ASPECTS OF THE PALEOZOIC HISTORY OF EPEIRIC SEAS OF THE IOWA BASIN

Iowa Geological and Water Survey
Guidebook Series No. 29

72nd Annual Tri-State and 33rd Great Lakes Section – SEPM Fall Field Conference
Guidebook for the 72nd Annual Tri-State and 33rd Great Lakes Section – SEPM
Fall Field Conference
October 5, 2013

COVER

Photograph looking north at the richly fossiliferous Lime Creek Formation exposed in the Floyd County Fossil & Prairie Park Preserve (old Rockford Brick and Tile Quarry), field trip Stop5. Photograph by J. Day, June 2006.

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Prepared for the

72nd Annual Tri-State and 33rd Great Lakes Section – SEPM Fall Field Conference

Prepared and led by

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Iowa Department of Natural Resources
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TABLE OF CONTENTS

OVERVIEW OF MIDDLE AND UPPER DEVONIAN NORTHERN SHELF FACIES IN THE IOWA BASIN

Jed Day, Brian J. Witzke, and Bill Bunker……………………………………………………..…..…….1

FAUNA FROM THE BROOKS HARDGROUND BED: LOWER SOLON MEMBER, LITTLE CEDAR FORMATION BRUENING INC. BROOKS QUARRY, INDEPENDENCE, IOWA

James E. Preslicka, Charles R. Newsom, Thomas E. Blume..……………………………………..…...…41

STROMATOPOROID BIOSTRATIGRAPHY OF THE IOWA GIVETIAN AND FRASNIAN

Carl W. Stock ……………………………………………………...……………….……….……53

AMMONOIDS FROM THE DEVONIAN OF IOWA

James E. Preslicka, Charles R. Newson, and Thomas E. Blume……………………….…..………..…63

FIELD TRIP STOPS AND DISCUSSIONS

Jed Day, Joanne Kluessendorf, Donald G. Mikulic, Bill Bunker, and Brian J. Witzke ……….....73

STOP 1. BROOKS QUARRY – BRUENING CONSTRUCTION COMPANY, INDEPENDENCE, BUCHANAN COUNTY, IOWA

Jed Day, Brian J. Witzke, and James Preslicka………………………………………...75

STOP 2. THE MIDDLE DEVONIAN (GIVETIAN) LITTLE CEDAR AND CORALVILLE FORMATIONS AT BASIC MATERIALS CORPORATION'S RAYMOND QUARRY, BLACKHAWK COUNTY, IOWA

Jed Day, Brian J. Witzke, Bill Bunker, and Sherman Lundy……………………………...83

STOP 3. STRUCTURALLY-COMPLEX, CARBONATE-MOUND FACIES IN THE LOWER HOPKINTON FORMATION (SILURIAN) IN THE PAUL NIEMANN CONSTRUCI'ION COMPANY'S TRIPOLI QUARRY, BREMER COUNTY, IOWA.

Jed Day and Brian J. Witzke …………..…………………………….……………………89

STOP 4. JOHLAS QUARRY – GREEN LIMESTONE,FLOYD COUNTY, IOWA

Jed Day, Brian J. Witzke, and James Preslicka………………………………………...99

STOP 5. ROCKFORD BRICK AND TILE QUARRY – FLOYD COUNTY FOSSIL AND PRAIRIE CENTER AND PARK PRESERVE

Jed Day……………………………………………………………………………….……109

OVERVIEW OF MIDDLE AND UPPER DEVONIAN NORTHERN SHELF FACIES IN THE IOWA BASIN

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INTRODUCTION

In this study we provide an overview of the key aspects of the Devonian stratigraphy and of the paleontology of the northern part of the Iowa Devonian outcrop-subcrop belt that is the focus of the combined 2013 Great Lakes Section-SEPM and 72nd annual Tri-State geological field conference (Fig. 1). The richly fossiliferous lower Wapsipinicon and Cedar Valley Group epeiric carbonate platform deposits of the Iowa Basin (Figs. 1-4) accumulated during the interval of the Late Eifelian (*kockelianus* Zone) to Late Frasnian (Montagne Noire Zone 13c) and provide a record of 9 3rd order and number of other 4th order relative sea level changes (Transgressive-Regressive [T-R] cycles) outlined in studies by Witzke and others (1989), Witzke and Bunker (1992, 1996, 1997, 2006a), Day (1996, 2004, 2006), and Day and others (1996, 2006, 2008). 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 Wapsipinicon and Cedar Valley groups 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 Ie to IIe of Johnson and others (1985,1996), and subdivisions proposed by Day and others (1996), Day (1998), Day and Whalen (2005), Whalen and Day (2008).

In Northern Iowa quarry and outcrop exposures of Wapsipinicon (Figs. 1-5) and upper Cedar Valley group strata (Spillville to Shell Rock formations) of Late-Eifleian 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 seven major 3rd order relative sea level fluctuations recognized as Iowa Devonian transgressive-regressive (T-R) cycles 1 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). Deposits of the Pinicon Ridge Formation of the upper Wapsipinicon Group consist of peritidal facies that accumulated in a restricted Iowa Basin during the latest Eifelian to Middle Givetian. Cedar Valley Groups T-R cycles 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 deepening events, followed by intervals of carbonate platform depositional progradation during sea-level highstand or forced regression related to global sea level falls.

Most of the Wapsipinicon Group and 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 Devonian T-R cycles 5 to 6 events that provide the basis for subdivision of North

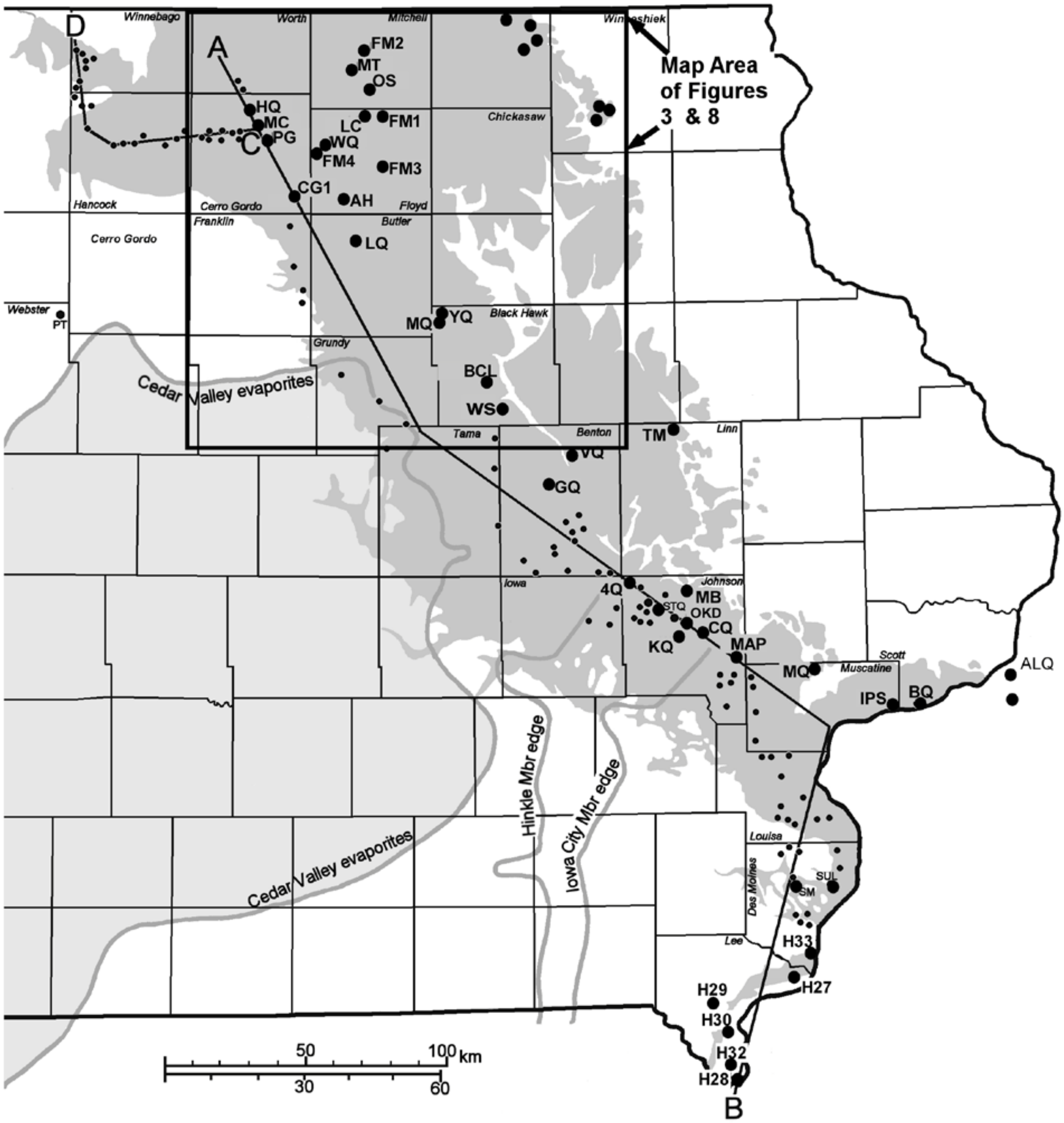

Figure 1.—Map showing the locations of core, well and outcrop sections of Middle-Upper Devonian (Eifelian-Middle Frasnian) Wapsipinicon and/or Cedar Valley Group strata in the eastern Iowa Basin (cross-section A-B shown in Figure 8). Dark shading = Devonian outcrop belt, light shading shows extent of Givetian-lower Frasnian evaporites within the Cedar Valley Group (after Witzke et al., 1989). The distal margins of the Hinkle and Iowa City members (labeled lines) mark the general south-eastward extent of Late Givetian inner-shelf facies within the Cedar Valley Group. Large dots = locations of core and outcrop sections (see Witzke et al., 1989; Bunker et al., 1986; Witzke and Bunker, 1997; Witzke, 1998 for descriptions and precise locations); small dots = well sections based on well cuttings only. County boundaries are outlined, relevant counties are labeled. Locations of well and outcrop sections available in the IGS Geosam database (www.igsb.uiowa.edu/webapps/geosam). Modified from Fig. 1 of Witzke and Bunker, 2006a.

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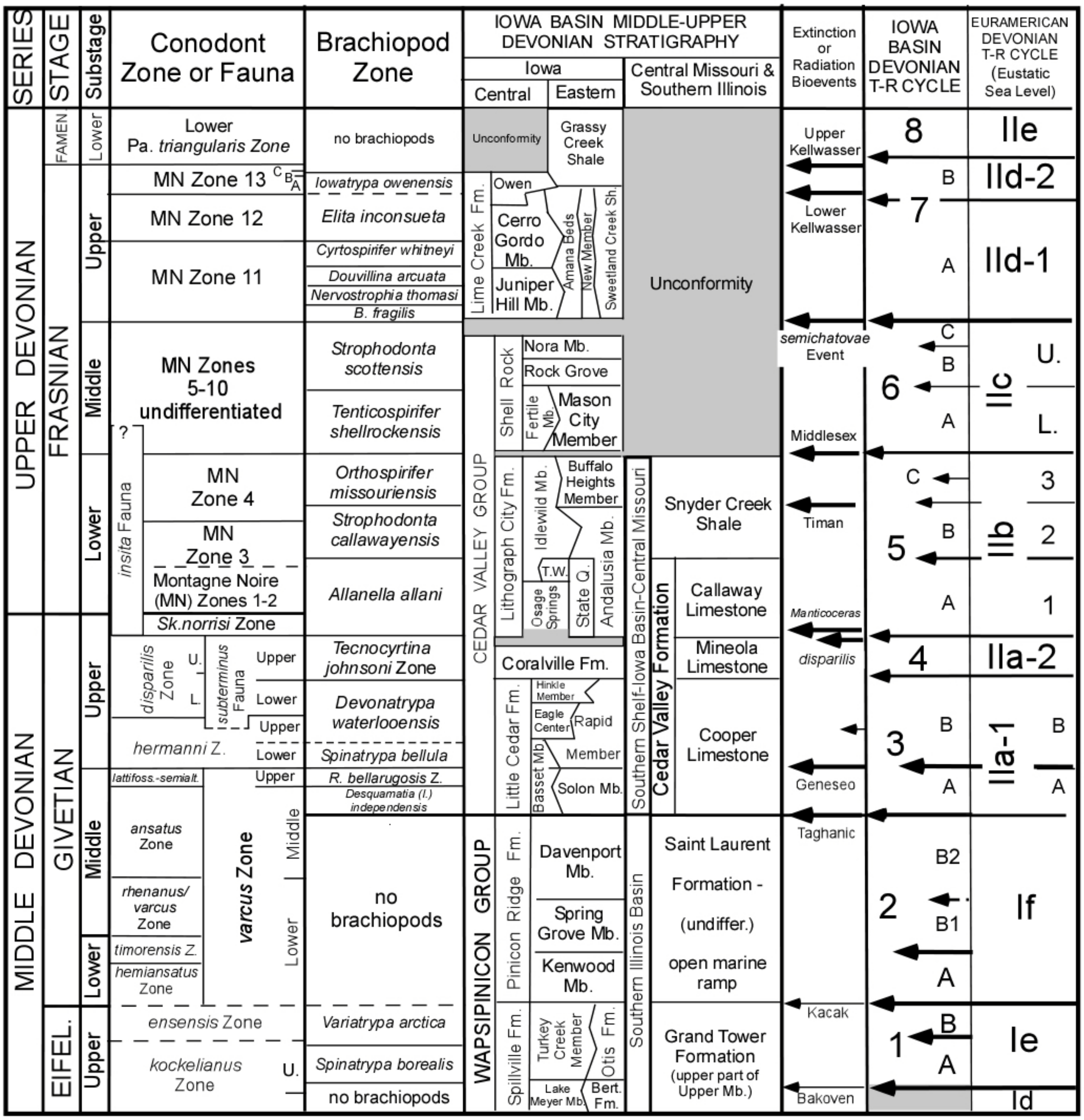

Figure 2.—Stratigraphic and biostratigraphic framework for the Middle-Late Devonian (late Eifelian-early Famennian strata of the Iowa Basin showing relationships between: the qualitative eustatic T-R cycles of Johnson et al. 1985), Johnson and Klapper (1992), Day et al. (1996), Day (1998), Whalen and Day (2008); and Iowa Basin Devonian T-R cycles of Witzke et al. (1989), Bunker and Witzke (1992), and Witzke and Bunker (1996, 2006). Iowa Devonian conodont biostratigraphy follows Witzke et al. (1985, 1989), Klapper in Johnson and Klapper (1992), Bunker & Witzke (1992), Witzke & Bunker (1996), Day (1990, 1992, 2006), and Over (2002, 2006), Frasnian conodont zones after Klapper (1989). Devonian brachiopod biostratigraphy from Day (1989, 1992, 1996, 1997, new data). Iowa Basin Devonian stratigraphy after Witzke et al. (1989), Witzke and Bunker (1992, 1996), Day (1997), Day et al. (2008). Modified from Fig. 3 of Day (2006) and Day et al. (2008). Abbreviations: Bert. = Bertram Fm. = Formation, Mb. = Member, L = Lower, M. = Middle, U. = Upper.

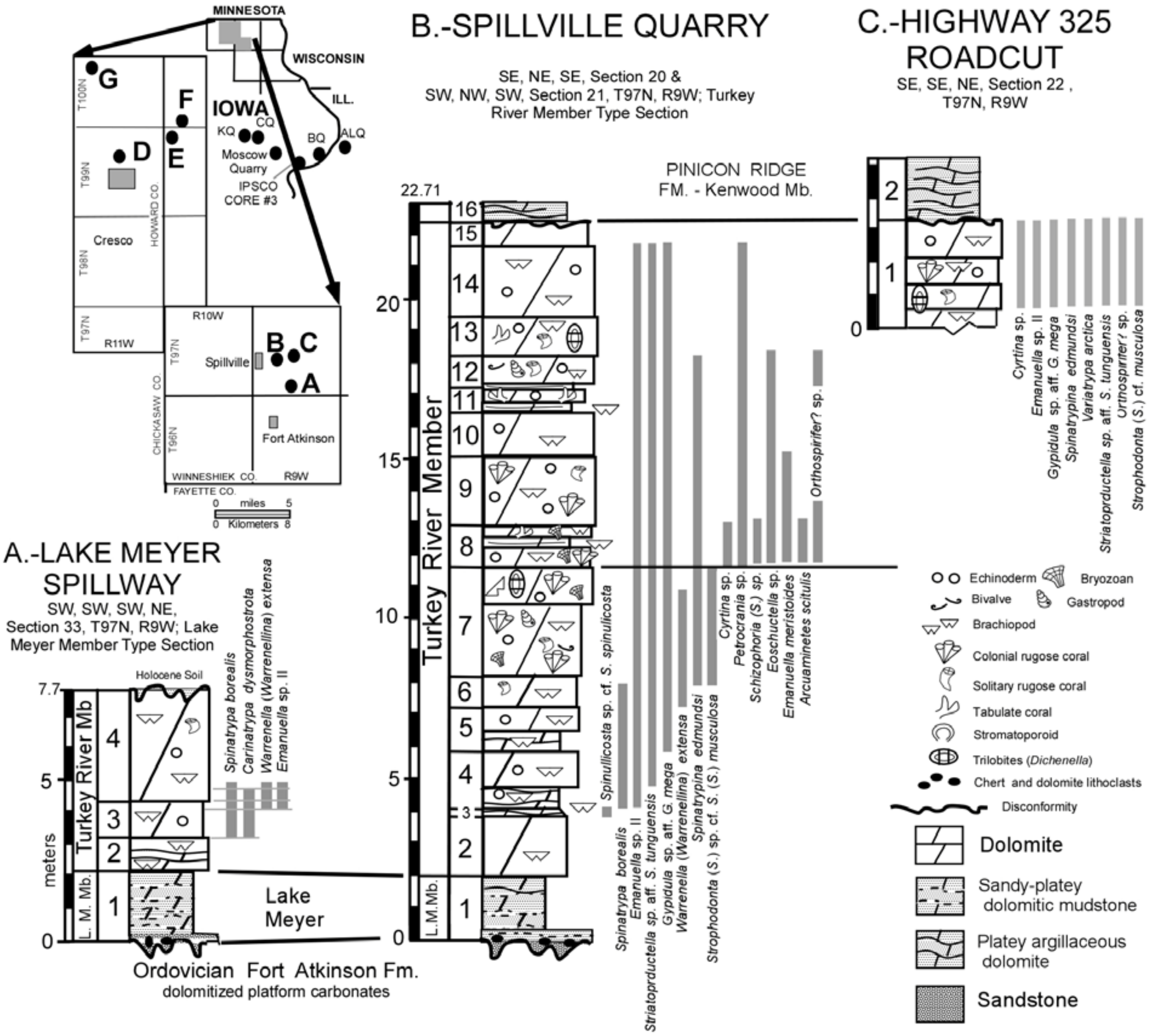

Figure 3.—Stratigraphy and brachiopod fauna in the Spillville Formation and lower Pinicon Ridge Formation (lower Wapsipinicon Group) in Winneshiek County, Iowa. Gray vertical bars show local ranges of brachiopod species in numbered and sampled lithic units at each section locality. Map shows locations of quarry exposures in Winneshiek and Howard counties. Modified from Fig. 4 of Day and Koch (1994), Koch and Day (1996). Abbreviations: Fm. – Formation; Mb. = Member; L. M. Mb. = Lake Meyer Member.

American Devonian T-R cycles IIb-2 of Day and others (1996), and confirm development of the two late Frasnian deepening 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 and offshore equivalents of the Sweetland Creek and lower Grassy Creek shales (Fig. 2).

Significant sea level low-stand events led to platform emergence and erosional incision and/or karst formation in platform carbonates of the Wapsipinicon and Cedar Valley groups in the Middle Givetian, the very late Givetian and 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 City

Member) across the inner shelf areas of northern and western Iowa (Day et al., 1996, 2008; 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).

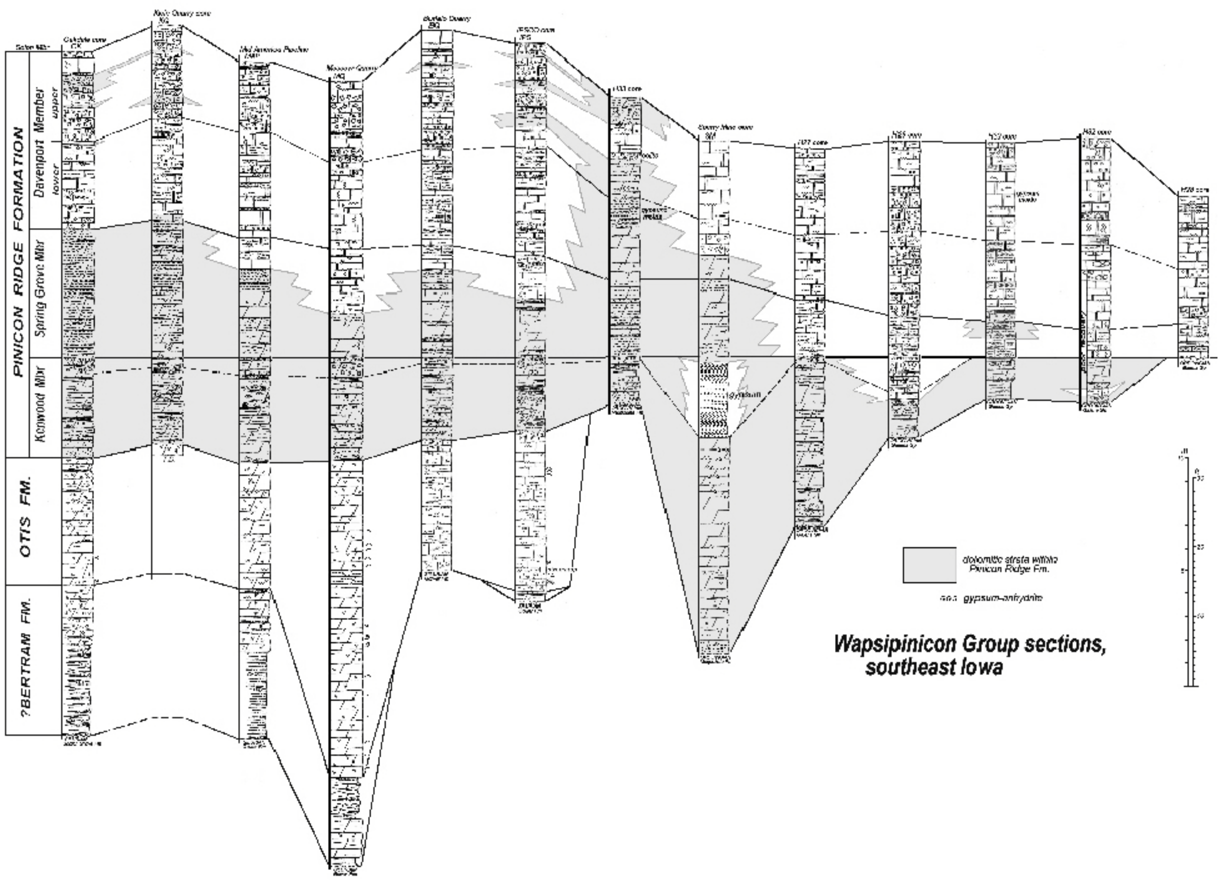

Figure 4.--Graphic sections and proposed correlation of Wapsipinicon Group strata in southeastern Iowa. Locations are shown on Figure 1 in the accompanying article on Cedar Valley Group stratigraphy. Symbols as in Figure 1 (see also Fig. 7 in Cedar Valley article). Cores are archived at the Iowa Geological Survey. Moscow Quarry (MQ) and Sperry Mine (SM) sections are based on core logs stored at the Iowa Geological Survey; MQ Otis section after J. Day (2006, pers. comm.).

MIDDLE-UPPER DEVONIAN STRATIGRAPHY OF NORTHERN IOWA

Epeiric carbonate platform deposits of the Wapsipinicon and Cedar Valley Groups and Lime Creek Formation make up the surface bedrock and subcrop across northern Iowa (Figs. 1 and 4). Field conference stops will focus attention on important quarry exposures of units of the upper Wapsipinicon and Cedar Valley groups, and the Lime Creek Formation. As defined by Witzke and others (1989) the Wapsipinicon and Cedar Valley groups consists of seven formations with all but one (Bertram, Fig. 2) corresponding to large-scale 3rd order Transgressive-Regressive (T-R) cycles (depositional sequence) deposited during a cyclic rise and fall of sea level. In ascending order, these include the Bertram, Otis or Spillville, Pinicon Ridge, 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 Middle Frasnian Cedar Valley Group carbonate platform deposits in northern Iowa and comprises parts of two 3rd order T-R cycles (Fig. 2). Third order depositional sequences, 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, 2006a) 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). The quarries visisted during the field conference are located in the inner shelf region, and consequently are the focus of discussion below. The inner and middle shelf 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. 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. Late Frasnian deposits display similar trends, although middle shelf facies expanded into northern Iowa, with inner shelf edge defined by the eastern and southern edge of the Owen Member shallow platform facies marking the transition to ramp shelf that became progressively deeper to the southeast towards the Illinois Basin during the Late Frasnian (Fig. 2)

WAPSIPINICON GROUP, CEDAR VALLEY GROUP AND LIME CREEK FORMATION STRATRATIGRAPHY ANS SEA LEVEL EVENT HISTORY

Deposition of Wapsipinicon Group, Cedar Valley Group and Lime Creek Formation T-R cycles during the late Eifelian to late Frasnian was marked by significant expansion of the subtropical seaways during transgressive and sea level high-stand intervals. During most sea level rises 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 Eifelian, 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 seven significant 3rd order, and additional 4rth order sea level rises that controlled the timing of upper Wapsipinicon Group, 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. 2).

WAPISIPINICON GROUP IN NORTHERN IOWA

The Wapsipinicon Group overlies a deeply eroded megasequence boundary (Sloss's Tippecanoe-Kaskaskia cratonic unconformity) in northern and eastern Iowa, where it is known to unconformably overlie Silurian (Gower, Scotch Grove, Hopkinton-Blanding formations) and Ordovician units (Maquoketa Formation, Galena Group). An overview of the general stratigraphy of the group is provided by Bunker and others (1985), Witzke and others (1988), and Witzke and Bunker (2006a). The strata of the Wapsipinicon Group are economically important in Iowa providing high quality aggregate and gypsum resources. Stratigraphic nomenclature within the Wapsipinicon Group was modified by Witzke and others (1989) who recognized the succession, in ascending order: Bertram Formation, Otis Formation, and Pinicon Ridge Formation (Kenwood, Spring Grove, Davenport members). In Northern Iowa, the Wapsipinicon Group includes the basal Spillville (Figs. 2 and 3) and overlying Pinicon Ridge formations (Fig. 4). The latter with the same members as in southern and eastern Iowa.

The age of the Bertram and Pinicon Ridge formations of the Wapsipinicon Group is difficult to constrain because of the virtual absence of of biostratigraphically useful fossils. The basal Bertram Formation overlies an unconformity on Silurian strata, and it has not yielded any fossils. Bertram deposition is likely allied with the overlying Otis Formation, possibly associated with rising base levels associated with Otis marine transgression (Witzke et al., 1988, Witzke and Bunker, 2006a; Day, 2006). The Otis Formation has yielded an impoverished conodont fauna consisting only of *Ozarkodina raaschi*; the species is well represented in the Spillville Formation of northern Iowa, whose conodont faunas indicate an upper Eifelian age (Klapper and Barrick, 1983). The Otis Formation of southeastern Iowa is correlative with the Spillville Formation and is considered to be the same age. Zonally significant miospores from the Otis Formation agree with this age assignment (Klug, 1994). With the exception of Klug's (1994) miospore study of the Wapsipinicon Group, no other biostratigraphically significant fossils are known from higher strata of the group. The miospores generally support a Givetian age for the Pinicon Ridge Formation (Klug, 1994). The Wapsipinicon Group is constrained above by basal Cedar Valley strata which contain conodonts of the middle *varcus* subzone (mid Givetian age). Therefore, the Pinicon Ridge Formation appears to be a Latest Eiflian to Middle Givetian age based on its stratigraphic position.

Spillville Formation

Collectively both members of the Spillville Formation defined (Figs. 2 and 3) appear to comprise a 3rd order depositional cycle deposited during Iowa Devonian T-R cycle 1 (Fig. 2) and Euramerican T-R cycle Ie of Johnson and others (1985, 1996) and Johnson and Klapper (1992). In their original definition of the Spillville Formation Klapper and Barrick (1982) did not name members within the new formation. In subsequent studies (Witzke and Bunker, 1982; Witzke et al., 1989; Day and Koch, 1994; Koch and Day, 1996; Day, 1996; Day et al., 1996), the basal two meters of unfossiliferous dolomitic siltstones and sandy mudstone of the Spillville in the type area (Fig. 3) were informally referred to as the "Lake Meyer Member". Here we divide the Spillville into the Lake Meyer and overlying Turkey River members as shown in Figures 2 and 3.

Lake Meyer Member (new)

The type section of Lake Meyer Member consists of the lower 2.2 meters of the Spillville Formation exposed at the Lake Meyer Spillway (Fig. 3, locality A), and consists of thin basal sandy chert and dolomite lithoclast conglomerates, overlain by unfossiliferous dolomitic mudstones, siltstones, and sandstones (Fig. 3). The only other exposures of the Lake Meyer are in the drainage ditch along Iowa State Highway 325 at the entrance to the Spillville Quarry (Fig. 3, locality B). The Lake Meyer Member overlays the major unconformity developed on the Late Ordovician Maquoketa Formation throughout its type area in the vicinity of the town of Spillville in Winneshiek County (Fig. 3). The Lake Meyer ranges from 2.0-2.2 meters in thickness, and is overlain at all surface exposures and in the subsurface by the Turkey River Member.

Turkey River Member (new)

The Turkey River Member is proposed to include the fossiliferous dolomites making up the majority of the Spillville Formation as originally defined by Klapper and Barrick (1983) at its type section in the Spillville Quarry on the eastern side of the Turkey River valley in Winneshiek County in northern Iowa (Fig. 3, locality B). The Turkey River overlies the Lake Meyer Member in its type area (Fig. 3), and progressively onlaps the disconformity developed on the Late Ordovician Maquoketa Formation across western Winneshiek and Howard counties and southern Minnesota (Fig. 4, Klapper and Barrick, 1983). At the Spillville Quarry it is 20 meters thick, and ranges from 7.5 to 11.2 meters in thickness in quarry sections in Howard County and northwestern Winneshiek County. It is generally much thinner in southern Minnesota (see Klapper and Barrick, 1983). The upper contact of the Turkey River Member is a disconformity, overlain by the Kenwood Member of the Pinicon Ridge Formation of the upper Wapsipinicon Group (Figs. 3; Witzke and Bunker, 1982; Witzke et al. 1989).

There are two distinct intervals within the Turkey River Member in Winneshiek County (Figs. 2 and 3). The lower 7.6 meters of the Turkey River (Fig. 3, units 2-lower 4 at locality A, units 2-7 at locality B) consists of dolomitized middle shelf mudstones and wackestones with moldic byrozoan, echinoderms, solitary rugose corals, and characteristic brachiopods of the *Carinatrypa dysmorphostrota* and *Spinatrypina edmundsi* zones (Fig. 3, locality A, upper unit 6 and unit 7). The upper Turkey River consists of dolomitized skeletal platform carbonates (locally with abundant colonial rugose corals and stromatoporoids) with a diverse marine fauna including brachiopods of the *Variatrypa arctica* Zone. The upper Turkey River interval includes the upper 10.8 meters of the Spillville at the

Spillville Quarry (Fig. 3, locality A, units 8-15), exposures of along Highway 325 and Calmar Road (Fig. 3, locality C, unit 1), and all sections to the north in Howard County. Strata with faunas of lower Turkey River *Carinatrypa dysmorphostrota* and *Spinatrypina edmundsi* zones are apparently absent in sections north of the type area in northern Winneshiek and eastern Howard County (Fig. 3).

The restricted distribution the Lake Meyer Member and lower Turkey River intervals with brachiopods of the *C. dysmorphostrota* and *S. edmundsi* zones suggest that during the T-R cycle 1A marine flooding and highstand phase (Fig. 2, T-R cycle 1A) seaway deposition was localized within paleoembayments. This was followed by the T-R cycle 1B deepening (Fig. 2) and expansion of the Spillville seaway during which the paleotopographically higher parts of the unconformity eroded on the Ordovician were onlapped across parts of northern Iowa during the *V. arctica* Zone as shown in Figure 2.

Post-T-R cycle 1 Emergence and Sea Level Lowstand

Spillville and Otis deposition was terminated in the Iowa Basin by a marine offlap and sea level lowstand in the latest Eifelian and or earliest Givetian (Fig. 2). Emergence and erosion of the Otis platform is evidenced by the development of karst features associated with a capping erosional disconformity surface with up to 3 meters of local relief developed at the contact of the Otis-Pinicon Ridge in the Riverstone Group's Allied quarry (see Day 2006, Figs. 1 and 5, Section ALQ) in Rock Island County, Illinois as demonstrated by Day et al. (2006, Fig. 7). Sediments of the basal Kenwood Member of the Pinicon Ridge locally fill sinkholes (see Day et al., 2006, Fig. 7) and karst cavities penetrating the upper 2 meters of the Otis (Fig. 5). The observed erosional relief on the upper Spillville is minor where the Spillville-Pinicon Ridge contact is exposed in northeastern Iowa (Fig. 3).

Pinicon Ridge Formation

The Pinicon Ridge Formation is the most widespread unit of the Wapsipinicon Group and oversteps the preserved depositional edges of the Otis and Spillville formations to overlay the regional unconformity developed on Silurian or Ordovician rocks across large parts of the Iowa Basin (Figs. 2 and 4). Pinicon Ridge deposition coincided with Euramerican T-R cycle If of Johnson and others (1989, 1996) as outlined in earlier studies by Witzke and others (1989), Day and others (1996), Witzke and Bunker (1996).

The Pinicon Ridge was divided Witzke and others (1989) into the Kenwood, Spring Grove, and Davenport members (Figs. 2, 4, and 5). It is overlain throughout the basin by basal Cedar Valley Group marine deposits of the Middle-Late Givetian Little Cedar Formation (Fig. 2). The Kenwood is interpreted to comprise an Iowa Devonian T-R cycle 2A (Figs. 2 and 4), and is overstepped by deposits of the Spring Grove and Davenport members (Figs. 2 and 4) that collectively comprise Iowa T-R cycle 2B. Witzke and Bunker (2006b) cited evidence for recognition of the Spring Grove and Davenport as distinct T-R cycle within 2B, here referred to as subcycles 2B-1 and 2B-2 (Figs. 2 and 4).

The Kenwood Member

oversteps the edge of the Otis and Spillville formations of the lower Wapsipinicon Group, and it unconformably overlies eroded Ordovician and Silurian strata across most of its extent in Iowa, northeast Missouri, and northwestern Illinois (Fig. 2). The Kenwood Member is comprised of peritidal facies including evaporate collapse breccias (Figs. 3 and 4). Even though the Kenwood shows significant geographic expansion over the subtidal and peritidal facies of the Otis and Spillville formations, the lack of normal marine facies and faunas and burrow fabrics are evidence that the basin displayed restricted circulation and widespread hypersalinity over a

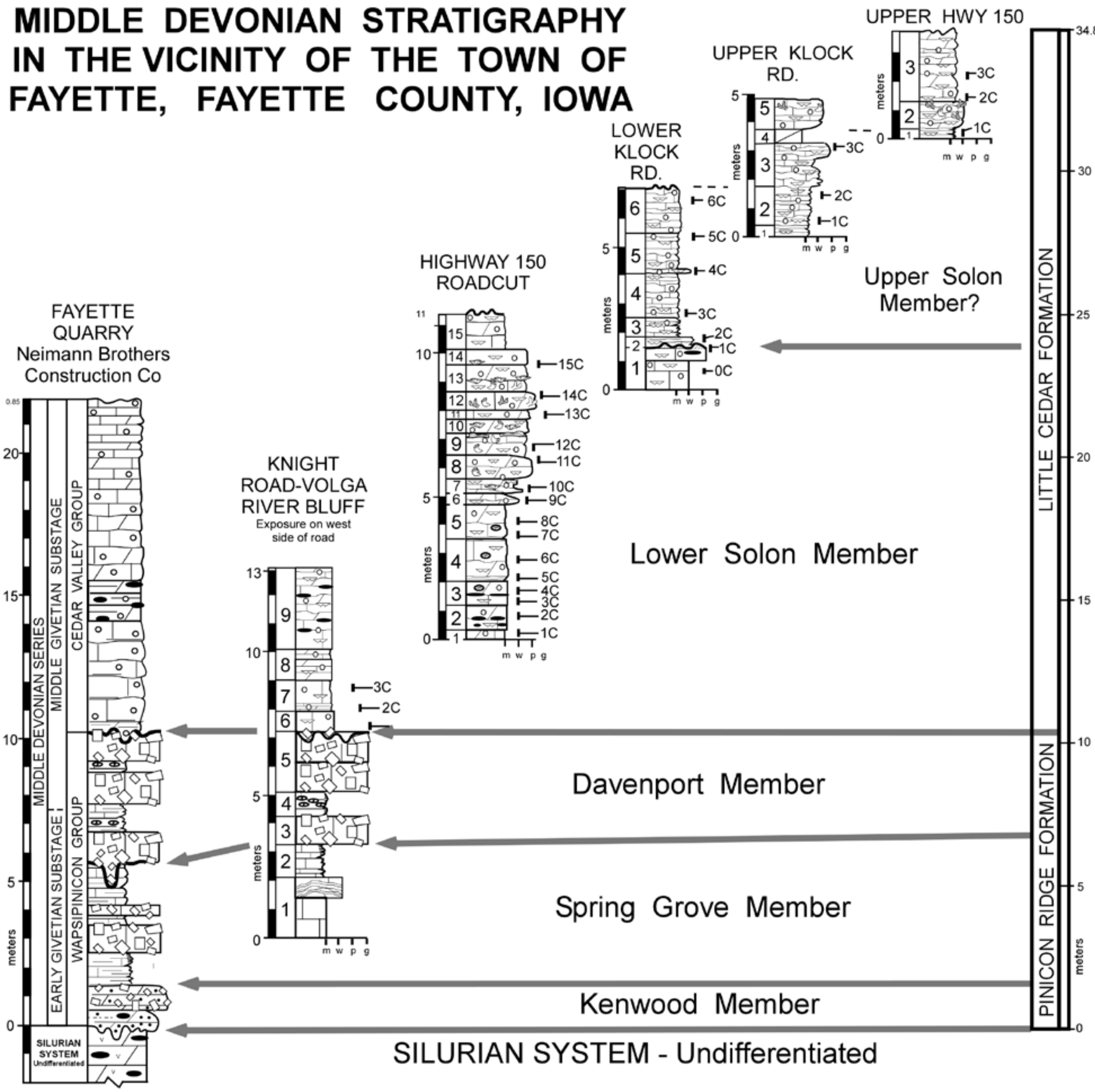

Figure 5.—Graphic sections and correlation of the Pinicon Ridge Formation (upper Wapsipinicon Group) and Solon Member of the Little Cedar Formation (lower Cedar Valley Group) in the vicinity of the town of Fayette in north-central Fayette County. Klock Road, Highway 150, and Knight Road sections measured and described by J. Day, June 2011. Fayette Quarry section adapted from Bunker et al. (1983, see stop 6-Fayette Quarry).

broad area (Witzke et al., 1989; Witzke and Bunker, 2006b, Day, 2006).

The Kenwood Member (also called the Kenwood Shale) is dominated by unfossiliferous argillaceous to shaley dolomite, in part silty to sandy, with lesser interbeds of gray to green shale, in part silty to sandy. Silt and sand grains are composed of quartz and chert. Some dolomite beds are irregularly laminated to mottled. Intraclastic and brecciated beds are common. Concretionary masses of chalcedony and chert are seen in many sections, and some dolomite beds are siliceous. The Kenwood Member includes gypsum and anhydrite evaporite units at localities in southeastern Iowa, and economic gypsum deposits are extracted from the upper Kenwood in subsurface mines near Sperry, Iowa (Sperry Mine section, Fig. 3). Nodular, mosaic, and bedded gypsum-anhydrite are identified, especially in the upper part (Giraud, 1986), and gypsum-anhydrite nodules and stringers are known to interstratify with dolomite beds in the lower part. Where evaporite facies are absent in southeastern Iowa, correlative breccia intervals are recognized, most notably in the upper part of the member (dashed correlations, Fig. 3). These breccias are interpreted to have formed by solution-collapse of interbedded carbonate-evaporite strata, recording the presence of formerly widespread evaporite units within the member. Gypsum crystal molds are locally observed within the upper Kenwood breccias (Fig. 1).

The Kenwood Member lacks evidence of marine biota, and burrow fabrics are also absent in most beds. Possible burrow fabrics and stromatolitic laminations at a few localities are the only evidence of possible benthic biota in the member. Klug (1994) recovered undiagnostic miospores from the Kenwood. The general absence of benthic fauna and the presence of evaporite units and evaporite collapse breccias suggest a highly restricted environment of deposition, certainly hypersaline at times, and probably with elevated salinities through much or all of its deposition. Even though the Kenwood shows significant geographic expansion over the Otis Formation, a unit that includes marine limestone facies, the Kenwood lacks normal marine facies and faunas. This suggests that the basin of deposition had marginal circulatory barriers which restricted open marine circulation and promoted widespread hypersalinity through net evaporation over a broad area (Witzke et al., 1988). The widespread continuity of the upper Kenwood evaporite and equivalent collapse breccias is interpreted to reflect overall depositional shallowing and increasing hypersalinity in the restricted basin,

Spring Grove Member

Spring Grove member overlies (possibly disconformably) the Kenwood Member and onlaps Ordovician or Silurian strata (Figs. 2 and 4) where the Kenwood Member is absent (especially above Silurian paleoescarpments in Fayette and Bremer counties). The Spring Grove and Davenport members of the Pinicon Ridge were interpreted by Witzke and Bunker (2006b) to represent distinct permitting recognition of Iowa Devonian T-R subcycles 2B-1 and 2B-2 (Fig. 2).

In Linn and Johnson counties (Figs. 1 and 4), the lower Spring Grove Member is dominated by laminated petroliferous dolomite strata, whereas the overlying Davenport Member is characterized by limestone strata with collapse breccias (especially in the upper part). Elsewhere in southeastern Iowa and parts of northern Iowa the distinction between limestone and dolomite strata is less distinct. In fact, the stratigraphic position that separates limestone and dolomite facies in southeastern Iowa varies significantly (Fig. 4), and Spring Grove strata locally include limestone facies, and Davenport strata are variably dolomitic in some sections. Except where coincident with the shift from dolomite to limestone, the boundary between the Spring Grove and Davenport members is gradational and arbitrary. The limestone-dolomite facies boundary within the succession (Fig. 4) is interpreted to be a diagenetic facies transition and not a primary depositional feature. The Spring Grove-Davenport interval is recognized over a broad area of eastern, northern, central, and southern Iowa, and it is known to extend into adjoining areas of southern Minnesota, northern Missouri, and western Illinois (Witzke et al., 1989). The interval generally overlies the Kenwood Member, possibly disconformably, but it unconformably overlies Ordovician or Silurian strata where the Kenwood Member is locally absent (especially above Silurian paleoescarpments in northern Iowa.

Typical Spring Grove dolomite strata are dominated by thinly-laminated dolomite facies, and the laminated units are petroliferous to varying degrees, producing a distinctive fetid odor when freshly broken. The organic-rich carbonaceous laminations are brown to black in color in unoxidized sections. The thin horizontal laminations, typically marked by alternations in organic content and dolomite crystal size, are often seen to be laterally continuous. Some crenulated to domal laminations are probably stromatolitic in origin (Fig. 4). The Spring Grove dolomites are porous to vuggy to varying degrees. Some units within the member are only faintly laminated, and non-laminated vuggy dolomite beds are also observed. The member appears to be generally unfossiliferous, but burrows, stromatolites, and ostracodes, indeterminate medusoid forms, and placoderms have been noted (Witzke et al., 1988; Hickerson, 1994), the latter two groups noted from a single locality (Fig. 1, Milan Quarry, Illinois). Minor breccias and intraclastic units are seen at some localities (Figs. 4 and 5). Giraud (1986) observed nodular to mosaic anhydrite in the Spring Grove within evaporite-bearing Wapsipinicon successions in southeastern Iowa, and gypsum-anhydrite void fills are also noted locally.

The laterally continuous laminations and general absence of desiccation features within the Spring Grove Member at most localities was interpreted by Sammis (1978) to support deposition in a subtidal setting within a restricted basin of elevated salinity. However, Hickerson (1994) observed a prominent desiccation surface exhibiting large polygonal cracks in the upper 50 cm of the Spring Grove at the Milan Quarry, as well as a disconformity that separates upper and lower strata. He also interpreted upper Spring Grove deposition to include peritidal/supratidal environments, based on his discovery of a local desiccation surface. As such, the Spring Grove succession may represent a general shallowing-upward T-R cycle 2B-1 (Fig. 2).

Hickerson's (1994) remarkable discoveries of ptycodontid placoderm skeletons (bitumen impregnated) in the upper Spring Grove and a possible arthrodire placoderm cranium in the lower Spring Grove at the Milan Quarry (Figs. 1 and 4) are particularly enlightening. Although the Spring Grove Member is largely devoid of macrofauna, these discoveries indicate that certain fish taxa were capable of living in the shallow restricted environments of Spring Grove deposition, at least at times.

Witzke and Bunker (2006b) summarized evidence that the Spring Grove Member represents a distinct shallowing-upward cycle (Figs. 2 and 4). The prominent desiccation surface with mud cracks in the upper 50 cm of the Spring Grove is associated with the disconformity (noted by Hickerson, 1994) at its contact with the Davenport Member at the Milan Quarry (Fig. 1).

Davenport Member

A third T-R cycle, represented by the Davenport Member, was recognized within the Pinicon Ridge Formation by Witzke and Bunker (2006a). The Davenport onlaps the disconformity capping the Spring Grove carbonates in southeastern Iowa and western Illinois. Strata including pelletal and oolitic units were deposited in shallow subtidal settings (Sammis, 1978; Witzke et al., 1989; Witzke and Bunker, 2006a). The absence of a marine benthic shelly macrobiota, and presence of stromatolitic laminations, burrows and ostracodes in some beds, fenestral limestones, desiccation surfaces, evaporites and evaporite solution-collapse breccias in the bulk of Davenport indicates deposition in a hypersaline environment in the Iowa Basin during the Middle Givetian (Figs. 4 and 6).

The Davenport Member is dominated by limestone across most of its extent, primarily characterized by dense 'sublithographic' limestone, laminated to stromatolitic in part, and with common stylolites. The term 'sublithographic' refers to the resemblance to limestones used in lithographic engraving, and these dense lime mudstones often break with a conchoidal fracture. The Davenport limestones are dominantly mudstones, but pelletal and intraclastic units are also commonly present. Rare oolitic packstone-grainstone beds are noted (H33, Fig. 2). A few limestone beds display calcite-filled fenestral and 'birdseye' fabrics and gypsum crystal molds (Figs. 4 and 5). Scattered chalcedony concretions are recognized locally. Although the member is dominated by limestone, discontinuous and local dolomite and dolomitic limestone beds are recognized at a number of localities (Fig. 4). Thin shales (in part silty to sandy) and argillaceous to shaley units are observed in many sections. The Davenport Member is dominated by evaporite facies in some areas of southeastern Iowa, where nodular, mosaic, and massive gypsum-anhydrite units are observed to interbed with limestone and dolomite strata (Giraud, 1986).

The Davenport Member is best known for its well-developed limestone breccias (Fig. 5, Day et al., 2013, Stop 1, Fig. 3), a characteristic feature in most sections across its geographic extent. These breccias consist of irregular unsorted angular clasts of limestone (varying in size from a few millimeters to large blocks in excess of 1 meter diameter) generally in a limestone to argillaceous limestone matrix. The Davenport breccias have been interpreted to have formed by solution-collapse processes (Sammis, 1978). This process results from the dissolution of evaporite layers causing the fracturing and internal collapse of intervening carbonate beds. Most breccia clasts consist of lithologies seen in within the Davenport Member, primarily sublithographic and laminated limestone. However, the upper breccias also contain scattered fossiliferous limestone clasts derived from overlying strata of the Solon Member.

The Davenport Member can be divided into upper and lower units across much of its extent in southeastern Iowa. The lower interval consists predominantly of sublithographic limestone beds, commonly laminated to stromatolitic (Figs. 1, 2, 4). Breccias are locally present, but they are subordinate to the bedded limestone strata. By contrast, the upper interval contains abundant limestone breccias, and breccias form the dominant lithology at many localities (Figs. 1, 2, 4). Nevertheless, breccia units are replaced laterally by bedded limestone units at some localities, and the upper interval, although brecciated in part, is dominated by bedded limestones in the Quad Cities area (Fig. 4).

Post-Pinicon Ridge Sea Level Lowstand

Exposure and solution collapse breccias indicate that a lowstand terminated Davenport platform deposition. Sammis (1978) outlined evidence for subaerial exposure, erosional relief, and meteoric diagenesis of the Davenport Member prior to deposition of basal Cedar Valley marine strata. Evaporite solution-collapse was initiated during the Middle Givetian episode of subaerial exposure and freshwater diagenesis. The presence of fossiliferous clasts derived from the late Middle Givetian age Solon Member of the Little Cedar Formation within the upper Davenport collapse breccias (Figs. 4 and 5) indicates that solution of underlying Davenport evaporite units and brecciation was coincident with early Cedar Valley Group deposition during the Middle *varcus* Zone (Witzke et al., 1989; Witzke and Bunker, 2006a).

CEDAR VALLEY GROUP IN NORTHERN IOWA

The basal Cedar Valley Group onlaps and oversteps strata of the Middle Devonian Wapsipinicon Group northwestward in Iowa to directly overlie Ordovician strata across northern and northwestern Iowa (Figs. 1 and 7). The succession of individual formations (T-R sequences) within the group progressively onlaps and oversteps underlying strata in a northwestward direction (Figs. 1 and 7), delimiting the depositional margins of the succession of Cedar Valley sequences across northwestern Iowa and south-central Minnesota. The Cedar Valley Group locally overlies Silurian strata along the trends of two erosional Silurian paleoescarpments in northeastern and southeastern Iowa (Witzke et al., 1989).

Cedar Valley Group epeiric carbonate platform deposits of the Iowa Basin (Figs. 2, 6 and 7) accumulated during the interval of the middle Givetian (upper Middle *varcus* Zone = *ansatus* Zone) to middle Frasnian (Montagne Noire Zone 10?), and record four 3rd order and as many as five additional “4th order” relative sea level changes (Fig. 2, Iowa T-R cycles 3 to 6) outlined in studies by Witzke and others (1989), Witzke and Bunker (1992, 1996, 1997, 2006a), Day (1996, 1997, 1998, 2004, 2006), and Day and others (1996, 2008). Cedar Valley Group T-R cycle sequence packages are bounded regionally by disconformities, and regressive portions of these cycles developed in the inner shelf facies belt are typically marked by progradation of peritidal or marginal-marine facies bounded by sub aerial exposure and erosional surfaces in northern and central Iowa (Figs. 2). Across the middle shelf facies belt in southeastern Iowa and western Illinois, sequence packages are developed entirely in condensed subtidal deposits (Figs. 7 and 8).

The marine transgression that initiated deposition of Iowa Devonian T-R cycle 3 corresponds to one of the most significant eustatic sea level rises of the Devonian first recognized as the Taghanic Onlap of Johnson (1970), and later designated as Euramerican Devonian T-R cycle IIa of Johnson and others (1985, 1989, 1996). Deposition of the lower interval of Euramerican T-R cycle IIa (see fig. 12 of Johnson et al., 1985, fig. 12) in the Iowa Basin involves at least two significant stepped sea level rises (Fig. 2, Witzke et al., 1989, Witzke and Bunker, 1992, 1996, 2006a). The first Cedar Valley Group sea level rise of T-R cycle 3A coincided with the major flooding initiating Devonian T-R cycle IIa (IIa-1 of Day et al, 1996) within the Middle *varcus* Zone (base of *ansatus* Zone), and the second and intra-IIa event occurred at the base of the *hermanni* Zone (Fig. 2). Johnson et al. (1985, fig. 12) showed a third stepped sea level rise within the upper part of the interval of their T-R cycle II. Day et al. (1996) defined the upper T-R cycle IIa deepening event as IIa-2, coinciding with Iowa Devonian T-R cycle 4 (Figs. 2 and 8, Coralville Formation).

All major Cedar Valley Group Middle Givetian-Middle Frasnian age T-R cycles (see Figs. 2, 7-17) are widely traceable and have been correlated with coeval sea level events in carbonate shelves in central and western North American basins (Day et al., 1996; Day and Whalen, 2005; Whalen and Day, 2008), and the Appalachian foreland Basin. Discussion below is focused on Middle Givetian-Early Frasnian Iowa T-R cycles 3 to 5 and further subdivisions of North American Devonian T-R cycles IIa and IIb of Johnson and others (1985).

Little Cedar Formation

The Little Cedar Formation comprises Iowa Devonian T-R cycle 3 (Figs. 2, 5 to 7) deposited during two sea level events (Witzke et al., 1989; Witzke and Bunker, 1996). The first is the most-widely traceable marine flooding event of the Middle Devonian that was referred to as the Taghanic Onlap by Johnson (1970) and later designated as the initial flooding event of Euramerican Devonian T-R cycle IIa of Johnson and others. (1985).

The Little Cedar is divisible into two subcycles represented by the Solon and Rapid members in the middle shelf facies tract, and an expanded Solon and or Bassett, Eagle Center, and Hinkle members of the proximal middle and inner shelf facies tract in the northern, central and western parts of the basin (Figs. 5 to 7). The Rapid Member deepening event resulted in back-stepping of the older Solon Member platform and permits subdivision of Iowa Devonian T-R cycle 3 into subcycles 3A and 3B, and permits subdivision of Euramerican cratonic T-R cycle IIa-1 of Day and others (1996) into subcycles IIa-1A and IIa-1B (Fig. 2). The Rapid Member is not recognized in the northern Iowa outcrop belt (Figs. 6 and 7) and is not discussed in detail below. The deepening event that began at or near the base of the *hermanni* Zone coincides with Tully carbonate platform drowning by dark grey-black shales of the Geneseo Formation in the Appalachian Basin. This same deepening event is recognizable in some sites in western Canada (Day et al., 2009).

Solon Member and lower Basset Member

The lower Little Cedar Formation comprises a shallowing-upward succession (Figs. 2, 5 7) designated as Iowa T-R subcycle 3A by Witzke and Bunker (1994, 1996, 2006a), and Day (2006). The Solon disconformably overlies the Wapsipinicon Group in the middle shelf region and the basal contact locally displays over one meter of vertical relief (Figs. 5 and 8). The Solon is traceable into northern Iowa as far north as Fayette and southern Winneshiek counties (Figs. 1, 5 to 8) and is up to four times thicker in this region than it the type are of the Solon in its type area (Fig. 6).

Condensed middle shelf facies of the Solon Member forms the basal interval of the Little

Cedar Formation in east-central and eastern Iowa (Fig. 6), and thins significantly in southeastern Iowa (Figs. 2 and 6), locally as thin as 2 m, and reaches its maximum condensation in Scott, eastern Muscatine, Louisa, Des Moines, and northern Lee counties (Fig. 6). Multiple hardground surfaces are recognized within the thin Solon succession of southeast Iowa, and a well-developed sculpted hardground surface comprises the Solon-Rapid contact in that area. Hardgrounds are observed at different positions in the expanded Solon Member sections in northern Iowa in Buchanan (Brooks Quarry, Figs 8 and 9), and Fayette County (Figs. 5 and 9). At the Brooks Quarry

The Solon Member correlates with the lower Bassett Member northwestward across Iowa as well as southward into northeastern Missouri (Figs 6 and 7). The type locality of the Solon Member occurs in Johnson County, Iowa (Witzke et al., 1989), where the member averages about 6 m thick. The Solon disconformably overlies the Wapsipinicon Group in the region, locally displaying up to 1 m or so of vertical relief, and basal Solon strata are locally sandy. The lower Solon ("*independensis* beds") in Johnson County is characterized by slightly argillaceous fossiliferous limestone (wackestone and packstone) with a diverse marine fauna (brachiopods, crinoid debris,

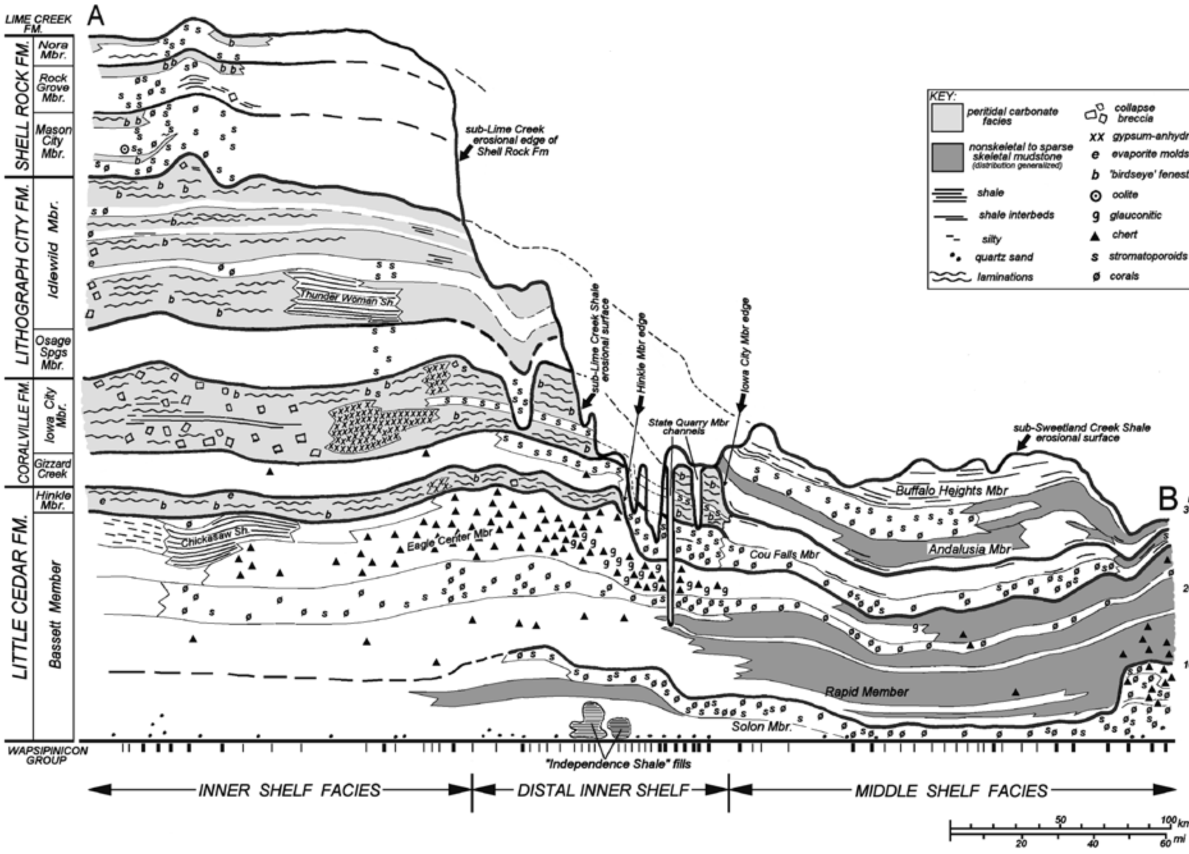

Figure 6.—Northwest-southeast stratigraphic cross section of the Cedar Valley Group in eastern Iowa (Fig. 1). Significant Late Givetian (pre-*norrisi* Zone) post-Coralville and Middle Frasnian sub-Lime Creek/Sweetland Creek erosion has truncated Cedar Valley strata, especially in the distal inner-shelf area. "Independence Shale" fills are stratigraphic leaks of the Late Frasnian Lime Creek Formation within Cedar Valley karst networks and openings. See Fig. 1 for location of cross-section line (AB) and data points used in the cross-section construction. After Fig. 2 of Witzke and Bunker (2006a). Datum = top Wapsipinicon Group.

bryozoans, etc.). A widespread submarine hardground surface occurs near the top of the lower Solon interval in southeastern and in northern Iowa (Fig. 5). The upper Solon ("*profunda* beds") in Johnson County is dominated by fine skeletal packstone with accumulations of corals and stromatoporoids, in part forming widespread biostromes. Upper Solon strata were deposited in shallower environments than the lower Solon.

Rapid Member

Rapid Member in southern and eastern Iowa is replaced northwestward in Iowa by subtidal inner-shelf facies of the middle to upper Bassett Member, Eagle Center Member, and Chickasaw Shale members that are capped by progradational peritidal facies of the Hinkle Member across the inner shelf (Figs. 6 and 7). The Rapid biostrome beds of Johnson County are replaced northwestward by coral- and stromatoporoid-rich facies (locally biostromal) within the Bassett Member (Fig. 7). Upper Rapid facies are replaced by similar cherty and glauconitic facies of the Eagle Center Member in the central to distal areas of the inner shelf, and by facies of the upper Bassett and Chickasaw Shale in more proximal areas of the inner shelf (Figs. 6 and 7). The Hinkle Member marks the final regressive phase of shallowing sedimentation for the Little Cedar sequence, culminating in subaerial exposure (sub-Coralville erosional surface) as the seaway withdrew from the inner-shelf area.

The Rapid Member and inner shelf equivalents assigned to the upper Basset, Eagle Center, Chackasaw Shale and Hinkle members (Figs. 1 and 6 and 7) are interpreted to represent T-R subcycle 3B (Figs. 2 and 7) within the larger Little Cedar T-R sequence 3 (Witzke and Bunker, 1994, 1996, 2006a; Day, 2006). T-R cycle 3B deposition was initiated in the basal *hermanni* Zone (Figs. 2, 6). Open marine middle shelf deposits of the lower Rapid Member strata with conodonts of the *hermanni* Zone are associated with a diverse brachiopod fauna of the *Spinatrypa bellula* Zone (Figs. 2 and 6). The overlying biostromal units and upper Rapid strata in the type area yield conodonts of the Lower *subterminus* Fauna and brachiopods of the *Devonatrypa waterlooensis* Zone (Figs. 2 and 6).

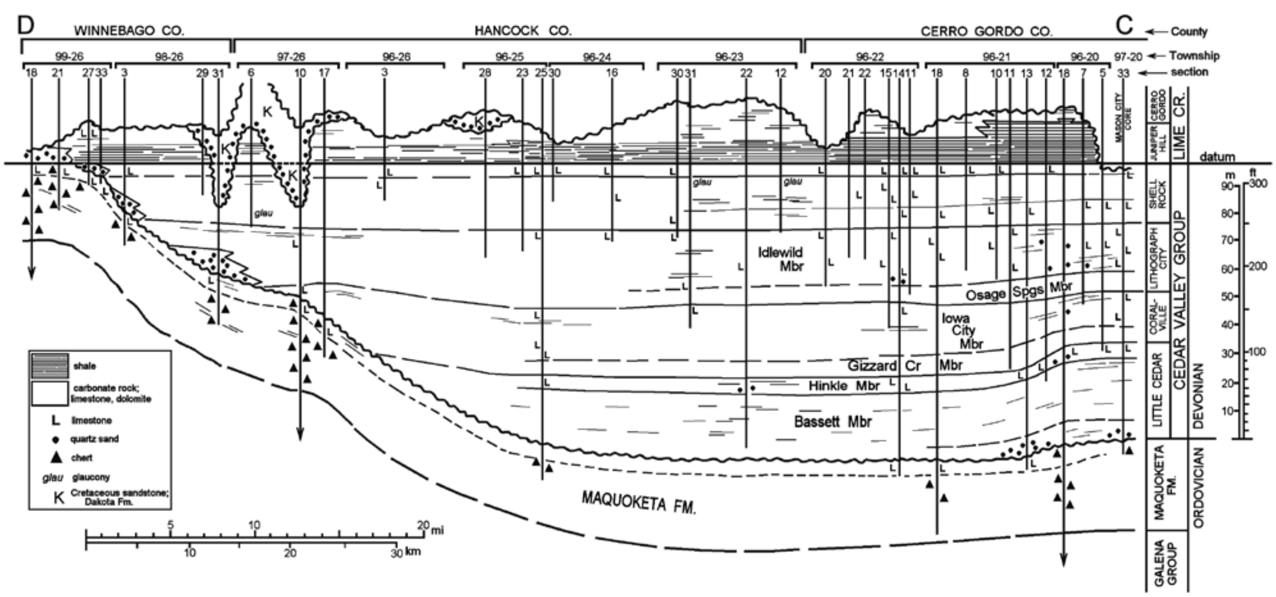

Figure 7.-- Interpretive stratigraphic cross section showing northwestward onlap of units within the Cedar Valley Group across the Devonian-Ordovician unconformity in north-central Iowa. Datum is base of Lime Creek Formation (interpolated where truncated by Cretaceous strata). See Figure 1 for location of cross-section line (CD) and well points used in the construction (well descriptions and locations available on Geosam database, http://gsbdata.igsb.uiowa.edu/geosam/).

Bassett Member

The Bassett Member (Figs. 6 and 10) is dominated by slightly argillaceous to argillaceous dolomite, commonly vuggy, and containing scattered to abundant fossil molds. Limestones and dolomitic limestones generally increase in abundance throughout the member southward in the Iowa outcrop belt. Chert nodules occur locally, generally in the upper half. Stylolites and hardgrounds are present, especially in the lower half of the member. The basal Bassett Member is silty, sandy, and/or conglomeratic in areas where it overlies Ordovician strata.

The Bassett Member disconformably overlies the Wapsipinicon Group throughout most of the outcrop belt, but overlaps the Wapsipinicon edge to the west in the subsurface to overstep the eroded surface developed on Upper Ordovician strata. The member locally overlies beveled Silurian rocks along the trend of the Hardin-Bremer High, where its basal unit is coralline (Dorheim and Koch, 1962). The Bassett is overlain conformably by the Chickasaw Shale in the northern outcrop belt, where it ranges in thickness from 19 to 25 m. The Bassett is overlain conformably by the Eagle Center Member to the south where it ranges in thickness from 15 to 25 m. The Chickasaw Shale and Eagle Center members are not recognized west of the outcrop belt in the subsurface of north-central and central Iowa; the Bassett averages 30 m in thickness and is conformably overlain by the Hinkle Member in those areas.

The Bassett Member is dominated by dense, sparsely fossiliferous calcilutite and coralline to brachiopod-rich calcarenites near its southern limit. It interfingers with characteristic lithologies of the Solon and lower to middle Rapid members in that area, where it locally overlies the Solon Member and is overlain by upper Rapid strata. Conodonts from the lower part of the Bassett include *Icriodus brevis, I. latericrescens latericrescens, Polygnathus linguiformis linguiformis* (gamma and epsilon morphotypes), *P. ovatinodosus, P. alveoliposticus, P. ansatus, P. varcus, P. xylus xylus*, and others (Klug, 1982b; Klapper and Barrick, 1983; Witzke et al., 1988; Rogers, 1990). This fauna indicates assignment to the Middle *varcus* Subzone (now the ansatus Zone, Fig. 2) and indicates correlation with most or all of the Solon Member to the south. The lower unit contains an abundant brachiopod fauna, typically atrypid-dominated (*Desquamatia* (*Independatrypa*) and *Spinatrypa*). Conodonts of the middle and upper intervals of the Bassett Member are not zonally significant but include *I. brevis, I. latericrescens latericrescens, P. xylus xylus*, and *P. ovatinodosus* (middle unit); stratigraphic position suggests correlation with the lower and middle parts of the Rapid Member. The middle part of the Bassett is typified by sparsely fossiliferous burrowed calcilutite fabrics, but fossiliferous beds occur within the unit. This unit also includes local packstone beds of *Rensselandia* and sparse corals (pachyporids and favositids) near the southern limits of the member. The upper part contains biostromal beds rich in corals and/or stromatoporoids, variably dominated by favositids, solitary rugosans, *Hexagonaria*, or domal or laminar stromatoporoids, and including *Asterobillingsa* near its southern limit. Glauconitic and phosphatic strata below the Eagle Center Member have produced an interesting fish fauna, as well as conodonts of the basal subterminus Fauna (Denison, 1985).

Chickasaw Shale Member

The Chickasaw Shale Member (Figs. 6 and 10) is composed of medium-gray dolomitic shale and argillaceous to shaly dolomite, in part silty. Nonskeletal, sparse to abundant burrow-mottled fabrics dominate, but skeletal material is noted in the lower 1 to 1.8 m at most localities (bryozoans, *Devonatrypa,* and other brachiopods). The Chickasaw Shale ranges from 5.4 to 6.5 m in thickness. It is replaced to the south by strata of the Eagle Center Member and to the west by argillaceous and silty beds in the upper Bassett Member (Witzke and Bunker, 1984).

Eagle Center Member

The Eagle Center Member (Fig. 6 and 10) consists of an interval of argillaceous and generally cherty, laminated dolomite below the Hinkle Member and above the Chickasaw Shale or Bassett Member. The member is dominated by sparsely fossiliferous to unfossiliferous burrowed argillaceous dolomite and contains prominent chert nodules and bands in the lower one-half to seven-eighths. Faint to prominent laminations, in part disrupted by scattered burrow mottles, characterize much of the member at most sections; some laminations are pyritic (Anderson and Garvin, 1984). Thin dolomitized or silicified fossiliferous calcilutite and calcarenite beds are interspersed locally within the generally unfossiliferous sequence. The Eagle Center is not dolomitized to the southeast of the type area, where it is dominated by sparsely fossiliferous to unfossiliferous, burrowed, cherty, argillaceous calcilutite, in part laminated, and contains thin skeletal calcarenite beds. Upward it becomes dominantly finely calcarenitic. Upper Eagle Center strata, primarily in areas where the member overlies the Chickasaw Shale, contain stromatoporoids or corals and are locally biostromal. The Eagle Center Member ranges in thickness from 8 to 11 m where it overlies the Bassett Member, and is 1.4 to 4.2 m thick where it overlies the Chickasaw Shale.

Conodonts from the Eagle Center Member (*Icriodus subterminus* and *Polygnathus xylus xylus*) are assigned to the Lower *subterminus* Fauna (Witzke et al., 1988; Rogers,1990), equivalent to the Lower *disparalis* Zone (Fig. 2, Day, 2010). Macrofauna is sparse in the member, but scattered fish debris (placoderm and shark) is noted in the laminated dolomites. Thin fossiliferous beds within the laminated sequence have yielded brachiopods (*Devonatrypa waterlooensis*, *Orthospirifer*, *Cranaena*, and "*Cupularostrum*"), bryozoans, and crinoid debris (Anderson and Garvin, 1984). Upper strata are locally biostromal, primarily in the northern sections, and have yielded corals (*Hexagonaria,* solitary rugosans, and favositids), domal stromatoporoids, brachiopods, crinoid debris, and rostroconchs. The fauna and stratigraphic position indicates correlation of the Eagle Center with upper Rapid strata.

Hinkle Member

The Hinkle Member (Figs. 2, 6 and 10) is the uppermost member of the Little Cedar Formation in northern and central Iowa, where it conformably overlies the Eagle Center or Bassett members and is disconformably overlain by the Coralville Formation. It conformably overlies the upper Rapid Member along its southernmost extent. The Hinkle Member is characterized by dense unfossiliferous "sublithographic" limestone and dolomitic limestone, in part with laminated, pelletal, intraclastic, and "birdseye" fabrics. Similar fabrics are noted at all known sections, but the member is partially to completely dolomitized over most of north-central and central Iowa. Hinkle strata are generally unfossiliferous, but burrows, ostracodes, and sparse brachiopods have been noted locally. The member is commonly fractured to brecciated, and argillaceous beds and minor shale (locally carbonaceous) are present at many sections. Laminated carbonates are petroliferous in part, and desiccation cracks and minor erosional disconformities occur within some Hinkle sequences. Gypsum molds are present locally (e.g., Klug, 1982b, p. 47), and the member includes extensive evaporites (gypsum and anhydrite) in central Iowa (Fig. 10). The Hinkle changes character near its eastern margin where faintly laminated limestones are interbedded locally with thin fossiliferous limestone beds containing brachiopods, echinoderm debris, favositids, and domal stromatoporoids. The Hinkle Member averages about 2.5 m in thickness and is known to vary between 0.4 and 4.1 m. Erosional relief, locally to 1 m, is evident below the Coralville Formation at some localities.

Coralville Formation

Keyes (1912) proposed the term Coralville for these coral-bearing rocks, and included it as a stratigraphic unit within the Cedar Valley Limestone. Stainbrook (1941a) designated the type section at Conklin Quarry adjacent to the city of Coralville, Johnson County, Iowa. In 1988, Witzke et al. designated the Coralville as a formation within the Cedar Valley Group. The Coralville Formation includes a lower fossiliferous carbonate member with an abundant marine fauna (Cou Falls or Gizzard

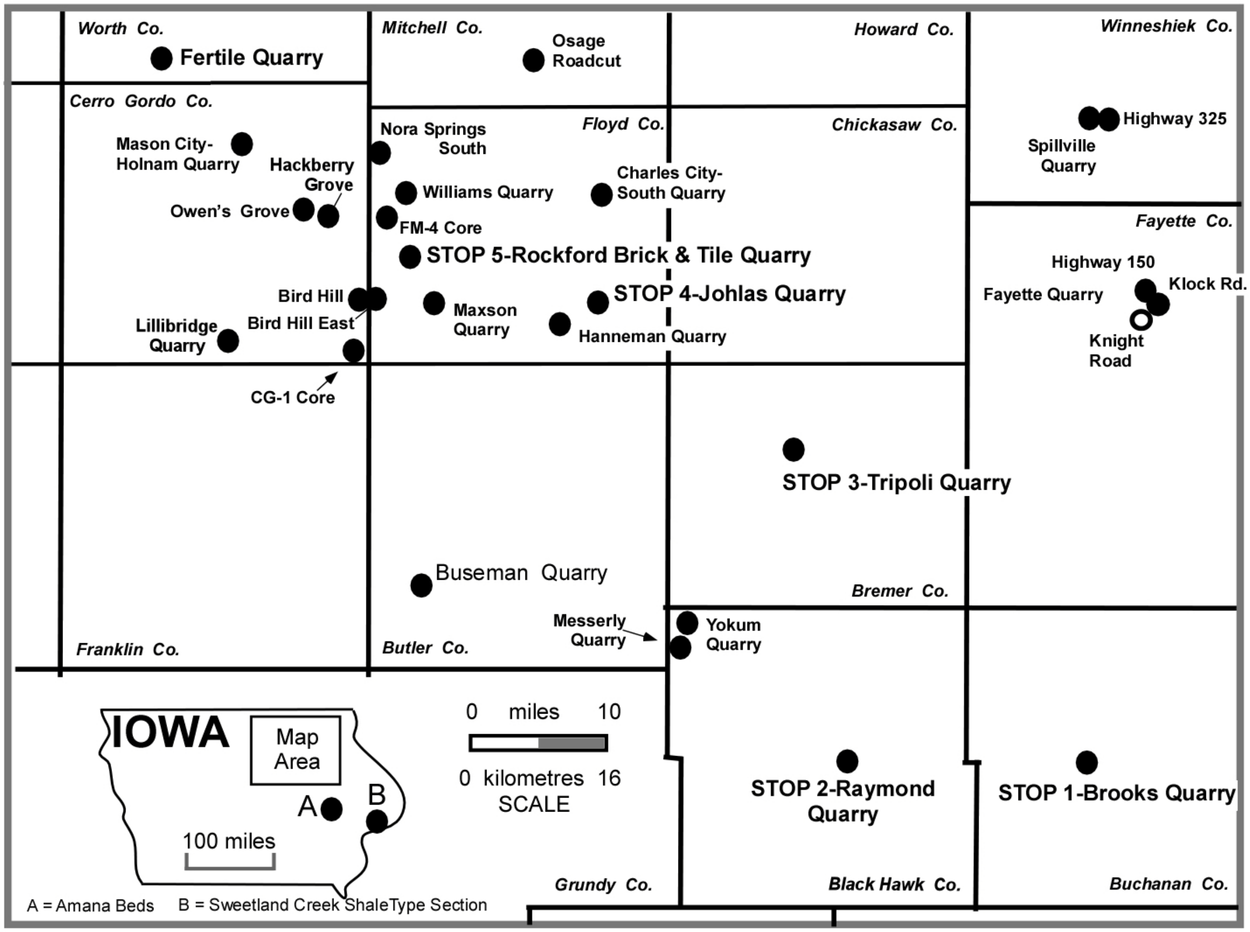

Figure 8.—Map of north-central and northeastern Iowa showing locations of Saturday's field conference stops 1 to 5 and other important quarry and subsurface well core sections discussed and or illustrated in this study.

Creek members) and an upper carbonate-dominated unit with laminated, brecciated, or evaporitic textures and some restricted-marine faunas (Iowa City Member). The Coralville Formation was deposited during a single T-R depositional cycle and is bounded above and below by disconformities or discontinuity surfaces. The formation overlies the Little Cedar Formation at all known localities, and where capped by younger Devonian strata is variably overlain by the Lithograph City, Sweetland Creek, or Lime Creek formations. The Coralville formation varies greatly in thickness across Iowa, reaching a maximum thickness of 20 to 25 m in areas of central and northern Iowa. It is as thin as 3.9 m in parts of southeastern Iowa (Figs. 6 and 10).

Regional inner- and middle-shelf facies and stratigraphic relations of the Coralville Formation in Iowa (Figs. 6 and 10) are summarized in detail by Witzke and Bunker (1997, 2006a). In Northern Iowa the Coralville formation consists of a basal Gizzard Creek Member consisting of proximal middle and shallow subtidal inner shelf facies that include lagoonal biostromal stromatoporoid packstones, shaley skeletal pack- and wackestones,, and grainstones, and The Coralville succession in its type area includes subtidal packstones and biostromal facies of the Cou Falls Member and an upper Iowa City Member (Fig. 10) comprised of peritidal carbonate facies and minor stromatoporoid biostromes. Just to the east in eastern Johnson County (Figs. 6 and 10), the succession abruptly loses the upper Iowa City Member peritidal interval, and is replaced entirely by the subtidal succession bounded above and below by subtidal hardgrounds or discontinuity surfaces, and define the abrupt transition between inner- and middle-shelf facies and the preserved seaward limit of Iowa City Member tidal flat progradation in eastern Iowa (Figs. 6 and 10).

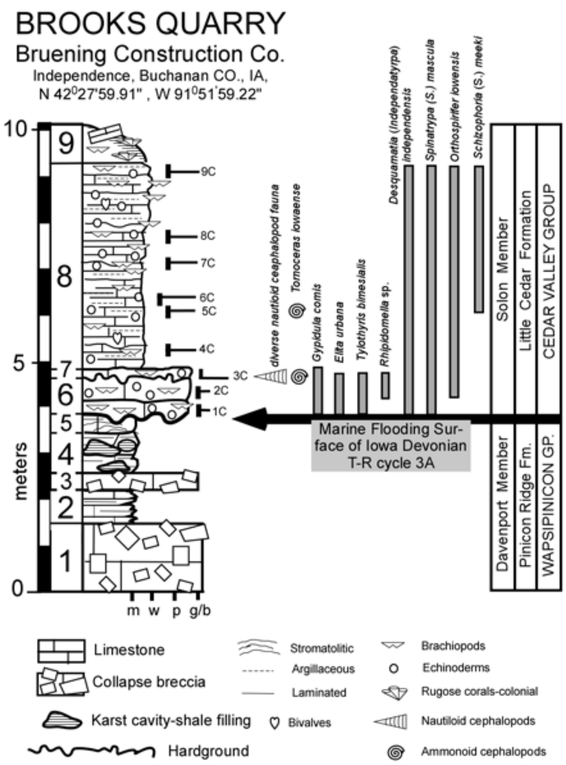

Figure 9.—Middle Devonian strata of the upper Pinicon Ridge and lower Little Cedar formations exposed in the Bruening Construction Company's Brooks Quarry in Independence, Buchanan County, Iowa (Stop 1, Fig. 3). Measured by J. Day and B. Witzke, June, 2011.

The lower Cou Falls interval across the middle shelf correlates with the entire Cou Falls Member of the distal inner-shelf area (Figs. 6 and 10). In the Buffalo Quarry section lower Cou Falls strata are richly fossiliferous and are characterized by coral-stromatoporoid framestones, packstones with common to abundant brachiopods and echinoderms associated with corals and stromatoporoids in grainstone units (Figs. 6 and 10), and abundant brachiopods, echinoderms, and bryozoans in overlying skeletal wackestone and packstone units (Figs. 6 and 12, units 27 to 31). Middle shelf deposits in eastern Iowa are markedly thinner as compared to central Iowa (Figs. 7), and progressively thin in the southeastern-most sections interpreted as the area of maximum relative stratigraphic condensation similar to the older deposits Middle Givetian of T-R cycle 3A (Figs. 6 and 10).

Coralville deposition was terminated by a significant sea level fall that exposed the Cedar Valley Group carbonate platform across the Iowa Basin to subareal erosion. This event affected most other cratonic basins in central and western North America as discussed by Day et al. (1996) and Day and Whalen (2005). During the post-Coralville lowstand erosional episode, karst features and fluvial erosional channels were incised into the Cedar Valley Group platform, and cut through the entire Coralville and part of the Rapid Member of the Little Cedar in Johnson County in east-central Iowa (Figs. 7 and 8), and new biostratigraphic evidence (Figs. 10 and 11) supports the interpretation of exposure across much of the middle shelf across southeastern Iowa.

Cedar Valley Group T-R cycle 4 is represented by strata of the Coralville Formation (Figs. 2, 6 and 10) which is placed in the upper part of T-R cycle IIa of Johnson et al (1985) by Witzke and others(1989) Bunker and Witzke (1992), Johnson and Klapper (1992), Witzke and Bunker (1997, 2006a), and designated as Euramerican Devonian T-R cycle IIa-2 by Day and others (1996). As such, the Coralville Formation represents the last intra-T-R cycle IIa deepening event recorded in the Iowa Basin (Fig. 2). Transgressive facies of lower Cou Falls and basal Gizzard Creek members yield conodonts of the Upper *subterminus* Fauna (Figs. 2, 6, 7 and 10; Witzke et al., 1985; Witzke et al., 1989; Bunker and Witzke, 1992; Day et al., 1996; Day, 1997, 2006), and brachiopods of the *Tecnocyrtina johnsoni* Zone (Fig. 2; Day 1997). Equivalents of the Coralville are represented by Mineola limestone of the Cedar Valley Limestone in central Missouri that yield conodonts of the Upper *Icriodus subterminus* Fauna and brachiopods including *Tecnocyrtina m. missouriensis* (see Day, 1997).

Gizzard Creek Member

The Gizzard Creek Member (Figs. 6 and 10) is dominated by dolomite, generally medium-Medium- to thick-bedded in the lower part and

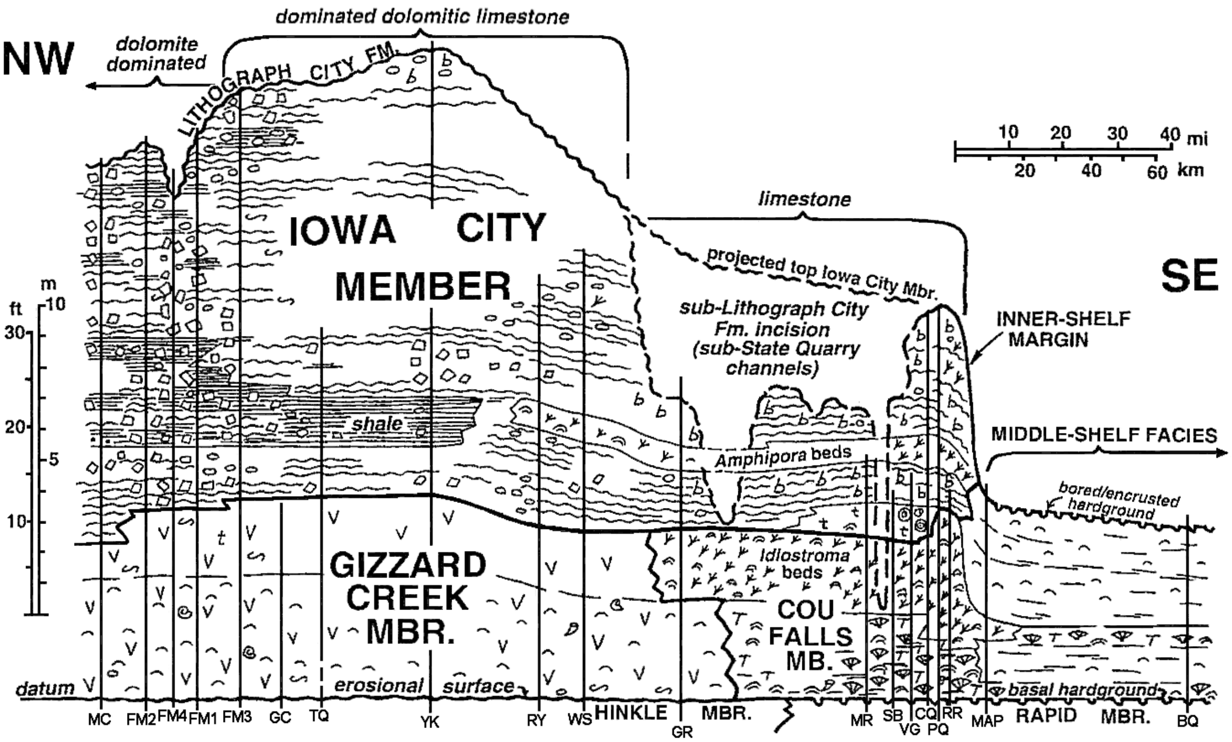

Figure 10.—Cross section showing facies architecture of the Coralville Formation across eastern Iowa. The line of cross section (Witzke and Bunker, 1997, fig. 3) corresponds to most of line AB and localities shown on Figure 1 northwest of Locality BQ. After fig. 6 of Witzke and Bunker (1997).

medium- to thin-bedded in the upper part, but dolomitic limestones and calcite-cemented (poikilotopic sparites) dolomites are present. The Gizzard Creek Member is slightly argillaceous in part, and calcite-filled vugs are common. Intraclasts are present locally in some beds. The member contains scattered to abundant fossil molds, locally with calcitic fossils, and displays wackestone (calcilutite) to rare packstone texturess, in part burrow mottled. The Gizzard Creek Member disconformably overlies the Hinkle Member at all localities, and is conformably overlain by the Iowa City Member at most localities. The Gizzard Creek Member ranges from 3.7 to 7 m in thickness.

Conodonts of the Gizzard Creek Member include *Icriodus subterminus*, *Mehlina gradata*, and *Polygnathus angustidiscus* (Witzke et al., 1988; Rogers, 1990; Day, 2010) which are assigned to the Upper *subterminus* Fauna. Faunas of the Gizzard Creek are generally of low diversity and are characterized by sparse to abundant crinoid debris and brachiopods (Independatrypa, Athyris, and rare Tecnocyrtina; Day, 1988 & this guidebook). Rare gastropods and bryozoans have been noted, and branching stromatoporoids and favositids are present locally near the southern limits of the member in the outcrop belt.

Iowa City Member

The Iowa City Member (Fig. 3) is characterized by a diverse assemblage of lithologies that commonly share significant lateral facies variations over short distances. The member in the type area of central Johnson County includes the following lithologies: 1) laminated and pelleted calcilutites, commonly “sublithographic” with “birdseye” voids and stylolites; 2) pelleted calcilutites with scattered to abundant corals and/or stromatoporoids; 3) intraclastic, brecciated, or oncolitic limestones; and 4) some thin shales, in part carbonaceous (Kettenbrink, 1973; Witzke, 1984). Mudcracks and vadose pisoliths are noted in some beds, and erosional surfaces occur locally within the sequence (Witzke, 1984).

The Iowa City Member in the northern outcrop belt and in the subsurface of central Iowa is characterized by sedimentary fabrics similar to those of the type area, but includes dolomites and dolomitic limestones. There is a general increase in the relative abundance of shale, with shaly intervals locally up to 2 m thick, breccia, and intraclastic strata in this area, and some beds are locally sandy. Crystallotopic molds after sulfate evaporites have been identified locally. The thickest development of evaporites (gypsum and anhydrite) in the Cedar Valley Group occurs within the Iowa City Member of central Iowa. The Iowa City Member in the type area is disconformably overlain by the State Quarry Member of the Lithograph City Formation or by the Lime Creek Formation. The member is disconformably overlain by the Osage Springs Member of the Lithograph City Formation across northern and central Iowa. The Iowa City Member ranges from 0 to 8 m in thickness in the type area, and from 8 to 17 m across northern and central Iowa. The Iowa City Member is absent 12 km to the southeast of the type locality, where the entire Coralville Formation is represented by fossiliferous calcarenites of the Cou Falls Member. The edge of the Iowa City Member trends south-southwest from the type area, and the member is absent in southeastern Iowa and adjacent parts of northeastern Missouri and western Illinois (Figs 6 and 10). Conodonts have not been recovered from the Iowa City Member. Laminated and "birdseye"-bearing strata are sparsely fossiliferous in part (stromatolites, calcareous algae, foraminifers, ostracodes and gastropods), and some calcilutites are burrow mottled.

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 (Fig. 6). 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, Day, 2010) as shown in (Fig. 2), and also affected the Elk Point Basin and western Canadian Sedimentary Basin of Manitoba and northern Alberta, respectively (see Day et al., 1996).

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. 6). The type locality of the formation was designated in the Jones Quarry near the abandoned town of Lithograph City in Floyd County, Iowa (Fig. 1; Groves and Hubscher, 2008), 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 6). 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. 6).

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 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. 2), 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, 1967) 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. 2).

Osage Springs Member

The Osage Springs Member is characterized by fossiliferous dolomite and dolomitic limestone, in part slightly argillaceous, in the type area. 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) sin the southern outcrop belt, and stromatoporoids (locally biostromal) also become increasingly common in that direction as seen in the Yokum Quarry (Fig. 11; Witzke et al., 1986, stop 1, unit 16) 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 Figure 11, and in the subsurface of central Iowa. The Osage Springs Member varies from 3.4 to 7.5 m in thickness (Figs. 6, 7 and 11).

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; Day 2006, 2010), 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 (Groves and Hubscher, 2008) 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 allani, Athyris 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 (Groves and Hubscher, 2008; Day, 1989, 1992; Day et al. 2008). Stromatoporoids become abundant to the south and include both massive and branching forms in the Messerly and Yokum Quarry sections (Stock, 2008, 2013). Echinoderm debris is present in all sections, and bryozoans, gastropods, corals, and burrows have been noted locally.

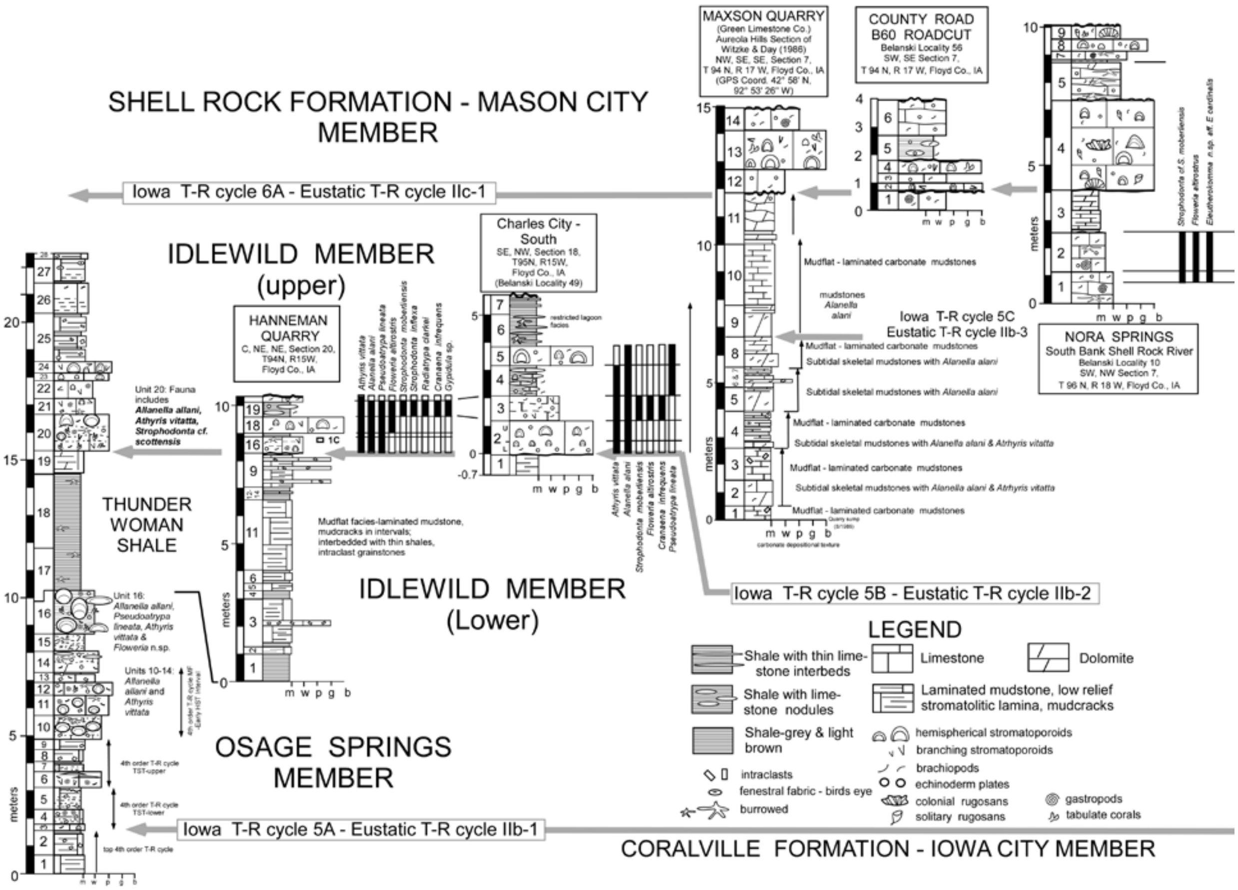

Figure 11.—Middle and Upper Devonian strata of the Cedar Valley Group (upper Coralville and Lithograph City formations) exposed in the Yokum Quarry in northwestern Black Hawk County; and the Hanneman, Maxson (County Road B60) and Charles City South quarries, and Nora Spring South section in Floyd County, Iowa (quarry locations shown in Figs. 1 and 8). Gray arrows denote positions of major flooding events of Iowa Devonian T-R cycles IIb-1, IIb-2, and IIb-3 (Fig. 2). Vertical black arrows denote 4th order T-R cycles or parasequences within the Lithograph City Formation.

Thunder Woman Shale Member

The Thunder Woman Shale Member (Figs. 2, 6, 7 and 11) 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 in the Yokum Quarry (Fig. 11, Witzke et al., 1986, 1989) that is now inactive and flooded. 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. 6 and 11). The Thunder Woman Shale ranges from 3 to 6 m in thickness.

Idlewild Member

The Idlewild Member (Fig. 2, 6, 7 and 11) 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 mud cracks, "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 mud cracks 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. 11). 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. 11). They are rhythmically interbedded with lithologic group 2 in most of the upper Idlewild in the and Maxson Quarry near the town of Marble Rock and the Jolie Quarry south of Charles City in Floyd County (Fig. 11) comprising small-scale 4th order T-R cycles (parasequences). Fossiliferous skeletal mudstone and wackestones of group 4 are seen near the top of the Idlewild Member at in the Maxson Quarry and at the Nora Springs South locality (Fig. 11) 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 (Fig. 11). 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. 2), 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 (Figs. 6 and 7), 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 (Figs. 6). Where capped by the Shell Rock Formation, the Idlewild Member ranges from 16 to 24 m in thickness.

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. 2). 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 3 (Fig. 2). 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; Day et al., 2008). Echinoderm debris is common in some beds, and bryozoans, gastropods, and ostracodes also occur. Small-scale cycles consisting of lithologic groups 1 to 3 interbedded with fossiliferous group 4 skeletal carbonates contain monospecific or low diversity assemblages that include *Allanella allani*, *Athyris vitatta*, or *Pseudoatrypa lineata*. At the Maxson 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 (Witzke 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 vitatta, Eleutherokomma* sp. aff. *E. cardinalis, Floweria altirostrum, Pseudoatrypa lineata, Productella* sp. cf. *P. fragilis, Strophodonta* (*S.*) *moberliensis*, *Cranaena infrequens*, and *Gypidula* sp. The skeletal mudstone and wackstones in the upper 2 to 3 meters of the Idlewild Member at the 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 Early Frasnian of North America, with *Athyris 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 north of Cedar Falls, 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 Jolie, 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, 2013) 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*? v*esiculosum, 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.

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 T-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 quarry (Fig. 11) 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 the Thunder Woman Shale has grades to 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 Idlewild as seen in across of Floyd County (Stop 4; Fig. 11).

Iowa T-R cycle 5B (Figs. 2 and 11) 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. 2). This flooding coincides with Devonian T-R cycle IIb-2 of Day et al. (1996). In quarry sections (Fig. 11) 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 an 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 (Fig. 6). Brachiopods of the *Orthospirifer missouriensis* Zone have their first occurrences in the Buffalo Heights Member with conodonts of M.N. Zone 4 (Fig. 2; Day 2006). In a number of locations in Floyd County in northern Iowa (Fig. 11, Nora Spring South), 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).

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. 8 and 12; Day and Witzke, 2008, stop 6), with a closely similar section in the subsurface in the nearby Floyd-Mitchell # 4 well core (locality FM; Figs. 1, 8 and 13). The Shell Rock Formation is now included in the upper Cedar Valley Group (Witzke et al., 1988; Figs. 2 and 6). A comprehensive summary of the stratigraphy of the formation in the type area is given by Koch (1970) and Witzke and others (1988). The Shell Rock Formation is characterized by fossiliferous carbonates with some shale in the type area (Figs. 12 and 13). It disconformably overlies the Idlewild Member of the Lithograph City Formation, and erosional relief has been noted locally (see Fig. 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 was onlapped 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 observed in quarry exposures and cores in Cerro Gordo and Worth counties (Fig. 13) that 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 observed by Witzke and Bunker (1984) where they re-interpreted Devonian units in northern Iowa. They initially used a 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 (Fig. 13).

The westward facies change in the lower Shell Rock is noted at the Holnam Quarry in Mason City area (Witzke, 1998, fig. 2), where nearly 12 meters of the "Mason City Member" consists of biostromal and stromatoporoid-rich lagoonal facies, nearly twice the thickness as in the Nora Springs area to the east 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 (see Day and Witzke, 2008, stop 8). Unlike in sections around the Mason City area, the upper Rock Grove and Nora members are readily identifiable in the exposures and cores in and near the Fertile Quarry (Fig. 13). 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).

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. 2). Iowa Devonian T-R cycle 6A includes strata of the Fertile, 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 (Fig. 13, Fertile Quarry), with brachiopods of the *Strophodonta scottensis* Zone (Fig. 2.) 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 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 and in the adjacent FM-4 core (Figs. 11 and 12).

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 as seen at Stop 1 (Brooks Quarry, Figs. 1 and 9,) is developed in older Wapsipinicon Group and Silurian units and infilled by stratigraphic leaks of late Frasnian Lime Creek shales referred to as the "Independence Shale" (see Fig. 6). 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 (Fig. 6), and entirely absent across the middle-shelf region of southeastern Iowa, northeastern to central Missouri, or central Illinois (Fig. 6) and appears 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).

Fertile Member 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, Day and others (2008) proposed 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. 13) section that was drilled in the south pit area and subsequently removed by quarry operations since that time. In the Holnam (Witzke, 1998, fig.2) and Fertile (Fig 13) 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, 2008) 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). The Shell Rock 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, 2008) summarized and updated the diverse brachiopod fauna (32 species) of the Shell Rock and defined 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 12.

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 Stock (1973, 1982, 1984a, 1984b, and 2008). The Mason City stromatoporoid fauna occurs in biostromal units, patch reef 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 the Nora Springs and Mason City area (Holnam Quarry, Figs. 1 and 8).

Twenty-Four brachiopod species first appear in the Mason City Member (Day, 1989, 1996, 2008), 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) 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. 13; Day and Witzke, stop 5). Other important species with first occurrences in the Mason City are *Pseudoatrypa witzkei*, *Spinatrypa* (*S.*) *bunkeri*, *Lorangerella gregaria, Hypothyridina magister*, *Cyrtina* n.sp., *Nervostrophia* n.sp., *Productella fragila* and *Strophodonta* (*S.*) s*cottensis*, 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 *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 lowest occurrence is now known to be 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. Nora Member rugose corals do occur and are described by Sorauf (1998). The sparse stromatoporoid fauna reported by Stock (2008, 2013) 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 Nora brachiopods are known to range into the Rock Grove 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 type area of the Shell Rock.

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 (Fig. 12). The fauna described from the Nora includes stromatoporoids (Stock, 2008, 2013), 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. 13) and Cerro Gordo County. Stock (2008, 2013, 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 5 (Fig. 8) 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 the stratigraphy and fauna of the "Hackberry

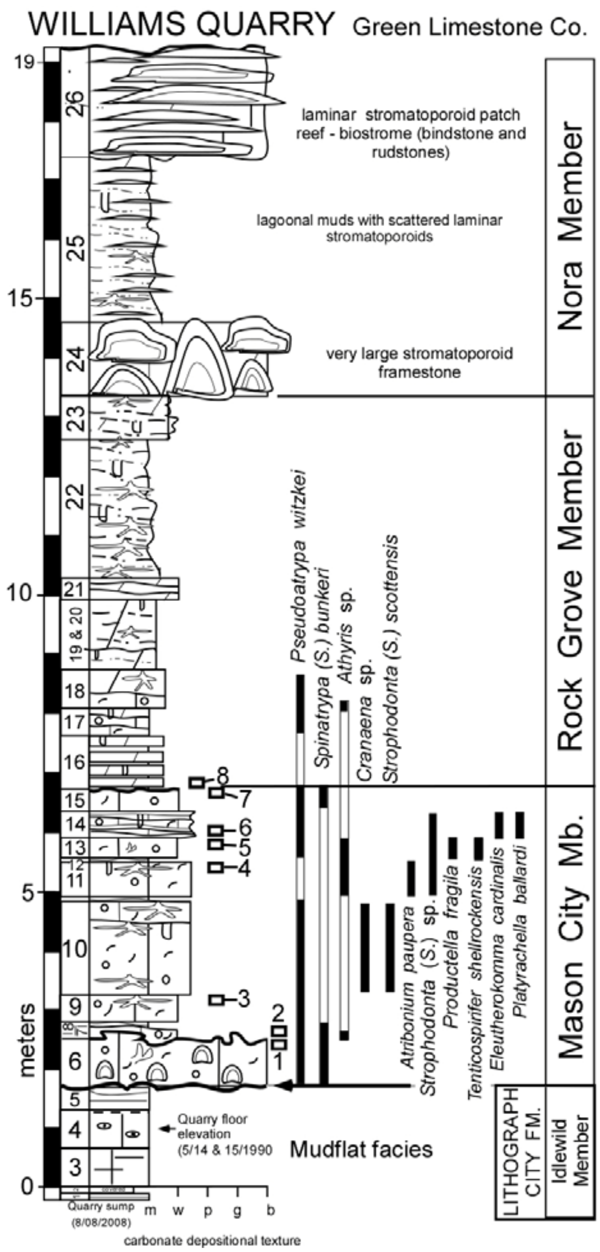

Figure 12.—Upper Devonian stratigraphy of the upper Idlewild Member (Lower Frasnian) of the Lithograph City Formation and Shell Rock Formation exposed in the Williams Quarry (Greene Limestone Company), south of Nora Springs in northwestern Floyd County. Measured by J. Day, 1990 and 2008, modified from Day and Witzke (2008, stop 6). 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). After Fig. 8 of Day and others (2008).

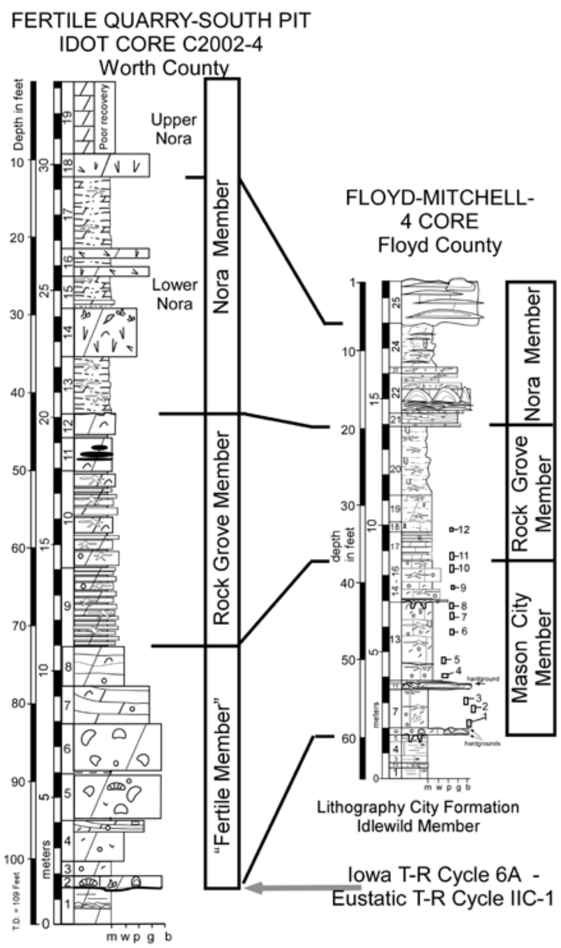

Figure 13.—Contrasting stratigraphy of the Shell Rock Formation in the IDOT C2002 Core from the active south pit of the Fertile Quarry, southern Worth County and the Floyd-Mitchell # 4 Core, located just southwest of the Williams Quarry, northwestern Floyd County. Measured by J. Day in 2008.

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 (Figs. 14 and 15). It 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 currently 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 the Juniper Hill Shale, Cerro Gordo Member, and the Owen members (Figs. 2 and 14). 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 known to be of Middle Famennian age. Calvin (1897) clearly included this shale-dominated unit 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. 14). 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 Belanksi in the old pits of the Rockford Quarry on the northern side of the quarry property (see Belanski Register, locality 4 = Rockford Quarry).

In most surface exposures the member lacks significant megafossils, but does yield conodonts (Anderson, 1966; Day, 1990) and other microfossils. Fossils have been reported in earlier reports by Webster (1908), Thomas (1922). Fossils are common in the Juniper Hill Shale in the CG-1 core in the subsurface of southeastern Cerro Gordo County (Figs. 8 and 14) where a relatively diverse brachiopod fauna was documented by Day (1989, 1995, 1996) along with crinoid debris and other fossils. Body fossils (small brachiopods, carbonized logs and branches, hexactinellid sponges and conularids) were 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 (Day, 2008, 2013, Stop 5). 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

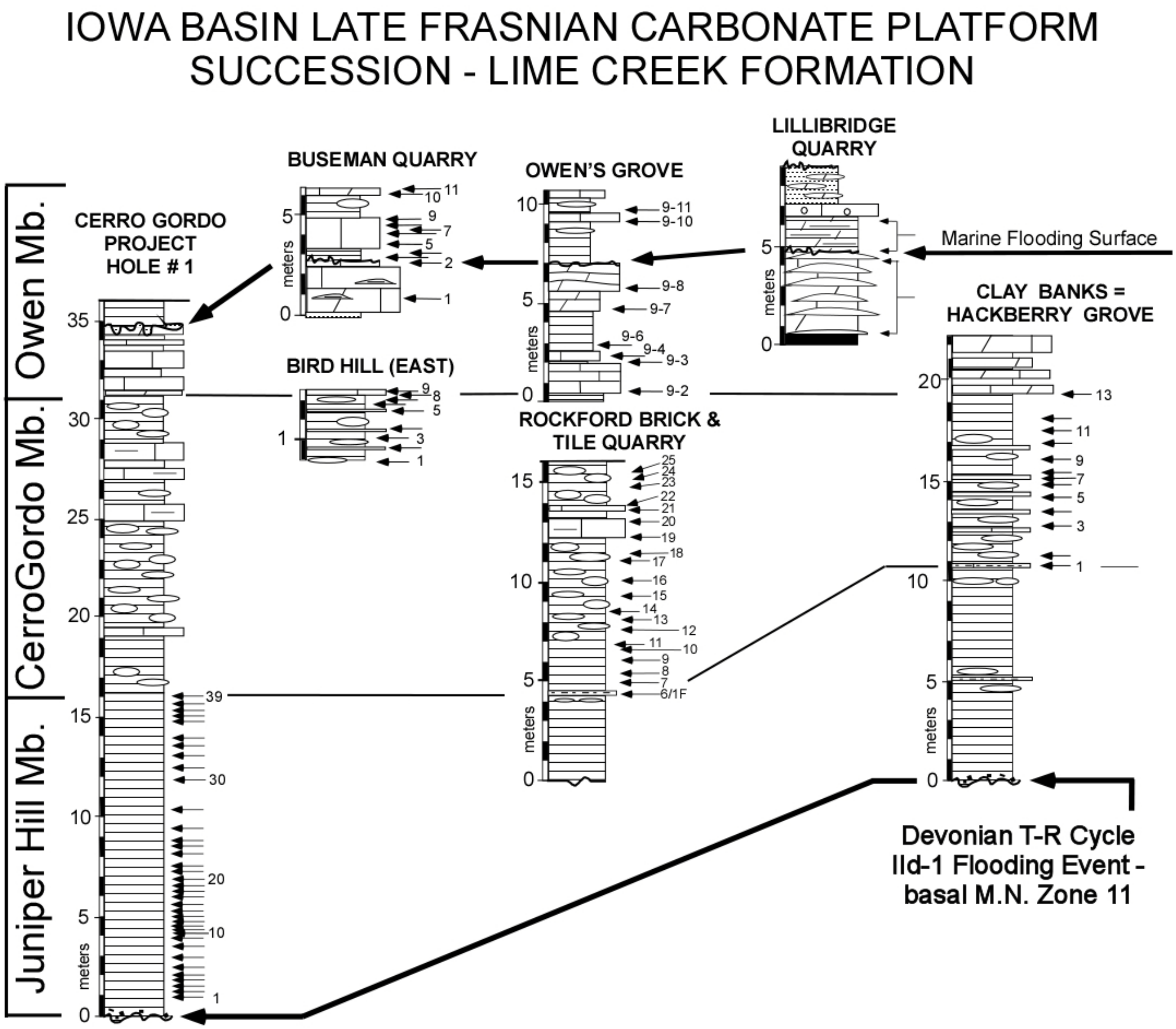

Figure 14.—Stratigraphy of the Lime Creek Formation at key surface and subsurface reference sections in its type area in eastern Floyd and western Cerro Gordo counties (Figs. 2 and 4) in north-central Iowa sampled for conodonts by Day (1990) and brachiopods (Day, 1989, 1995). Sample positions of brachiopod 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).

and at the Clay Banks section (Figs. 8 and 14) consist of an indurated shaly pyritic phosphatic lag deposit with abundant placoderm fish plates, conodonts (see Day, 1990), and millions of fossils of the green algal structure *Tasmanites*.

Cerro Gordo Member

The Cerro Gordo Member consists of fossiliferous calcareous shales with intervals of nodular shaley limestone and beds of argillaceous limestone (Fig. 14). It ranges in thickness from 7.3 meters at its type section at Clay Banks Nature Preserve, to up to 16 meters (composite thickness) determined from exposures at the Rockford Quarry and the nearby Bird Hill localities (Figs. 8 and 14). The member is best known for its remarkable brachiopod fauna described in studies dating to the late 1850s that includes at least 40 species (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 (Fig. 14) are shown in figure 3 of Day (2008, 2013, Stop 5). 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 (Sorauf,1998), bryozoans (cyclostomes, cryptostomes, trepostomes), bivalves, gastropods, cephalopods (nautiloids, the ammonoid *Manticoceras*, 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 placoderm fish and shark material (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, 2013, Stop 5).

Owen Member

The upper member of the Lime Creek Formation, the Owen Member, is the least shaley interval of the formation, and is characterized by fossiliferous limestone, dolomitic limestone, and dolomite, interbedded with calcareous shale (Fig.14). 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 (Figs. 14 and 15), 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 (Fig. 15). 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 (Fig. 15).

By contrast, the Lime Creek Formation of northern and western Iowa includes carbonate facies deposited in oxygenated shallower-water settings (Figs. 14 and 15). 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

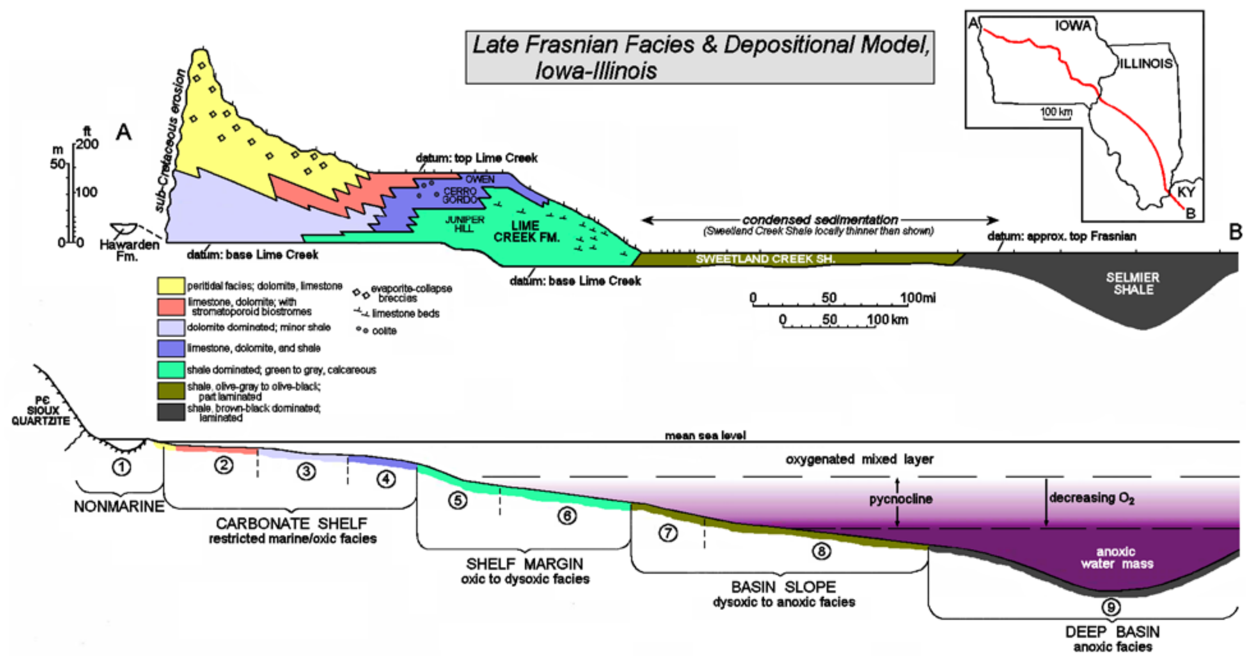

Fig. 15.—Regional cross-section and depositional model for Late Frasnian Lime Creek – Sweetland Creek shelf to basin system in the Iowa and deeper water setting in the Illinois Basin. Figure by Witzke.

Member, which includes oolitic and biostromal 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.).

Two late Frasnian sequence packages can now be identified in the carbonate platform succession of the Lime Creek Formation in northern Iowa (Figs. 2 and 13). 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 with the marine flooding of T-R cycle IId-1 as proposed by Day (1998). Iowa Devonian T-R cycle 7A (Fig. 2) 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 outcrop area in Floyd and Cerro Gordo counties (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.*

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 (Figs. 1 and 15). In those locations strata across the boundary appear conformable.

CONCLUDING REMARKS

The Middle and Upper Devonian strata and faunas of the Wapsipinicon and Cedar Valley groups 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 Eifelian-Frasnian in central 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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FAUNA FROM THE BROOKS HARDGROUND BED: LOWER SOLON MEMBER, LITTLE CEDAR FORMATION BRUENING INC. BROOKS QUARRY, INDEPENDENCE, IOWA

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INTRODUCTION

The Bruening Rock Products Inc. Brooks Quarry east of Independence, Iowa, exposes a particularly instructive stratigraphic horizon of middle Devonian age. This horizon has produced an abundance of cephalopod fossils, many species of which were either poorly known or not known from Iowa prior to discovery of this locality. The purpose of this paper is to briefly discuss the stratigraphy of these beds, as well as to provide a summary of the contained fossils. In depth studies of the cephalopod fauna will be the subject of future publications.

STRATIGRAPHY

The Brooks Quarry exposes (Figure 1) the uppermost part of the Davenport Member of the Pinicon Ridge Formation, and most of the Solon Member of the overlying Little Cedar Formation. The contact between the two marks a regionally extensive unconformity.

The Buchanan County area lies within what is termed the distal inner shelf facies (Witzke and Bunker, 2006) of the Cedar Valley Group

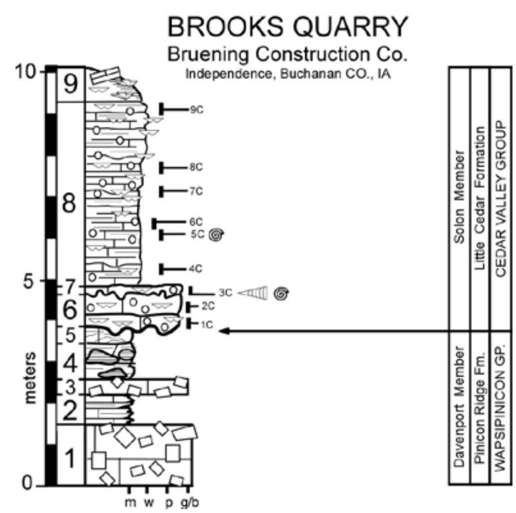

Figure 1. Brooks Quarry composite section measured and compiled by Dr. Jed Day. Three main facies of the Solon Member are evident. Unit 6 is a basal transgressive limestone unit, capped by the Brooks Hardground Bed (Unit 7). Unit 8 is a sparsely fossiliferous mudstone. A brachiopod and trilobite producing limestone marks the transition into the coralline limestone beds of Unit 9. See Table 1 for Faunal List from Units.

Table 1. Unit Faunal List for Figure 1.

Unit 6 - Basal Solon Member Limestone, very fossiliferous with: Brachiopods (many genera including *Independatrypa independensis*), crinoid columnals, solitary and colonial corals, bryozoans, bivalves, rare gastropods, rare trilobites (*Phacops* sp.), and cephalopods. This unit greatly resembles *I. independensis* Zone (Day, 1992) outcrops known further south in Iowa, "an abraded brachiopod packstone". The cephalopod fauna present in this unit is the similar to that seen in those southern Solon Member outcrops, dominated by several species of large Oncocerid nautiloids, with orthocones also occurring.

Unit 7 - The BHB hardground interval, mineralized black when fresh, rusty red when oxidized, extremely fossiliferous with: abundant cephalopods (including *Tornoceras (Tornoceras) iowaense* Miller 1936), brachiopods (including *I. independensis*), bivalves, bryozoans, fish plates (placoderm arthrodires), large conularids, gastropods (including rare *Mastigospira sp.)*, rare trilobite debris (*Phacops* sp., *Greenops* sp., Proetids), and corals. Epibionts such as spirorbid worms occasionally encrust other fossils.

This unit has yielded approximately 13 cephalopod species, including the lowest in-situ appearance of the goniatitc ammonoid *T.* (*T.) iowaense* Miller 1936, as well as the distinctive large Rutocerid gyroconic nautiloids (*Tetranodoceras? sp.*) which are so prominent in the Brooks Quarry. This cephalopod fauna differs from that seen in southern outcrops of the Solon Member principally with the addition of *T.* (*T.) iowaense_* as well as several species of small Oncocerid nautiloids, which are rare to absent elsewhere, but common in the BHB.

Unit 8 - Sparsely fossiliferous mudstone interval with: scattered cephalopods, bivalves, rare gastropods, and scattered brachiopods. Fossils in this unit are decidedly less common than in Units 6 and 7. Most of the cephalopods from Unit 7 range up into the lower portions of Unit 8, including rare compressions of *T. (T.) iowaense*, as well as the large Rutocerid gyrocones. This unit represents the highest known in-situ occurrence of *T. (T.) iowaense*. The small Oncocerid nautiloids from Unit 7 are not known to range up into Unit 8. Lenses of brachiopod shell hash become more common moving up section, probably coincident with general seaway shallowing allowing storm currents to impinge upon the sea floor.

Unit 9 - Limestone with: abundant corals (solitary and colonials including: *Hexagonaria* sp., *Favosites* sp., and *Asterobillingsa* sp.), brachiopods, bryozoans, rare trilobites (*Phacops* sp., *Greenops* sp.), and gastropods. The lower bed yields brachiopods and trilobites in the transition zone from Unit 8 into Unit 9. This unit strongly resembles the "profunda beds" of Stainbrook (1941) known further south in Johnson County. We tentatively correlate Unit 9 with the Upper Solon Member, *Rhyssochonetes bellarugosis* Zone of Day, 1992. Cephalopods have not been found in this unit at Brooks Quarry as of yet, however large Oncocerid nautiloids are known to occur in this interval in the Jesup South Quarry (see Figure 5). Unit 9 is truncated by the Quaternary unconformity.

(Figure 2). This area had been subject to intervals of erosion prior to and after deposition of the Little Cedar Formation, leading to the formation of large numbers of karst features: caves, sinkholes, and collapse features, which can be seen throughout the quarry.

The upper portion of the Davenport Member of the Pinicon Ridge Formation has also been extensively brecciated due to evaporite solution/collapse processes. This brecciation often affects the bedding in the overlying Solon Member (Witzke, et al, 1989). The brecciation and karst features combine to create a sometimes confusing and chaotic stratigraphic sequence (Figure 3).

Deposition of the Solon Member was initiated by widespread marine transgression during the upper Middle Devonian Taghanic Onlap (T-R Cycle IIa-1 of Johnson and Klapper, 1992). This resulted in establishment of open-marine conditions over the older supratidal evaporite mudflat deposits of the Upper Pinicon Ridge Formation with open marine subtidal carbonates of the Lower Little Cedar Formation. The Lower Solon Member contains conodonts typical of the Middle *varcus* Zone (Witzke, et. al., 1989).

The presence of hardgrounds in association with the main fossil producing bed were observed by Jed Day (Illinois State University)

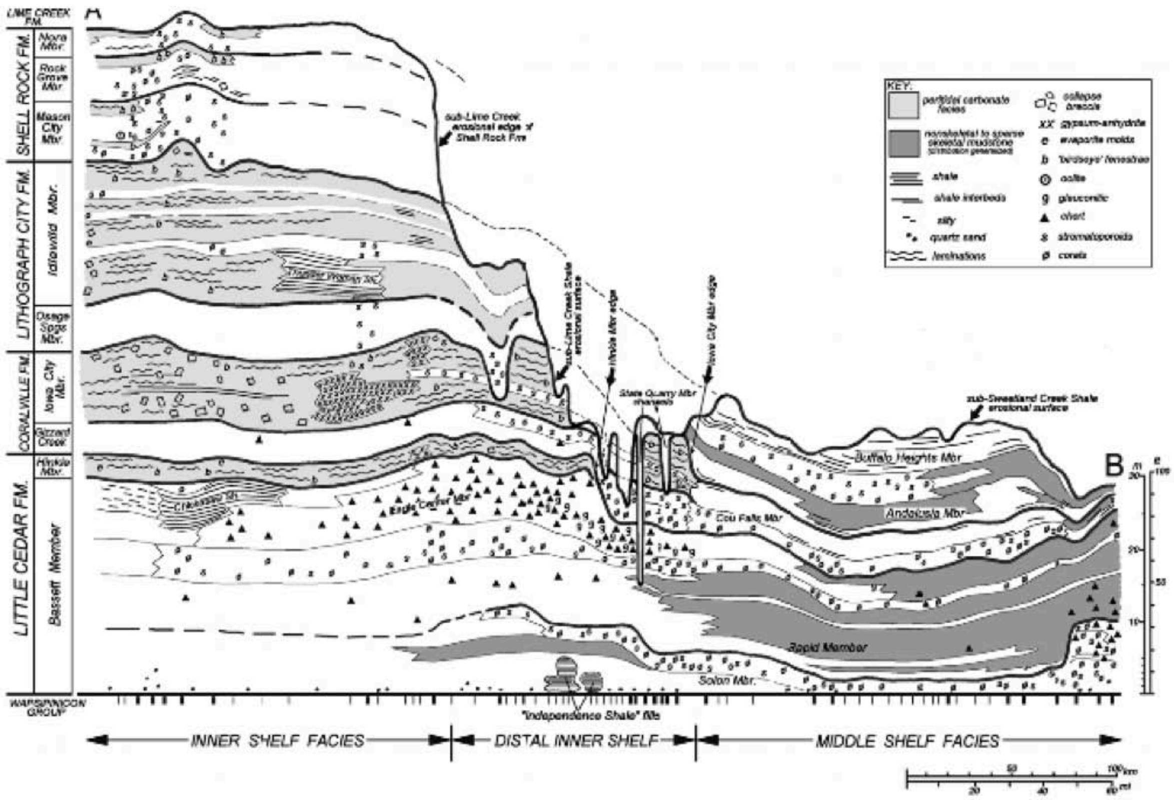

Figure 2. Northwest-southeast stratigraphic cross section of the Cedar valley Group in eastern Iowa. Significant sub-Lime Creek/Sweetland Creek erosion has truncated Cedar Valley Strata, especially in the distal inner-shelf area. "Independence Shale" fills represent stratigraphic leaks of the late Frasnian Lime Creek Shale within Cedar Valley karst networks and openings. (From Witzke and Bunker, 2006). The Brooks Quarry lies within the Distal Inner Shelf setting.

Figure 3. View of east wall of Bruening Inc. Brooks Quarry. The arrows point to two large caverns filled with black shales. Note people to the right of outcrop for scale.

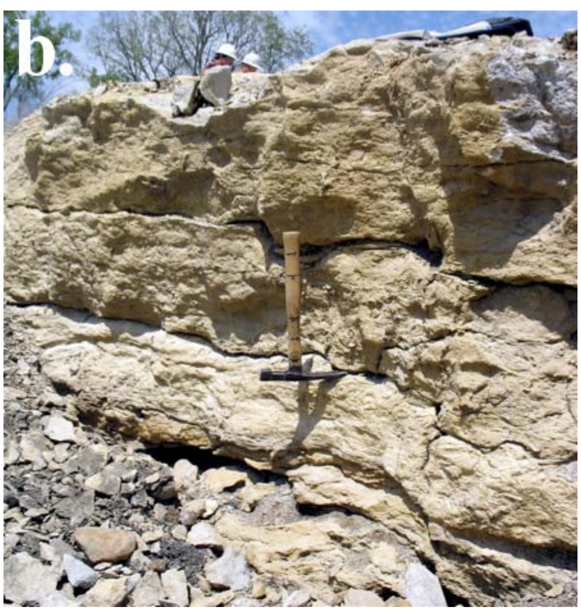

Figure 4. Views of north bench area of Brooks Quarry.

Fig. 4a. Bottom arrow points to horizontally bedded Upper Davenport Member. Middle arrow points to contact of Davenport Member with overlying Solon Member. Top arrow points to level of bedding plane exposure of BHB, 1.0m above the Davenport-Solon contact.

Fig. 4b. Close-up of strata in north bench area. Hammer head lies at contact of Davenport and Solon Members. The BHB lies at the top.

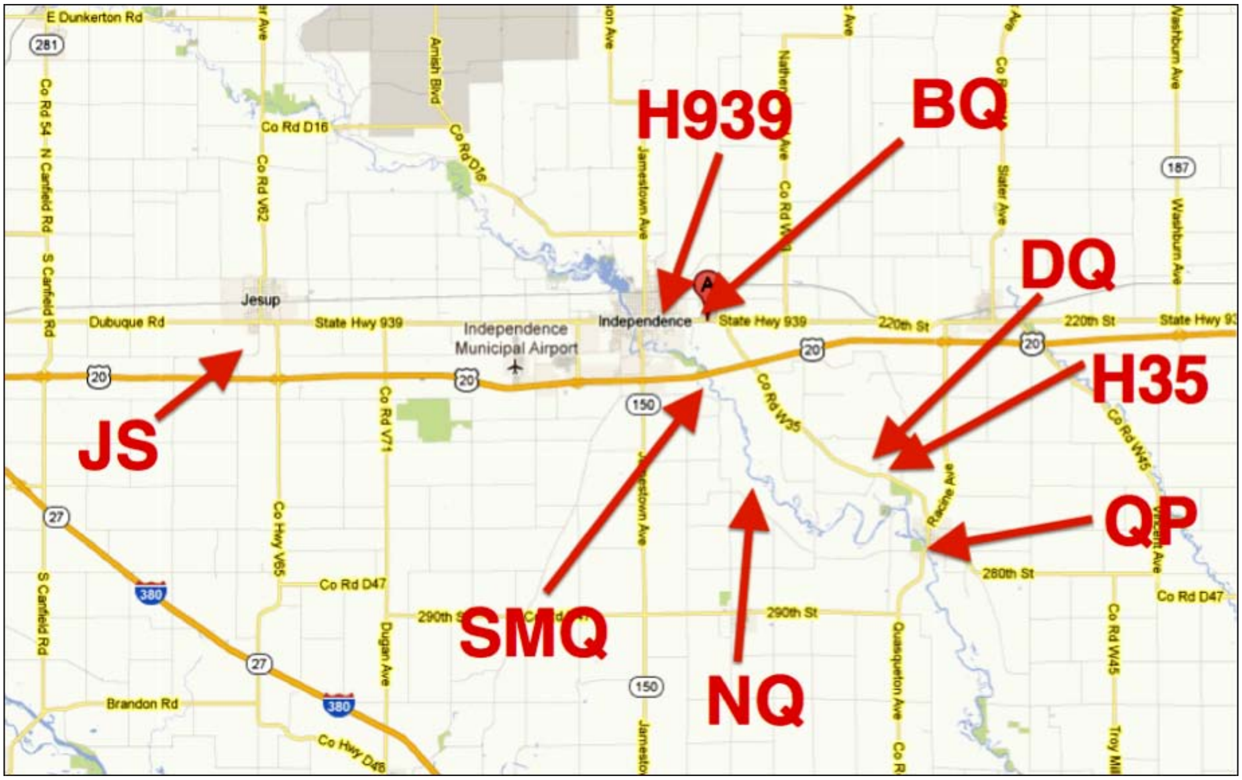

Figure 5. General locality map - arial extent of the BHB. BHB present at Brooks Quarry (BQ), Steve Miller Quarry (SMQ), also at Niemann Quarry (NQ). BHB not exposed or not present at Jesup South (JS), Highway 939 roadcut (H939), Diagonal Quarry (DQ), Highway 35 roadcut (H35), Quasqueton proper riverbank exposures (QP).

and Brian Witzke (University of Iowa) (pers. Comm. 2008), and they have proven correct (Figure 7a). The Brooks Hardground Bed (BHB) likely coincides with the maximum sea level highstand of the Taghanic Onlap, where sediment sources have been drowned, leading to an extended period of low sediment accumulation resulting in the formation of the hardground. During this time of slow sedimentation an abundance of invertebrate shells and fish bones accumulated on the sea floor (Figure 6).

The contact between the Pinicon Ridge and Little Cedar Formations is well exposed at various spots in the quarry, but along the north bench area the Upper Davenport Member's horizontal bedding is intact and thus underlies an undisturbed exposure of the Lower Solon Member (Figure 4).

Preservation of the north bench area during quarrying activities was serendipitous. The most economically valuable rocks in the quarry are from the Upper Davenport-basal Solon interval, which are used in road aggregate. The rocks from the overlying mudstone interval, as well as the shales infilling the various karst features, are not of great economic value. So typically during

Figure 6. Slab of limestone from the BHB showing concentration of cephalopod shells which is typical for this unit. Found by Marv Houg.

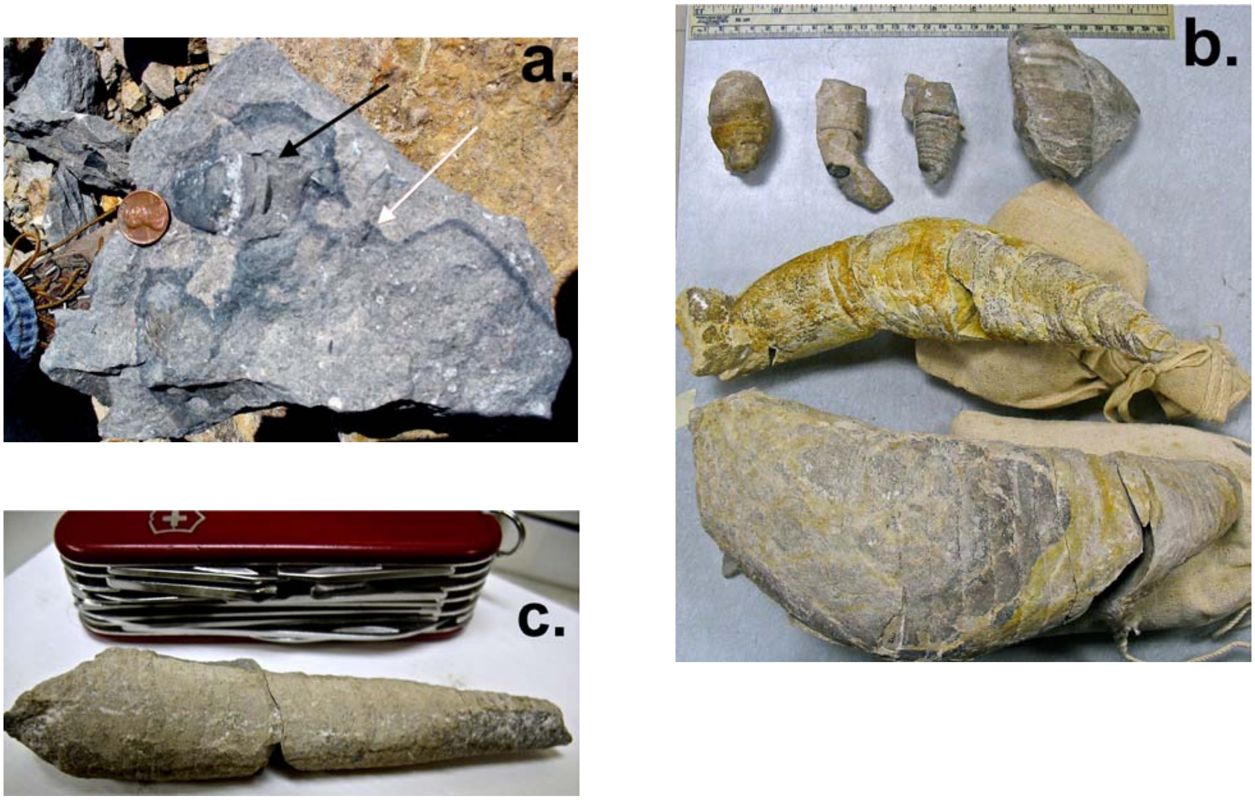

Figure 7. Oncocerid nautiloid specimens from the BHB. **a.** Bottom (white) arrow points to BHB mineralized surface. Top (black) arrow points to a small Oncocerid nautiloid (*Ovoceras? sp.*) preserved in the hardground. Note penny for scale**,** **b.** six different species of Oncocerid nautiloids from the BHB, all specimens exhibit mature modifications, **c.** a specimen likely belonging to the Oncocerid Family *Tripleuroceratidae*, previously not known from the Iowa Devonian

quarrying activity, the mudstone rocks are stripped away and drilling is immediately stopped if any shale pocket is encountered (R. Reed, Bruening Construction Company, pers. comm. 2010). In the north bench area, the mudstone rock was removed, but it turned out that the bench was surrounded on three sides by shale filled karst features, and thus a bedding plane exposure of the BHB was left intact.

The BHB is also known to occur in the nearby Steve Miller Quarry, 2.9 km to the south-southwest. It may also occur in the Niemann Brothers Quarry which lies 6.2 km to the south of the Brooks Quarry (Figure 5). It is not known to extend further to the south into the Quasqueton area nor to the west in the Waterloo-Cedar Falls area.

DISCUSSION

The Brooks Quarry has produced the most diverse Devonian cephalopod fauna known from Iowa. Frequent collecting by members of the Blackhawk Gem and Mineral Society (BHGMS) discovered that approximately 13 species (at least 12 nautiloid, 1 ammonoid) of cephalopods occur at the Brooks Quarry, although that number may be adjusted up or down once more extensive specimen preparation work is done. Prior to discovery of the BHB at Brooks Quarry, roughly 9 species of cephalopods were known to occur in the Lower Solon Member (Preslicka et al, 2010).

Ammonoid cephalopods

Of greatest biostratigraphic interest in the BHB fauna is Iowa's oldest known ammonoid, *Tornoceras (Tornoceras) iowaense* Miller, 1936 (Figure 8). Prior to the work of the BHGMS, only three specimens of this species were known in 150+ years of collecting in the rocks of the Cedar Valley. To date, the BHGMS has recovered and donated ~135 specimens of *T. (T.) iowaense* to the University of Iowa Geoscience Repository. *T. (T.) iowaense* has potential to be a guide fossil for the Lower Solon Member, were it not for its limited geographic range, as all known specimens are from only three counties in east-central Iowa. *T. (T.) iowaense* also appears to be endemic to Iowa, and as such is not known from outside the state. A study redefining this species is currently being undertaken.

At the time of Miller's original 1936 description, the age of the rocks yielding the ammonoid were correlated incorrectly and given as Upper Devonian (Frasnian). For a discussion of this correlation controversy (see Cooper 1967). This misconception has carried through into more recent times (Makowski, 1991, p. 252) as, due to paucity of specimens, no further work was done on *T. (T.) iowaense.* In fact, *T. (T.) iowaense* has a very limited range in the Givetian, correlating to the MD II-d *Maenioceras* Stufe in the ammonoid zonation of New York (House and Kirchgasser, 2008, pp. 72-73). *T. (T.) iowaense* is not known to range above the Lower Solon Member and is the only ammonoid cephalopod known from the entire Cedar Valley Group.

Figure 8. A specimen of *Tornoceras (Tornoceras) iowaense* Miller, 1936. Specimen found, prepared, and photographed by John Catalani. Actual specimen diameter 8.0 cm.

Nautiloid cephalopods

The remainder of the cephalopod fauna consists of approximately twelve species of nautiloids. An array of shell morphologies is present ranging from straight conical shells to brevicones, cyrtocones, gyrocones, and nautilicones. Very little work has been done on North American Devonian nautiloids since the works by Rousseau H. Flower (1936), over fifty years ago. Identification of nautiloid species often requires examination of internal structures, which necessitates many hours of preparation work to cut and polish specimens for identification. The BHGMS club has just begun to undertake this systematic study of the BHB nautiloids with the intent to publish several articles describing the cephalopod species in the coming years.

It is possible however, to give a general overview of the nautiloid cephalopods present in the BHB fauna. Oncocerids dominate in terms of species diversity with at least seven present but orthocones are by far the most common individual cephalopod encountered in the BHB.

The oncocerids range in size from a few inches in length (*Ovoceras? sp*.) to large comma (*Acleistoceras sp*.) and oval shaped individuals over a foot in length (see figure 7). Another recently recognized oncocerid is likely an un-described species belonging to the Family *Tripleuroceratidae*, a group which have not been noted from the Iowa Devonian prior to this study (Figure 7c).

Rutocerids are present as well with large gyrocones (*Tetranodoceras? sp*., Figure 9) being the most conspicuous member of the BHB cephalopod fauna. *Tetranodoceras*? sp. has some potential to serve as a guide fossil for the Lower Solon Member. It is abundant in the Lower Solon, and has a wide geographic range within the Cedar Valley outcrop belt, occurring from the Davenport area well up into north central Iowa. It also has a limited stratigraphic range, with only a single specimen known from the Upper Solon Member, and it is not known from younger strata.

At least one nautiliconic species is also present, probably referable to *Nephriticeras sp.* (Figure 10). It is very similar both in overall shell

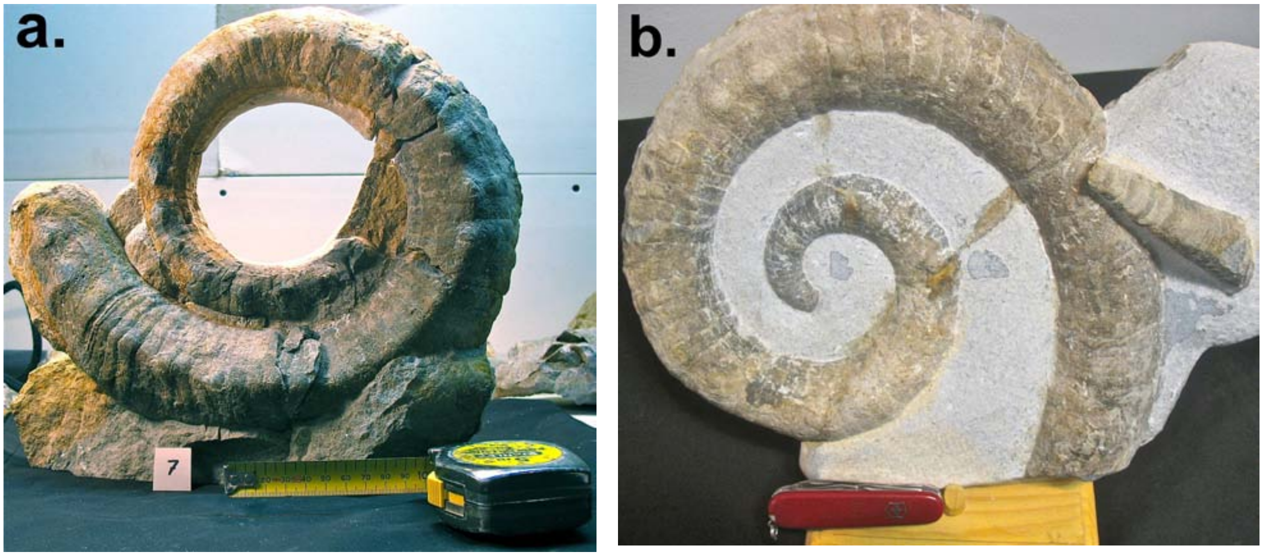

Figure 9. Two large rutocerid gyroconic nautiloids, probably *Tetranodoceras sp*., from the BHB. Note variability in coiling rates. **a.** found and prepared by T. Blume, **b.** found by T. Blume and prepared by Jack Petersen of the BHGMS.

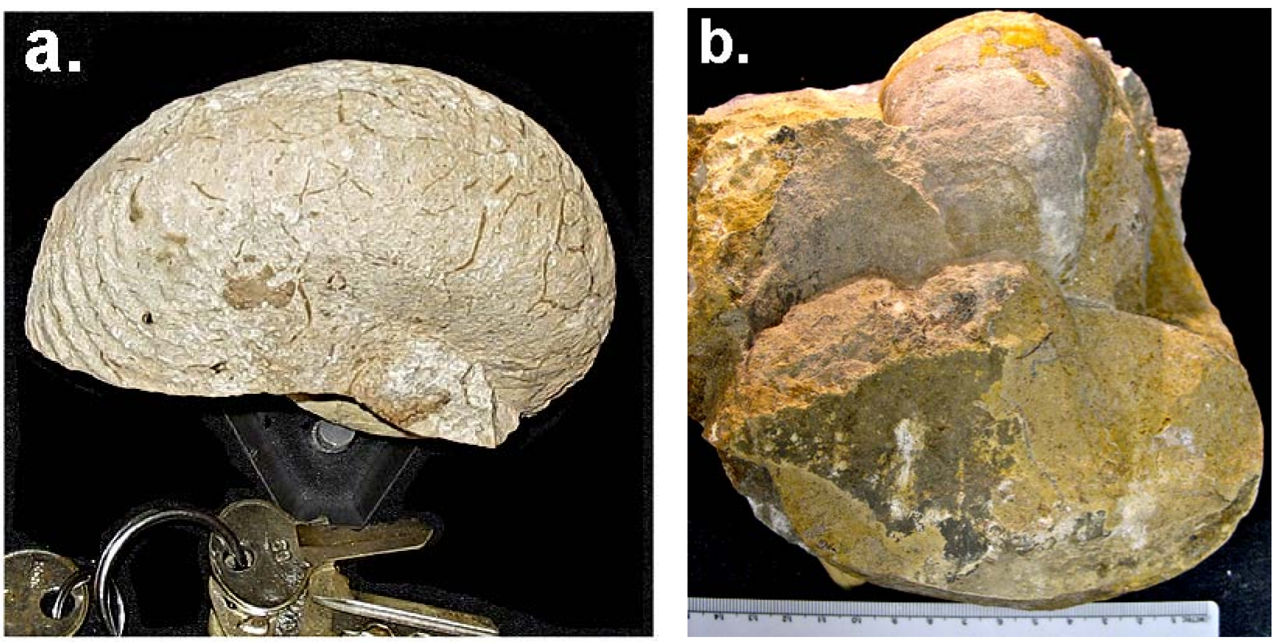

Figure 10: Two specimens of *Nephriticeras? sp.*, a large coiled nautiloid cephalopod from the BHB. **a.** Found and prepared by BHGMS' Mike Powelka, note growth lines, **b.** found by C. Newsom and prepared by T. Blume. Note aperture size, lower half of frame.

form and size to the modern day *Allonautilus scrobiculatus.* Similarity of shell form suggests similarity of life habit, so the *Nephriticeras* sp. from the BHB may have looked and behaved in a similar fashion to the extant *Allonautilus*. This demonstrates why the nautilus is often referred to as a living fossil.

The rarest of the molluscan fossils from the BHB may be either a gastropod or a cephalopod (Figure 11). It strongly resembles specimens from the Upper Devonian (Famennian) of Iowa

Figure 11. This is the rarest of the molluscan fossils from the BHB. They greatly resemble specimens from the Upper Devonian (Famennian) of Iowa which have been identified as the nautiloid cephalopod *Tylodiscoceras n. sp*. However, unlike all other cephalopod specimens from the BHB, they do not appear to have septa preserved, so it is possible that they may represent a gastropod. .**a.** top view, **b.** view of keel, note furrow.

which have been identified as *Tylodiscoceras n. sp.*, however unlike every other cephalopod specimen from the BHB septa do not seem to be preserved. Therefore it may actually represent a gastropod.

Bivalves

The BHB has also produced an unexpectedly diverse bivalve fauna, which preliminarily includes approximately 20 species. This diversity is quite anomalous for the Iowa Devonian and emphasizes the unusual nature of the BHB. Most of the forms we have recovered are not represented in the collections of the University of Iowa Geoscience Repository. It has become clear that a systematic study of these bivalves needs to be undertaken. We are currently consulting with Judith Nagel-Myers of the Paleontological Research Institution of New York State in this regard.

The presence of so many bivalve species indicates that bottom conditions during the formation of the BHB were generally hospitable for benthic organisms.

Other fossil groups of note

Brachiopods are a conspicuous member of the BHB faunas, including *Desquamatia* (*Independatrypa*) *independensis*, the name bearer of the Lower Solon Member D. (*I.*) *independensis* Zone (Day, 1992). Many other genera also occur.

Fish plates, bones, and teeth are fairly commonly encountered in the BHB. There is a large range is size, from small shell crushing plates up to bone and dermal plates from very large arthrodires (placoderms; Figure 13).

Large conularids are locally abundant in the BHB (Figure 12). Gastropods, trilobites, corals, and bryozoans are also found in the BHB, though they tend to be rather uncommon.

CONCLUSIONS

The collections from the Independence area have provided a great number of specimens of previously poorly known Iowa cephalopod and bivalve species, amongst others. The study set put together by the BHGMS over the past six years is extensive and provides a snapshot of the diversity of life present in the Middle Devonian Cedar Valley Sea. Continued examination, preparation, and study will no doubt glean even more information from these voluminous collections.

Figure 12. A conularid specimen (arrow) from the BHB.

Figure 13. A placoderm arthrodire skin plate from the BHB. Found by BHGMS' Glen Rocca.

ACKNOWLEDGEMENTS

This entire undertaking was made possible by the contributions of many people. In particular, Randy and Denise Reed of Independence were critical to this project. They supervised field trips, helped with specimen extraction, investigated other potential sites, and provided many specimens to the collections including the first specimens of several species previously unknown to us.

Mr. Kenny White and his son Gary, of Independence, initially investigated the Steve Miller Quarry, which was known as the collecting locality for one of the previously known specimens of *T. (T.) iowaense*. Mr. Miller graciously allowed access to the quarry, arranged visits to other quarry sites nearby, and helped provide information on the geographic extent of the BHB.

Tiffany Adrain, Curator of the University of Iowa Geoscience Repository, provided storage space for the collections, arranged for grants to fund research and specimen preparation, and provided help in cataloging, labeling, and photographing the collections. This study was funded in part by Iowa Academy of Science grant ISF 11-15.

Finally, the BHGMS can rightfully take pride in the thorough collection that has been put together over the past six years. Their willingness to put in many hours of collecting, and donations of many of specimens for this study set made this project possible.

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STROMATOPOROID BIOSTRATIGRAPHY OF THE IOWA GIVETIAN AND FRASNIAN

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INTRODUCTION

The Givetian (upper Middle Devonian) through Frasnian (lower Upper Devonian) of Iowa is the only place on the North American craton where stromatoporoids are found throughout almost the entire section.

Two occurrences of only lower Frasnian stromatoporoids are about 20 species from the Callaway Member of the Cedar Valley Formation, and two species from the Snyder Creek Shale 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 U.S. (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 include the Givetian as well, and present species distributions wherever possible. Publication on the Givetian-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. In a master's thesis, Shapo (2003) described Solon and Rapid Member stromatoporoids of the Little Cedar Formation. Jannusch (nee Shapo, 2008), in her doctoral dissertation, described stromatoporoids from the Coralville Formation, and Osage Springs Member of the Lithograph City Formation.

Solon Member, Little Cedar Formation

The Solon Member is upper middle Givetian (Day, 2013), and correlates with the onset of the sea-level rise known as the Taghanic Onlap. Shapo (2003) reported four species of stromatoporoids from the Solon Member that are left in open nomenclature (Table 1), making intra-state correlations impossible.

Rapid Member, Little Cedar Formation

The Rapid Member is Late Givetian (Day, 2013). As she did for the Solon Member, Shapo (2003) reported four species left in open nomenclature (Table 2). Three genera are found in both the Solon and Rapid: *Petridiostroma*, *Stictostroma*, and *Coenostroma*.

Cou Falls & Iowa City Members, Coralville Formation

According to Day (2013) the Coralville Formation is upper upper Givetian. Jannusch (2008) reported seven species of stromatoporoids from the Cou Falls Member (Table 3), and three species from the Iowa City Member (Table 4). Two species occur in both members: *Clathrocoilona abeona* and *Hermatostroma insulatum*.

Osage Springs Member, Lithograph City Formation

The Osage Springs Member is very uppermost Givetian through lowermost Frasnian (Day, 2013). According to Jannusch (2008) there are eight species of stromatoporoids in the Osage Springs Member (Table 5). *Clathrocoilona abeona* and *Hermatostroma insulatum* also occur in the Cou Falls and Iowa City Members of the Coralville Formation, and *H. insulatum* is found in the Idlewild Member of the Lithograph City Formation.

Andalusia Member, Lithograph City Formation

The Andalusia Member of eastern Iowa ranges from the uppermost Givetian through mid-lower Frasnian (Day, 2013). There is a stromatoporoid biostrome in the upper part of the Member (Witzke and Bunker, 2006, Fig. 11), which correlates with the middle part of the Idlewild Member (see below). 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 Idlewild Member is middle-upper lower Frasnian (Day, 2013). 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 6. Six of her species also occur in the overlying Mason City Member of the Shell Rock Formation (Table 7) (*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

The Mason City Member is lower middle Frasnian (Day, 2013). Stock (1982) described 11 species in 10 genera from the Mason City Member. Table 7 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*? *conferta*), and all other species, plus one specimen of *S.*? *conferta*, 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

The Rock Grove Member is middle middle Frasnian (Day, 2013). 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 8. 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

The Nora Member is upper middle Frasnian (Day, 2013). 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 9).

Cerro Gordo Member, Lime Creek Formation

The Cerro Gordo Member is middle upper Frasnian (Day, 2013). The middle-upper Frasnian boundary in Iowa is represented by an unconformity (Day, 2013). The lower upper Frasnian Juniper Hill Member of the Lime Creek Formation does not contain stromatoporoids, which with the above-mentioned unconformity represents the greatest break in the upper middle Givetian through Frasnian stromatoporoid record in Iowa. Only two species occur in the Cerro Gordo Member (Table 10). 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

The Owen member is upper upper Frasnian (Day, 2013). Stromatoporoids from the Owen Member are listed in Table 11. 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

As neither I nor my students have studied the Givetian stromatoporoids of Iowa, correlations of these species with areas outside Iowa will not be undertaken here; however, there is one case where a correlation with the stromatoporoid assemblages of Stearn (2001) is noted below.

Beginning in the late middle through late Givetian, a sea-level rise known as the Taghanic Onlap occurred, breaching a barrier that had inhibited exchange of tropical marine organisms between the eastern and central parts of North America

(Eastern Americas Realm) with the rest of the world (Old World Realm) (e.g., Stock, 2005). Consequently, 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. Few Frasnian 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. 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.

Recent work by Aul (2010) has revealed the presence of several Iowa species in the lower Frasnian of southeastern Nevada.

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 12. 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 Poland to Kazmierczak (1971), and those in the 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 Member of the Cedar Valley 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 Member of the Cedar Valley 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 non-branching 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 Member of the Cedar Valley Formation and Snyder Creek

Formation 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 Republic, Italy, Russia, Uzbekistan, China, and Australia, and the Frasnian of the 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 Member of the Cedar Valley 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 Member of the Cedar Valley Formation of Missouri, and *Hermatostroma polymorphum* occurs in the Frasnian of Belgium and the 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, the 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

Seven stromatoporoid species found in the Iowa Givetian-Frasnian are also diagnostic species used by Stearn (2001) in his biostratigraphy of the Devonian stromatoporoids of arctic and western Canada. His Assemblage 5 is lower Givetian, Assemblage 6 is middle Givetian, Assemblage 7 spans the Givetian-Frasnian boundary, Assemblage 8 is lower-middle Frasnian, and Assemblage 9 is upper Frasnian.

Trupetostroma warreni occurs in the Cou Falls Member of the Coralville Formation (Shapo, 2003), and the Osage Springs Member of the Lithograph City Formation (Jannusch, 2008). Stearn (2001) considered the long-ranging *T. warreni* to be diagnostic of his Assemblages 5-8.

Hammatostroma albertense and *Hermatoporella hayensis* co-occur in the Idlewild Member of the Lithograph City Formation (Table 6), and the Mason City Member of the Shell Rock Formation (Table 7)—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.

NEW CORRELATIONS WITH THE LOWER FRASNIAN OF NEVADA

In a recent study Aul (2010) described eight species of stromatoporoids from the lower part of the Guilmette Formation of southeastern Nevada (Table 12). Two of Aul's species, *Hammatostroma albertense* and *Trupetostroma bassleri* also occur in the Idlewild Member of the Lithograph City Formation and the Mason City Member of the Shell Rock Formation of Iowa. His *Stictostroma maclareni* has also been reported from the Cou Falls Member of the Coralville Formation, and the Osage Springs and Idlewild Members of the Lithograph City Formation.

SUMMARY

Stromatoporoids are a prominent component of the fossil fauna of Givetian and Frasnian-age strata in Iowa. During the Givetian there is an overall increase in species diversity, lows of four each in the Solon and Rapid Members of the Little Cedar Formation, with a high of eight in the Osage Springs Member of the Lithograph City Formation. After that, there is an overall upward decrease in species diversity per member in the Frasnian, 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 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 the Frasnian of western and central Europe, a correlation made possible in large part due to important monographic publications on the Devonian stromatoporoids of Belgium, Poland, and the 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.

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Table 1. Stromatoporoids of the Solon Member of the Little Cedar Formation (from Shapo, 2003).

Petridiostroma sp.
Schistodictyon sp.
Stictostroma sp.
Coenostroma sp.

Table 2. Stromatoporoids of the Rapid Member of the Little Cedar Formation (from Shapo, 2003).

Petridiostroma sp.
Clathrocoilona sp.
Stictostroma sp.
Coenostroma sp.

Table 3. Stromatoporoids of the Cou Falls Member of the Coralville Formation (from Jannusch, 2008).

Clathrocoilona abeona Yavorsky
Stictostroma maclareni Stearn
Trupetostroma warreni Parks
Hermatostroma insulatum Birkhead
Idiostroma roemeri Nicholson
Stromatopora monoensis Galloway & St. Jean
Coenostroma monticuliferum (Winchell)

Table 4. Stromatoporoids of the Iowa City Member of the Coralville Formation (from Jannusch, 2008).

Clathrocoilona abeona Yavorsky
Hermatostroma insulatum Birkhead
Amphipora ramosa (Phillips)

Table 5. Stromatoporoids of the Osage Springs Member of the Lithograph City Formation (from Jannusch, 2008).

Clathrocoilona abeona Yavorsky
Stictostroma maclareni Stearn
Trupetostroma warreni Parks
Hermatostroma insulatum Birkhead
Idiostroma roemeri Nicholson
Stromatopora sp.
Coenostroma monticuliferum (Winchell)
Habrostroma sp.

Table 6. 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 7. 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 8. Stromatoporoids of the Rock Grove Member of the Shell Rock Formation.

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

Table 9. 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 10. Stromatoporoids of the Cerro Gordo Member of the Lime Creek Formation.

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

Table 11. 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 12. Stromatoporoids from the lower Guilmette Formation of southeastern Nevada (from Aul, 2010).

Atelodictyon sp.
Hammatostroma albertense Stearn
Actinostroma cf. *A. clathratum* Nicholson
Clathrocoilona cf. *C. involuta* Stock
Stictostroma maclareni Stearn
Trupetostroma bassleri Lecompte
Hermatoporella sp.
Arctostroma contextum (Stearn)

Table 13. Non-Iowa North American formations mentioned in this paper, in alphabetical order, by stage.

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

AMMONOIDS FROM THE DEVONIAN OF IOWA

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INTRODUCTION

Ammonoid cephalopods had their origins in the Devonian Period, quickly becoming an important component of mid-Paleozoic through Mesozoic marine faunas. With the main focus of this year's Tri-State Field Trip being the Devonian of north-central Iowa, it seemed reasonable to discuss the ammonoid genera and species present in the Iowa Devonian and to tie them into the proper stratigraphic intervals or standard ammonoid zones where possible.

Though sparse, discoveries over the past several decades have shown that ammonoids from Iowa's Devonian rocks are not as rare as once thought. In fact, ammonoids are encountered with some frequency if one knows exactly where to look. Iowa's Devonian rock record has three principal ammonoid producing intervals (see Figure 1). Previous works on Iowa's Devonian ammonoids (e.g. Miller, 1936; Fenton and Fenton, 1924) have become quite dated in respect to zonal correlations. More recent works (e.g., Baker, Glenister, and Levorson 1986; Hanson and Preslicka, 1996; Preslicka, Newsom, Blume and Rocca, 2010) focused on or mentioned ammonoids from a single formation and did not attempt to provide a complete ammonoid species list for the entire Iowa Devonian.

Currently known ammonoid species from the Devonian of Iowa, from oldest to youngest, include:

Little Cedar Formation
Lower Solon Member
Tornoceras (Tornoceras) iowaense Miller 1936;

Lime Creek Formation
"Amana Beds"
Manticoceras regulare Fenton and Fenton 1924;
Sphaeromanticoceras rhynchostomum (Clarke 1899);
Tornoceras (Tornoceras) uniangulare (Conrad, 1842);

Cerro Gordo Member
Manticoceras regulare Fenton and Fenton 1924;

Owen Member
Crickites lindneri (Glenister 1958);
Sphaeromanticoceras rhynchostomum? (Clarke 1899)

Maple Mill Formation
English River Siltstone Member
Cymaclymenia striata (Münster 1832);
Cyrtoclymenia strigata House 1962;
Imitoceras opimum (White and Whitfield 1862);

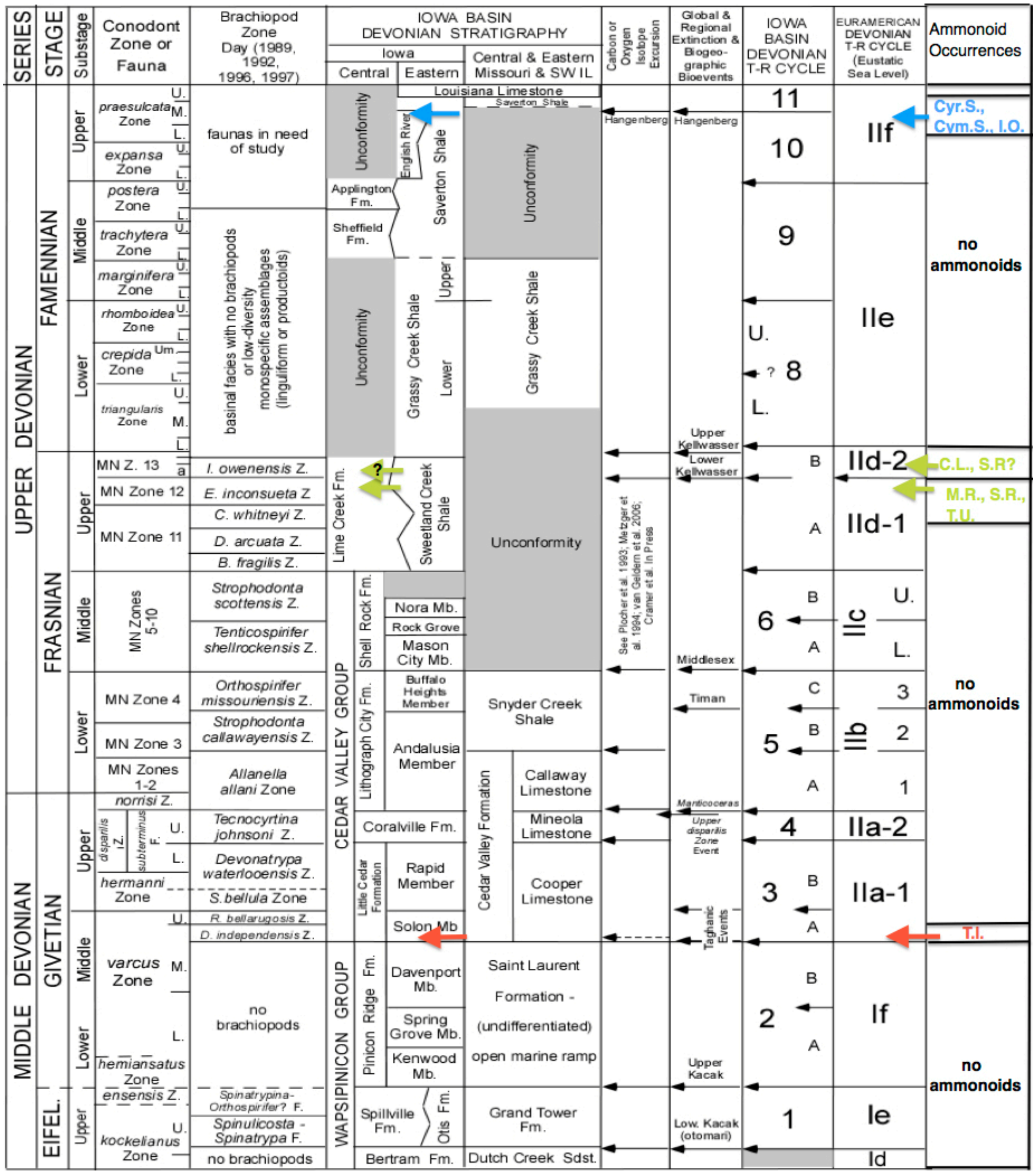

Figure 1. **(**Modified from Figure 3 of Day 2006.) Stratigraphic and biostratigraphic framework for the Middle-Late Devonian (late Eifelian- Famennian) strata of the Iowa Basin.

Abbreviations for Ammonoid Occurrence column:

T.I. = *Tornoceras (Tornoceras) iowaense*;
T.U. = *Tornoceras (Tornoceras) Uniangulare*;
S.R. = *Sphaeromanticoceras rhynchostomum*;
M.R. = *Manticoceras regulare*;
S.R? = *Sphaeromanticoceras rhynchostomum?*;

C.L. = *Crickites lindneri*;
I.O. = *Imitoceras opimum*;
Cym.S. = *Cymaclymenia striata*;
Cyr.S. = *Cyrtoclymenia strigata*.

Colored arrows point to approximate level of known occurrences: Red (lowest) = Little Cedar Formation; Green (middle) = Lime Creek Fm; Blue (upper) = Maple Mill Fm.

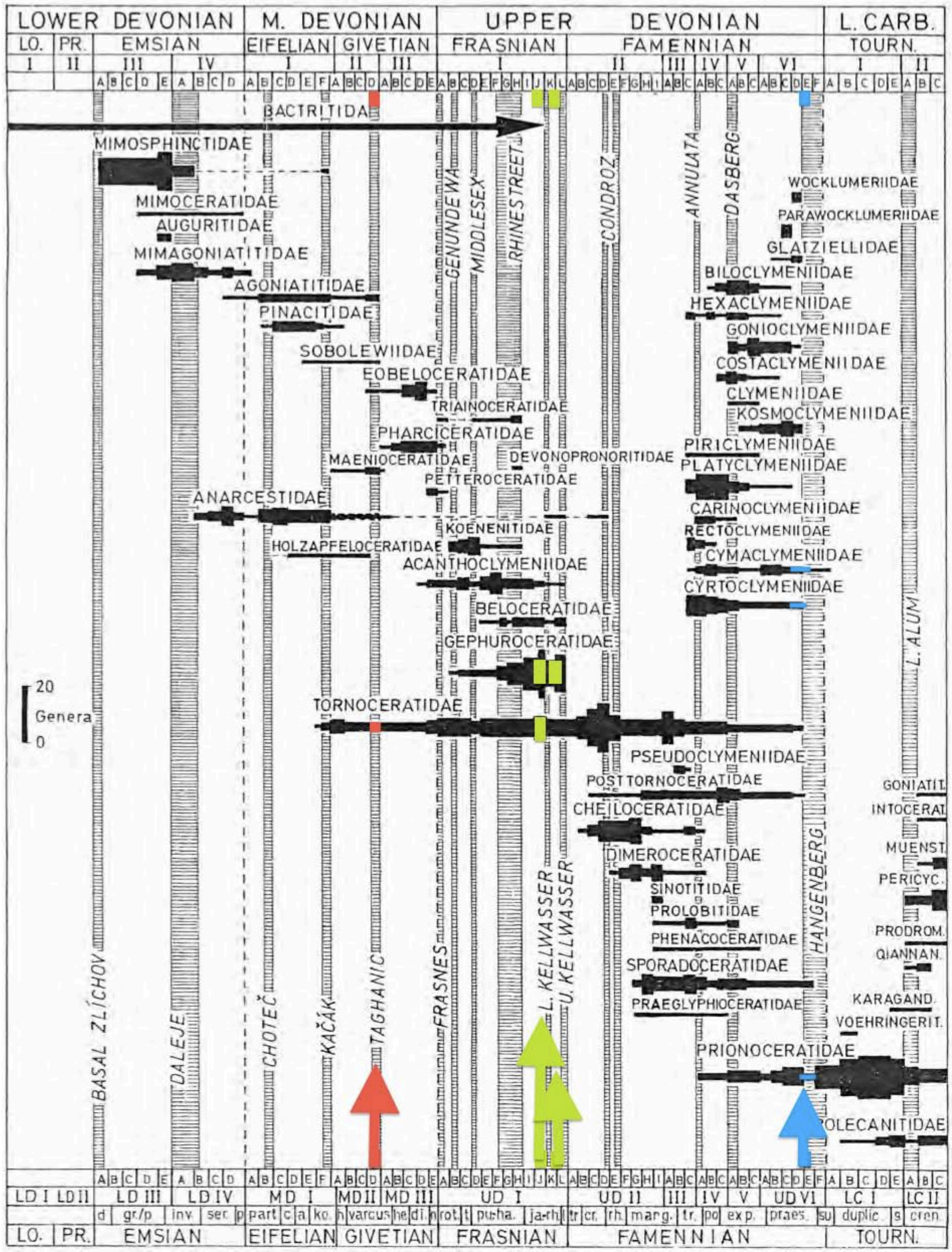

Figure 2. (Modified from House and Kirchgasser 2008, Figure 20.) Diagram illustrating the evolution of Devonian ammonoid families. The width of the bars corresponds to the number of genera at particular times as indicated by the scale. Also indicated are the named environmental stress events. (Colored) arrows/bars mark approximate levels of Iowa Devonian ammonoid occurrences: Lower (Red-left) = Little Cedar Formation; Middle (Green-center) = Lime Creek Fm; Upper (Blue-right) = Maple Mill Fm.

MIDDLE DEVONIAN - GIVETIAN STAGE CEDAR VALLEY GROUP, LITTLE CEDAR FORMATION

Lower Solon Member

Iowa's oldest known ammonoid species is *Tornoceras (Tornoceras) iowaense* Miller 1936. Miller described this species from the two specimens known to him at the time, and the age of the rocks yielding this fossil were mis-correlated as well. Recent discoveries by members of the Black Hawk Gem & Mineral Society (BHGMS) in east-central Iowa have recovered over one hundred specimens of this species (see Figure 3), contained in the most diverse Devonian cephalopod fauna, containing at least 13 species (~12 nautiloid, 1 ammonoid), known in the state. The BHGMS is presently working with the University of Iowa Geoscience Repository on a series of articles describing this unique cephalopod fauna.

Figure 3. *Tornoceras (Tornoceras) iowaense*, the oldest known ammonoid from Iowa's rock record. This is the only ammonoid species known from the entire Cedar Valley Group (Late Middle and Early Upper Devonian). Recent discoveries by members of the Black Hawk Gem & Mineral Society have recovered over a hundred specimens of this rare species. Specimen found and prepared by T. Blume.

Tornoceras (T.) iowaense is known to occur only in the Lower Solon Member (see Figure 1), and thus would potentially be of use as a guide fossil were it not for its limited geographic range - all known specimens are from a three county area in east-central Iowa. *Tornoceras (T.) iowaense* is also of limited correlation use in the worldwide ammonoid zonation, as it is an endemic - that is, a local species - it is not known to occur outside of Iowa.

Tornoceras (T.) iowaense occurs with conodonts of the Middle v*arcus* Zone, and as such, correlates to the *Maenioceras* Stufe, MD-II-D (see Figure 2) of the standard ammonoid zonation of New York (House and Kirchgasser 2008).

Tornoceras (T.) iowaense is the only ammonoid known from the Cedar Valley Group, which encompasses four formations, each comprising a major transgressive-regressive cycle (Witzke et al, 1989). The absence of other (younger) ammonoid genera is somewhat puzzling, given that the remaining Cedar Valley sequence is generally quite fossiliferous. It seems likely that a unique set of environmental circumstances led to *T. (T.) iowaense*'s presence in the Lower Solon Member. Paleozoic ammonoids were known to prefer deeper water offshore environments, and much of the remaining Cedar Valley interval was deposited on a relatively shallow water carbonate platform - perhaps too shallow to attract ammonoids.

There are a few specimens of *T.(T.) iowaense* which hint at the possibility of a sexual dimorph - that is shells of males and females which are differing sizes at maturity. Recognition of dimorphism requires examination of large collections of well preserved adult specimens that have retained mature modifications (Davis, Furnish, and Glenister, 1969).

One of the Tri-State Field Trip stops will be to the Bruening Rock Products Inc. Brooks Quarry in Independence, a site which has produced ~95% of all of the known specimens of *T. (T.) iowaense.*

UPPER DEVONIAN - FRASNIAN STAGE
LIME CREEK FORMATION

"Amana Beds"

Ammonoids have been collected from the Lime Creek Formation of northern Iowa for well over a century (Miller 1936). However, most of the specimens from the type area of the Formation are fragmentary and rather poorly preserved. During the past few decades, strata producing well preserved ammonoids were discovered in east-central Iowa, and are known informally as the "Amana Beds" of the Lime Creek Formation.

Figure 4. Exposure of upper portion of the "Amana Beds" of the Lime Creek Formation (Upper Devonian - Frasnian) in east-central Iowa. Highest in-situ occurrences of *Manticoceras regulare* and *Sphaeromanticoceras rhynchostomum* are in Unit #6. Hammer head (arrows) is at possible Lower Kellwasser Event (black shale bed at base of Unit 9). Shelly benthic fossils are common in the layers up to that boundary. Above the hammer head no shelly benthic fossils are known, only ammonoid aptychii and conodonts (Hanson and Preslicka 1996). The most likely explanation for this sudden faunal and lithographic change is a transgressive event (sea level rise).

The "Amana Beds" are interbedded shales and limestones which reach a thickness of up to 200' in well logs in east central Iowa. However, only the top ten feet or so are exposed at the surface at the two main exposures, and the rocks are not very resistant and weather quickly. One of these is a highway roadcut which can only be viewed for a short time after the road is regraded. The other exposure is a stream cut on private land, which provides productive exposures only during wet cycles when the creek is actively cleaning off the exposures.

However, thanks to road reconstruction in the 1980's and the flood of '93 leading to more collecting in the 1990's, the most abundant and best preserved ammonoid fauna from the Devonian of Iowa was assembled from these exposures (see Figures 5-8). That is not saying much of course, considering only three genera and species are represented in the "Amana Beds" outcrops and another one (possibly two) different species (see Figures 9-10) in other exposures of the Lime Creek Formation to the north. Still, one of them, *Sphaeromanticoceras rhynchostomum* (Clarke, 1899) (see Figure 7) has a worldwide distribution and allows direct correlation of the "Amana Beds" to the *Manticoceras* Stufe, UD-I-J Neomanticoceras Geozone (see Fig. 2).

The "Amana Beds" fauna also include the largest and best preserved specimens of the previously poorly known *Manticoceras regulare* Fenton and Fenton 1924. This species is the most commonly encountered ammonoid in the "Amana Beds", but appears to be endemic to Iowa, and therefore of limited stratigraphic use beyond the state's borders. *M. regulare* also hints at possibly being dimorphic (see Figures 5-6), although more specimens which retain mature modifications will be needed to verify this.

The "Amana Beds" have also yielded a single specimen of *Tornoceras (Tornoceras) uniangulare* (see Figure 8) which is a long ranging species and of little use stratigraphically.

The exposed portion of the Price Creek outcrop of the "Amana Beds" are entirely contained within a single condont zone, that of *Palmatolepis foliacea* which indicates Zone 12 of the Frasnian Montagne Noire conodont zonation (Klapper 1989). Flooding in the late 1990's revealed that the "Amana Beds" also likely contain deposits recording the Lower Kellwasser Event near the top of exposure (see Figure 4). This is the lower of two major transgressions near the end of the Frasnian Stage of the Devonian. The upper Kellwasser Event is a major extinction horizon and marks the transition into the Famennian Stage of the Devonian. This upper interval has been largely removed by erosion in East-Central Iowa.

Cerro Gordo Member

The Cerro Gordo Member of the Lime Creek Formation has produced rare fragmentary specimens of *Manticoceras regulare* Fenton and Fenton in northern Iowa since the time of Calvin (Miller 1936). These specimens pale in comparison both in numbers and quality of preservation with those specimens of *M. regulare* known from the "Amana Beds" to the south. One possible explanation for this discrepancy is that *M. regulare* may have clustered in the sea in the "Amana Beds" area, and the battered shell fragments found to the north in the Rockford area represent drift shells from dead or dying animals.

Figure 5. *Manticoceras regulare* (SUI #62376 diameter 16.5cm) from the Lime Creek Formation in east-central Iowa. Fragments of this species have been found near Rockford, IA for over a century, but the specimens from the east-central Iowa area tend to be much more complete and better preserved. Note the crowding of the last few septa, indicating this is a mature individual. This specimen may represent a macroconch (female). Specimen found by J. Preslicka and Douglas Hanson. Photo by D. Hanson.

One of the Tri-State Field Trip stops will be to the Rockford Brick and Tile Claypits in north-central Iowa. The Cerro Gordo Member is well exposed at this famous collecting site which is now a park. Cephalopod fossils do occur here though they are extremely rare and often fragmentary as mentioned above.

Figure 6. *M. regulare* (SUI #62349) from the Lime Creek Formation of East-Central Iowa. This specimen may represent a microconch (male). It retains septa crowding at a diameter of 12.5cm, and is noticeably thinner as well. Specimen found by J. Preslicka and D. Hanson.

Owen Member

The Owen Member of north-central Iowa has produced specimens of two ammonoid genera, *Crickites lindneri* (Glenister 1958) and *Sphaeromanticoceras rhynchostomum*? (Clarke 1899) (see Figures 9-10). The problem lies in the fact that the precise stratigraphic position of the ammonoid specimens within the rocks of the Owen Member is not known. The Owen Member is now known to record the Lower Kellwasser Event (see Figs. 1 and 2) within its strata. *Crickites lindneri* is known from New York state only after the first Kellwasser event but prior to the Upper Kallwasser extinction bioevent (House and Kirchgasser, 2008 p 79). *Sphaeromanticoceras rhynchostomum* is not known to range that high in the New York section. There are several possible explanations for this discrepancy. The Owen Member specimen in question could be misidentified and perhaps could properly belong to *S. aff. rickardi* which does occur after the first Kellwasser event

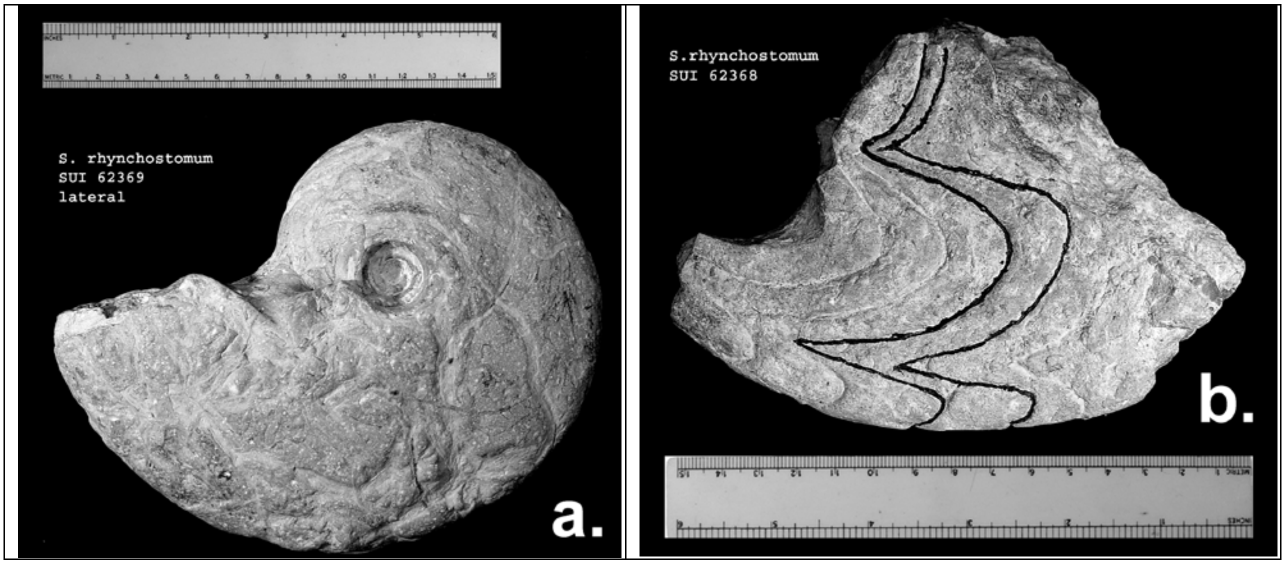

Figure 7. Specimens of *Sphaeromanticoceras rhynchostomum* from the Lime Creek Formation in east-central Iowa. **a.** (SUI # 62369) Complete whorl, entirely phragmocone (no body chamber), showing small umbilicus, **b**. (SUI #62368) Compressed fragment, with suture marks emphasized in black ink. Specimens found by J. Preslicka and Douglas Hanson. Photos by D. Hanson.

and co-occurs with *C. lindneri* in New York state (House and Kirchgasser 2008, p 79). Another possibility is that the *S. rhynchostomum*? specimen was found from Owen strata below the Lower Kellwasser event interval and is therefore older than the *C. lindneri* specimens.

Figure 8. *Tornoceras (Tornoceras) uniangulare* (SUI #54333), from the "Amana Beds" of the Lime Creek Formation. This is a long ranging genus in the Upper Devonian. Specimen found by C.H. Belanski.

The only solution to this problem will be to find in-situ ammonoid specimens in the Owen Member, and note their position relative to the positions of Kellwasser Events. This will allow proper correlation with the "Amana Beds" to the south as well as to worldwide ammonoid biozones.

Figure 9. *Sphaeromanticoceras rhynchostomum?* (SUI #50157) from the Owen Member of north-central Iowa. Precise stratigraphic position within the Owen Mb. relative to the Kellwasser events is not known. Specimen found by Calvin O. Levorson.

Figure 10. *Crickites lindneri*, (plaster cast of SUI #31835) from the Owen Member of the Lime Creek Formation of north-central Iowa. This species has a very limited range in the New York ammonoid succession, and could be an important marker species in Iowa. Specimen found by Calvin O. Levorson.

UPPER DEVONIAN - FAMENNIAN MAPLE MILL FORMATION

English River Siltstone Member

This interval yields a potentially important fauna of ammonoids, albeit one that is not particularly well preserved. The specimens from this level are often fragmentary and are poorly cemented siltstone molds, frequently without sutural preservation which makes identification difficult. Many times the only preserved sutures will be along the edge where the original shell happened to have broken along a suture line prior to burial and fossilization. Exposures of the English River Member occur mainly in two areas of far southeast Iowa, along the English and Mississippi Rivers.

Cyrtoclymenia strigata House 1962 is the most common ammonoid encountered in the English River Member, and produces the largest known ammonoid specimens (diameter up to 25cm) from the Iowa Devonian. Fragments of this species are known to the authors from both English River Member outcrop areas (see Figure 11). This species is characterized by its rapidly expanding shell whorl height, and its relatively small umbilicus.

House (1962) also listed *Cymaclymenia striata* and *Imitoceras opimum* as being found in the English River Member along the Mississippi River (see Figures 12-13). *Imitoceras* is a long ranging genus, and is of little stratigraphic use. *Cymaclymenia* is of potentially more interest as its occurrence is worldwide, and its presence may indicate that the English River specimens belong to the Wocklumeria Stufe UD-VI-E, Cymaclymenia Geozone.

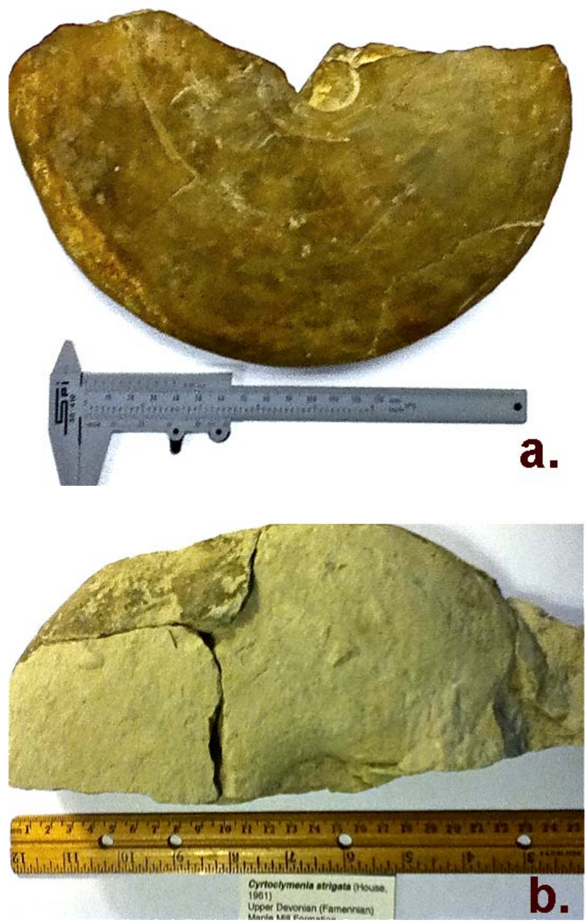

Figure 11. *Cyrtoclymenia strigata*, a potentially very important guide fossil from the English River Siltstone Member of the Maple Mill Formation. **a.** holotype specimen (SUI #8041) which was designated by House (1962), diameter ~25cm, from exposures along the Mississippi River,. **b.** specimen from exposures along the English River, diameter ~22.0cm, found by J. Preslicka and D. Hanson.

Ammonoids from the English River Member are potentially important as the New York section does not include specimens from this time interval (House and Kirchgasser, 2008). The English River Member provides a glimpse into faunas from some of the youngest Devonian rocks known in the north american midcontinent area. Only one younger formation, the Louisiana Limestone, lies below the Devonian-Mississippian boundary.

Figure 12. *Imitoceras opimum* (SUI #46916) from the English River Siltstone of southeast Iowa. White arrow points to umbilicus of specimen, note caliper for scale. Specimen found by William M. Furnish.

CONCLUSIONS

Ammonoids from the Devonian of Iowa, while not common, are not as rare as was once assumed. The purpose of this article was to summarize what genera and species are currently known and to try to tie this information into the modern ammonoid zonations.

Further collecting is needed at all three of Iowa's Devonian ammonoid producing levels. More specimens which retain mature modifications are needed to verify or disprove whether the endemic species *Tornoceras (Tornoceras) iowaense* and *Manticoceras regulare* are dimorphic in nature.

More careful collecting will be especially important in the Owen Member and English River Member intervals, whose ammonoid faunas are of greatest stratigraphic interest and may be able to shed some light on the Late Devonian end Frasnian and end Famennian ammonoid extinction events.

Figure 13. *Cymaclymenia striata* (SUI #9627) from the Upper Devonian of Morocco. This same species occurs in the English River Siltstone of Iowa, according to House (1962). Specimen found by Brian F. Glenister.

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FIELD TRIP
STOP DESCRIPTIONS AND DISCUSSIONS

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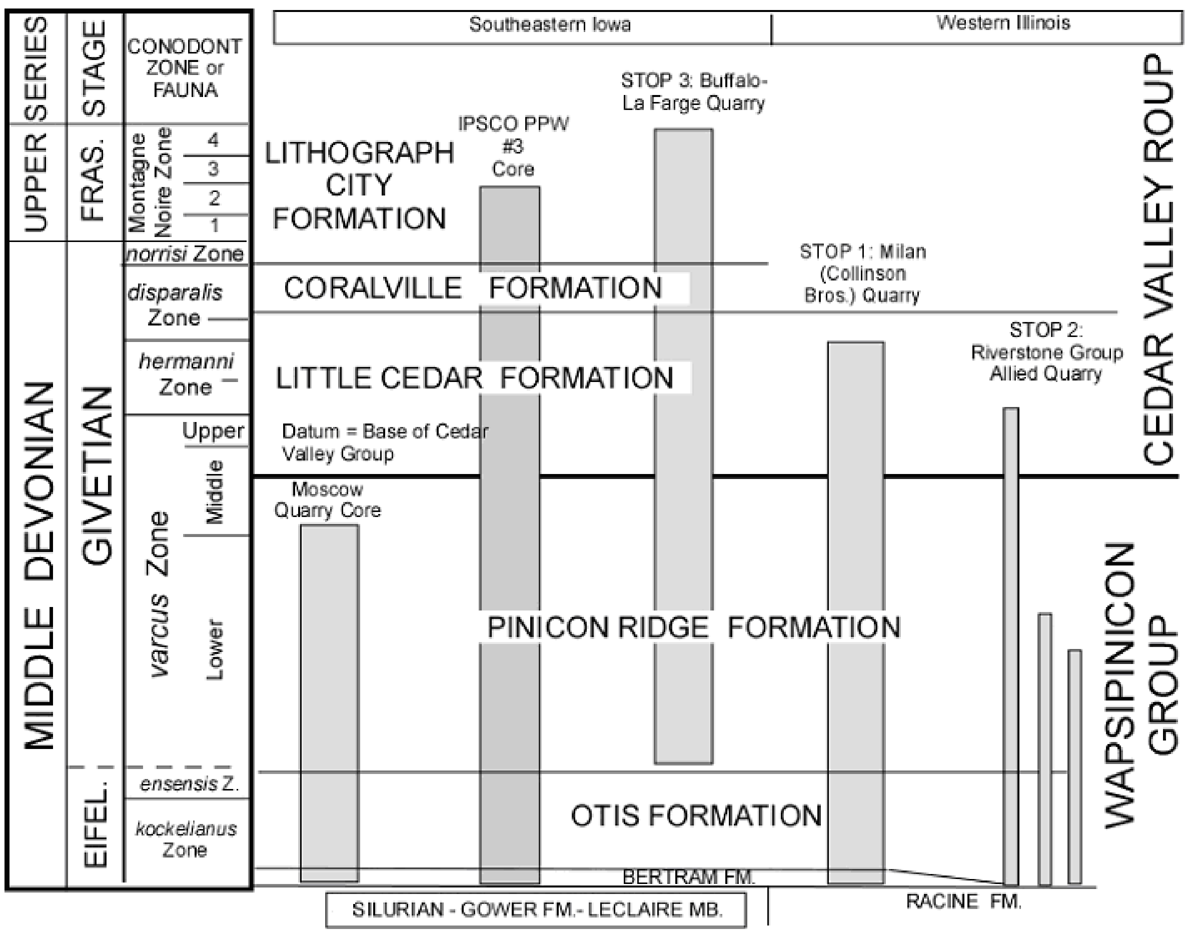

Figure 1. Chart showing Silurian and Devonian Wapsipinicon and Cedar Valley Group stratigraphic units exposed in quarries and present in cores shown in Stop Descriptions. At the Allied Quarry (Stop 2) the longest column is the generalized stratigraphic section and the two shorter columns are the 671 and 67-2 core sections. The IPSCO PPW # 3 and 67-1 and 67-2 cores will be on display for inspection in the Field Conference banquet hall.

STOP 1. BROOKS QUARRY – BRUENING CONSTRUCTION COMPANY, INDEPENDENCE, BUCHANAN COUNTY, IOWA

NW1/4, Section 2, T. 89 N., R. 8 W, Buchanan County, Iowa
(GPS Coordinates Lat. 43°02´45.64´´N, Long. 92°58´42.04´´W)

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STRATIGRAPHY AND PALEONTOLOGY OF THE UPPER WAPSIPINICON GROUP AND LOWER CEDAR VALLEY GROUP

Devonian exposures in and around the city of Independence in central Buchanan County have been studied by geologists for over a century. The presence of karst cavities filled with fossiliferous Upper Devonian and Pennsylvanian shales and been the source of confusion and controversy in the interpretation of the age of the Devonian carbonate platform facies now included in the Middle Devonian (Givetian) Wapsipinicon and Cedar Valley Groups (Fig. 1, p. 73). Exposures in and around the quarry consist of the upper part (Davenport Member) of the Pinicon Ridge Formation of the upper Wapsipinicon Group and basal Solon Member of the Little Cedar Formation of the Cedar Valley Group as shown in Figures 1 to 5.

Wapsipinicon Group

Pinicon Ridge Formation

Davenport restricted marine peritidal carbonates are still intact and abruptly overlain by open marine middle shelf facies of the Solon Member of the Little Cedar Formation along the north wall of the section locality (Figs. 1A and1B). In most parts of the Brooks Quarry and throughout much of central and eastern Iowa, most of the Davenport consists of collapse breccias (Fig. 2, units 1 and 3), with leaks of overlying sediments of the Solon Member admixed in the upper part of the Davenport breccias indicating that the collapse event(s) occurred during the early phase of Little Cedar deposition here, and across the extent of Pinicon Ridge deposition within Iowa Basin (Bunker and Witzke, 1992; Bunker et al., 1985; Witzke and Bunker, 2006a).

Where not brecciated, the Davenport Member in the Brooks Quarry consists of laminated mudstones, fenestral-birdseye mudstones, with mudcracks, with stromatolitic laminated intervals (units 2, 4 and 5 of Fig. 2). No marine shelly megafossils are known from the Davenport Member, nor other members of the Pinicon Ridge Formation in northern Iowa. Evaporites associated with peritidal carbonate mudstones of the Pinicon Ridge Formation were likely removed by solution during one or more collapse events associated with a rising water table flushing fresh water followed by normal salinity marine waters migrating through the older Wapsipinicon Group carbonate platform deposits during the sea level rise that initiated Cedar Valley Group deposition in the Middle Givetian (Witzke and Bunker, 2006b; Day, 2006).

The Davenport Member was deposited as the fourth and youngest Wapsipinicon Group Transgressive-Regressive cycle, Iowa basin Devonian T-R cycle 2B-2 during the latter part of the Middle Givetian (upper Middle Devonian) as shown in Figure 4. Davenport deposition was terminated by the major marine transgression that established open marine conditions throughout much of the Iowa Basin that initiated deposition of the Little Cedar Formation (Figs. 1B, 2 and 3).

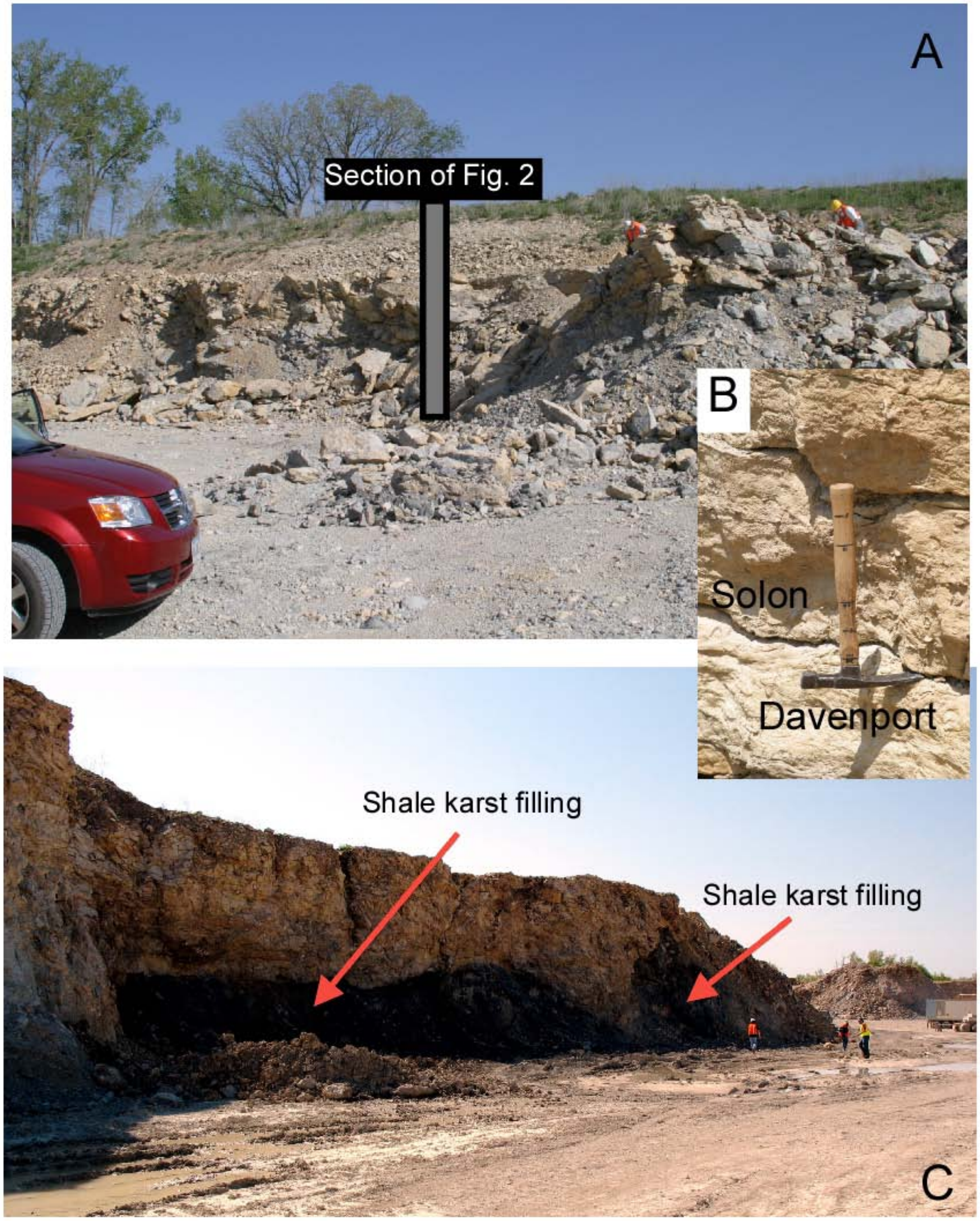

Figure 1. **A**. - Exposure of the Pinicon Ridge (Davenport Member) and Little Cedar Formation (Solon Member) in the Brooks Quarry described by J. Day and B. Witzke in 2011. Location of measured section of Figure 2 is shown. Photograph A by J. Day and geologists in hardhats are collecting cephalopods from unit 7 of the section shown in Figure 2. **B.** – Photograph of contact of the Davenport Member of the Pnicon Ridge Formation and Solon Member of the Little Cedar Formation. Hammer is 35 cm in length. Photograph by J. Day. **C.** - Large karst cavities the Pinicon Ridge Formation filled by Pennsylvanian shales in exposed just southeast of our measured section in 2011 (after fig. 3 of Prelicka et al., 2013). Photograph of karst cavities by J. Preslicka circa 2011.

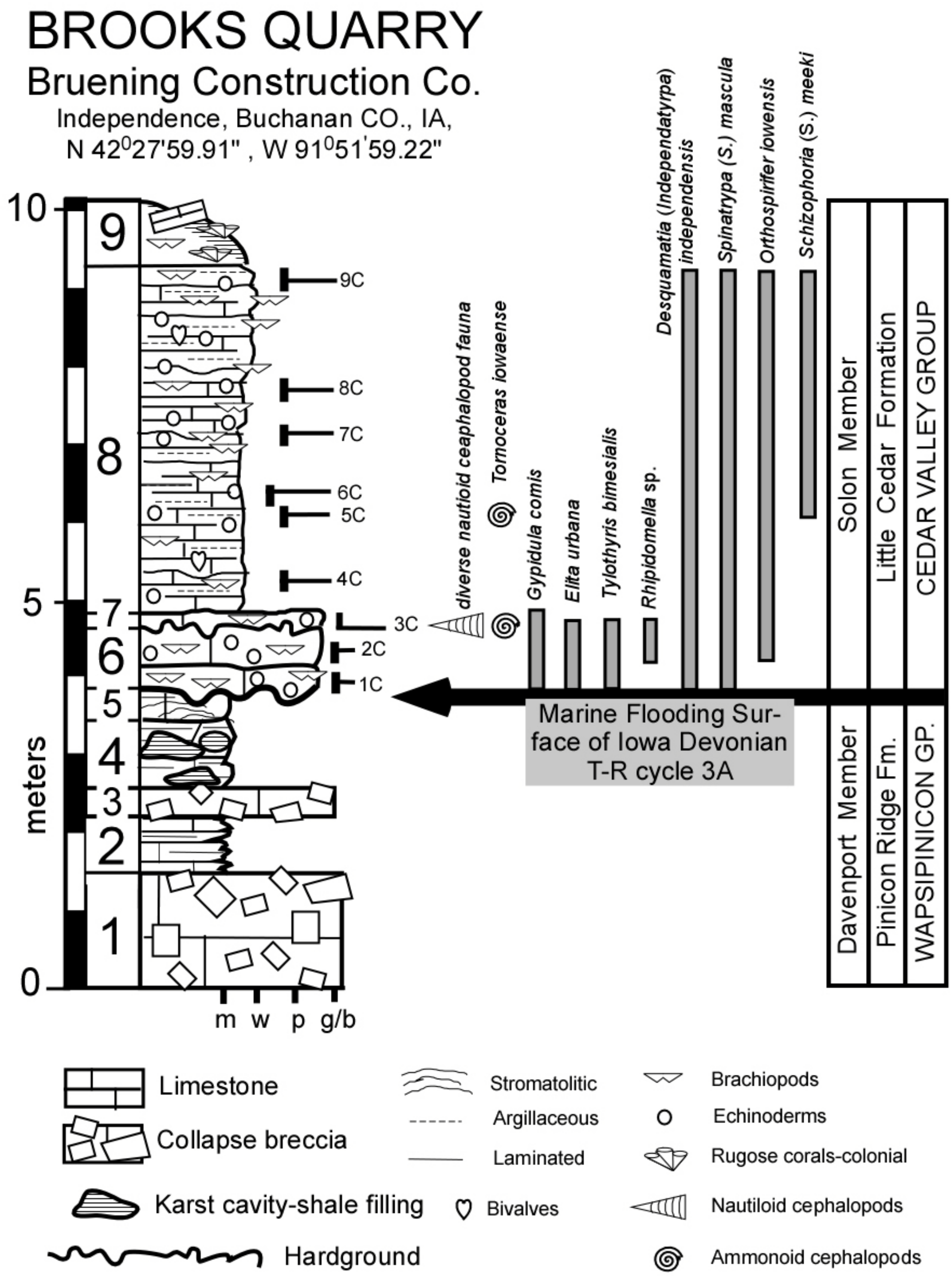

Figure 2. Stratigraphy and paleontology of the Middle Devonian Pinicon Ridge and Little Cedar formations in the Bruening Construction Company's Brooks Quarry on the west side of the town of Independence, in Buchanan County, Iowa. Section measured and sampled by J. Day and B.J. Witzke, July 28, 2011.

Major karst solution and cavern systems are developed in the Davenport Member carbonates in the Brooks Quarry and may be partially to entirely filled with Upper Devonian (Late Frasnian) shales of the Lime Creek Formation (Independence Shale of Stainbrook, 1945), or most frequently by dark gray to black carbonaceous pyritic shales of Pennsylvanian age (Fig. 1C).

Cedar Valley Group

Exposures in the upper part of the Brooks Quarry include the lower Solon Member of the Little Cedar Formation (Figs. 1A, 1B and 2). At the Raymond Quarry in Blackhawk County to the west (Stop 2), we will examine younger shallow water inner shelf deposits of upper Little Cedar Formation included in the Eagle Center and Hinkle members, and Coralville Formation (Figs 3 and 4).

Little Cedar Formation

The Solon Member in north central Iowa is substantially thicker that in its type area to the south in Johnson County (Fig. 3). It is up to eight meters thick in the Brooks quarry, and is over 24 meters in thickness to the northeast around the town of Fayette in Fayette County demonstrating substantial Solon platform thickening to the north. The exposures along the north side of the quarry studied in 2011 include over six meters of the Solon Member (Figs. 1 and 2) that include basal abraded and whole shell skeletal packstones with common brachiopods (Fig. 2, unit 6) separated by a hardground from the overlying cephalopod-bearing skeletal packstone-wackestone of unit 7 (Fig. 2). The upper contact of the skeletal carbonates of unit 7 (Fig. 2) is another pronounced hardground surface, overlain by platy argillaceous skeletal mudstones of unit 8. The upper part of the 2011 exposure consisted of highly weathered biostromal carbonates of unit 9 with numerous silicified tabulate corals and solitary and colonial rugose coral skeletons scattered in regolith derived from unit 9 (Fig. 2). These upper biostromal beds are exposed in the working highwall and upper strip bench in the newly reactivated north pit just north of the Stop 2 exposures. Similar biostromal beds are also seen in the upper part of the “Lower” Solon Member in the US Highway 150 roadcut section just north of the Volga River Bridge in Fayette County (See fig. 4 of Day, 2013).

All units of the Solon Member section in the Brooks Quarry (Fig. 2) are fossiliferous and yield diverse brachiopod, mollusc (bivalve, gastropod and cephalopod) faunas, with solitary and colonial rugose corals (mainly unit 8 of Fig. 2), byrozoans, and echinoderm skeletal plates. A diverse and abundant cephalopod fauna including nautiloids and ammonoids was recovered in unit 7 (Fig. 2) by the hard-working members of the Blackhawk Gem and Mineral Society (BHGMS) as discussed by Preslicka and others (2013a and b). The cephalopod fauna of Unit 7 includes the ammonoid *Tornoceras iowaense,* also recovered higher in the section from the lower part of unit 8 in sample 5C (Fig. 2) by B. Witzke and members of the BHGMS.

A moderately diverse brachiopod fauna is well developed in the skeletal carbonates of the Solon Member in the section at the Brooks Quarry Fig. 2). The brachiopod taxonomy of much of the diverse Little Cedar Fauna was described in a series of papers by Hall (1858), Webster (1921) and Stainbrook (1938a, 1938b, 1940a, 1940b, 1943a, 1943b). Day (1992, 1996) updated the taxonomy of most the fauna. The distribution of most species brachiopod recovered by J. Day and members of the BHGMS from the Solon Member is shown in Figure 2. The fauna in the lower Solon Member (Fig. 2, units 6 and 7) includes: *Desquamatia* (*Independatrypa*) *independensis*, *Spinatrypa* (*Spinatrypa*) *mascula*, *Gypidula comis*, *Elita urbana*, *Tylothyris bimesialis*, *Orthospirifer iowensis*, and *Ripidomella* sp.. Argillaceous skeletal mudstones of the lower part, and inter-bedded thin skeletal packstones (storm beds-tempestites) in the middle and upper part of Unit 8 (Fig. 2) include *D.* (*Independatrypa*) *independensis*, *Spinatrypa* (*S.*) *mascula*, *Tylothyris bimesialis*, *Orthospirifer iowensis*, *Schizophoria meeki*, *and Cyrtina robusta.* Skeletal storm lag beds feature large numbers of *D.* (*Independatrypa*) *independensis,* often with large *Orthospirifer iowensis,* with less common species listed above. See Preslicka and others (2013a) for a discussion of the cephalopods and other molluscs and fish material recovered from the Solon Member at the Brooks Quarry.

Upper Devonian and Carboniferous Stratigraphic Leaks

Independence Shale

Stratigraphic leaks of fossiliferous (brachiopods and conodonts) of the Upper Devonian Lime Creek Formation were discovered by older investigators (most notably Calvin, 1878, and Stainbrook, 1945) who gave them the name Independence Shale based on their initial discovery in the vicinity of the town of Independence in Buchanan County, Iowa (see Figs. 2 and 3). Stainbrook (1945) described most of the brachiopods from these cave-filling Upper Devonian shales (hosted in what are known to be older Pinicon Ridge or younger Little Cedar Carbonates) in Buchanan County, and in-place outcrop exposures with similar shelly fossils of the Amana Beds in Iowa County. He claimed their occurrences were in-place above the Davenport Member and underlying the Cedar Valley Group carbonates. Given that given the brachiopod faunas of the Independence Shale (including the Amana Beds) clearly is of Upper Devonian age, Stainbrook (1945) placed much of the overlying Cedar Valley Group within the Upper Devonian. Cooper (in Cooper et al., 1942) clearly recognized that the Independence Shale of Stainbrook (1945) and Calvin (1878) were cave sink or karst cavity fillings hosted in Middle Devonian carbonates, back-filled during the Upper Devonian by much youngerfossiliferous marine shales of the Lime Creek Formation. Cooper discussed the Independence Shale problem at length in his monograph on the Middle and Upper Devonian brachiopods of New Mexico (in Cooper and Dutro, 1982).

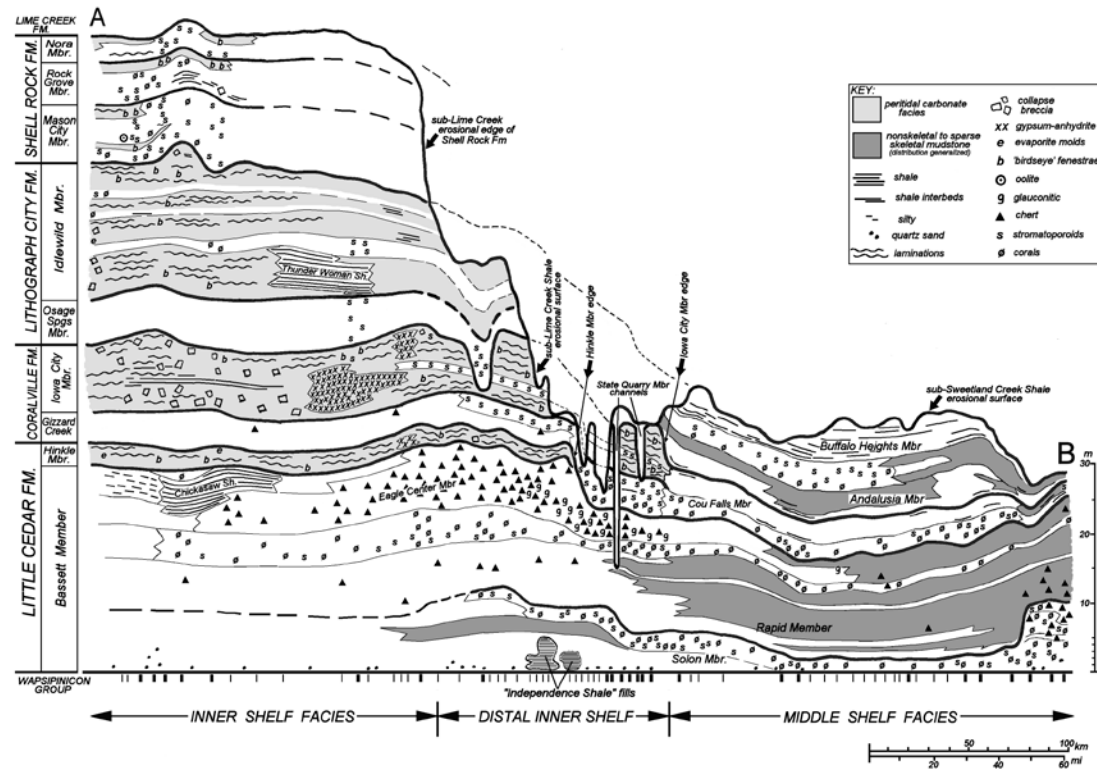

Figure 3. Northwest-southeast stratigraphic cross section of the Cedar Valley Group in eastern Iowa (see locations of cores and quarries in fig. 1 of Day et al., 2013,). Significant Late Givetian post-Coralville and Middle Frasnian sub-Lime Creek/Sweetland Creek erosion has truncated Cedar Valley strata, especially in the distal inner-shelf area. "Independence Shale" fills are stratigraphic leaks of the Late Frasnian Lime Creek Formation within Cedar Valley karst networks and openings. See Fig. 1 for location of cross-section line (AB) and data points used in the cross-section construction. After fig. 2 of Witzke and Bunker (2006a). Datum = top Wapsipinicon Group.

This Devonian-age karst system was reactivated during the Late Carboniferous when older Paleozoic carbonate bedrock units were subjected to karstification, and back-filled by Pennsylvanian terrestrial deposits leaking into the active karst cavern systems across much of Iowa, Illinois, Missouri, Wisconsin and Minnesota.

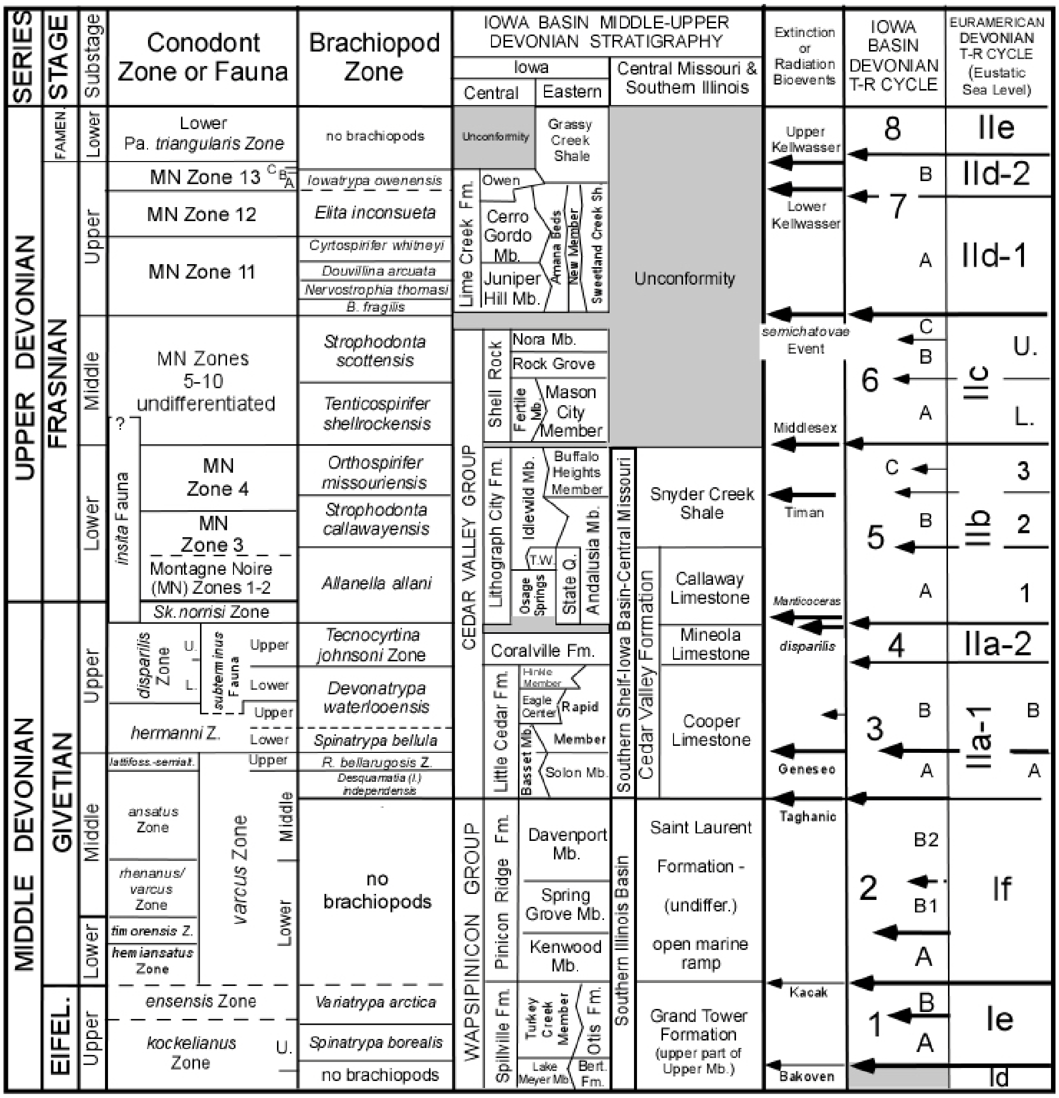

Figure 4. Stratigraphic and biostratigraphic framework for the Middle-Late Devonian (late Eifelian-early Famennian strata of the Iowa Basin showing relationships between: the qualitative eustatic T-R cycles of Johnson et al. 1985), Johnson and Klapper (1992), Day et al. (1996), Day (1998), Whalen and Day (2008); and Iowa Basin Devonian T-R cycles of Witzke et al. (1989), Bunker and Witzke (1992), and Witzke and Bunker (1996, 2006). Iowa Devonian conodont biostratigraphy follows Witzke et al. (1985, 1989), Klapper in Johnson and Klapper (1992), Bunker & Witzke (1992), Witzke & Bunker (1996), Day (1990, 1992, 2006), and Over (2002, 2006), Frasnian conodont zones after Klapper (1989). Devonian brachiopod biostratigraphy from Day (1989, 1992, 1996, 1997, new data). Iowa Basin Devonian stratigraphy after Witzke et al. (1989), Witzke and Bunker (1992, 1996), Day (1997), Day et al. (2008). Modified from fig. 3 of Day (2006) and Day et al. (2008). After fig. 4 of Day and others (2013). Abbreviations: Bert. = Bertram Fm. = Formation, Mb. = Member, L = Lower, M. = Middle, U. = Upper.

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STOP 2. THE MIDDLE DEVONIAN (GIVETIAN) LITTLE CEDAR AND CORALVILLE FORMATIONS AT BASIC MATERIALS CORPORATION'S RAYMOND QUARRY, BLACKHAWK COUNTY, IOWA

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INTRODUCTION

During Middle and Late Devonian time, major rises in global sea level resulted in the expansion of enormous epicontinental (epeiric) seas into central and western North America via the Cordilleran margin to the west, and from the Illinois Basin and the Ouachita continental margin facing the Rheic ocean to the south and east. Cedar Valley Group deposition involved development of a major carbonate ramp system with and expansive inner shelf region covering most of western and north-central Iowa and adjoining parts of Nebraska, northern Missouri, Minnesota and Wisconsin, with deeper subtidal middle shelf deposits accumulating across eastern and southeastern Iowa (Fig. 1). Middle and Upper Devonian sea level changes resulted in deposition of as many as four carbonate platform third order depositional sequences or Transgressive-Regressive (T-R) cycles that make up the Cedar Valley Group in the Iowa Basin.

Part of the first two Cedar Valley Group Devonian T-R cycles are represented by carbonate platform facies of the Little Cedar and Coralville exposed the Basic Materials Comporation's Raymond Quarry in eastern Black Hawk County (3B and 4, Figs. 1 to 3). One of the most significant sea level rises of the Devonian during Middle Devonian (Middle Givetian) basal initiated deposition of the Little Cedar Formation and was referred to by Johnson (1970) and Johnson et al. (1985, 1996) as the Taghanic Onlap or Euramerican Devonian T-R cycle IIa (see fig. 2 of Day, 2013). Witzke and Bunker (2006b), Day (2006) and Day et al. (2008) designate the initial Little Cedar T-R cycle as Iowa Devonian T-R cycle 3A, with overlying Rapid Member and its equivalents in northern Iowa (lower Basset, Eagle Center and Hinkle members) representing the next Iowa Devonian T-R cycle 3B, and the Coralville Formation representing T-R cycle 4 of the Cedar Valley Group (Figs. 1 to 3).

As shown in Figure 1, inner shelf environments were characterized by peritidal facies including mudflat deposits,evaporites, breccias,and intraclast conglomerates, overlying thin transgressive marine carbonates deposited in shallow subtidal inner- or more open-marine fossiliferous subtidal middle-shelf facies. Middle shelf environments were dominated by subtidal, open-marine carbonates with mud-supported textures including skeletal mudstones wackestones and packstones with diverse marine fossils and fossil debris.

THE CEDAR VALLEY GROUP

The Cedar Valley Group (previously Cedar Valley Formation or Limestone) was elevated to group status by Witzke et al. (1989). Four formations comprise the Cedar Valley Group. These are, in ascending order, the formations are Little Cedar, Coralville, Lithograph City, and Shell Rock (Figs. 1 to 3). Each formation corresponds to a T-R cycle, and each is separated from adjacent formations by a discontinuity or disconformity erosional surface. The basic stratigraphic framework of Iowa's Cedar

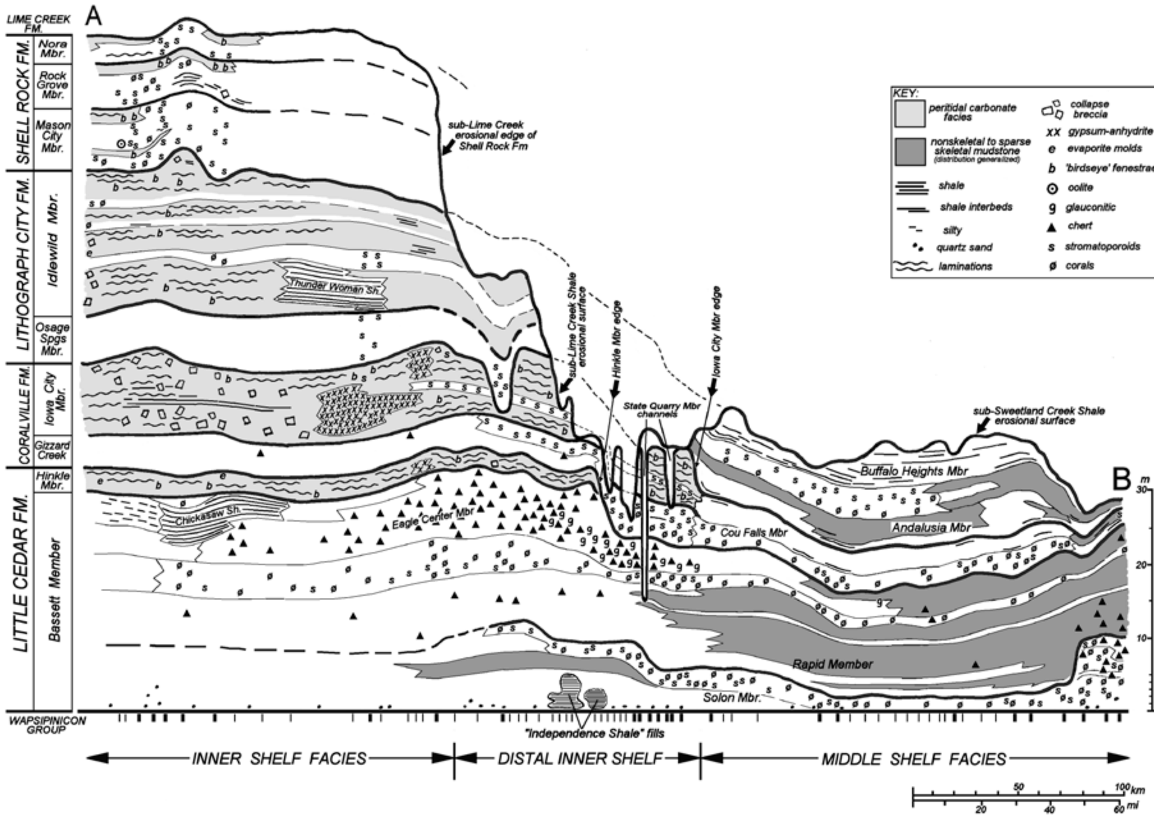

Figure 1. Northwest-southeast stratigraphic cross section of the Cedar Valley Group in eastern Iowa (Fig. 1). Significant post-Coralville and post-Shell Rock sub-Lime Creek/Sweetland Creek erosion has truncated Cedar Valley strata, especially in the distal inner-shelf area. "Independence Shale" fills are stratigraphic leaks of the Late Frasnian Lime Creek Formation within Cedar Valley karst networks and openings. See Day (fig. 1 for location of cross-section line (AB) and data points used in the cross-section construction. After figure 2 of Witzke and Bunker (2006). Datum = top Wapsipinicon Group.

Valley Groups is comprised of carbonate Transgressive-Regressive (T-R) cycles (Witzke et al., 1988; Witzke and Bunker, 1992, 1997; Day 2006; Day et al., 2008). Figure 2 shows the timing of Iowa Devonian relative sea level changes calibrated to the existing brachiopod biostratigraphy.

A typical Cedar Valley Group T-R cycle in the inner shelf facies belt of northern Iowa (Fig. 1) is marked by abrupt facies changes with a basal fossiliferous interval that marked open-marine deposition over a major transgressive marine flooding surface, overlying restricted marine facies of the preceding cycle. These transgressive deposits are capped by facies of the regressive or progradational phase of the cycle during sea level highstand or sea level fall (forced regression terminating Coralville deposition). Such deposits reflect shallow-marine, restricted-marine, and tidal-flat settings. The regressive deposits capping sequences across much of northern Iowa are peritidal facies (see Hinkle and Iowa City Member facies in the Raymond Quarry section, Fig. 3). Peritidal deposits accumulated in environments in a zone ranging from intertidal mudfalts, tidal channels, restricted lagoons, and supratidal mudflats, salinas or sahbkas.

THE LITTLE CEDAR AND CORALVILLE FORMATIONS AT THE RAYMOND QUARRY

Carbonate platform strata of the Little Cedar and Coralville formations of the Cedar Valley Group are exposed in the Basic Materials Corporations' Raymond Quarry (Fig. 3) just east of the town of Raymond, Iowa (Fig. 3). The Little Cedar and Coralville formations were deposited during Iowa Devonian T-R cycles 3A to 3C (Fig. 2).

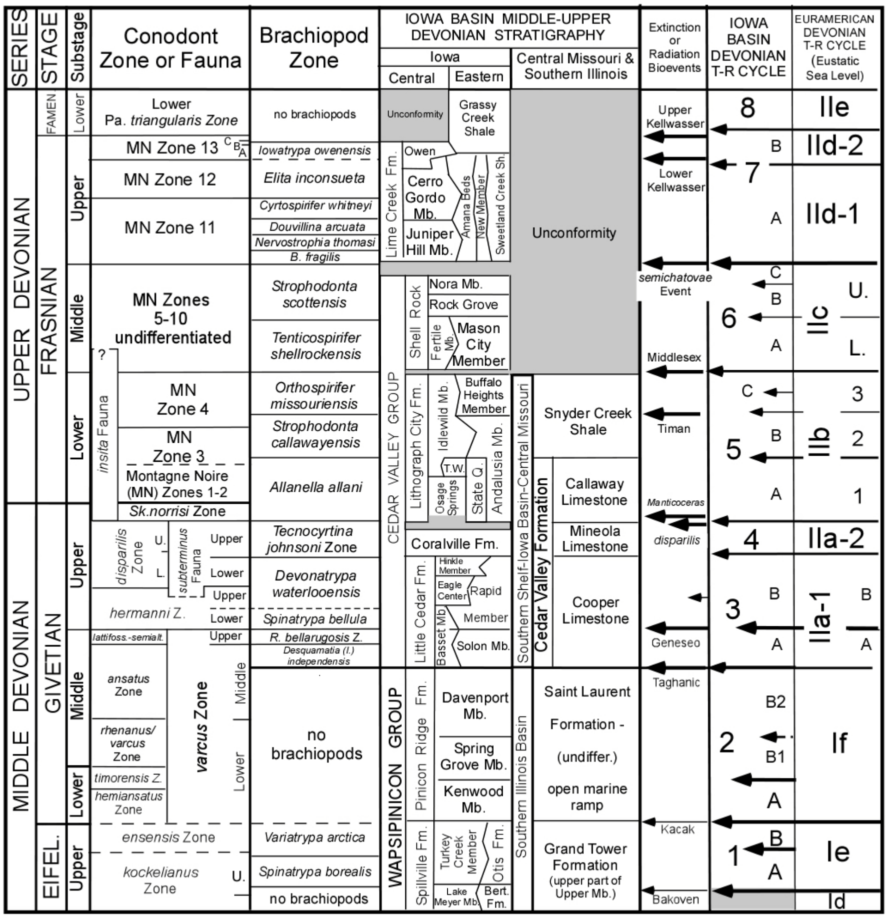

Figure 2. Stratigraphic and biostratigraphic framework for the Middle-Late Devonian (late Eifelian-early Famennian strata of the Iowa Basin showing relationships between: the qualitative eustatic T-R cycles of Johnson and others 1985), Day and others (1996, 2008), Day (1998), Whalen and Day (2008); and Iowa Basin Devonian T-R cycles of Witzke and others (1989), Bunker and Witzke (1992), and Witzke and Bunker (1996, 2006). Modified from fig. 3 of Day (2006) and Day and others (2008). Abbreviations: Bert. = Bertram Fm. = Formation, Mb. = Member, L. = Lower, M. = Middle, U. = Upper.

Beds of the Eagle Center Member of the Little Cedar Formation are interpreted as open-marine deposits, and where they are not dolomitized, consist of laminated to thinly bedded skeletal packstones or even grainstones, often cherty. Mudflat deposits of the Hinkle Member accumulated in a restricted peritidal setting. The Coralville Formation consists of open-marine subtidal carbonates of the basal Gizzard Creek Member (dolomitized in the Raymond Quarry, Fig. 3) overlain by restricted peritidal carbonates of the Iowa City Member.

A variety of fossils can be collected or observed in the Gizzard Creek Member in the Raymond Quarry, most notable are modlic brachiopods of the atrypid *Desquamatia* (*Independatrypa*) *randalia*, with *Devonatrypa waterlooensis* noted from the underlying Eagle Center Member of the Little Cedar by Witzke at this locality (Fig. 5). Stromatolites, the products of sediment trapping, binding, and /or precipitation on the surfaces of cyanobacterial biofilm mats (filametaceous photosyntheitc bacteria) are well developed in the Iowa City Member of Coralville Formation. Structures in unit 3 of Hinkle Member of the Little Cedar Formation are labeled "wavy stromatolites" (Fig. 3). Similar structures were noted in the old nearby Pint's Quarry by Kettenbrink (1972) who interpreted the "ripple-like" features as the product of soft-sediment deformation. These features are now known to be low-amplitude stromatolites that formed in a high-intertidal setting. Unit 15 of the Coralville Formation (Fig. 3) is a prominent stromatoporoid biostrome with hemispherical and digitate stromatoporoids (*Idiostroma*). Stromatoporoids are and extinct group of hypercalificed sponges that occupied shallow subtidal inner shelf lagoonal and restricted regions of the Devonian carbonate ramp shelf systems, as well as major contributors to the contraction of Silurian carbonate mound systems in Iowa and other tropical shelf systems worldwide. Stromatoporoids are common in Cedar Valley Group inner shelf deposits and are often associated with tabulate, and solitary and colonial and solitary rugose corals in laterally-extensive tabular bedded biostromal deposits.

Mississippi Valley type lead-zinc mineralization has also been noted noted in Cedar Valley Group carbonates in the Raymond and other nearby quarries. Sphalerite, barite, and rare galena have been recovered, as well as fluorite, marcasite, pyrite and calcite. The most common mineral occurrences are calcite-lined solution vugs.

Sherman Lundy (Basic Materials Corporation geologist) indicates that the Raymond Quarry is one of the company's primary producers of aggregate. Between 100,000-170,000 tons of rock are produced here in a typical year, with amounts exceeding 200,000 tons during peak periods of road construction such as the recently completed 2013 construction work on Interstate Highway 380 in Waterloo and Cedar Falls area. Units A-G (Fig. 3) are quarried for roadstone, as are other beds lower in the Coralville Formation. Beds in the formation below units A-G produce Class 2 concrete stone. Most of the Little Cedar Formation is not mined for quarry products, although bed 16 of the Eagle Center Member (Fig. 3) can be crushed for roadstone.

ACKOWLEDGEMENTS

Sherman Lundy provided a stratigraphic log and lithologic descriptions for the Raymond Quarry. Brian Witzke, Bill Bunker, Sherman Lundy, J. and UNI undergraduate students Karpel and M. Whitsett (UNI undergraduate students) measured the stratigraphic section on April 2, 1996 as shown in Figure 3. Wayne Anderson (1996) wrote the original guidebook stop description adapted here for this locality.

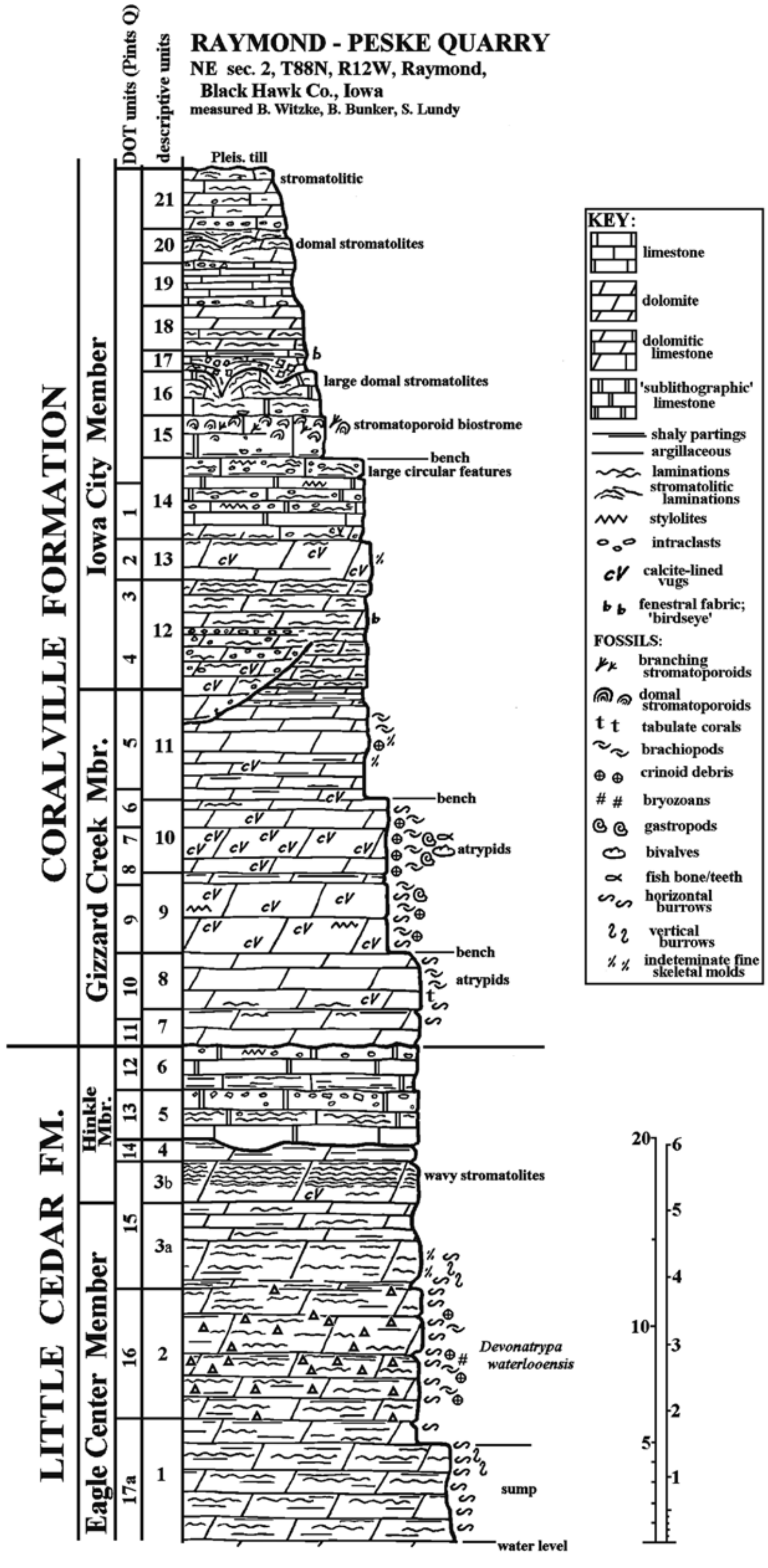

Figure 3. Stratigraphic section of Cedar Valley Group strata exposed in the Basic Materials Corporation's Raymond Quarry. Measured by B. Witzke, B. Bunker, and S. Lundy. After figure 5 of Anderson (1996).

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STOP 3. STRUCTURALLY-COMPLEX, CARBONATE-MOUND FACIES IN THE LOWER HOPKINTON FORMATION (SILURIAN) IN THE PAUL NIEMANN CONSTRUCI'ION COMPANY'S TRIPOLI QUARRY, BREMER COUNTY, IOWA.

SWl/4, SEC.36, T.93N., R.13W.

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INTRODUCTION

The exposures in the Tripoli Quarry (Figs. 1 to 9) were deposited during the Early Silurian (Llandoverian Stage) sea level rise that initiated Iowa Silurian Transgressive-Regressive Cycle IB in the Iowa Basin (Figs. 1-5). Deposition of the Hopkinton Formation in the Iowa Basin marked the first major major expansion of Early Silurian carbonate platform facies across much of central and western North America (Figs. 3, 4 and 5). Hopkinton Formation carbonates onlap the older Silurian Tetes de Mortes Formation and older Ordovician units across much of the Iowa Basin and adjacent states in the central US. Silurian reef or mound facies represent the oldest episode of mound construction known within the Iowa Basin (Fig. 5). Younger episodes of mound construction are well documented in the Scotch Grove and Gower Formations and were unreported from the Hopkington until the 1990s. At the Tripoli Quarry Hopkinton Formation deposits display structurally-complex relationships as seen in the highwall exposures (Figs. 6, 7 and 8). Vertical dips (Figs 6 and 8) displayed by Hopkington strata in the highwall exposures are difficult to reconcile with soft sediment deformation of mound flank beds, and may been structurally deformed during faulting (tranpression?) along the trend of the Fayette structural zone (Fig.2), although faults are not apparent in the exposures in the Tripoli Quarry in Bremer County.

Historically the presence of Silurian strata in Bremer County was noted by Harmon (1906) in his report on the geology of the county. He clearly recognized folded Silurian exposures in Bremer County and attributed the deformation to structural causes. He stated that local upwarps lifted the Silurian to the surface at several points in the county-about three and a half miles west of Tripoli and southeast of Waverly, on Baskin run and near the mouth of Quarter Section run. During Norton's (1906) mapping in Bremer County, the distribution of the Silurian and Devonian rocks were becoming better known in other areas of the state. Norton noted that the outcrop near Tripoli is aligned with the “Oelwein-Fairbank anticline”. The “Oelwein-Fairbank anticline” is associated with structurally deformed bedrock associated with the Fayette Structural Zone (Fig. 2). The erosional surface on the Silurian bedrock in Bremer, Black Hawk and Fayette counties were part of a low structural paleotopographic feature called the Hardin-Bremer High (Fig. 2), that was onlapped by Middle Devonian platform carbonates of the Wapsipinicon and/or Cedar Valley groups shown on Figure 2.

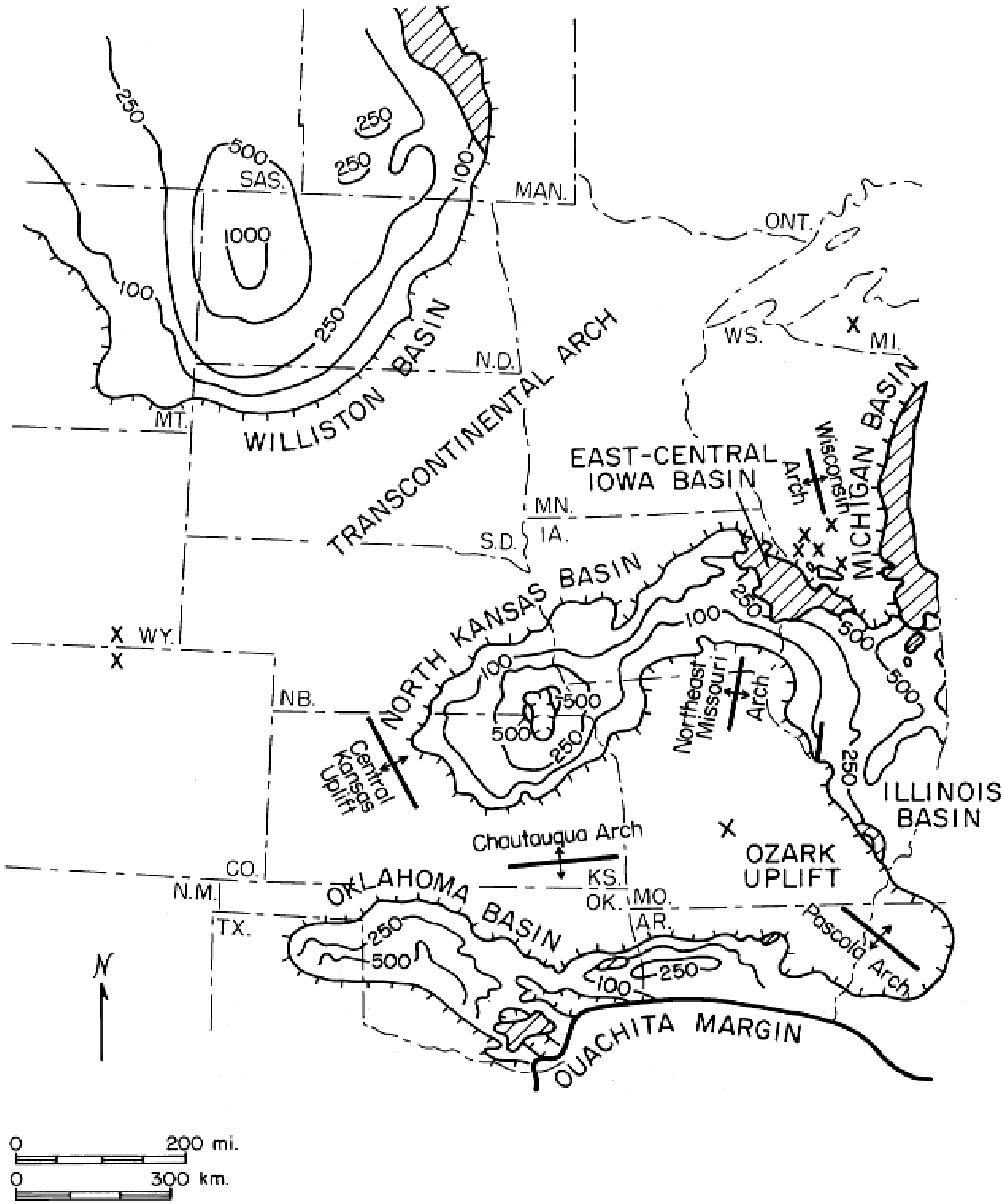


Figure 1. Generalized Silurian isopach map of central North America (isopachs in feet). Structural elements are labeled. Location of Silurian outliers are marked by X. Silurian erosional-depostional edge is hachered. Silurian outcrop areas are cross-ruled. After fig. 7 of Witzke (1992).

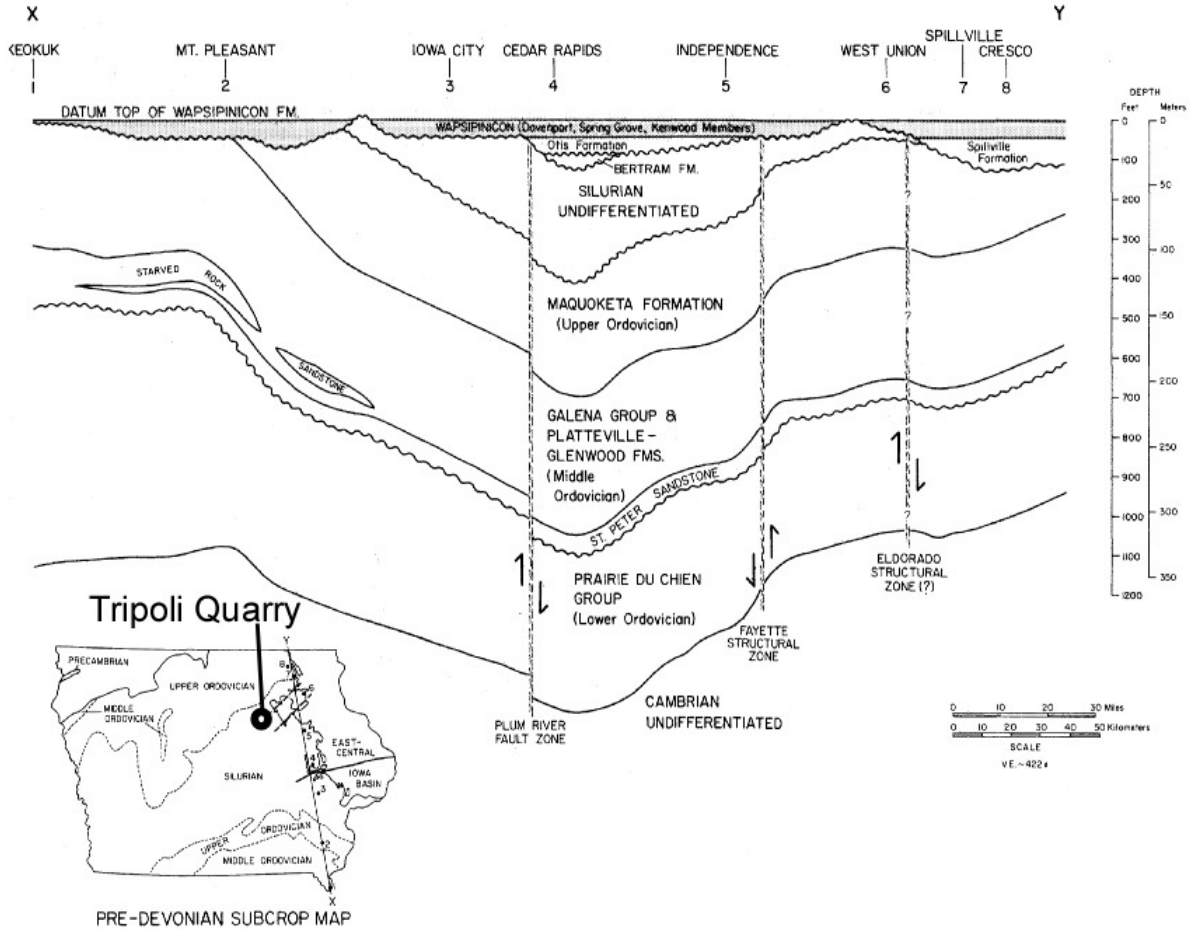
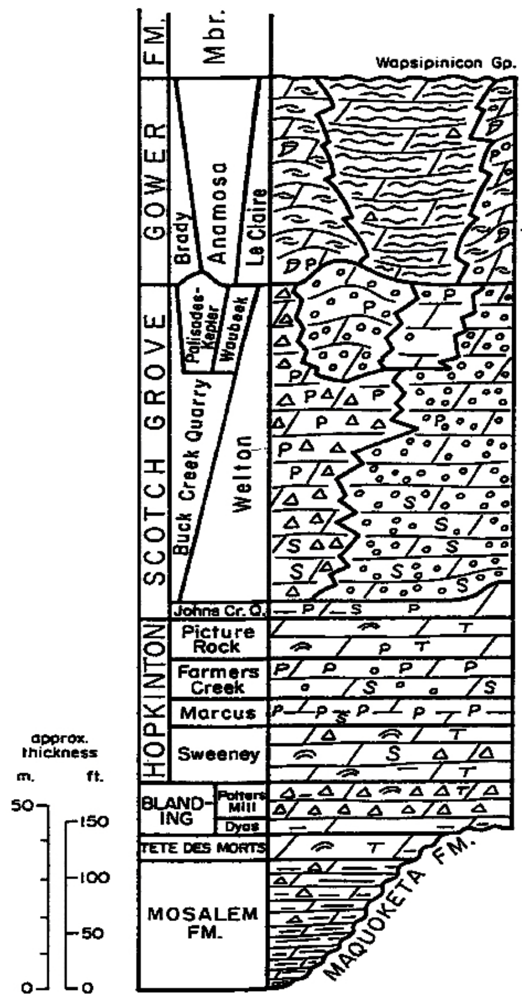


Figure 2. Main fault systems known in eastern Iowa shown in the north-south cross-section with the top of the Wapsipinicon Group as the datum. The location of the Tripoli Quarry is shown at the western terminus of a projected fault system associated with the Fayette structural zone. After fig. 31 of Bunker and others (1984).

SILURIAN STRATIGRAPHY, STRUCTURE AND DEPOSITIONAL ENVIRONMENTS

The generalized stratigraphy of the Silurian System of eastern Iowa is shown in Figure 3. Silurian rocks in the Tripoli Quarry consist of fine to medium grained crystalline dolomites with abundant moldic fossils in the large blocks within the quarry. Even though the platform carbonate rocks are extensively dolomitized, their original depositional textures are recognizable as skeletal wackestone and packstones according to Dunham's (1962) classification of carbonate rocks. Anderson (1996) suggested a correlation of the Tripoli Quarry Silurian carbonates with the lower Hopkinton Formation as probable equivalents of the Sweeney-Marcus members interval (Figs. 3 to 5).



P = pentamerid brachiopods
S = stricklandiid brachiopods
T = tabulate corals
⁖ = crinoidal content
⌒ = laminar stromatoporoids
△ = chert
~ = brachiopods

Figure 3. Generalized Stratigraphy of the Silurian System of eastern Iowa. After fig. 4 of Witzke (1992).

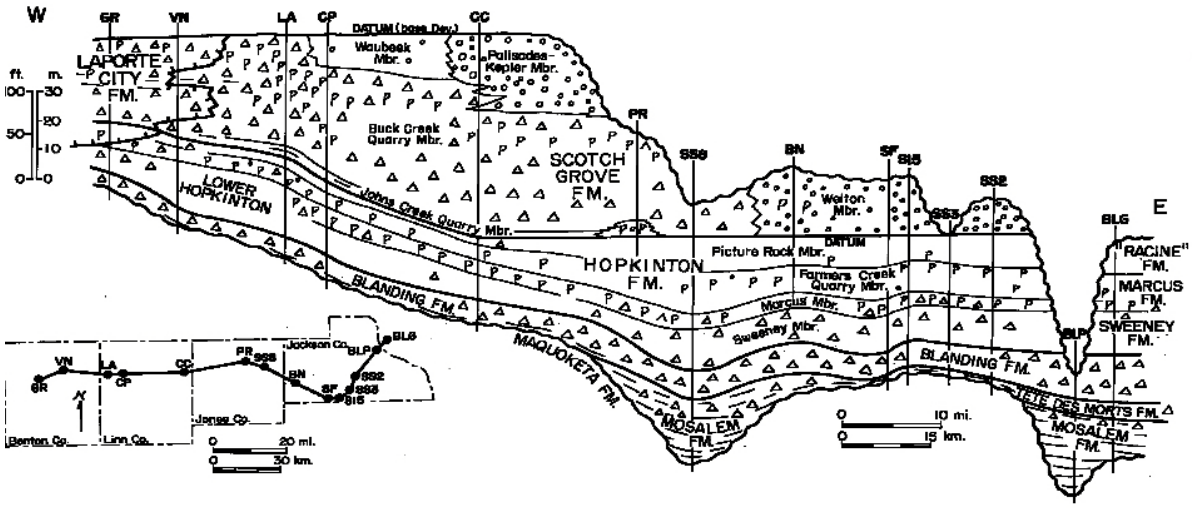


Figure 4. Stratigraphic cross-section of Silurian strata in east-central Iowa. The Laporte City Formation is a western limestone facies. Control points include core and outcrop sections. Datum shifts from base of the Devonian to base of the Scotch Grove Formation in the eastern outcrop belt. After fig. 6 of Witzke (1992).

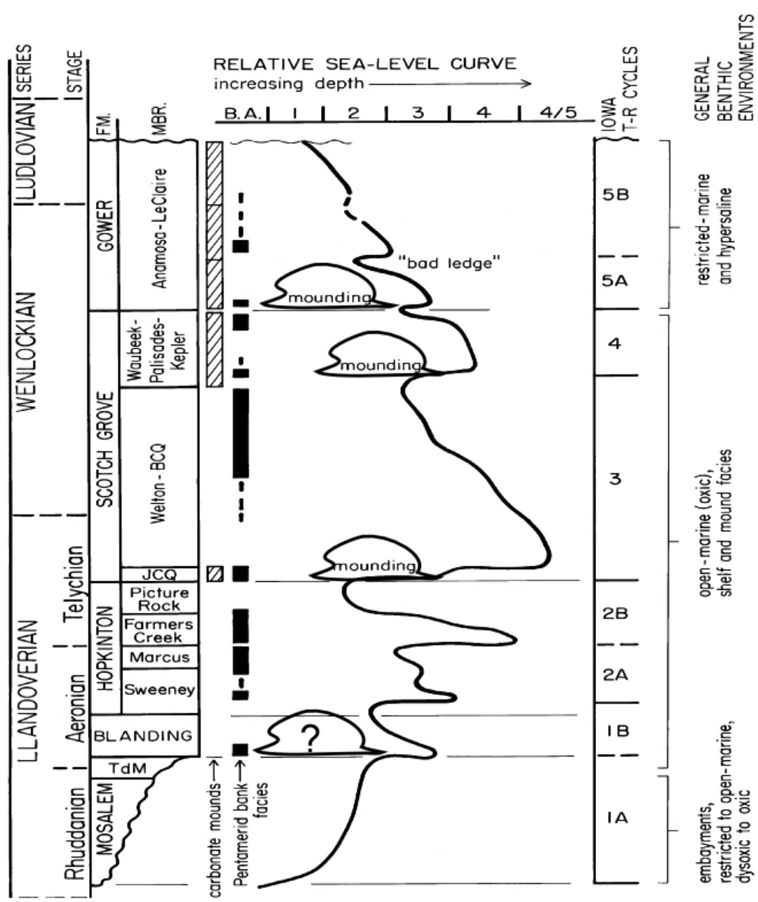


Figure 5. Relative sea level curve for the Silurian System in Iowa. Numbered benthic assemblages (B.A.) are used to interpret relative paleobathymetric position, based on recurring fossil associations and sedimentary criteria. After fig. 18 of Witzke (1992).

Figure 6 illustrates the structural configuration of beds along the south and west walls of the quarry. Beds with dips of approximately 30 degrees are common on the west face of the quarry, and inclinations of 10 to 20 degrees are the norm for beds on the north wall of the quarry. Steeply-inclined, nearly-vertical, and overturned beds dominate the south face of the quarry (Figs. 6 to 8). Anderson (1996) suggested that some dipping beds in the 10 to 40 degree range may reflect original depositional dips, with later enhancement of inclinations by compaction processes. The more steeply-inclined unitson the south face of the quarry probably represent post-depositional compaction and slumping. The origin of the structural complexity found in the Tripoli Quarry is not completely resolved; it may involve slumping of beds and rotation of blocks over a carbonate mound (or mounds) with complex original geometry. Witzke's relative sea-level curve for the Silurian sequence of eastern Iowa five Transgressive-Regressive cycles are recoded in Iowa's Silurian succession(Fig. 5). The Hopkinton Formation was deposited during the Silurian T-R cycle 1B and represents open-marine deposition with well-oxygenated bottom waters (Witzke,1992).

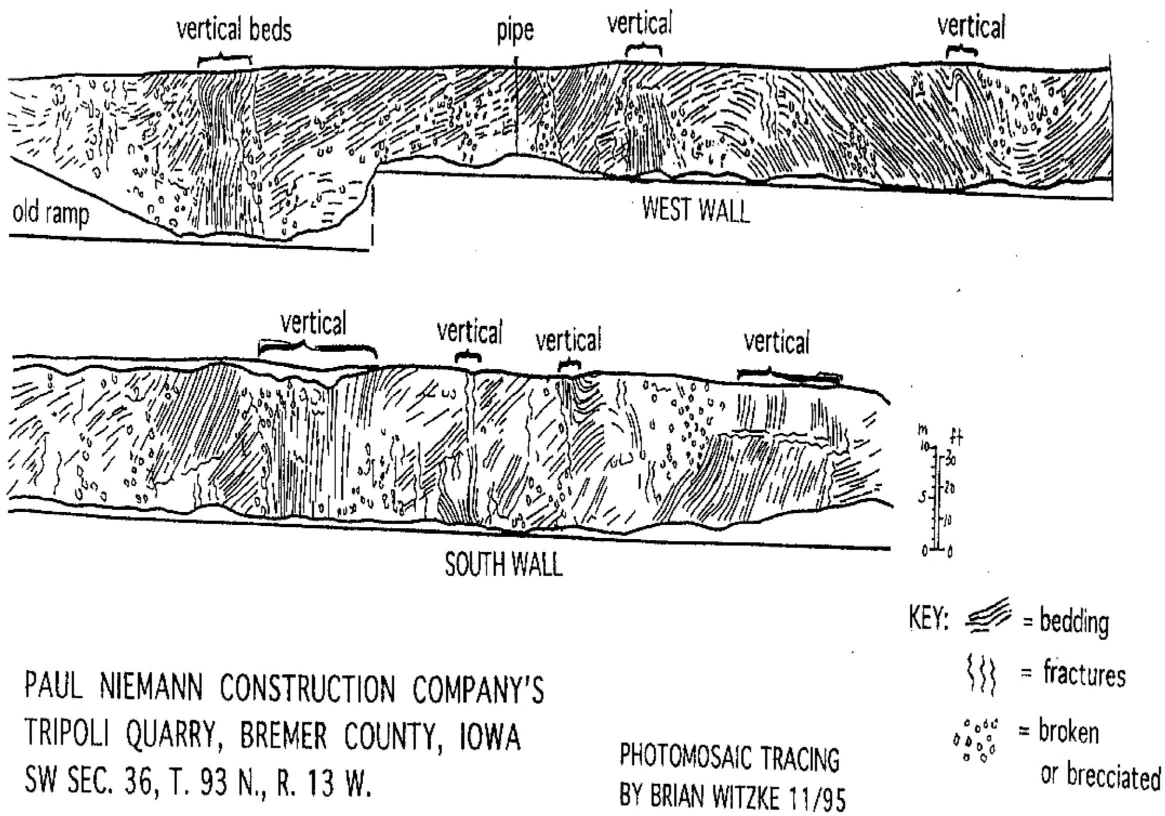


Figure 6. Diagram showing the structural relationships of Silurian Hopkinton Formation strata exposed in the south and west walls of the Tripoli Quarry in 1995. After fig. 5 of Anderson (1996).

Figure 7. Hopkinton carbonate mound and flank bed facies exposed in the west highwall of the Tripoli Quarry in 2011. Photograph by Bob McKay of the Iowa Geological and Water Survey.

Carbonate mounds occur in the Scotch Grove and Gower formations of eastern Iowa (Figs. 3 to 5). The Scotch Grove and Gower mounds are usually associated with intervals of sea level rise and pronounced deepening of the epeiric seaway (Fig. 5). Although no carbonate mounds have been recognized previously in the Hopkinton Formation, the depositional setting of the formation does not rule out the possibility of mound development. Note that two cycles of deepening occur within the interval when the Hopkinton Formation was deposited (Fig. 5). Johnson (1988) provided estimates of depths in the Silurian seas based on the occurrences of benthic fossil assemblages. According to Johnson, the Pentamerid Brachiopod Community was associated with water depths of 30-60 meters and the Coral-Stromatoporoid Community corresponded to water depths of 10-30 meters. Pentamerid brachiopods are common in the Tripoli Quarry, as are tabulate corals and stromatoporoids. If Johnson's estimates for water depths are correct and applicable to this locality, water depths in the Bremer County area likely were between 10 to 60 meters.

Figure 8. Near vertical dip of Hopkinton Formation along north highwall in the Tripoli Quarry. Bob McKay of the Iowa Geological and Water Survey in the foreground for scale.

CARBONATE MOUNDS

Carbonate mounds are well documented in the Late Llandoverian and Wenlockian Scotch Grove and Gower formations (Figs. 4 and 5) of in the Iowa Basin Silurian in studies by Witzke (1985, 1987, 1992). The exposures of mound facies in the Tripoli Quarry document an even older Early Llandoverian period of mound construction that was not recognized until the 1990s. Consequently, Hopkinton Formation mound facies are the oldest known mud-mound features in the Silurian of Iowa. The following points about Silurian carbonate mounds are summarized from Witzke (1992):

1) Eastern Iowa contains the westernmost exposures of carbonate mounds within the Midwestern reef belt.

2) Silurian carbonate mounds in Iowa and elsewhere in the midwest have been described by a variety of terms such as reefs, mounds, buildups, bioherms, and clinothems.

3) If the term reef' is used in a genetic sense to suggest a wave-resistant feature with a rigid organic framework, then it is inappropriate terminology for the Silurian mounds of Iowa.

4) The carbonate mound facies in Iowa's Silurian are dominated by carbonate mud fabrics, with no evidence of an organic framework.

5) Although corals and stromatoporoids are present in the Silurian carbonate mounds of lowa, they are insignificant components compared to carbonate mud and to other skeletal grains and skeletal debris (especially crinoids and brachiopods).

6) An ecological reef model based on modem coral reefs fails to explain the features found in the carbonate mounds of lowa's Silurian.

7) The Lower Carboniferous Waulsortian mounds of North America and Europe (Wilson, 1975) have several features in common with the Silurian mounds of central North America, namely:

   a) central mounds dominated by lime muds which display skeletal mudstone and wackestone textures;

   b) the presence of skeletal debris of crinoids, with scattered corals, brachiopods, and other fossils;

   c) mounds that lack an organic framework;

   d) mounds that are surrounded by inclined beds (5-50 degrees), with some slump features;

   e) the occurrence of submarine cements and the suggestion of early lithification;

   f) mounds that display a wide variation in scales, ranging between 3-150 meters in height with lateral dimensions of 60 meters to 3 kilometers;

   g) mounds that often display a simple haystack geometry, although complex growth forms and bank facies are also known;

   h) mounds that have been interpreted as forming below fair-weather wave base. According to Byers and Dott (1995), [fair-weather wave base in modern marine settings varies from as little as 20 meters to more than 70 meters.)

ACKNOWLEDGEMENTS

This stop description was adapted and modified from Stop 11B of Anderson (1996). Brian Witzke and Bill Bunker, Geological Survey Bureau of the Iowa Department of Natural Resources, spent time with Anderson in the Tripoli Quarry 1995. Photographs of Silurian exposures in the Tripoli Quarry used in figures 7 to 9 are courtesy of Bob McKay of the Department of Natural Resources-Iowa Geological and Water Survey.

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STOP 4. JOHLAS QUARRY – GREEN LIMESTONE, FLOYD COUNTY, IOWA

W1/2 Section 7, T94W, R15W, Floyd Co., Iowa (See GPS Coordinates in Fig. 2)

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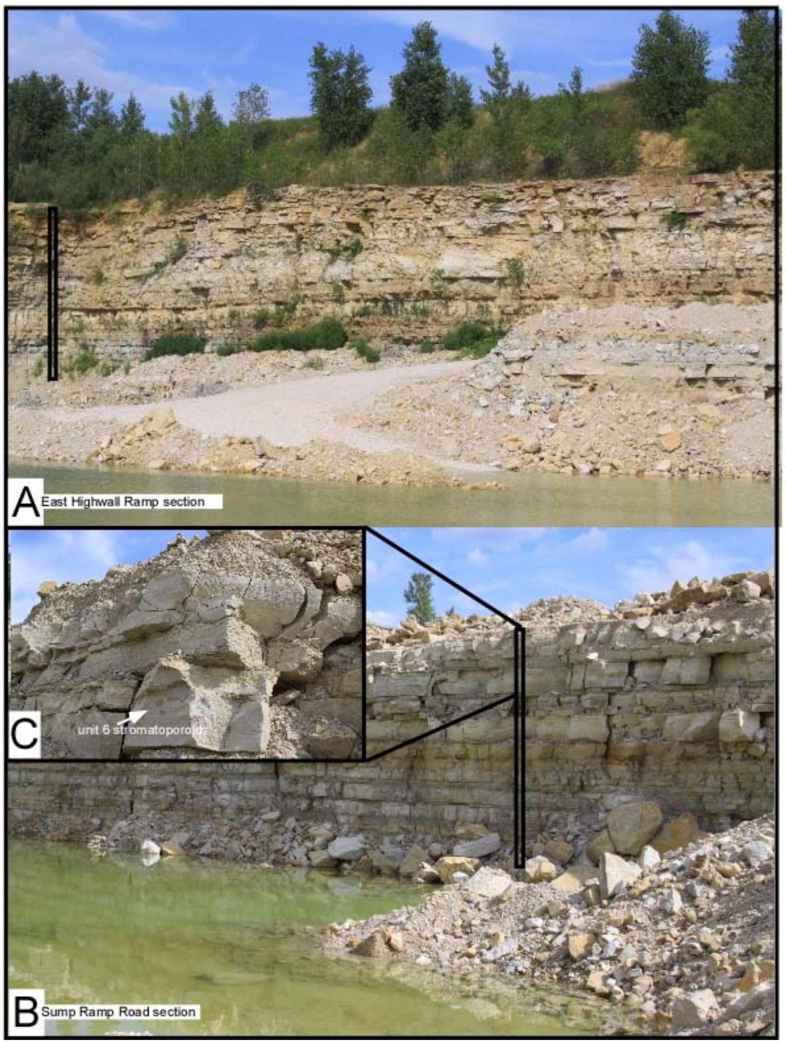

Figure 1. Photographs of measured section locations and exposures of the Upper Devonian (Early Frasnian) Idlewild Member of the Lithography City Formation in the Johlas Quarry (Greene Limestone Company) in Floyd County, Iowa. A.-East highwall with elongate rectangle shoing location of the base of the section measured by J. Day in 2011, shown in Figure 3 below. B.-Location of the short section described in the short highwall along the south side of the sump pit that was deepened in 2012-2013; described by J. Day in August of 2013; shown below in Figure 3. C.-Biostromal unit with hemispherical stromatoporoids in unit 6 of the Sump Ramp Road section of Figure 3.

STRATIGRAPHY AND PALEONTOLOGY OF THE LITHOGRAPHY CITY FORMATION OF THE CEDAR VALLEY GROUP-NORTHERN OUTCROP AREA

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). Three 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 and Buffalo Heights 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, 1997, 1998, 2006, 2010; Day et al., 1996, 2008; Day and Copper, 1998). Lithograph City Formation deposition was initiated by a major sea level rise in the latest Givetian that followed the sea level lowstand that terminated Coralville carbonate platform sedimentation. This sea level rise is referred to as Euramerican Devonian T-R cycle IIb of Johnson and others (1985) and Johnson and Klapper (1992); T-R cycle IIb-1 of Day and others (1996); coinciding with Iowa Devonian T-R cycle 5A of Bunker and Witzke (1992), Witzke and others (1989), Witzke and Bunker (2006b) and Day and others (2008, 2013).

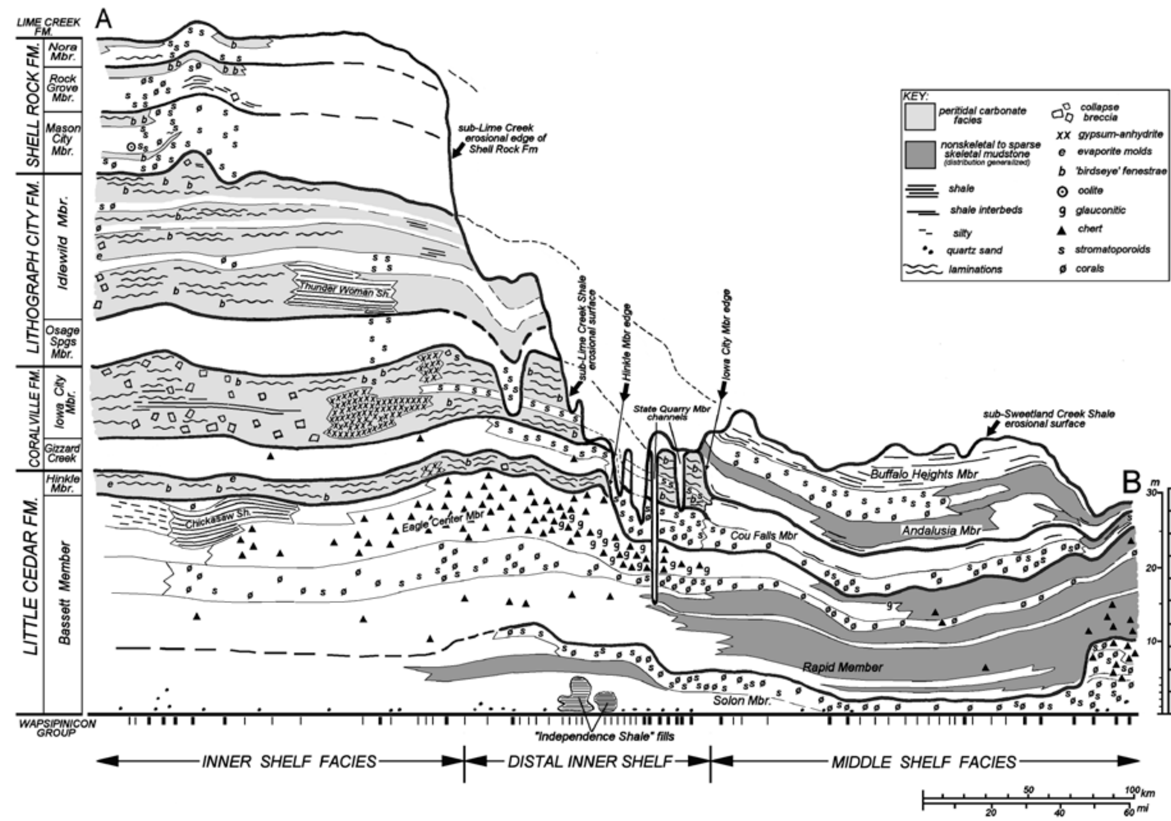

Figure 2. Northwest-southeast stratigraphic cross section of the Cedar Valley Group in eastern Iowa. Significant sub-Lime Creek/Sweetland Creek erosion has truncated Cedar Valley strata, especially in the distal inner-shelf area. "Independence Shale" fills represent stratigraphic leaks of the late Frasnian 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).

Osage Springs Member

The Osage Springs Member (Fig. 2) is not seen in exposures at Stop 4, but is characterized by fossiliferous dolomite and dolomitic limestone, in part slightly argillaceous, in the type area north-northwest of Charles City (see type section in Groves and Hubscher, 2008, stop 1). 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. 2; Witzke et al., 1986, stop 1, unit 16) and nearby Messerly (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 as shown in Figure 2, and in the subsurface of central Iowa. The Osage Springs Member varies from 3.4 to 7.5 m in thickness (Fig. 2).

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; Day 2006, 2010), 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 (Figs. 5 and 6). In its type section at the Osage roadcut (Groves and Hubscher, 2008) 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 allani*, *Athyris 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 (Groves and Hubscher, 2008; Day, 1989, 1992; Day et al. 2008). Stromatoporoids become abundant to the south and include both massive and branching forms in the Messerly and Yokum Quarry sections (Stock, 2008, 2013). 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 is present in the southern part of the northern outcrop belt of the Lithograph City Formation (Fig. 2), and extends into the subsurface of central Iowa in Butler and southern Floyd counties (Bunker et al., 1986). Its type section in the Yokum Quarry (Witzke et al., 1986, 1989) is now flooded. 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 (Figs. 2 and 3). The Thunder Woman Shale ranges from 3 to 6 m in thickness.

Idlewild Member

The Idlewild Member (Figs. 2, 3 and 4) 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 mud cracks, “birdseye,” or evaporite molds (see lower and upper Idlewild Member in Figs. 2 and 3); 2) non-laminated dolomite and limestone, in part “sublithographic,” pelleted, oncolitic, intraclastic, brecciated, and/or sandy, and locally containing mud cracks 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 in Figs. 2 and 3).

Lithologic groupings 1 and 2 dominate the sequence at most localities in northern outcrop area as seen in the Johlas), but stromatoporoid bearing group 4 lithologies are well developed in the upper Idlewild at the Johlas (Fig. 3) and nearby Hanneman and Charles City South quarries (Fig. 3). They are rhythmically interbedded with lithologic group 2 in most of the upper Idlewild in the Johlas Quarry (Fig. 3) south of Charles City comprising small-scale 4^{th} order T-R cycles (parasequences). Fossiliferous skeletal mudstone and wackestones of group 4 are seen near the top of the Idlewild Member at in the Maxson Quarry and at the Nora Springs South locality (see Day et al. 2013) in northern Floyd County on the south bank of the Shell Rock River.

Certain fossiliferous to biostromal carbonates of group 4 with a distinctive and diverse brachiopod fauna (Figs. 5 and 6) can be correlated from section to section in Floyd County as shown in Figures 3 and 4. At the Johlas Quarry (Fig. 3) and the nearby Hanneman and Charles City South quarries (Fig. 4), fossiliferous group 4 strata of the upper part of the member abruptly overly mudflat facies of lithologic group 1 of the lower Idlewild Member (Fig. 3 and 4). This abrupt facies change records a seaway major deepening and platform backstepping event in the inner shelf region of the Lithograph City platform during 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).

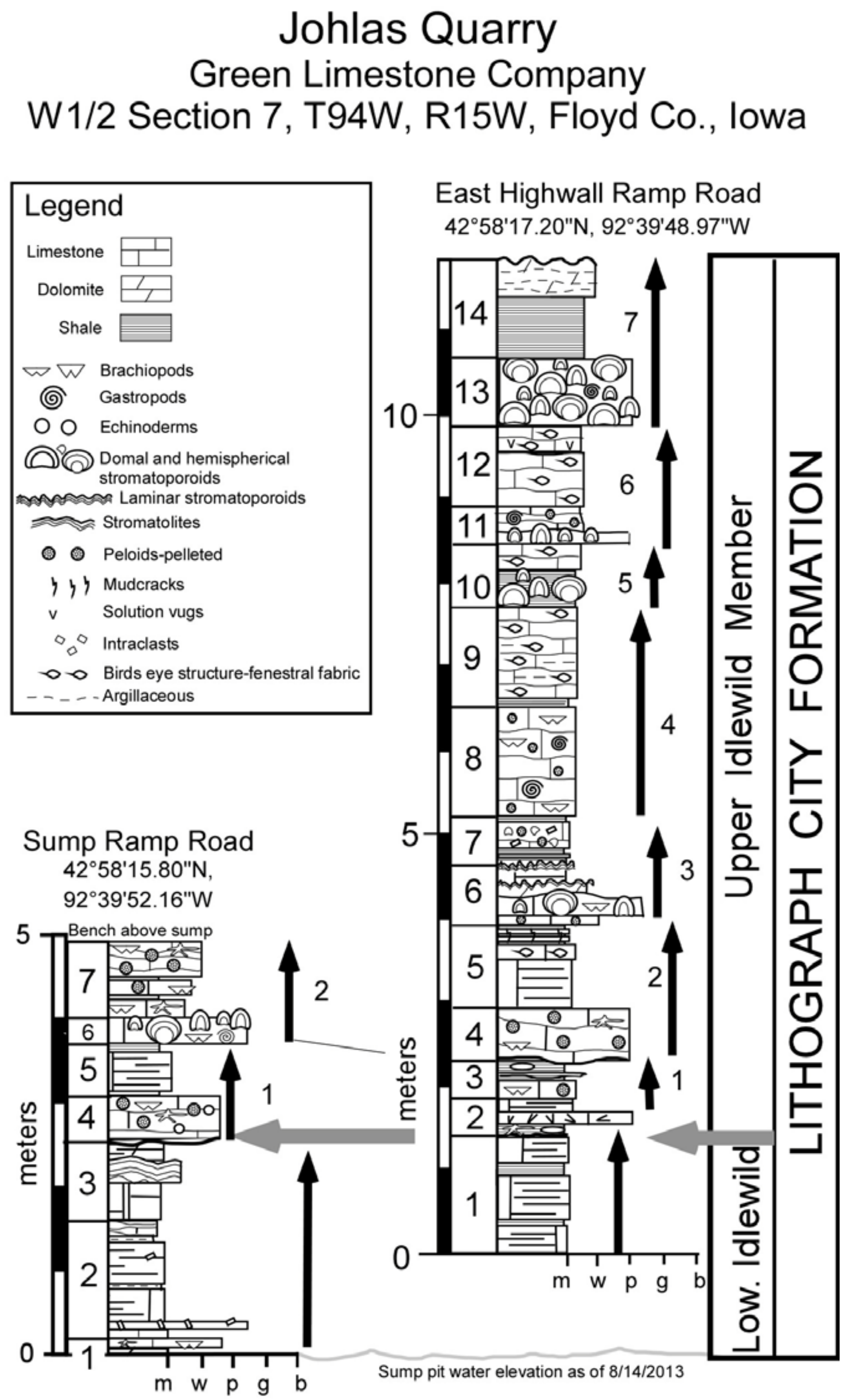

Figure 3. Lithostratigraphy and cyclostratigraphy of the Idlewild Member of the Lithograph City Formation in the Green Limestone Company'a Johlas Quarry in Floyd County, Iowa (Stop 4). The gray arrow is a major flooding event that initated upper Idlewild deposition over peritidal carbonates of the Lower Idlewild. Vertical black arrows denote meter-scale 4th order Transgressive-regressive cycles (parasequences) comprised of group 1 and 4 lithofacies as described in the discussion the Idlewild Member Stop 4.

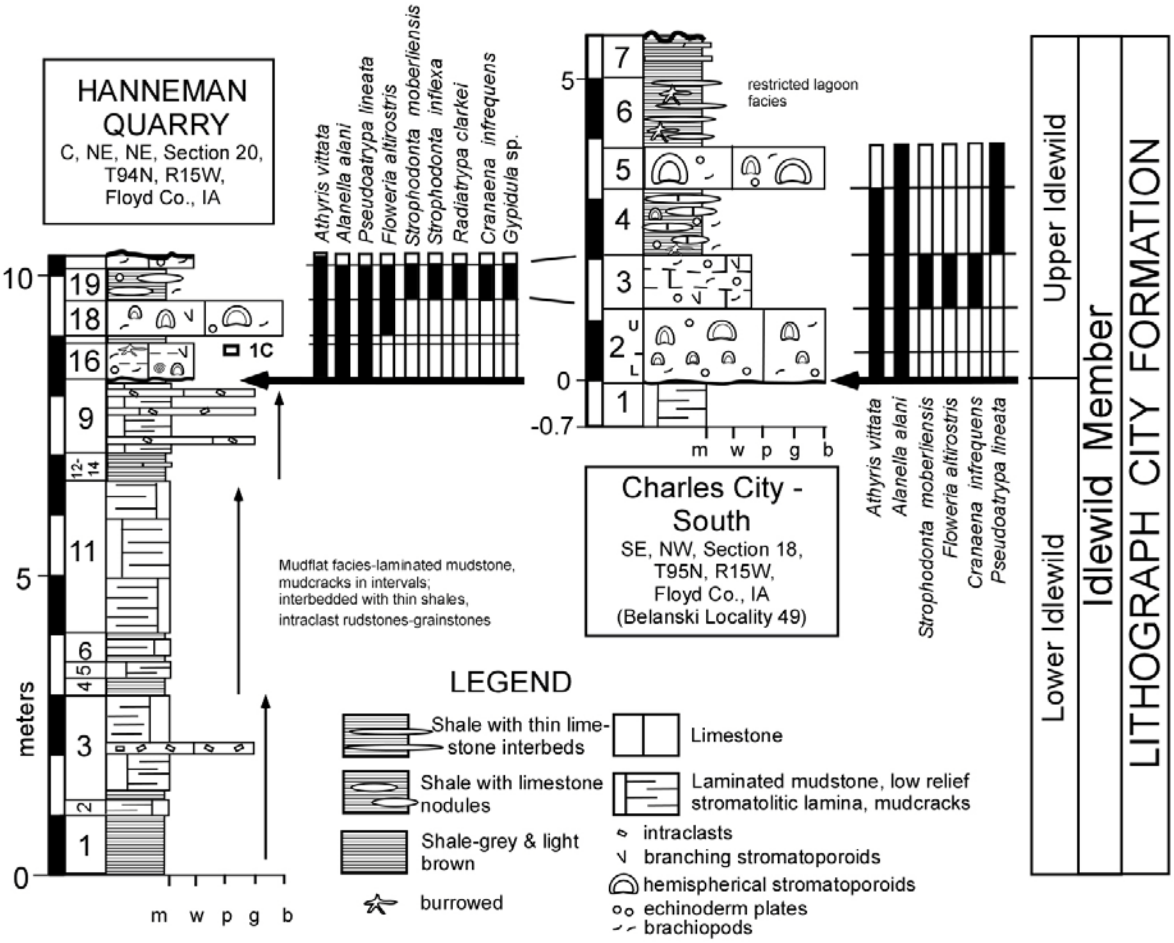

Figure 4. Upper Devonian (Lower Frasnian) stratigraphy of lower and middle parts of the Idlewild Member of the Lithograph City Formation exposed in the Hanneman and Charles City South quarries in central and northeastern Floyd County, Iowa (Figs. 2 and 4). Hanneman Quarry section modified from figure 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 3. Modified from fig. 5 of Day and others (2008). Vertical black arrows denote meter-scale 4th order Transgressive-regressive cycles (parasequences) comprised of group 1 and 2 lithofacies as described in the discussion the Idlewild Member Stop 4.

The Idlewild Member contains gypsum and anhydrite in the subsurface of central Iowa (Fig. 2), 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.

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 and in Day and others (1996, 2008 and 2013). Given its position above the Osage Springs Member, the Idlewild is entirely Early Frasnian, likely spanning parts of Montagne Noire Zones 1 to 4. Lithologic groupings 1 and 2 commonly contain ostracodes and are burrowed in part; stromatolites and gastropods have been noted locally.

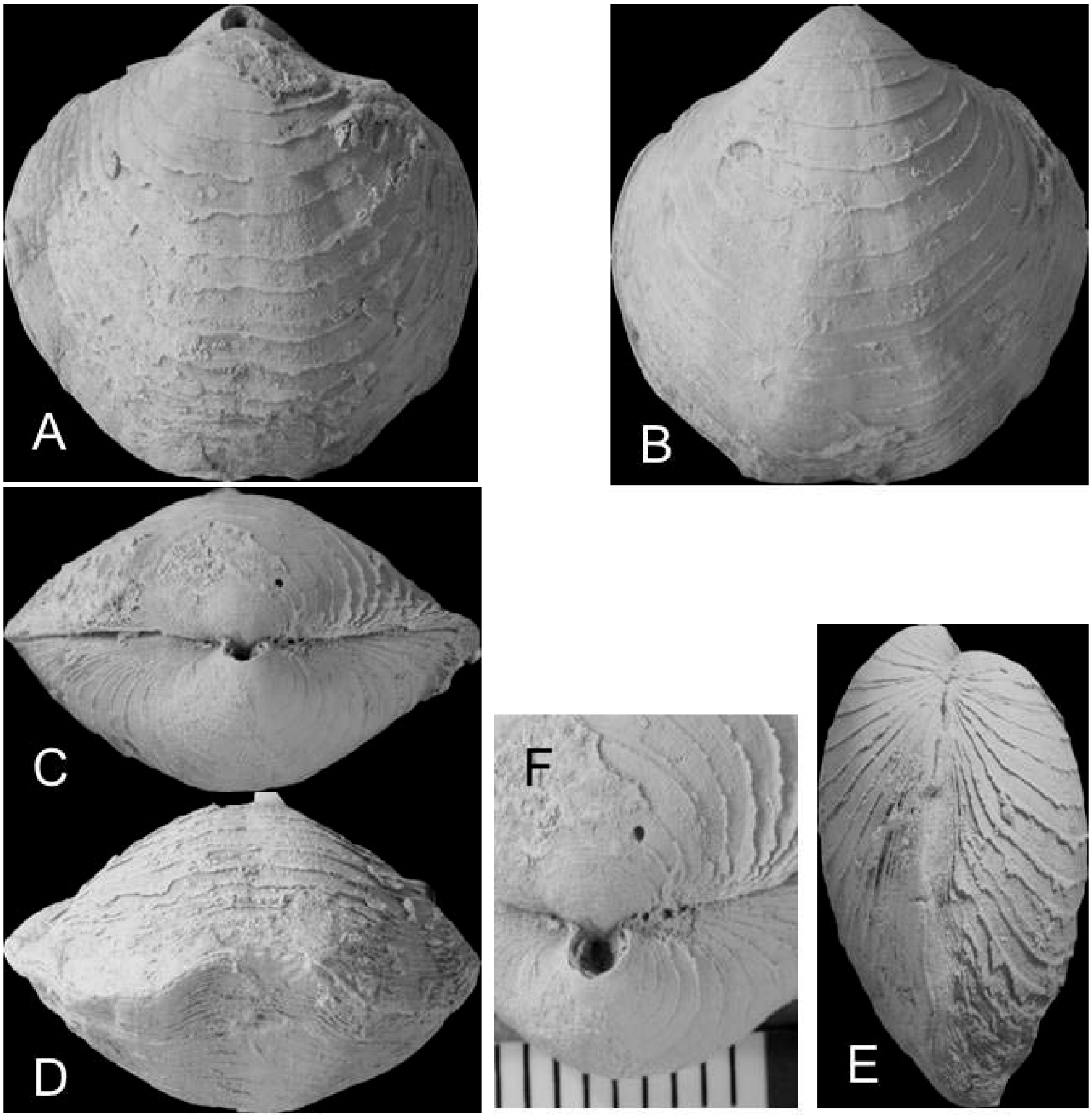

Figure 5. Illustration of the brachiopod *Athyris vitatta* found in shallow inner platform facies in the Osage Springs and Idlewild member of the Lithograph City Formation in northern Iowa. A-dorsal view, B-ventral view, C-posterior view, D. anterior view, E lateral view, F-oblique posterior view of gastropod predatory drill hole in dorsal valve with scale.

Fossiliferous beds of the Idlewild throughout the member contain brachiopods (Day, 1986, 1989, 1992, 1998; Day and Copper, 1998; Day et al., 2008), some of which are shown in Figures 5 and 6. Echinoderm debris is common in some beds, and bryozoans, gastropods, and ostracodes also occur. Small-scale cycles consisting of lithologic groups 1 to 3 interbedded with fossiliferous group 4 skeletal carbonates contain monospecific or low diversity assemblages that include *Allanella allani*, *Athyris vitatta*, or *Pseudoatrypa lineata*. As shown in Figure 4, fossiliferous skeletal carbonates (some biostromal) in the middle part of the Idlewild at the nearby Hanneman and Charles City South quarries yield a diverse fauna including: *Athyris vitatta*, *Eleutherokomma* sp. aff. *E. cardinalis*, -*Floweria altirostrum*, *Pseudoatrypa lineata*, *Productella* sp. cf. *P. fragilis*, *Strophodonta* (*S.*) *moberliensis*, *Cranaena infrequens*, and *Gypidula* sp. The skeletal mudstone and wackstones in the

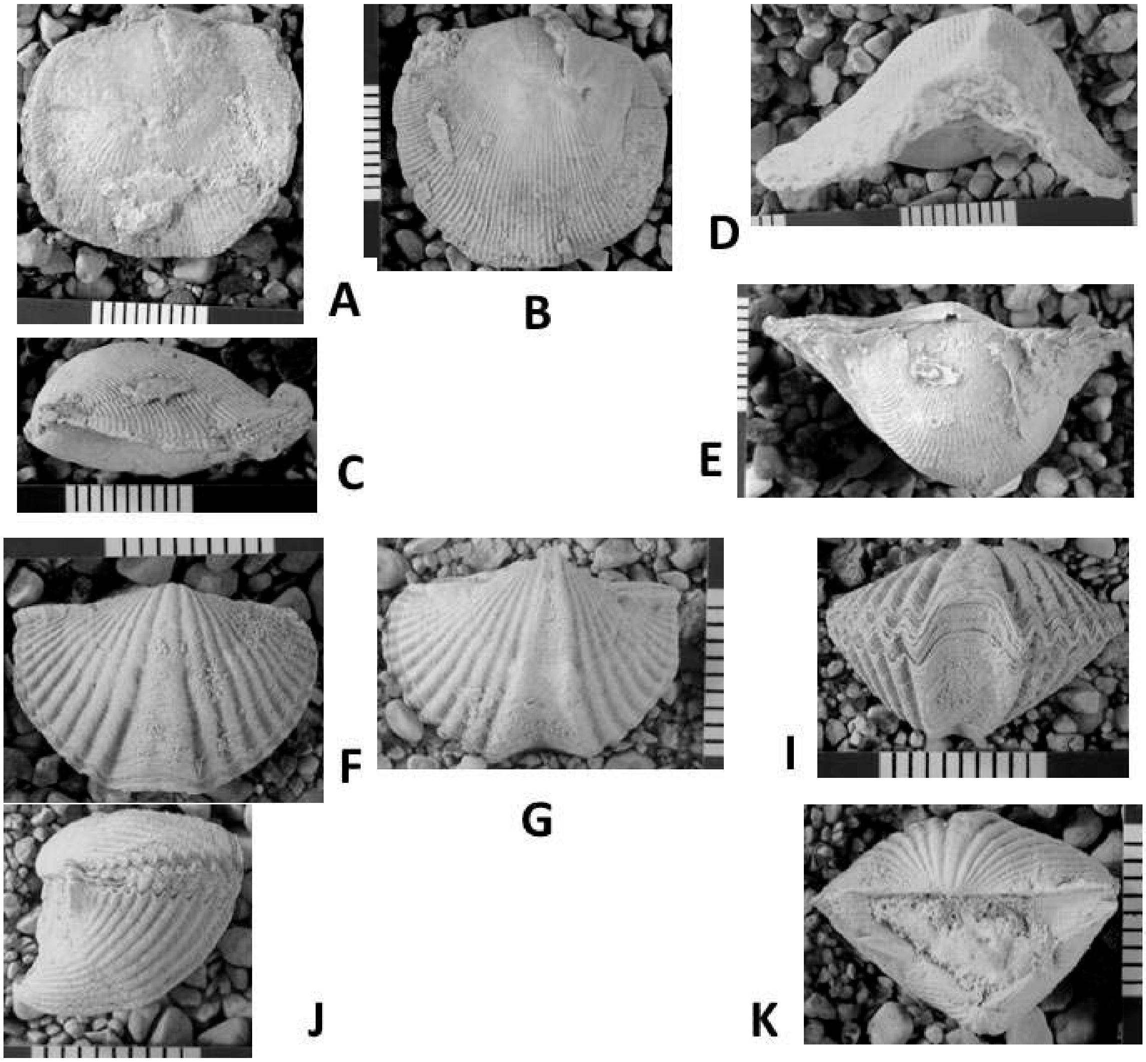

Figure 6. Atrypid and spiriferid brachiopods common in the Osage Springs and Idlewild members of the Lithograph City Formation in northern Iowa. A-E. *Pseudoatrypa lineata*; specimen shown in Figs. A-C is from the shaley stromatoporoid unit of the upper Osage Spring Member at the Messerly Quarry (Fig.), specimen shown in figs. D & E is from unit 16 at the Yokum Quarry (Figs. 1 and 2). F-I. *Allanella allani*; from the shaly stromatoporoid unit of the upper Osage Spring Member at the Messerly Quarry (Fig. 1). This species ranges through most of the Lithograph City Formation in northern Iowa.

upper 2 to 3 meters of the Idlewild Member at the Maxson Quarry, Floyd County Road B-60 roadcut, and Nora Springs South sections (see Day et al. 2013 figs. 1 and 7) yield a brachiopod fauna that includes *Eleutherokomma* n. sp. aff. *E. cardinalis*, the highest occurrences of *Allanella Allani* in the Early Frasnian of North America, with *Athyris vitatta*, *Pseudoatrypa lineata*, *Floweria altirostrum.*

The biostromal carbonates of the Idlewild in northern Iowa yield diverse stromatoporoid fauna documented in studies by Smith (1994) and Turner and Stock (2006, 2013 table 6). As discussed by Stock (2008, 2013) 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*? v*esiculosum, 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, 2013), 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.

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STOP 5. 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)

STRATIGRAPHY AND PALEONTOLOGY OF THE LATE FRASNIAN (UPPER DEVONIAN) LIME CREEK FORMATION AT THE ROCKFORD QUARRY

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

Exposures of the Lower Upper Devonian Lime Creek Formation west of the town of Rockford, Iowa, and south of the Winnebago River in the area of the Rockford Brick and Tile Quarry and at other nearby localities are known internationally as the best documented late Frasnian stratigraphic successions in North America. Late Frasnian age shelly fossils weathering from calcareous shales, nodular shales, and thin platy argillaceous skeletal wacke- and packstones of the Cerro Gordo are extremely abundant and well preserved, and have been collected from exposures west of Rockford since the 1850s (see discussions by Day, 1989, 1995, 2008a, 2008b; Anderson 1995a, 1995b).

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 to 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, 2008; Witzke and Bunker, 1997; Over 2002, 2006). Conditions in the area that is now northern

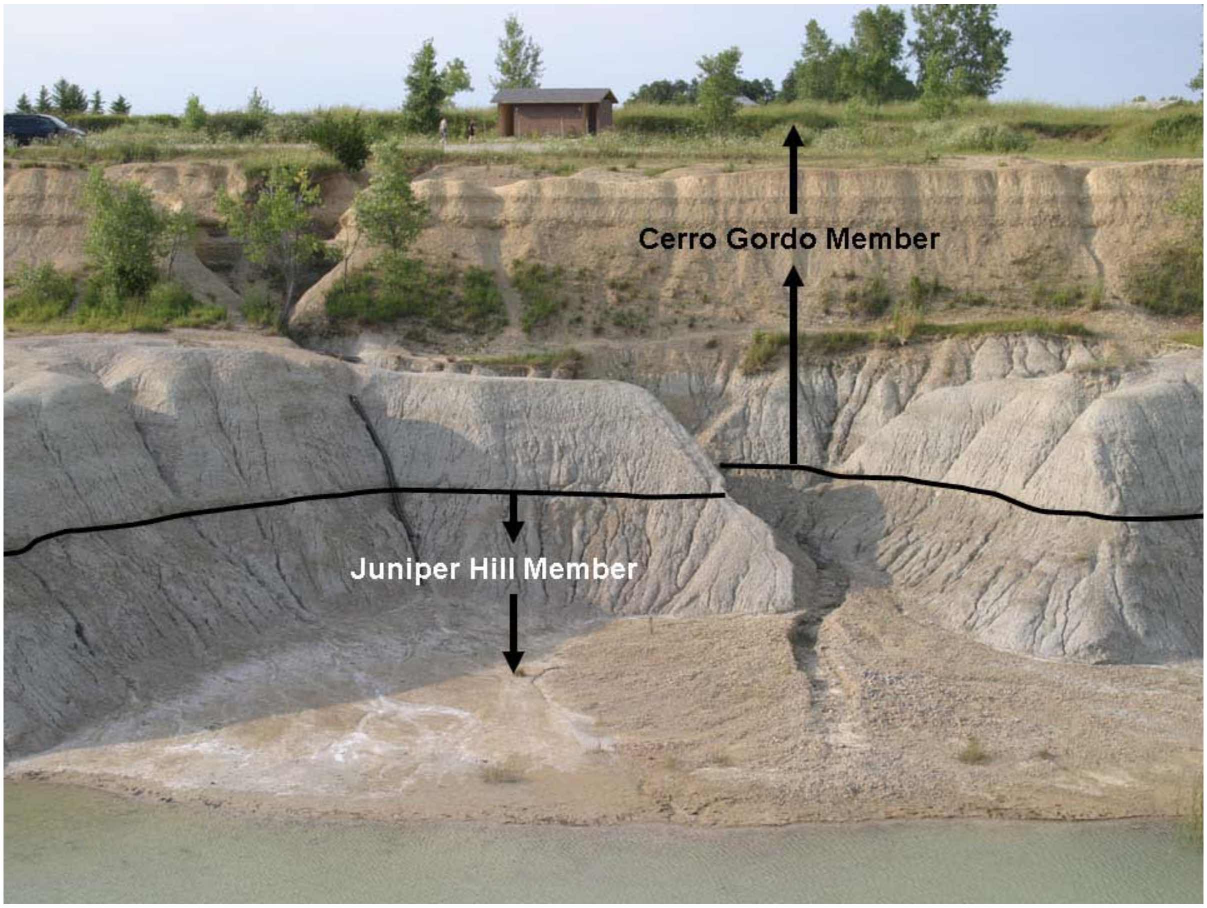

Figure 1. Photograph of exposures of the Lime Creek Formation (Late Frasnian age) along the old north highwall of the northwest pit of the Rockford Brick and Tile Quarry at the Floyd County Fossil and Prairie Center and Park Preserve west of the town of Rockford, Iowa. Exposures in the inactive quarry 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).

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 middle shelf and deeper shaley ramp slope facies in eastern and southeastern Iowa and adjacent areas of the Illinois Basin.

The Cerro Gordo Member 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 (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 and others (1986), Day (1990) and Preslicka and others (2013); 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 2013 article in this guidebook.

Juniper Hill Member

In Floyd and Cerro Gordo counties the Juniper Hill ranges from 9-16 meters in thickness, and is 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 as 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 linguloid 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 un-described species of the widespread rhynchonellid *Navalicria.* This species is similar to *N. rectangularis* 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 of ambocoelid brachiopod related to *Eudoxina*) 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*.

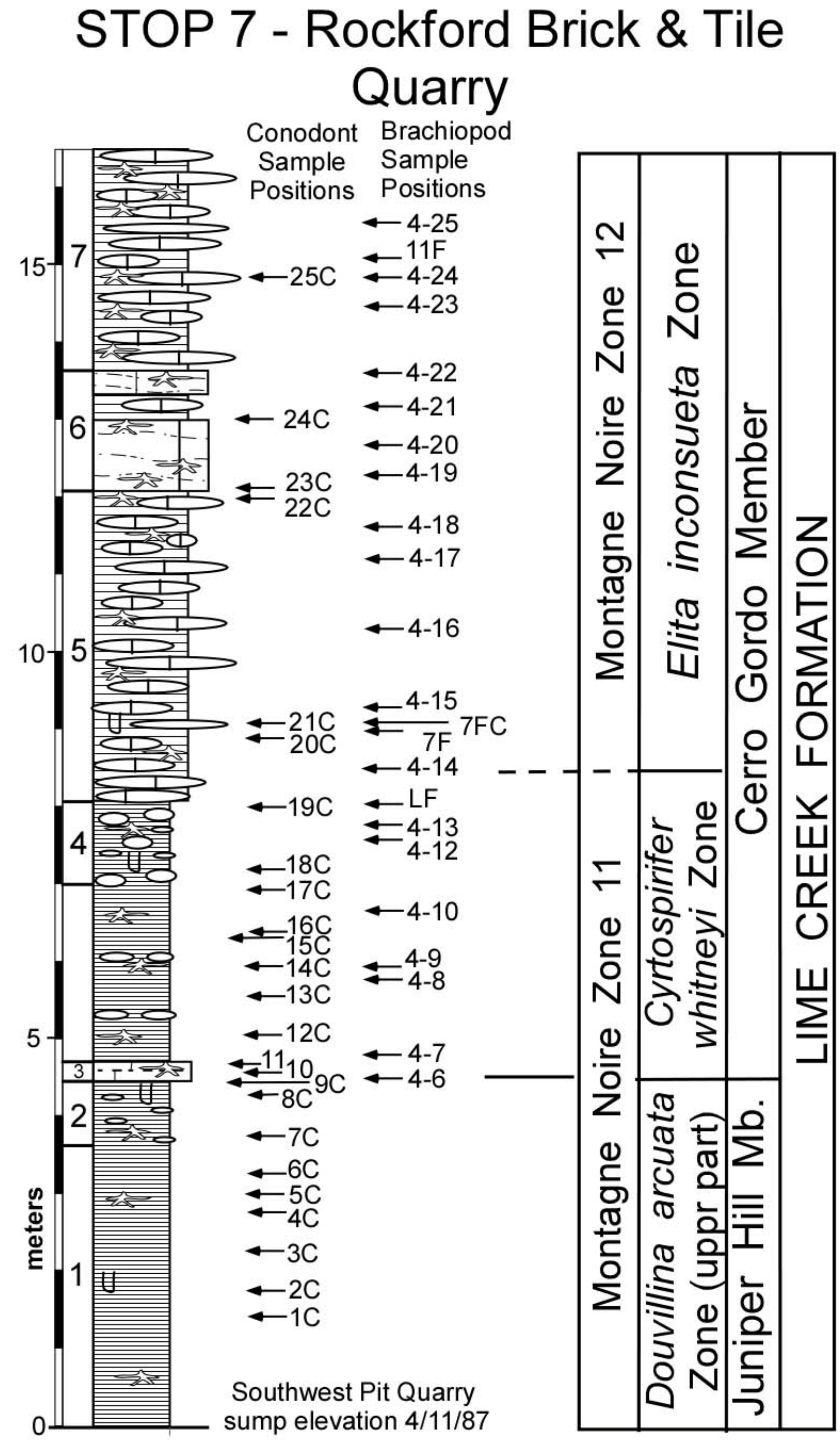

Figure 2.—Graphic section of the Lime Creek Formation in the Rockford Quarry (see location above) described by J. Day, B. Bunker and B.Witzke in July of 1985, and J. Day in April of 1987). Positions of conodont samples of Day (1990) shown just to right of column. Positions of brachiopod samples and assemblage 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). After figure 2 of Day (2008).

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															

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.). After figure 3 of Day (2008).

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 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 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 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, Table1).

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 "*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 from 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 large 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).

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					

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.

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