensis, Productella fragilis, Tenticospirifer shellrockensis, Atribonium paupera, Athryis* sp.) & echinoderms, with upper 5 cm echinoderm packstone lag below upper contact. Conodont sample WQ-4C from 5.5-5.6 m.

Unit 12 (5.4-5.5 m): Shale-nodular (skeletal mudstone), with brachiopods & echinoderms.

Unit 13 (5.5-5.75 m): Skeletal Mudstone- intensely bioturbated, brachiopods (*P. witzkei, Strophodonta sp., T. shellrockensis, Athryis* sp.), echinoderms, tabulate corals (*Thamnopora* sp.). Conodont sample WQ-5C from 5.85-5.95 m.

Unit 14 (5.75-6.15 m): Skeletal Wackstone to Packstone-thin-bedded, platy, extremely fossiliferous with echinoderm lag concentrations along undulatory bedding surfaces, brachiopods include: *Eleutherokomma cardinalis, Platyrachella ballardi, & Strophodonta sp.* Conodont sample WQ-6C from 5.95-6.05 m.

Unit 15 (6.15-6.7 m): Skeletal Wackstone-thick bed of intensely bioturbated skeletal wackstone with brachiopods (*P. witzkei & Spinatrypa bunkeri*), echinoderm plates and grastropods, with pyrite-encrusted discontinuity surface at upper contact with unit 16. Conodont sample WQ-7C from 6.65-6.8 m.

Rock Grove Member

basal contact at pyrite discontinuity surface at top unit 15 of Mason City Mb.

Unit 16 (6.7-7.65): Skeletal Mudstone & Thin Interbedded Shale-thin (5-10 cm) laminated to burrowed skeletal mudstones, interbedded with thin (1-3 cm) argillaceous recessive shale-thin-bedded silty mudstone.

Unit 17 (7.65-8.1 m): Skeletal Mudstone-intensely bioturbated, echinoderms and indeterminate brachiopods.

Unit 18 (8.1-8.7 m): Skeletal Mudstone - Dolomitic Mudstone-argillaceous intensely bioturbated skeletal mudstone in lower 20 cm, upper 45 cm dolomitized skeletal mudstone.

Unit 19 (8.7-9.1 m): Dolomite-dolomitized mudstone, single bed.

Unit 20 (9.1-9.9 m): Dolomite-dolomitized mudstone, single very thick bed.

Unit 21 (9.9-10.3 m): Dolomite-dolomitized mudstone, in three medium beds with thin shale partings.

Unit 22 (10.3-12.65 m): Shale & Mudstone-light blue-green when freshly exposed, intensely burrowed with *Planolites, Rhizocorallum* and thallasiniform burrows (shafts and side tunnels up to 2 cm in diam.), no megafossils apparent.

Unit 23 (13.05-13.35 m): Argillaceous Dolomite-argillaceous, thin-medium bedded blocky carbonate mudstone, possibly laminated mudstone.

Nora Member

Unit 24 (13.35-14.65 m) Large-Massive Hemispherical Stromatoporoid Framestone-very large (some up to 1.3 meters in height, and over 3 meters in width) hemispherical stromatoporoid coenostea/skeletons forming growth framework.

Unit 25 (14.65-17.4 m): Dolomitic Shale-Mudstone-formerly a calcareous shale/mudstone with laminar stromatoporoids and thallasiniform burrows (shafts and tunnels up to 1 cm in diam.) throughout unit, no shelly megafossils apparent.

Unit 26 (17.4-19.25 m): Laminar Stromatoporoid Framestone-low relief platy stromatoporoid coenostea, grain-contact with mud matrix.

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STOP 7 – ROCKFORD BRICK AND TILE QUARRY

FLOYD COUNTY FOSSIL AND PRAIRIE CENTER AND PARK PRESERVE

SW1/4, NW1/4, Section 16, T. 95 N., R. 18 W, Floyd County, Iowa
(GPS Coordinates Lat. 43°02′45.64′′N, Long. 92°58′42.04′′W)

LIME CREEK FORMATION IN THE VICINITY OF THE ROCKFORD BRICK AND TILE QUARRY

The Lime Creek Formation is divided into the Juniper Hill, Cerro Gordo, and Owen member, and is named from natural exposures along the southern bank of Lime Creek, now termed the Winnebago River on maps published since the 1950s. The Rockford Brick and Tile Company was incorporated in 1910 and engaged in mining of shales of the Juniper Hill Member for face and common brick and agricultural drainage tile manufacturing until its sale to Allied Construction Company in 1977. In 1990 the Floyd County Conservation Board purchased the quarry property from Allied, and in 1991 the Rockford Fossil and Prairie Preserve was officially dedicated (see history of the Rockford area by Anderson, 1995a) insuring access by the public the incredibly fossiliferous deposits of the Lime Creek Formation. The stratigraphic section currently exposed in the Rockford Brick and Tile Quarry (Figures 1 and 2) is one of three important surface exposures of the Lime Creek Formation in its type area in Floyd and Cerro Gordo counties and includes the upper four meters of the Juniper Hill and lower half of the Cerro Gordo members. The type section of both the Juniper Hill and Cerro Gordo members is approximately three miles northwest of Stop 7 in the Cerro Gordo County Clay Banks Nature Preserve (see Day, 1995 Fig. 8) formerly referred to as Hackberry Grove (Anderson and Furnish, 1987; Day, 1990; Anderson, 1995b; Day, 1995).

The Lime Creek Formation is part of two 3rd order depositional sequences packages coinciding to Iowa Devonian Transgressive-Regressive (T-R) Cycles 7A and 7B deposited during two major marine transgression in the late and latest part of the Frasnian just before and during the stepped extinction events that wiped out the vast majority of Frasnian shelly taxa (see Day et al., 2008, Fig. 3) during the Lower and Upper Kellwasser Events (extinction bioevents) (Walliser, 1996). The Lime Creek was deposited in the middle shelf region of a an immense carbonate platform that deepened to the southeast into the Illinois Basin where condensed organic-rich facies of the Lime Creek are included in the Sweetland Creek and Grassy Creek shales (Witzke, 1987; Day, 1989, 1990, 1995, 2006; Witzke and Bunker, 1997; Over 2002, 2006). Conditions in the area that is now northern Iowa were optimal for most benthic invertebrates during much of Lime Creek deposition in the region, possibly afforded by upwelling and high primary productivity in the water mass over the Lime Creek shelf and deeper shaly ramp slope facies in eastern and southeastern Iowa and adjacent areas of the Illinois Basin.

The Cerro Gordo Member is incredibly fossiliferous, and features at least 40 species of brachiopods (Table 1). Most of these can be easily collected at the Rockford Quarry and other surface exposures in Floyd and Cerro Gordo counties (Day et al. 2008, Figs. 4 and 12). Brachiopods from these intervals have weathered in the millions and have been collected by generations of professional and amateur paleontologists since the 1800s, (Owen, 1852; Hall, 1858, 1867; Hall and Whitfield, 1873;

Calvin, 1883, 1897; Webster, 1908, 1909, 1921; Fenton, 1918, 1919, 1930, 1931; Fenton and Fenton, 1924; Belanski, in Fenton and Fenton, 1924, 1933; Stainbrook, 1945) and are common in paleontology teaching collections across the globe because of their abundance and superb state of preservation. Modern systematic studies have resulted in major revisions to the brachiopod fauna

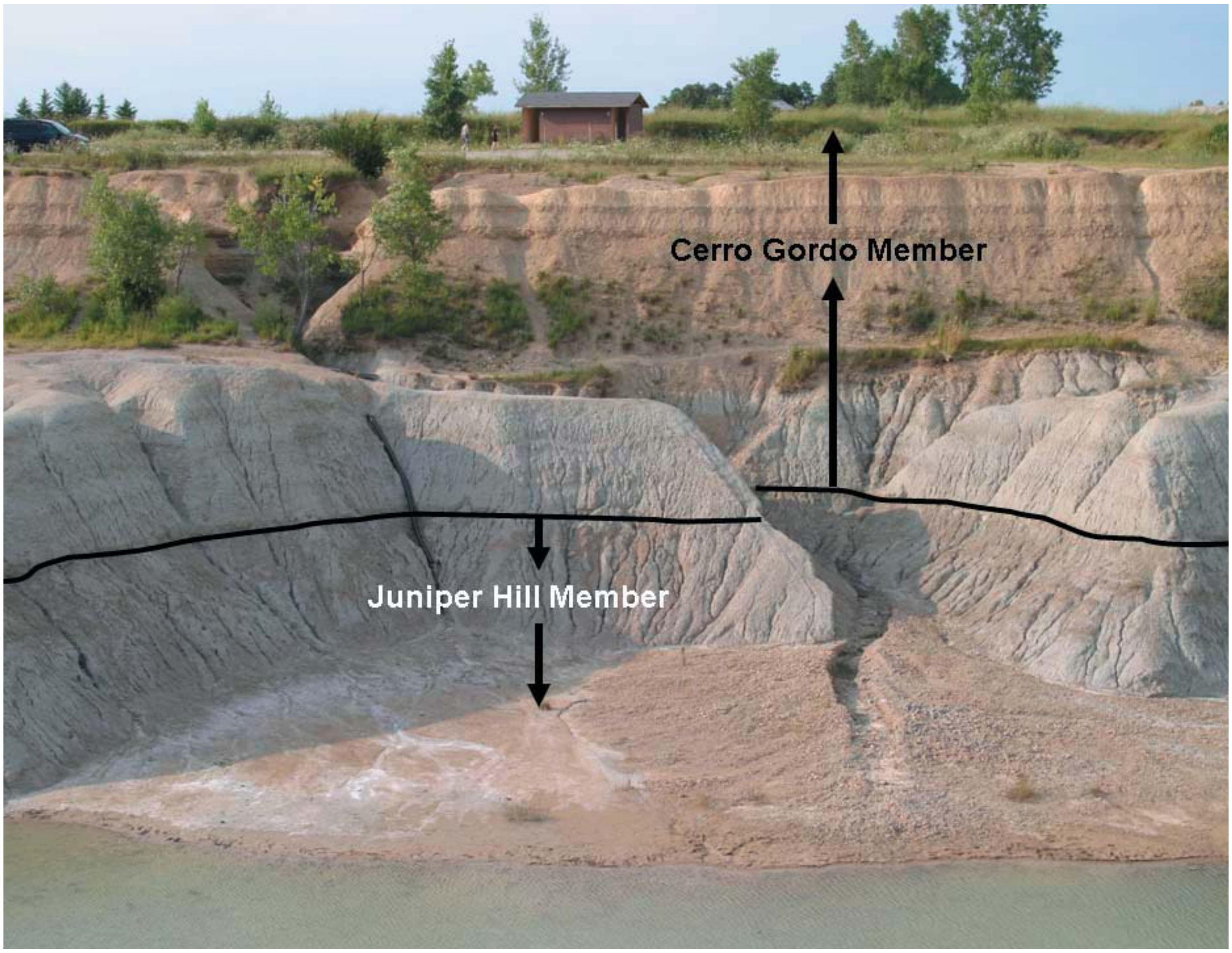

Figure 1. Photograph of exposures of the Lime Creek Formation (Late Frasnian age) along the old north highwall of the northwest pit of the Rockford Brick and Tile Quarry at the Floyd County Fossil and Prairie Center and Park Preserve west of the town of Rockford, Iowa. Exposures in the inactive quarry pits include shales of the upper 4.4 meters (13.4 feet) of the Juniper Hill, and lower 12.1 meters (36.6 feet) of the Cerro Gordo members of the Lime Creek Formation. Photograph by J. Day (8-08).

(Copper, 1973, 1978; Copper and Chen, 1994; Cooper and Dutro, 1982; Day, 1998; Day and Copper, 1998; Ma and Day, 2000, 2003).

Other studies featuring descriptions or discussions of other groups of common Lime Creek fossils include: foraminifers in Cushman and Stainbrook (1943), Metzger (1989), and Day (1990); conodonts in Anderson (1966), Metzger (1989), Woodruff (1990), Day (1990), Klapper (1990), and Klapper and Foster (1993); gastropods by Day (1987), ammonoids by Miller (1936), Baker et al. (1986) and Day (1990); and corals by Webster (1889, 1905), Stainbrook (1946b), Sorauf (1998). The sparse stromatoporoid fauna from the Cero Gordo and Owen members is discussed elsewhere by Stock (2008), and readers are directed to see his article.

Juniper Hill Member

In Floyd and Cerro Gordo counties the Juniper Hill ranges from 9-16 meters in thickness, and is

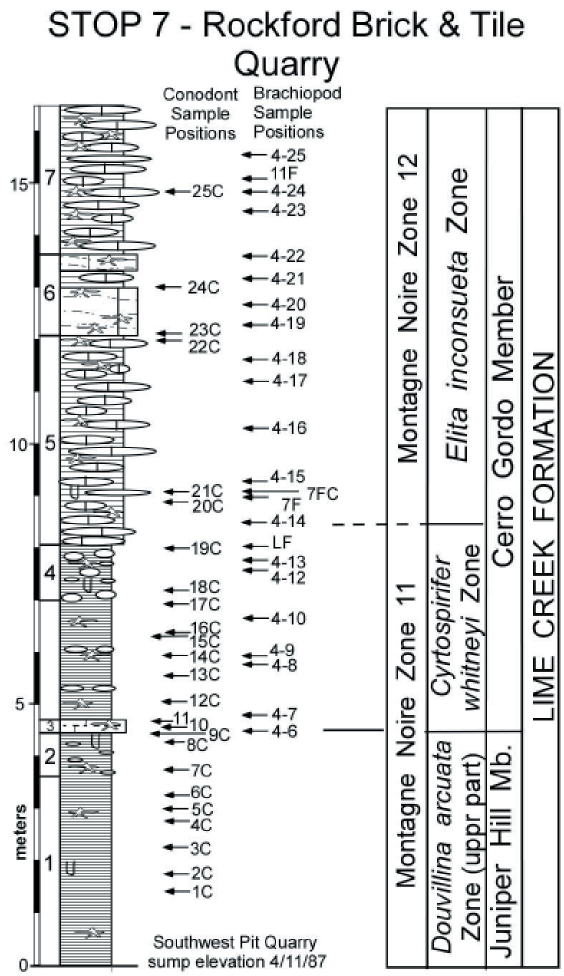

Figure 2. Graphic section of the Lime Creek Formation in the Rockford Quarry (see location above) described by J. Day, B. Bunker and B.Witzke in July of 1985, and J. Day in April of 1987). Positions of conodont samples of Day (1990) shown just to right of column. Positions of brachiopod samples and assemblage zones from Day (1989; see fig. 2 of Day, 2008). Modified from text-fig. 3 of Day (1990), text-fig. 6 of Day (1995). Brachiopod sample LF is the *Lioclema* bryozoan and brachiopod pavement on the quarry working bench surface of unit 4 below the old strip face in the lower Cerro Gordo Member as shown in Figure 1. Frasnian Montagne Noire conodont zones from Klapper (1989).

thickest (16.1 m) in the subsurface in the Cerro Gordo Project Hole # 1 in southeastern Cerro Gordo County (see Day et al., 2008, Figs. 4 and 12). The only known complete exposure of the Juniper Hill occurs in a series of outcrops on the south bank of the Winnebago River at Hackberry Grove (Figs. 6 and 8, Locality 4; =Cerro Gordo County Clay Banks Natural area). The upper third (4.3 m) of the member is seen in exposures in the pits at the Rockford Quarry locality (Fig. 2). In the 1920s and 1030s the operating pit of the Brick and Tile quarry was north of the recent pits that mark the location operations when the quarry ceased operating in the late 1970s. In the old pit (Fig. 3) most of the Juniper Hill Member (just over 11 meters) was exposed and described by Charles Belanski.

A sparse fauna described by Webster (1908) from surface exposures of the Juniper Hill Member at the Rockford Quarry (Figs. 2 and 3)6, included lingulid brachiopods (“*Lingula” fragila*) and carbonized vascular plant fossils. Hexactinellid sponges were later described by Thomas (1922). A sparse brachiopod fauna recovered in the 1920’s from the Juniper Hill at the Rockford Quarry (Fig. 3) is listed by discussed by Belanski (Belanski Register, University of Iowa Repository), Day (1989, 1995) and Day et al. (2008). The Juniper Hill brachiopod fauna is best known from the CG-1 core (Day et al., 2008, Figs. 4 and 12, table 1) in southeastern Cerro Gordo County where a moderately diverse brachiopod fauna occurs throughout the member as reported in Day (1989) and Day et al. (2008, fig. 12, table 1). The conodont fauna and sequence in the Lime Creek is well documented in studies by Anderson (1966), and the more detailed and recent study by Day (1990). Day’s (1990) conodont sequence in the Rockford Quarry is shown in Table 2. All of the Juniper Hill and lower part of the Cerro Gordo are correlated with late Frasnian Montagne Noire Zone 11 based on the occurrence of *Palmatolepis semichatovae* below the first occurrence of *Pa. foliacea* (symbol marked A, Table 1).

The Juniper Hill features an undescribed species of the widespread rhynchonellid *Navalicria.* This species is similar to *N. retangularis*

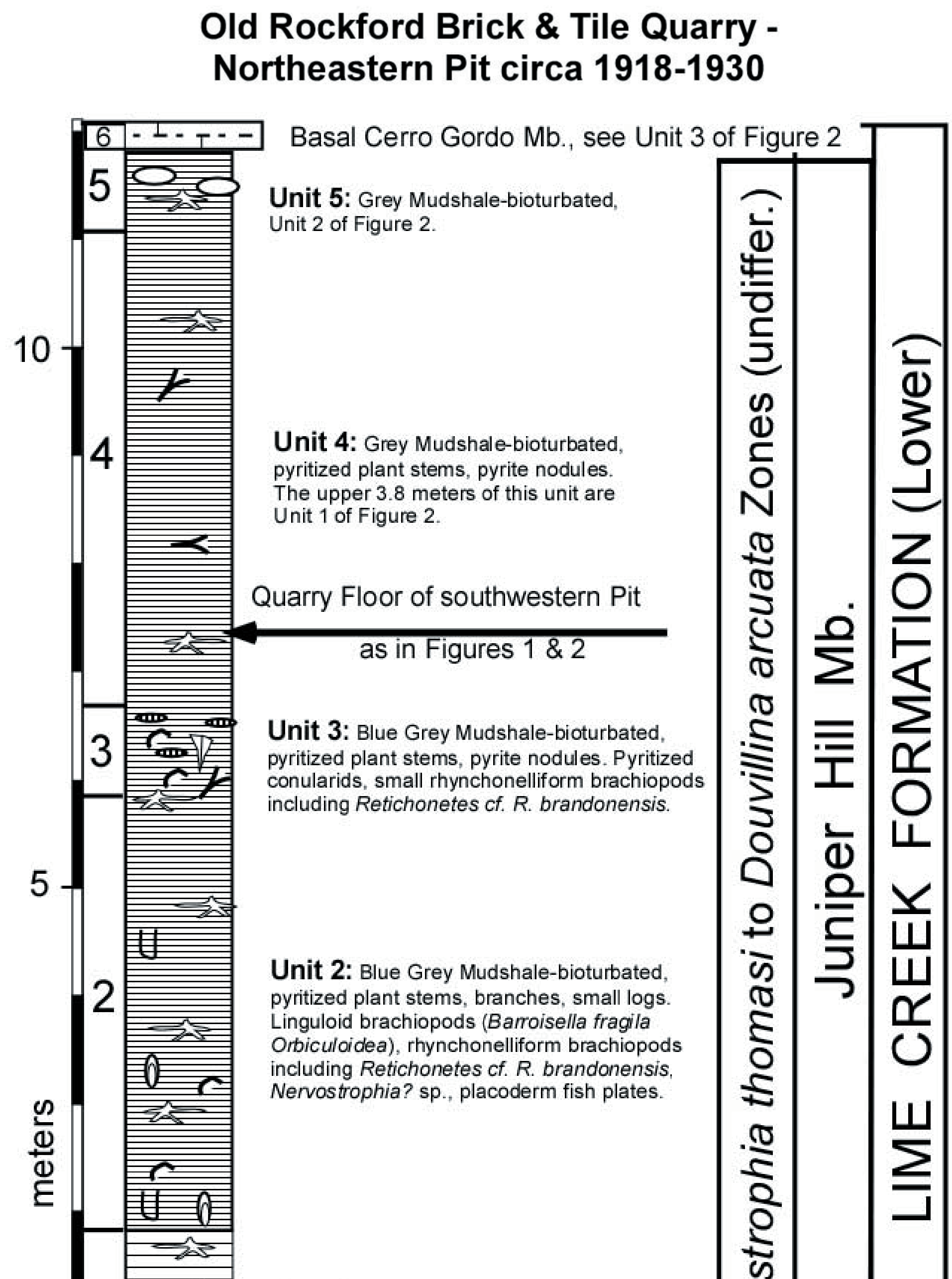

Figure 3. Exposure of the Juniper Hill Member in the working quarry pit on the northeastern side of the Rockford Brick and Tile Quarry property described by C.H. Belanski (see Belanski Register, University of Iowa Fossil Repository) during the period of 1918 to 1930. Plant and sponge (Thomas, 1922) fossils from units 2 to 4 are housed in the UI Repository in Iowa City.

described by Sartenaer and Xu (1991) from late Frasnian rocks in China. The two most common Lime Creek orthids first appear in the Juniper Hill. These are *Aulacella infera* and *Schizophoria iowensis*. Strophomenids first appearing in the Juniper Hill include the stropheodontids *Nervostrophia thomasi, N. rockfordensis*, and *Douvillina arcuata.* The latter two species are especially abundant in overlying rocks of the Cerro Gordo Member. The chonetid *Retichonetes brandonensis*, first described from the Independence Shale by Stainbrook (1945), was recovered from the Juniper Hill by the author, as well as from the Sly Gap Formation of New Mexico (Day,1988, 1989). Productellids occur in the upper half of the Juniper Hill and include *Devonoproductus walcotti* and *Productella* sp.

Thus far, only a single species of atrypid brachiopod has been recovered in the Juniper Hill Member. This is the distinctive frilled atrypid *Pseudoatrypa devoniana*. Juniper Hill spiriferids include: a undescribed species of *Ambocoelia*; the cyrtospiriferid *Conispirifer cyrtinaformis*; the "*Theodossia*" *hungerfordi* (not a genuine *Theodossia,* a new genus) the spinellid *Rigauxia orestes* (formerly assigned to the genus *Indospirifer,* see Brice, 1988, and discussion in Day, 1996); *Thomasaria altumbonata*; the distinctive and one of the last spinocyrtids *Platyrachella mcbridei*; and the spiriferidinid *Cyrtina inultus.*

Cerro Gordo Member

The Cerro Gordo Member ranges from 9-15 meters in thickness at surface exposures and in the subsurface in north-central Iowa (Day et al., 2008, figs. 4 and 12). The Cerro Gordo consists of extremely fossiliferous calcareous shales, nodular shaly limestones, and bedded argillaceous limestones. The only complete surface exposure occurs at its type section (Hackberry Grove; Day et al. 2008, figs. 4 and 12). The lower half to two thirds of the member are exposed in the Rockford quarry, and the upper half of the member is exposed in the vicinity of Bird Hill (Day et al. 2008, figs. 4 and 12). As with the Juniper Hill Member, the type section of the Cerro Gordo Member is located at what is now called the Clay Banks Natural Area, maintained by Cerro Gordo County as a nature preserve (Day et al. 2008, figs. 4 and 12).

The conodont fauna and sequence in the Cerro Gordo Member at the Rockford Quarry were documented by Anderson (1966) and Day (1990). Table 1 (Day's 1990 data, see fig. 7, section 2, p. 627-628) are correlated with the upper part of Frasnian Montagne Noire (M.N.) Zone 11, and the lower part of M.N. Zone 12. The base of Zone 12 coincides with the lowest occurrence of *Palmatolepis foliacea* as reported by Anderson (1966) and coincides with the base of the *Elita inconsueta* Zone of Day (1989) as shown in Figure 2.

Most of the Cerro Gordo brachiopod fauna was described and illustrated by Hall (1858), Hall and Whitfield (1873), Fenton (1931), Fenton and Fenton (1924, 1933), and Stainbrook (1945), and Cooper and Dutro (1982). Cerro Gordo Member brachiopods (Table 1) are associated with a diverse suite of molluscs, bryozoans, echinoderms, cnidarians (corals), and poriferans (stromatoporoids). The sampled intervals and distribution of brachiopods in the Cerro Gordo Member *Cyrtospirifer whitneyi* and *Elita inconsueta* Zones of Day (1989) are shown in Figure 2 and Table 1. The Late Frasnian age Lime Creek fauna suffered extinction in the very late Frasnian during the first of two extinction bioevents (=Lower Kellwasser Event) of the stepped Frasnian-Famennian mass extinction (Day, 1989, 1996; Day and Whalen 2006), with some surviving and persisting in the upper part of the Owen Member as seen at the Buseman Quarry in Butler County (Day et al. 2008, figs. 4 and 12). The position of the Lower Kellwasser Extinction horizon coincides with a major flooding surface in the middle part of the Owen Member (Day et al. 2008, figs. 4 and 12).

Craniform brachiopods are generally inconspicuous, but common elements of the Cerro Gordo fauna, and occur as closely cemented or attached forms on the surfaces of larger host species, usually other brachiopods or gastropods. *Philhedra sheldoni* will often mimic the features of the surface ornament of its host species as a

Table 1. Late Frasnian brachiopod sequence in the Cerro Gordo Member of the Lime Creek Formation at the Rockford Quarry established from sampling by C. Belanski (Belanski Register, Station 4=Rockford Quarry, and collections, University of Iowa Repository) and J. Day and B. Bunker. X's in sample boxes indicate a species occurrence in that sample interval, numbers in sample position boxes indicate specimen counts in those samples in the authors' and the Belanski Collection (University of Iowa Repository), gray columns indicate the local species range in the Rockford Quarry section. Brachiopod identifications after Day (1989), with revisions to brachiopod taxonomy and identifications in Day (1995, 1996, 1998), Day and Copper (1998), and Ma and Day (2000, 2003). Sample 6 at 4.4 meters is the basal Cerro Gordo Member and base of the *Cyrtospirifer whitneyi* Zone, and the vertical black line between samples LF (=*Lioclema* Fauna) and 14 is the base of the *Elita inconsueta* Zone of Day (1989) as shown in Figure 2.

SAMPLE NUMBER	6	7	8	9	10	12	13	LF	14	7F	7C	15	16	17	18	19	20	21	22	23	24	11F	25	27
Elevation meters above base	4.4	4.85	5.77	5.9	6.68	7.6	7.75	8.15	8.5	9	9.1	9.3	10.3	11.2	11.65	12.3	12.7	13.2	13.55	14.45	14.85	15.1	15.55	16
Pseudoatrypa devoniana	18				X	X		X	1	X	X	5	889		185	198		114	X	296	X	X		
Petrocrania sp.												X										X		
Conispirifer cyrtinaformis											X	2	13	X	1		5		1	2	X	X	X	1
Devonoproductus walcotti	23							X	1	X	X	1	125		272	312	44	12	1	114		X		
Schizophoria iowensis								X	4			11	189	X	211	77	14	27	1	38				
Ambocoelia n.sp.	X				X				X															
Douvillina arcuata	6		1	X	X	X	X	X	16	X	X	X	11		72	48	10	45	3	12	7	X		5
Stainbrookia infera																					X			
Cyrtina inulta	X				X						X		X	X	X	1	2	1	X			X		
Rigauxia orestes	2								4		X	17	3		3	5	X	3		3	3	X	1	3
"Theodossia" hungerfordi								X		X		17	13		2	5	9	X	5	3	X	X		
Cranaena navicella	X												1						1		X	X		
Platyrachella macbridei								X	3			1	1			1								
Nervostrophia canace	1									X		X	X	X	15	40	X	22		87	1	X		
Strophonelloides reversa	1							X	9	X		5	42	X	38	39	10	21	5	14	X		4	1
Cyrtospirifer whitneyi	1				X			X	X	X		X	318	X	24	6	7	5		23		X		3
Douvillinaria delicata	X				X				1			10	1			3	X		X					
Spinatrypa (S.) rockfordensis	X							X	5	X		10	190		157	28	7	30	X	18	2	X		
Strophodonta (S.) thomasi	X				X				X			X	X	X							X			
Spinatrypa (S.) planosulcata	X												1		3	3	1	8						
Gypidula cornuta	X	X																				X		
Tylothyris aff. T sulcocostata	5	35			1																			
Navalicria n.sp.		3			X				X															
"Cupularostrum" saxatilis					X				X			1	1				X							
Sulcatostrophia camerata								X	X		X	1	5		7	7	6	16	5	278	3	X	2	1
Floweria prava									X			1	1		10	5	6	2				X		
Coeloterorhynchus alta									X															
Nervostropia rockfordensis									X			X	3											
Elita inconsueta									1								X				X		1	
Iowatrypa minor									1															
Productella rugatula										X		X	X									X		
Pyramidaspirifer helenae												3	7		1	1				6				
Eostrophalosia rockfordensis												X							X					
Cranaena calvini															X									
Gypidula parva																X					X			
Cranaena sp.																	2			6				
Costatrypa varicostata																		4			1			
BRACHIOPOD ZONE	*Cyrtospirifer whitneyi* Zone								*Elita inconsueta* Zone															
CONODONT ZONE	Montange Noire Zone 11 (upper)								Montange Noire Zone 12															

form of camouflage, whereas *Petrocrania famelica* has a low conical ventral valve with simple concentric growth lines and fine radial costallate ornament, usually closely attached to the shell surface of the host species.

Rhynchonellids are generally rare in the Cerro Gordo Member, and are represented by three genera. These include: *Cupularostrum saxatillis, Coeloterorhynchus alta*, and an undescribed species of *Navalicria.* The first form can commonly be found in the interval of the *Cyrtospirifer whitneyi* Zone at the Rockford Quarry (Fig. 6). The

Table 2. Late Frasnian conodont sequence in the Juniper Hill and Cerro Gordo members of the Lime Creek Formation at the Rockford Quarry documented by Day (1990). Upper Devonian (Frasnian) Montagne Noire conodont zones of Klapper (1989). Abbreviations of genus names of conodont taxa: *P. = Polygnathus, I. = Icriodus, Pa. = Palmatolepis, A. = Ancryodella, An. = Ancryoganthus.* Occurrence shown as A in Day's (1990) sample 20 is the lowest occurrence of *Pa. foliacea* reported by Anderson (1966) marking the local position of the base of M.N. Zone 12.

SAMPLE NUMBER	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
SAMPLE POSITION (m)	1.4	1.75	2.25	2.75	3	3.25	3.75	4.25	4.4	4.55	4.7	5.05	5.55	5.9	6.3	6.4	6.9	7.2	8	8.85	9.1	12	12.1	13	14.8
P. evidens	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
P. unicornis	X							X	X	X	X		X	X		X	X		X	X	X		X		X
I. symmetricus		X																	X						
Pa. semichatovae		X	X		X	X		X	X	X	X								X						
P. alatus			X							X													X	X	
A. triangularis						X																			
I. subterminus							X							X											
An. sp.							X									X	X	X							
An. deformis									X							X	X		X	X					
P. brevis									X	X	X						X	X	X	X					
P. pacificus										X								X	X						
A. asymmetricus											X														
A. curvata late form												X	X				X	X	X	X					
Pa. kireevae																	X	X	X						
A. nodossa																			X						
Pa. foliacea																				A					
STRATIGRAPHIC UNIT	JUNIPER HILL MEMBER (Upper)							CERRO CORDO MEMBER (Lower)																	
MONTAGNE NOIRE ZONE	ZONE 11																			ZONE 12					

orthid *Schizophoria iowensis* is abundant in the Cerro Gordo and ranges throughout the member. Because of its small adult size (10-12 mm), *Aulacella infera* is usually overlooked, but is found in the lower part of the Cerro Gordo. In general, pentamerids are rare in the Lime Creek. By the late Frasnian, only a single genus (*Gypidula*) occurs in most faunas in North America. If found, usually it is the larger of the two Cerro Gordo species (*G. cornuta*).

Strophomenid brachiopods comprise a significant proportion of the Cerro Gordo fauna (Table 1). The most abundant are liberosessile (freelying-unattached) species of various stropheodontid genera including: *Douvillina arcuata, Sulcatostrophia camerata, Strophonelloides reversa, Nervostrophia canace,* and *N. rockfordensis*. Less common strophodontids include *Strophodonta thomasi* and *Douvillinaria delicata*. Productoids are abundant in the fauna, and include: the *Devonoproductus walcotti* with radial costellae on its ventral valve, and *Productella* cf. *thomasi;* and the strophalosids *Eostrophalosia rockfordensis* and *E. independensis.* The latter species is quite small and thin shelled, and was first described from the Independence Shale by Stainbrook (1945). This form was collected by C.H. Belanski and is in his Lime Creek collections (University of Iowa). Species of *Eostrophalosia* are usually cemented by their umbos to a hard substrate, as evidenced by the presence of ventral cicatrices (attachment scars) on the pedicle valves most specimens of both Cerro Gordo species. Another common fixosessile (cemented-attached) form in the Cerro Gordo fauna is *Floweria prava,* with a fine radial costellate ornament, a planer dorsal valve, an inflated convex ventral valve, and commonly with a visible apical ventral cicatrix.

All of the Lime Creek atrypid brachiopods were recently redescribed and illustrated by

Day and Copper (1998) Atrypid brachiopods are particularly abundant in the Cerro Gordo fauna (Table 1). The most common species is the frilled atrypid *Pseudoatrypa devoniana*, characterized by its numerous radial tubular costae, and conspicuous regularly spaced concentric frill bases (frills rarely preserved). *Spinatrypa rockfordensis* is also abundant, and is easily distinguished by its less numerous low rounded costae, concentric lamellose growth lamellae, and variably preserved spine bases (spines are preserved on many specimens). *Spinatrypa* (*S.*) *planosulcata* is an uncommon but distinctive distantly related to *S. rockfordensis*. Rare forms in the upper Cerro Gordo in the interval of the *Elita inconsueta* Zone interval include *Costatrypa varicostata* and *Iowatrypa minor* (Fig. 2, Table 1).

The Cerro Gordo yields a distinctive and superbly preserved suite of spiriferid brachiopods. Numerically, the most abundant taxa are: the spinellid *Regauxia orestes* with its prominent plicate anterior commissure, and prominent medial costae on the fold and in the sulcus; and the "*Theodossia hungerfordi"* with its finely costate radial ornament and highly reduced fold and sulcus and gently uniplicate anterior commissure. Other common spiriferids are the cyrtospiriferids *Cyrtospirifer whitneyi*, *Conispirifer cyrtinaformis, Pyramidaspirifer hellenae* (recent new genus defined by Ma and Day, 2000). The deluxe spinocyrtid spiriferid *Platyrachella macbridei* is found in the lower part of the Cerro Gordo. This species is one of the last representatives of its family prior to the extinction of the group at the end of the Frasnian. This form first appears in the upper Juniper Hill, and ranges into the lower part of the Cerro Gordo, and is commonly found at the Rockford Quarry in the fauna of the lower part of the *Cyrtospirifer whitneyi* Zone (Table 1). The reticularid *Elita inconsueta* is the nominal species of the *E. inconsueta* Zone (Day, 1989) of the Cerro Gordo Member of the Lime Creek, and is usually a rare but important element of the Cerro Gordo fauna (Fig. 2, Table 1). A rare species is a small undescribed species of *Tylothyris*, that is restricted to, the lower Cerro Gordo at the Rockford Quarry (Table 1). An undescribed species of *Ambocoelia* (Table 1) is a rare element of the lower Cerro Gordo fauna in the lower part of the *C. whitneyi* Zone that ranges up the older Juniper Hill.

Terebratuloids are another group commonly encountered in the Cerro Gordo Member fauna (Table 1). A single short-looped genus *Cranaena* is represented by four species in the Cerro Gordo described in the older literature. The most common and largest of these is *C. navicella*. Large adult specimens of this species may reach lengths of 70-80 mm, which is a whopper by Devonian terebratulid standards, and larger than nearly any other species of Lime Creek brachiopod.

Owen Member

This member and the upper part of the Cerro Gordo Member were eroded in the present vicinity of the Rockford Quarry, although exposures occur in outcrop, roadcut and quarry exposures to the south in Cerro Gordo and Bulter County. The Owen Member consists of limestones, dolomitic limestones, dolomites, and shales in surface exposures and the subsurface of north-central Iowa. The Owen ranges in thickness from 2-10 meters in surface exposures (Day et al. 2008, Figs. 4 and 12). The type section is located west and south of Clay Banks (Hackberry Grove) in Cerro Gordo County and is largely covered at present (Day et al. 2008, Figs. 4 and 12). The precise location of the type section and other important Owen Member outcrops and quarry exposures are discussed in Lynn (1978). Diversity of the Lime Creek brachiopod diversity lowest in rocks of the Owen Member which were deposited in much shallower water than the underlying outer to middle shelf facies of the Cerro Gordo Member, and above the marine flooding surface in the upper Owen when most Lime Creek taxa were extinct at that time (Day et al., 2008, Figs. 4 and 12).

Owen megafossil assemblages are usually dominated by corals and stromatoporoids, although molluscs and brachiopods (*Cyrtospirifer, Strophonelloides, Douvillina*, *Pseudoatrypa*, and *Rigauxia*) are locally abundant in the lower half of the member. One of the more distinctive brachiopods found in the Owen is *Iowatrypa owenensis* which serves as a zonal index fossil, first appears in the upper half of the member and defines the base of the *I. owenensis* Zone of Day (1989). Modern studies of this distinctive atrypid include those by Copper (1973), Copper and Chen (1994), and Day and Copper (1998).

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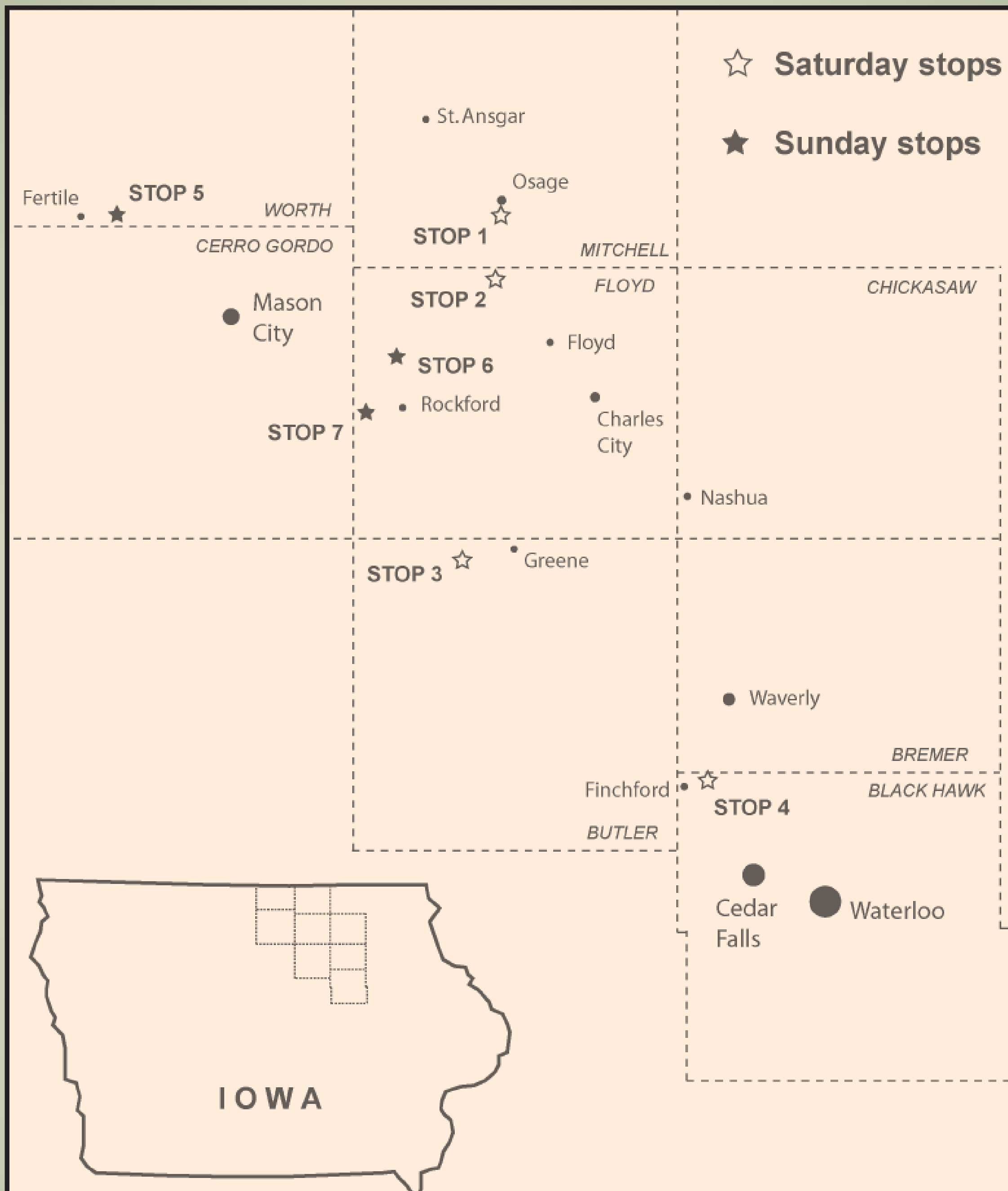

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