GEOLOGY OF THE MOSCOW QUARRY, NORTHWEST MUSCATINE COUNTY, IOWA

by
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Geological Society of Iowa

Oct 22, 2011 Guidebook 89

Cover Photograph

The cover photo was taken near the entrance of the Moscow Quarry looking west at the Devonian working face and the overlying Quaternary section.

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October 22, 2011

Geological Society of Iowa
Guidebook 89

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INTRODUCTION TO WENDLING QUARRIES INC. MOSCOW QUARRY

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Wendling Quarries Inc., one of the leading crushed limestone, sand and gravel producers in the Midwest, operates a number of quarries throughout eastern Iowa and western Illinois. A family business, it is owned by General Manager Tony Manatt, a brother, and two cousins, who are second-generation partners in Manatt's Inc., one of Iowa's largest general contracting/road building firms. In 1987, Manatt's acquired Wendling Quarries Inc. At that time their service area included Muscatine, Cedar, Linn, and Jones counties in Iowa. Since that time, Wendling Quarries has expanded operations to include 14 counties throughout Eastern Iowa and Western Illinois. Wendling currently operates approximately 100 quarries in the area, and employs about 200 workers. Along with the production of crushed stone, sand, gravel, and asphalt mix, a growing portion of their business has become the processing of recycled concrete and asphalt. The company also does custom crushing, survey work, custom drilling, and prospecting for itself, for other companies, and for governmental entities.

The Moscow Quarry is located just west of the Cedar River, about 2 miles west of the unincorporated town of Moscow on the west bank of the Cedar River just north of Highway 6. The quarry produces limestone and dolomite from the Otis and the Pinicon Ridge Formation of the Wapsipinicon Group, and the Solon and lower Rapid members of the Little Cedar Formation of the lower Cedar Valley Group.

Enjoy your field trip and please follow the instructions of the field trip leaders. We have been graciously allowed to visit this quarry by Wendling Quarries Inc. and we should thank them by following their rules and instructions.

Figure 1. Google Earth oblique view of the Moscow Quarry looking west-northwest. The Cedar River is visible in at left bottom of the image. Quaternary deposits are visible on the bench and wall of the far (west) end of the quarry.

QUATERNARY GEOLOGY NEAR THE MOSCOW QUARRY, MUSCATINE COUNTY, IOWA

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INTRODUCTION

The area examined for this trip lies in a complex depositional setting in the Iowa-Cedar Lowland formerly known at the Lake Calvin Basin (Figure 1). This area is surrounded by the Southern Iowa Drift Plain and is in close proximity to the Iowan Erosion Surface (IES) landform region (Prior and Kohrt, 2006). Surficial materials consist of a mix of thick eolian deposits (loess, loess and intercalated sand and sand), overlying glacial till (both Illinoian and Pre-Illinoian), and sand and gravel deposits related to the Cedar River and an older ancestral river systems. All investigations to date have not documented any evidence of lacustrine deposits related to the so-called “Lake Calvin Basin”. Further along in our discussion we will revisit the history behind the naming of Lake Calvin and the eventual debunking of this theory in the 1980’s. Multiple periods of Quaternary glaciations and subaerial erosion have led to the landscape we see today. In general, the map area consists of loess and eolian sand of variable thickness overlying Pre-Illinoian-age glacial sediments on the west side of the Cedar River (Moscow Quarry). On the eastern side of Cedar River eolian deposits overlie Illinoian-age glacial sediments (Figure 2).

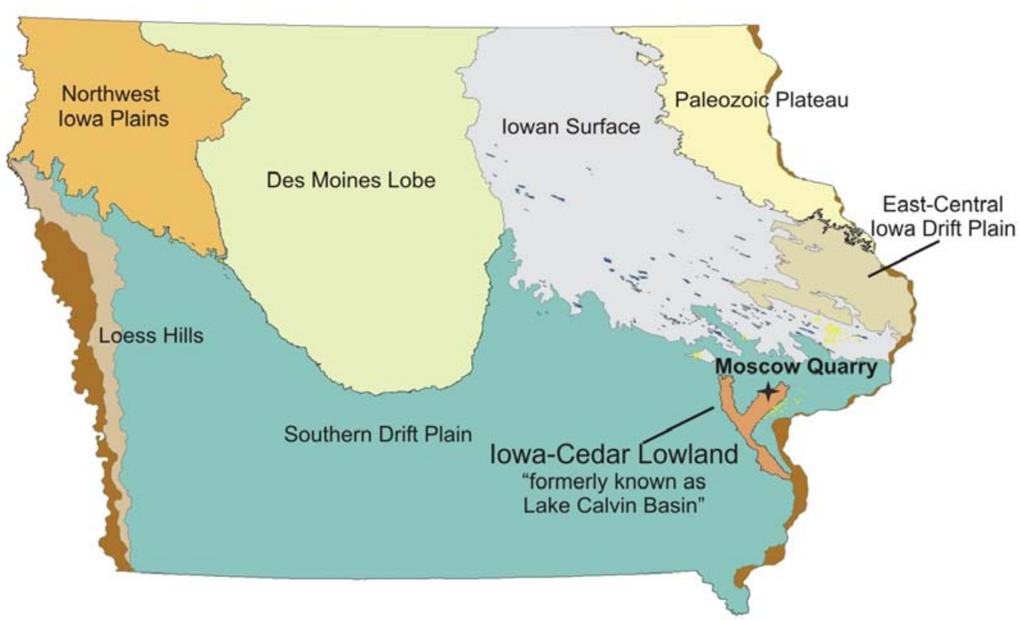

Figure 1: Landform regions of Iowa (Prior and Kohrt, 2006) showing the location of Moscow Quarry.

At least seven episodes of Pre-Illinoian glaciations occurred in this region between approximately 2.2 and 0.5 million years ago (Boellstorff, 1978a, b; Hallberg, 1980, 1986). Episodic erosion during the last 500,000 years has led to the destruction of pre-existing glacial landforms associated with Pre-Illinoian glaciations and created a landscape with steeply rolling topography that is characteristic of the Southern Iowa Drift Plain landform region. In east-central Iowa, Hallberg formally classified the Pre-Illinois units into two formations on the basis of differences in clay mineralogy: the Alburnett Formation (several undifferentiated members) and the younger Wolf Creek Formation (including the Winthrop, Aurora and Hickory Hills members). Both formations are composed predominantly of till deposits, but other materials are also present. Paleosols are formed in the upper part of these till units.

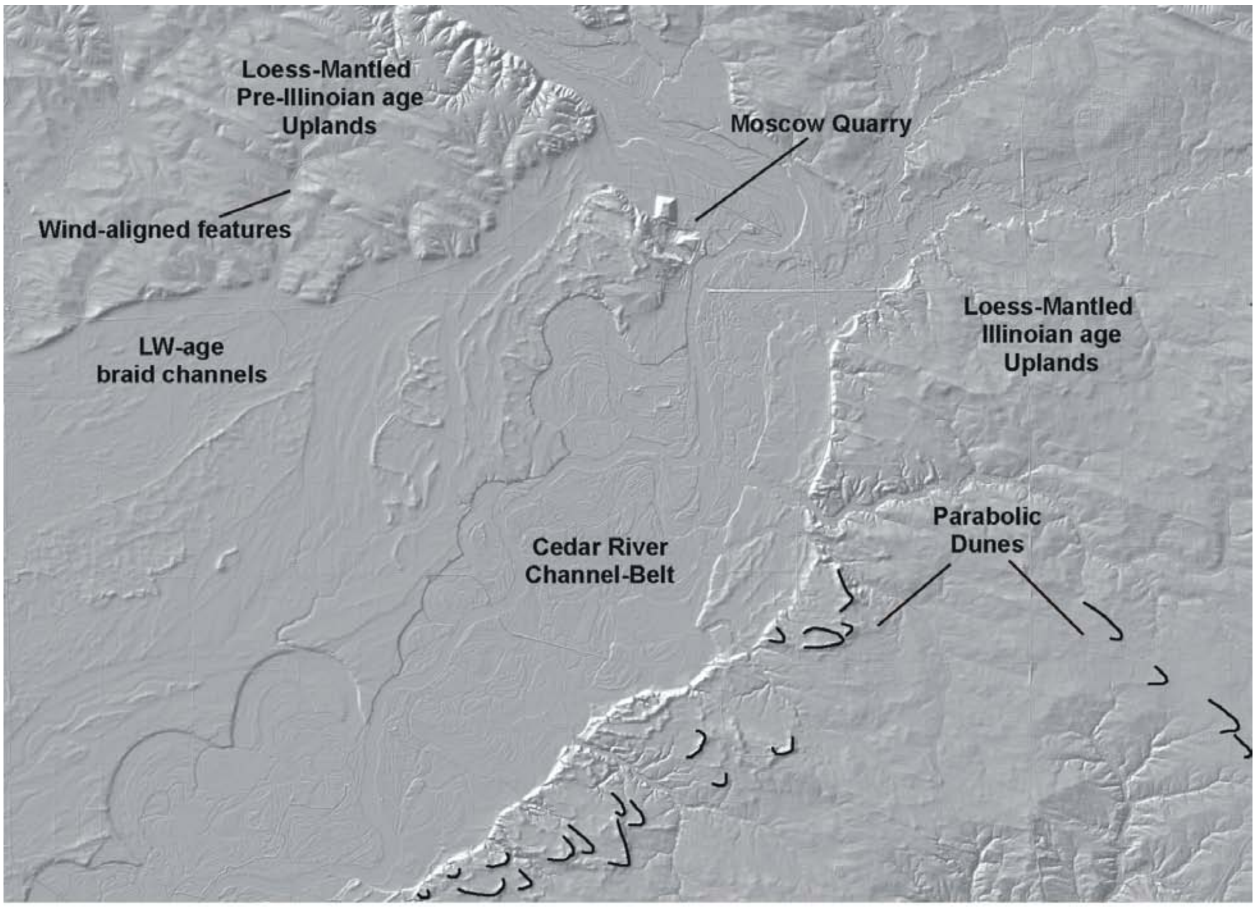

Figure 2: Shaded relief map of the Moscow Quarry area. Note the extensive Cedar River valley with modern day channel belt and the still present signature of relict Late Wisconsinan-age braid channels in the valley. The valley is bounded by loess mantled Pre-Illinoian age uplands to the west and Illinoian age uplands to the east. Note wind aligned features and parabolic dunes (east side of valley) on the loess mantled surfaces.

In addition, a limited area of southeastern Iowa was glaciated during the Illinoian Episode, around 300,000-130,000 years ago. Most of Scott County, with the exception of the area northwest of Mud Creek, was glaciated during this time, as well as portions of Muscatine County lying to the east of the Cedar River. Leverett (1898, 1899) was the first to study the Illinoian glacial deposits in southeast Iowa. The Illinoian till was deposited by the an ice sheet advancing out of the Lake Michigan lowland and moving across western Illinois into Iowa from the northeast (Leverett, 1899; Wickham, 1980). The Lake Michigan Lobe incorporated Paleozoic bedrock materials from the Lake Michigan Basin which are distinguished from other tills in Iowa by both the clay mineralogy of the matrix as well as the pebbles and clasts (Lineback, 1980; Wickham, 1980). The only Illinoian Episode till present in Iowa is the Glasford Formation Kellerville Till Member (Willman and Frye, 1970).

Following the Pre-Illinoian glaciations, most areas of eastern Iowa underwent extensive landscape development and erosion until the Wisconsin Episode loess began to be deposited. A period of intense cold occurred during the Wisconsin full glacial episode from 21,000 to 16,500 years ago (Bettis, 1989). This cold episode and ensuing upland erosion led to the development of the distinctive landform region recognized as the IES (Prior, 1976). A periglacial environment prevailed during this period with intensive freeze-thaw action, solifluction, strong winds and a host of other periglacial processes (Walters, 1996).

In eastern Iowa, the highly eroded and dissected Pre-Illinoian upland and older terraces are mantled by Wisconsin loesses of variable thickness (Ruhe, 1969; Prior, 1976). Unlike the Pre-Illinoian surface, the Illinoian surface is much less dissected. These sediments are the youngest regionally extensive Quaternary materials and were deposited between 30,000 and 12,000 years ago. Two loess units were deposited across eastern Iowa, the older Pisgah Formation and the younger Peoria Loess. The Pisgah is thin and includes loess and related slope sediments that have been altered by colluvial hillslope processes, pedogenesis and periglacial processes. The unit is characterized by the presence of a weakly developed soil recognized as the Farmdale Geosol. It is not uncommon to see the Farmdale developed throughout the Pisgah and welded to the underlying older Sangamon Geosol. Most likely the Pisgah loess was deposited on the eastern Iowa landscape from 30,000 to 24,000 years ago (Bettis, 1989). The Pisgah Formation is typically buried by Peoria Formation loess. The Peoria Formation loess accumulated on stable land surfaces in eastern Iowa from 25,000 to 14,000 years ago. The Peoria Formation consists of silt and a sand facies.

Esling (1984) undertook a regional study to document extensive post Illinoian-age alluvial deposits that had accumulated in major valleys (Iowa-Cedar) in eastern Iowa. Three major terrace assemblages with differing stratigraphy and age were identified: Early Phase High Terrace (EPHT), Late Phase High Terrace (LPHT) and Low Terrace (LT). EPHT deposits are characterized by the presence of Peoria and Pisgah Formation sediments overlying a Sangamon Geosol formed in the underlying alluvium. Esling theorized that these terraces are older than 40,000 years B.P. but younger than the Illinoian sediments in eastern Iowa (Bettis, 1989). LPHT deposits are characterized by the presence of Peoria Formation loess grading down into underlying alluvium with no paleosol. These terraces developed prior to 25,000 years ago and were buried by loess before 12,500 years ago. The LPHT terraces are typically inset into EPHT deposits. The LT is the youngest terrace and is not buried by Peoria loess. EPHT terrace deposits are present at the Moscow Quarry and overlie multiple Pre-Illinoian age tills. Weather and safety concerns permitting, field trip participants should have the opportunity to view the Quaternary exposure.

REGIONAL STRATIGRAPHIC UNITS

The stratigraphic framework of east-central Iowa consists of materials from the Pre-Illinoian, Illinoian, Wisconsin and Hudson episodes. Units exposed at the Moscow Quarry include multiple Pre-Illinois tills, the Sangamon Geosol, unnamed Pre-Wisconsin alluvium, the Farmdale Geosol and Peoria Fm. loess and sand. Pre-Illinoian age materials are composed of glacial tills of the Wolf Creek and Alburnett formations as well as the intervening paleosols and unnamed sand and gravel units (Hallberg, 1980). The Wolf Creek Formation is subdivided into the Winthrop, Aurora and Hickory Hills till members (oldest to youngest). The Alburnett Formation till members are ‘undifferentiated’. Although multiple till members may all be present in one area, laboratory analyses are necessary for differentiation.

East-central Iowa is mantled by two Wisconsin Episode loess deposits, the Peoria and Pisgah formations. These materials may overlie glacial till, Wisconsin age alluvium or unnamed Erosion Surface sediments. The Peoria Formation includes wind-blown materials and two facies are recognized: a silt facies (loess) and a sand facies (eolian sand). Materials are well-sorted, may be interbedded and range in texture from silt to medium sand. The Peoria Formation is time-transgressive, with deposition occurring between approximately 23,000 and 12,000 RCYBP (Bettis, 1989). Loess deposition was most rapid from about 21,000 to 16,000 years ago.

The Pisgah Formation originated as eolian silt and was altered by a combination of colluvial hillslope processes, pedogenesis and periglacial processes. The Pisgah ranges in texture from silt loam (loess) to loamy sand and includes loess, colluvium, slope deposits and mixing zone materials. The Pisgah Formation was previously referred to as the 'basal Wisconsin loess' (Ruhe, 1969) or the 'basal Wisconsin sediment' and is the stratigraphic equivalent of the Roxanna Silt of Illinois and the Gilman Canyon Formation of Nebraska, although the lithologic properties vary (Bettis, 1990). Pedogenic alteration at its base has welded it with the underlying Sangamon Geosol. The Pisgah Formation is typically much thinner than the Peoria Formation and has the Farmdale Geosol developed on its surface. The Pisgah Formation was deposited between approximately 30,000 and 24,000 RCYBP (Bettis, 1989).

The Farmdale Geosol is an interstadial soil that represents a brief period of landscape stability during the Wisconsin glacial. It is expressed as a thin, dark grayish brown buried soil, and commonly contains charcoal. Periglacial activity has often altered the contact resulting in a discontinuous or mixed horizon. The Farmdale is widespread throughout the Midwest and is commonly identified in Illinois and Indiana (Hall and Anderson, 2000). Dates for the Farmdale Geosol range from 28,000 to 16,500 RCYBP (Bettis, 1989).

GEOLOGIC BACKGROUND OF THE "LAKE CALVIN BASIN"

In the spring of 1984, the Geological Society of Iowa held a meeting in conjunction with the Iowa Natural History Association to discuss the "Natural History of the Lake Calvin Basin of Southeast Iowa". The trip was timely and was the culmination of Steve Esling's dissertation work which examined the stratigraphy of the Lower Iowa and Cedar River Valleys in southeastern Iowa (1983). Esling, as well as others (Bicki, 1981, Nott, 1981 and Updegraff, 1981) examined the Quaternary stratigraphy in southeastern Iowa under the guidance of George Hallberg, then Chief of Geologic Studies at the Iowa Geological Survey.

The Iowa-Cedar River Lowland (ICRL) "Lake Calvin Basin" occupies a geographic position that was once ice-marginal to the maximum extension of Illinoian glaciation into Iowa. The lowland is a regionally distinctive feature that spans portions of Louisa, Muscatine, Cedar, Johnson and Washington counties. To date, all investigations in the ICRL indicate that basin deposits are primarily Pre-Wisconsin, Wisconsin and Holocene in age rather than Illinoian. More importantly, all deposits are alluvial or eolian in nature, leaving the long-standing interpretation of an Illinoian-age lake in doubt.

The History of Lake Calvin

For many years, the Lake Calvin Basin was interpreted as a glacial lake related to the advance of the Illinoian ice sheet. It was theorized the lake was created as the advancing ice sheet from the east blocked the drainage of the Mississippi, Maquoketa, Wapsipinicon, Cedar and Iowa Rivers. Samuel Calvin first described the basin as lacustrine in 1894. In 1899, J. A. Udden published the "Geology of Muscatine County" and named the feature after Calvin. Schowe, 1920 completed a dissertation on the Lake Calvin area which was later published in IGS Annual Report Vol. 29. However, by 1954, Shaffer (1954) and later Ruhe (1969) and Ruhe and Prior (1970) were raising questions concerning the age and nature of the Lake Calvin Basin deposits. Thus, it was in the early 1980's that Hallberg sent a fleet of PhD students out to unravel the mystery concerning the drainage of the Illinoian ice sheet and to settle the question concerning the genesis of the Iowa-Cedar River Lowland.

Esling (1983), summarizes in his dissertation: "*Dramatic drainage adjustment likely occurred in response to the Illinoian ice advance, and perhaps a lake developed over the Iowa and Cedar River valleys. However, the present study area did not encounter any continuous lacustrine sediment. The* *terraces are composed of alluvium overlain by Wisconsinan and Holocene eolian and colluvial deposits which are too young to be associated with an Illinoian lake. If the lake existed at all, its deposits have been buried, reworked, or removed by a complex post-Illinoian history."*

Moscow Quarry

The Moscow Quarry is located directly west of the Cedar River and is located on loess and eolian sand mantled Pre-Wisconsin-age terrace which overlies a sequence of multiple Pre-Illinois glacial tills. The area is often referred to as the "Moscow Island", a bedrock-cored, upland surface (EPHT) surrounded by Wisconsin age LPHT and Late Wisconsin age terraces (LT). The Cedar River makes an unusual right-angle bend here which is coincident with the leading age of the Illinoian ice advance into southeastern Iowa (Figure 3). To the east is Mud Creek, considered the bounding line for the Illinoian front and which served as the southern portion of the Illinoian diversion channel (the Cleona Channel) for the Mississippi River. Originally, it was thought to mark the "inlet" into the "Lake Calvin Basin".

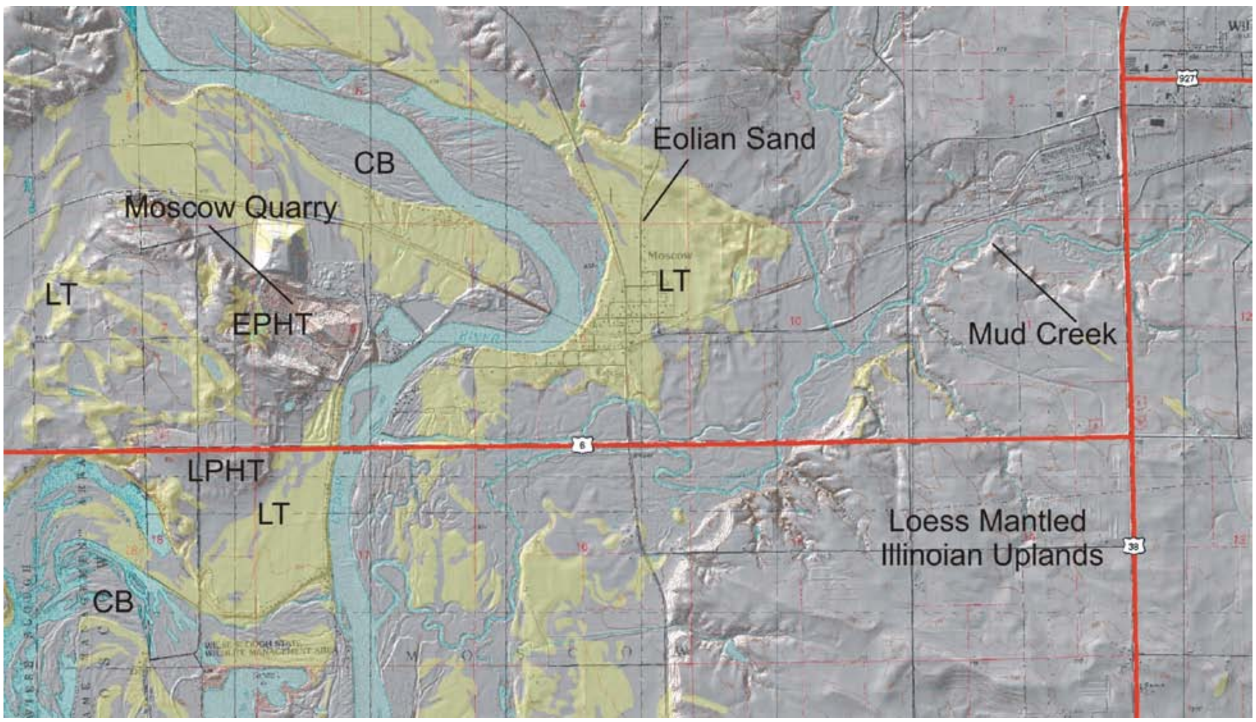

Figure 3. Location of Moscow Quarry, situated on an Early Phase High Terrace (EPHT) surface. Younger terraces surface are inset into the EPHT surface. Directly south of the quarry is a broad loess- mantled Late Phase High Terrace (LPHT) and directly east of the LPHT surface is a Low Terrace (LT) with no loess mantle. Extensive Holocene age channel belts are shown with (CB). Note Late Wisconsin (LT) and Early Holocene age terraces are mantled with extensive sand dunes (shaded).

Generalized Moscow Quarry Sections

The section we will most likely view today consists of eolian loess and an underlying sand sheet which mantles older alluvium (EPHT). The lower part of the sequence consists of a multiple Pre-Illinoian till sequence.

The upper Quaternary exposure was first described in some detail by G. Hallberg, in 1976 and again by G. Hallberg, S. Esling and J. Nott in 1980. They described a composite section along the north face of the Wendling Moscow Quarry. It was noted that the section varied laterally and depths were approximate. Their description follow, in abbreviated form.

Wendling-Moscow Quarry- Moscow, Iowa: Quaternary Description Hallberg, 1976 and Hallberg, Esling, and Nott (1980).

Depth (ft)	Weathering Zone	Description
0-28	OL/UU	**Wisconsin Loess and Eolian Sand-** Loess and eolian sand; lower .6 is unoxidized and unleached.
28-29	A1b	**Wisconsin- Basal Loess Sediment and Paleosol** Basal Loess Paleosol; charcoal flecks.
29-35	2A2b-Btb	**Sangamon-Early Late Sangamon Palesol** Reddish brown heavy loam and underlying poorly sorted sandy clay loam; ,moderate tp strong medium subangualr blocky structure in B horizon, leached alluvium
35-46	OL	**Sangamon Geosol (Late Sangamon)** Red and yellowish red sandy loam grading to medium to coarse sandy loam and fine gravel ; weakly bedded; some interbedded sits toward base; leached alluvium.
46-52.5	OL	**Sangamon Geosol (Late Sangamon)** Stratified fine and medium sand with armored till ball ad some blocks of till-like diamicton; lower 1.5 feet gravelly sandy loam; leached alluvium.

The following includes a series of figures that document the Quaternary sediment package as viewed in the fall of 2007. Also, included is a rough composite description of the section recorded on that visit to the Quaternary exposure.

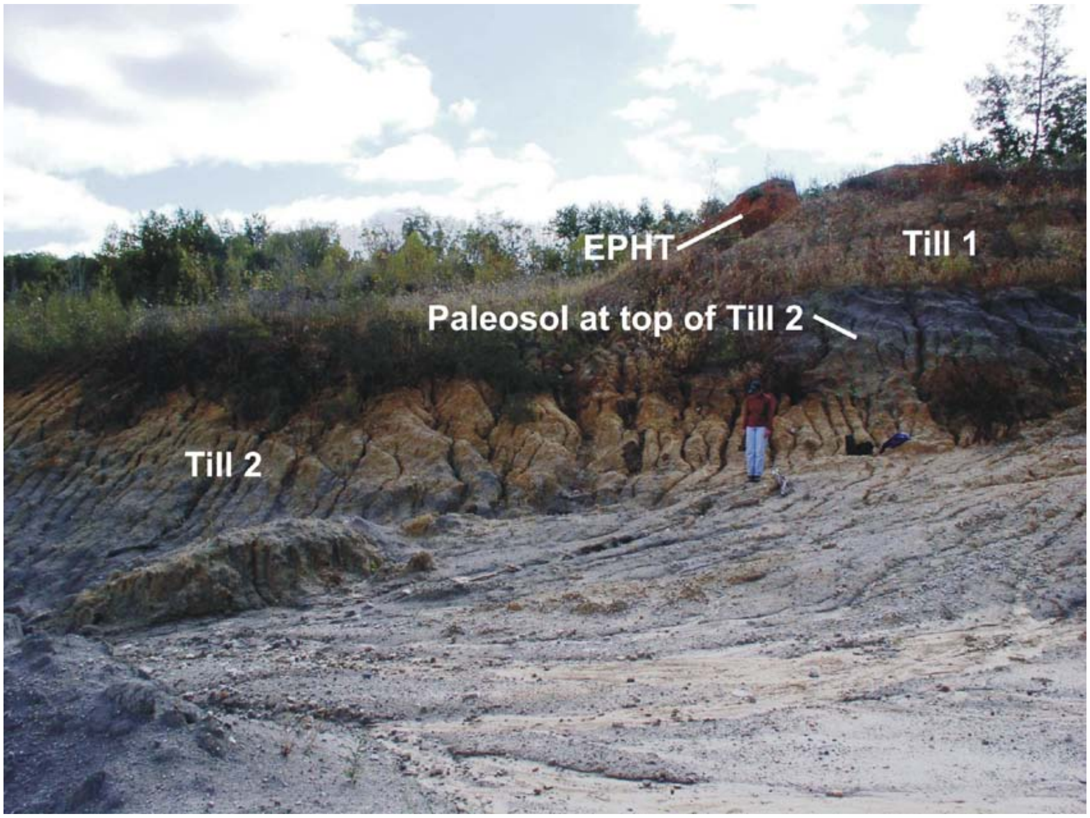

Figure 4: Exposed south end of the Quaternary section at Moscow Quarry in Fall 2007. Approximately five feet of Pre-Wisconsin alluvium (EPHT) overlie a multiple Pre-Illinois till sequence. Note poorly drained paleosol at Top of Till 2 sequence. Till 3 is exposed in a lower bench not visible in this photo. Photo by Kathy Woida.

West North

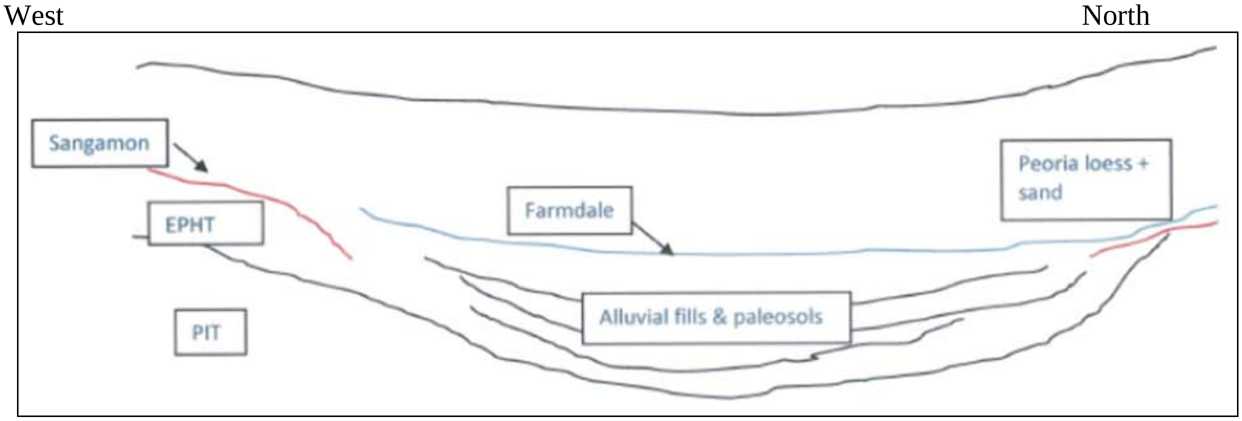

Figure 5. Sketch of Moscow Quarry outcrop to the west of figure 4 exposure. Sketch completed by Dr. Art Bettis. Photo below in Figure 6 provides a close up view of the section in 2007.

In Figure 5, the west wall of the pit had Peoria loess with eolian sand in its lower part over the Farmdale Soil which was formed in silty/clayey alluvium that grades into a sequence of alluvial fills and paleosols dating to >40ka. On the north side of the exposure the Sangamon Soil is formed in till-derived colluvium that diverges into the lower part of the paleosol sequence below the Farmdale Soil.

Figure 6. Upper exposed section at Moscow Quarry in Fall 2007. Windblown Peoria loess mantles a basal sand sheet which in turn overlies a Farmdale Geosol developed in Pisgah Fm. colluvial sediments overlying a Sangamon Geosol developed in a Pre-Farmdale age alluvial fill. Photo by Kathy Woida.

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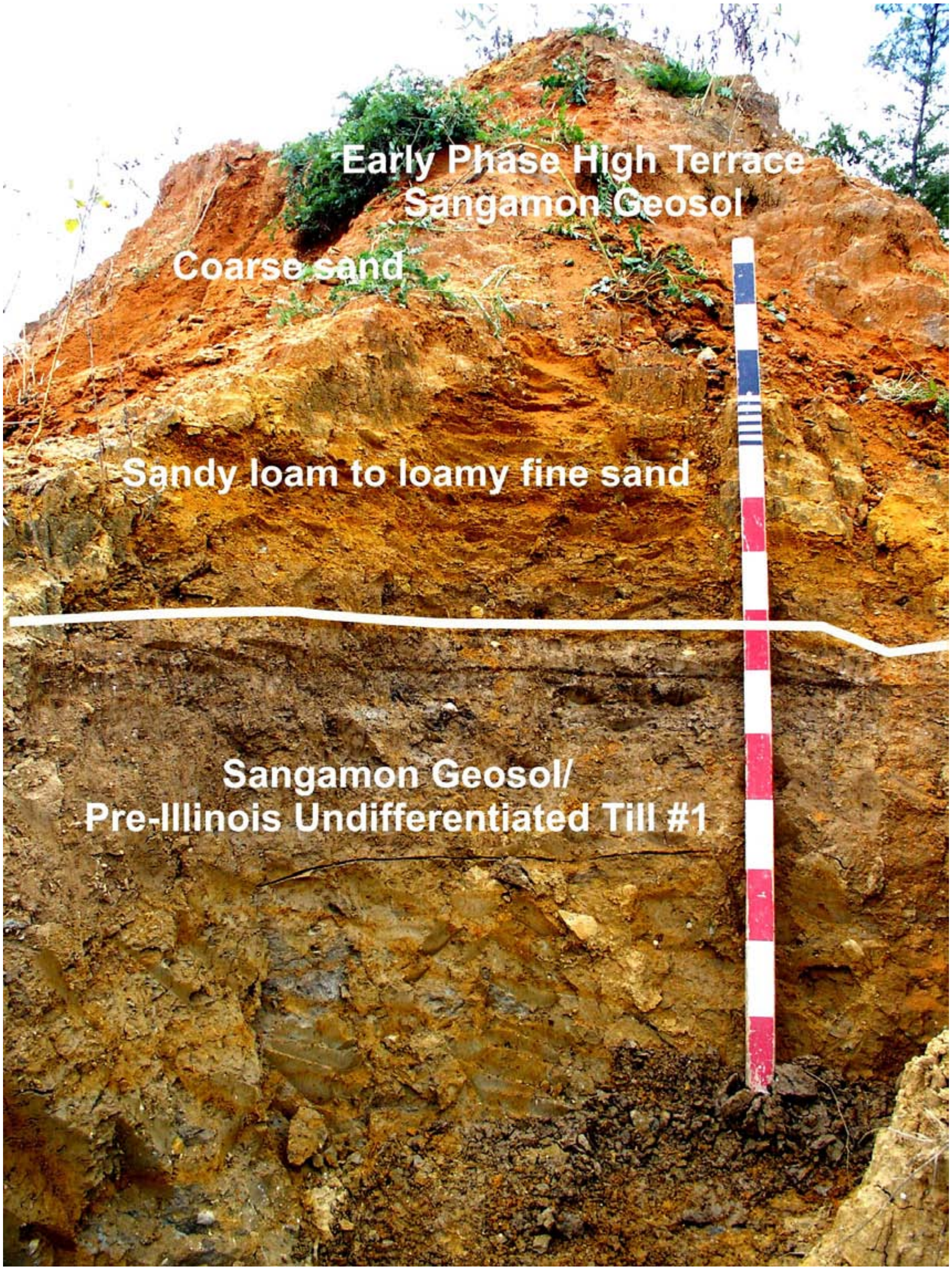

Figure 7. Remnant of Early Phase High Terrace overlying Pre-Illlinoian glacial till. A Sangamon soil is developed throughout the alluvial package and extends into the underlying glacial till. Photo by Kathy Woida.

Figure 8. Lowest Pre-Illinoian bench at Moscow Quarry. Approximately ten feet of a Till 3, a rubbly clay loam diamicton rests uncomformably on Devonian age bedrock. Many of the clasts are locally derived. Photo by Kathy Woida.

Moscow Quarry- Moscow, Iowa: Quaternary Description October 2007. K. Woida, D. Quade and S. Tassier-Surine. Site visited with E. Arthur Bettis who was describing upper eolian/EPHT alluvium profile.

Sangamon Geosol / Alluvium (Early Phase High Terrace)

0-3.5 OL

Yellowish red (5YR 4/6) coarse sand; massive, single grain; noneffervescent; clear boundary.

3.5-4.5 MOL

Brown (7.5YR 5/4 – 5/6) fine sandy loam to loamy fine sand; stratified in 1-5-cm layers, with thin sand partings and strong brown (7.5YR 5/8) and yellowish red (5YR 5/6 – 5/8) color bands; medium angular blocky structure (possibly due to exposure?); clear boundary.

Sangamon Geosol / Undiffentiated Pre-Illinoian Till #1

4.5-5.5 OL

Brown (10YR 5/3) sandy clay loam, with common pebbles (0.5-3 cm in diameter); strong coarse angular blocky structure; prominent 1-cm thick MnO seam at 4.75 ft and abundant MnO coatings on ped faces in upper 10 cm; clear boundary.

5.5-6.75 OL
Yellowish brown (10YR 5/4) sandy clay loam, with pebbles; moderate very coarse angular blocky structure (3-8 cm); prominent MnO coatings on vertical joints and prominent yellowish brown (10YR 5/8) and strong brown (7.5YR 5/6) coatings on oblique joints; gradual boundary.

Pre-Illinoian Formation—Undifferentiated Till #1
6.75-13.75 OJU
Light olive brown (2.5Y 5/4) sandy clay loam, with pebbles; increasing cobbles with depth; very jointed, with prominent MnO coatings on joint faces as in above horizon; gradual boundary.

13.75-17 UU
Black (5Y 2.5/1) clay loam, with pebbles and cobbles; very coarse angular blocky, breaking to coarse angular blocky structure; few small, fine- to medium-grained, yellowish brown (10YR 5/4-5/8) sand bodies, 30-40 cm in diameter; clear boundary.

Paleosol in Pre-Illinoian Formation—Undifferentiated Till #2
17-24 RL
Silty clay with fewer pebbles than above; Dark olive gray (5Y 3/2) inside peds, black (5Y 2.5/1) on outsides of peds above 20 ft, olive gray (5Y 5/2) below 20 ft; medium angular blocky structure; common slickensides with thick clay coatings; common FeO coatings below 20 ft; gradual boundary.

24-29 MRL
Olive gray (5Y 5/2-6/2) silty clay loam; coarse strong brown (7.5YR 5/6-5/8) mottles; massive; slickensided; few very dark gray (10YR 3/1) krotovinas(?), about 10 cm wide; gradual boundary.

Pre-Illinoian Formation—Undifferentiated Till #2
29-33 OJU (RJU?)
Olive brown (2.5Y 4/4) clay loam, with olive gray (5Y 4/2) weathering rinds along joint planes; exposure appears oxidized from a distance; clear boundary.

33-39 UJU (3rd ledge from bottom)
Very firm clay loam; massive, matrix-dominated; gradual boundary.

39-49 UJU (2nd ledge from bottom)
Very dark gray (5Y 3/1), very firm clay loam; wood fragments; rocks up to 30 cm in diameter; pebbly or sandy pods common at about 45 ft; clear boundary.

49-50 Cobble and gravel lag (1st ledge)

Pre-Illinoian Formation—Undifferentiated Till #3 ("Rubbly Till")
50-57 RU
Olive brown (2.5Y 4/3) to dark gray (5Y 4/1) cobbly clay loam; stratified in upper ft; gradual boundary.

57-60 UU
Very dark gray (5Y 3/1) cobbly clay loam; resting on bedrock.

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FIELD GUIDE TO THE DEVONIAN GEOLOGY AT THE MOSCOW QUARRY, MUSCATINE COUNTY, IOWA

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INTRODUCTION

Devonian exposures and core sections from the Moscow Quarry (Figs. 1 to 4) provide an opportunity to see stratigraphic relationships and basic features of the lithostratigraphy and cyclostratigraphy of the Middle Devonian Wapsipinicon Group and lower part of the Cedar Valley Group as they are developed in the southeastern and southern part of the Iowa Basin. The Devonian succession in the Muscatine and Quad-Cities area of southeastern Iowa and western Illinois serve as the primary reference sections for the open-marine and restricted shallow-water platform facies and three major 3rd order sequence packages of the Eifelian-middle Givetian Wapsipinicon Group, and middle shelf subtidal facies of at least five major Middle Givetian-early Frasnian sequence packages that comprise the Cedar Valley Group in this part of the Iowa Basin (Figs. 2, 4 and 5). The most intensely studied reference sections are exposures in the LaFarge Quarry in the town of Buffalo, Scott County, Iowa (Fig. 1, locality BQ; see Day, 2006, stop 3), and IPSCO PPW #3 Well core (Fig. 1, locality IPS; see Day, 2006, fig. 2, and 2010, fig. 2; Ellwood and Day, 2006, figs. 4 and 5) drilled in Muscatine County, approximately 19 miles (30 km) east-southeast of the Moscow Quarry (Fig. 1).

Exposures in the highwall at the Moscow Quarry feature the upper part of the Otis and the Pinicon Ridge Formation of the Wapsipinicon Group, and the Solon and lower Rapid members of the Little Cedar Formation of the lower Cedar Valley Group. Complete Wapsipinicon Group sections from the Moscow Quarry include the Wendling Quarries WQ1-C98-2 core section described below and shown in Figure 2, and the IGS Moscow Quarry core (Fig. 3) by Witzke and Bunker (2006b, fig. 2; also see fig. 4, locality A of Day, 2006; Fig. 3, this study), and The Bertram and Otis formations of the lower Wapsipinicon Group overlay a deeply eroded surface on the Silurian Hopkington Formation, and regionally overlay and onlap other Silurian units in southern Iowa. Middle Devonian (Eifelian-Middle Givetian) strata of the Wapsipinicon Group in core sections drilled on the quarry property or exposed in the quarry highwalls (Figs. 1 to 3) include the locally thin to absent Bertram Formation (cores only), overlain by shallow marine platform carbonates of the late Eifelian Otis Formation, the Early to Middle Givetian age Pinicon Ridge Formation. The Pinicon Ridge Formation is capped locally at the top of the highwall exposures along the west and northern part of the quarry by the Middle-Late Givetian Little Cedar Formation (Fig. 2).

WAPSIPINICON GROUP STRATIGRAPHY

In Johnson, Muscatine and Scott counties in eastern Iowa the Wapsipinicon Group consists of the basal Bertram, Otis, and Pinicon Ridge formations (Figs. 1 to 3). The Otis Formation consists of dolomites assigned to the Goggon Member, and relatively well preserved platform carbonates (limestones) assigned to the Cedar Rapids Member (Witzke et al., 1989; fig. 3 of Witzke and Bunker 2006b). The Pinicon Ridge Formation is subdivided into the Kenwood, Spring Grove, and he Davenport members (Witzke et al., 1989). In eastern Iowa (Fig. 3) the Bertram, Otis and Pinicon Ridge formations progressively onlap a deeply eroded megasequence boundary (Sloss's Tippecanoe-Kaskaskia cratonic unconformity), and

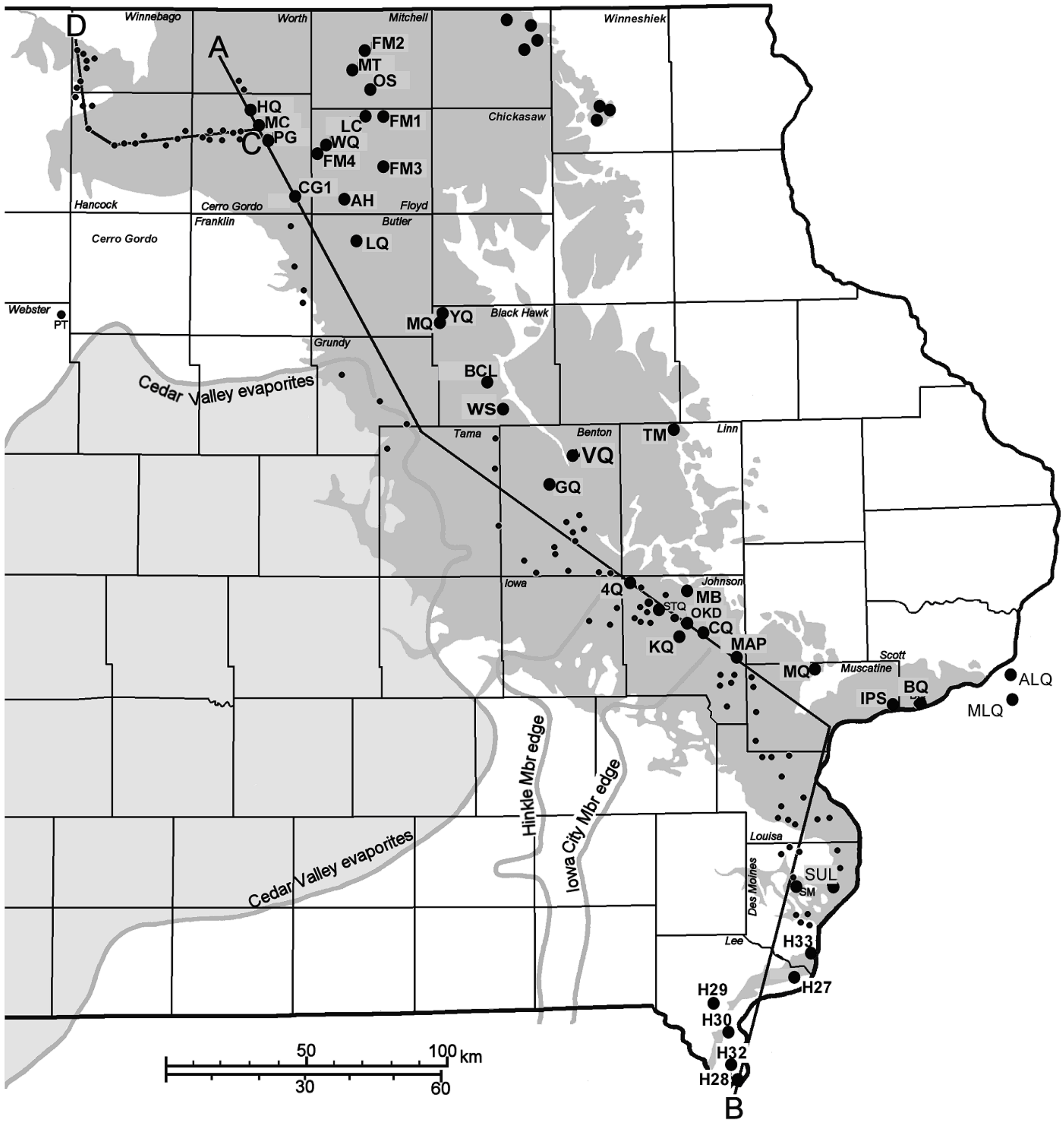

Figure 1.—Map showing the locations of the Moscow Quarry (MQ) in Muscatine County and other core, well and outcrop sections of Middle-Upper Devonian Wapsipinicon and/or Cedar Valley Group strata in the eastern Iowa Basin (cross section A-B shown in Figures 8). The location of the Moscow Quarry in north-central Muscatine County is designated as MQ. 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., 1985; 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).

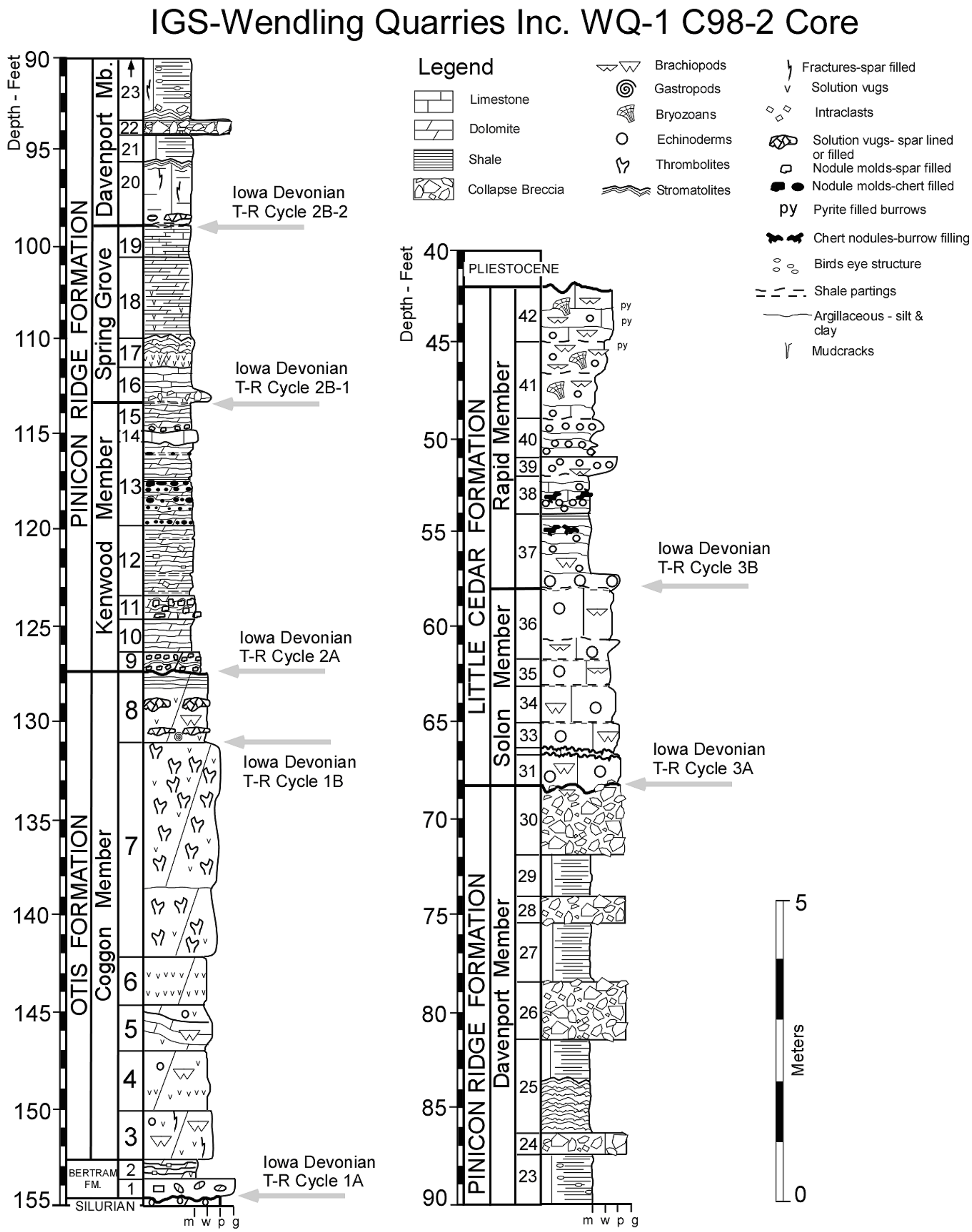

Figure 2.—Devonian stratigraphy in the Moscow Quarry from the Wendling Quarries Inc. WQ-1 C98-2 core. Core described by J.Day, core split now housed at the IGS Oakdale Core facility, in Oakdale, Johnson County, Iowa. Gray arrows indicate the positions of major sea level flooding events as shown in Figure 5.

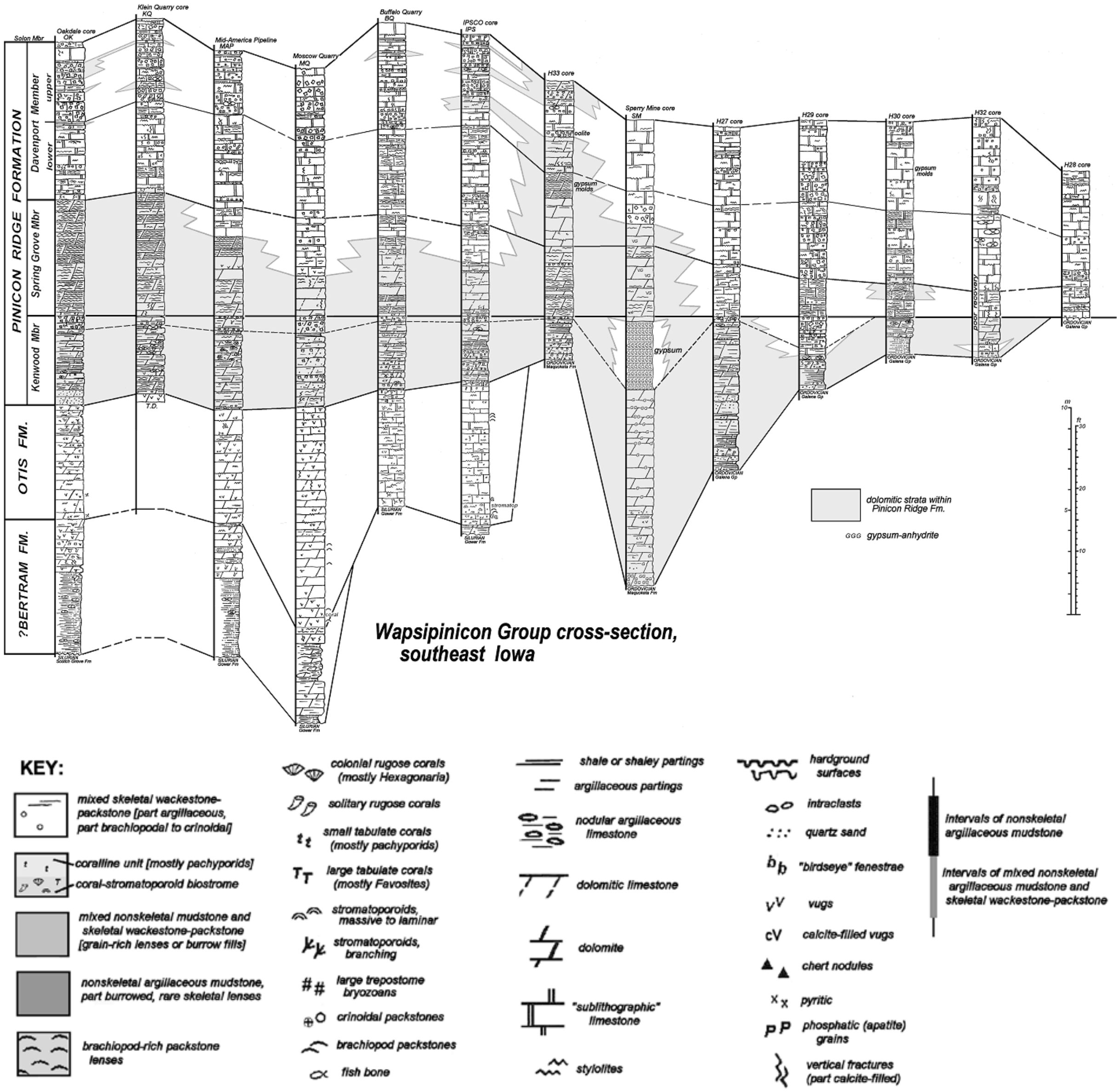

Figure 3.—Graphic sections and correlation of Wapsipinicon Group strata in east-central and southeastern Iowa. Section locations are shown on Figure 1. Moscow Quarry (MQ) and Sperry Mine (SM) sections are based on core logs at the Iowa Geological Survey; MQ Otis section adapted from Fig. 6 and Day (2006). After fig. 2 of Witzke and Bunker (2006b). Key of lithologic and symbols used in graphic sections of cross sections of Wapsipinicon and Cedar Valley Group strata (after fig. 7 of Witzke and Bunker, 2006a).

overlie Silurian (Gower, Scotch Grove, Hopkinton-Blanding formations) and Ordovician units (Maquoketa Formation, Galena Group) in different parts of the Iowa Basin.

Bertram Formation

The Bertram Formation of Johnson and Muscatine counties appears to be gradational with the overlying Otis Formation (Fig. 3) and ranges from less than 1 m (IPSCO, Fig. 1 and 4) to 6 m (Oakdale and MAP cores, Figs. 1 and 3) thick. It appears that the Bertram belongs within the same depositional sequence with the Otis Formation comprising the transgressive systems tract for the basal Wapsipinicon

Group Transgressive-Regressive Cycle (Figs. 2 and 5). The Bertram Formation is reworked erosional residuum and shallow water and arid coastal plain-sabhka deposit likely deposited during rising base level associated with the late Eifelian sea rise that initiated Otis Formation deposition in the southern part of the Iowa Basin during Iowa Devonian T-R cycle 1A (Figs. 2 and 5; Day, 2006; Witzke and Bunker, 2006b).

In the Wendling Quarries and IGS Moscow Quarry core (Fig. 2, units 1 and 2; Fig. 3) the Bertram Formation is two feet thick (61 cm) and consists of thin basal dolomite lithoclast conglomerate overlain by laminated to stromatolitic dolomite (Fig. 2,) and overlays the eroded surface of the Hopkinton Formation, and is over 2 meters thick in the IGS Moscow core (Fig. 4, see fig. 2 of Witzke and Bunker, 2006b).

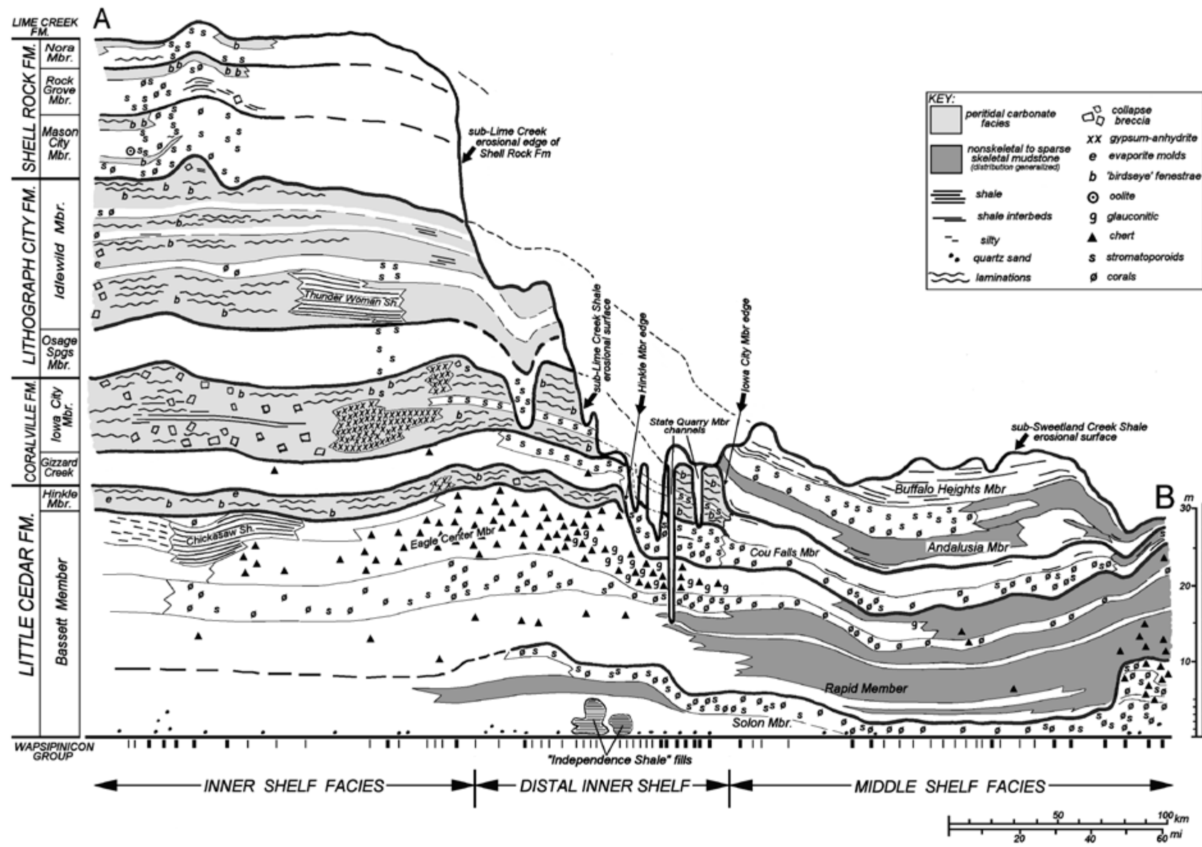

Figure 4.—Northwest-southeast stratigraphic cross section of the Cedar Valley Group in eastern Iowa. Significant Late Givetian (pre-*norrisi* Zone) post-Coralville and Middle Frasnian sub-Lime Creek/Sweetland Creek erosion has truncated Cedar Valley strata, especially in the distal inner-shelf area. "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.

Otis Formation

The Otis Formation occupies areas of Iowa and adjoining Illinois, and its southern margin stretches across the northern part of southeastern Iowa in Johnson, Muscatine and Scott counties (Bunker et al., 1985). It oversteps the Bertram Formation, and the Otis unconformably overlies an eroded Silurian surface across most of its extent (Fig. 4). The Otis Member is characterized by carbonate strata comprising a succession of shallow-marine, restricted-marine, and peritidal facies. In Linn County the formation has been subdivided into two members (Bunker et al., 1985; Witzke et al., 1988): the lower Coggon Member, an interval of dolomite, vuggy in part, with scattered molds of brachiopods (*Emanuella*), gastropods, rostroconchs, and trilobites; and an upper Cedar Rapids Member of limestone and dolomite, including sparsely fossiliferous dolomite and limestone (with *Emanuella*, gastropods, bryozoans), pelletal limestone (locally with spirorbids), locally oolitic limestone, laminated peritidal carbonates with stromatolites, “birdseye,” mudcracks, and intraclastic to brecciated units (Sammis, 1978; Witzke and Bunker, 2006b). In the Moscow Quarry, subtidal and peritdal facies of the Otis are entirely dolomitized and assigned to the Coggon Member (Fig. 2; Witzke and Bunker, 2006b, fig. 2). A facies change to limestones assigned to the Cedar Rapids Member occurs to the east (Fig. 4) as seen in the IGS IPSCO cores in eastern Muscatine County, in the IGS Linwood Mine cores in Scott County, and in the Milan and Allied quarries in Milan and Rock Island Illinois.(Day, 2006, fig. 4).

The Otis 3rd order T-R cycle was further divided into two small-scale 4th order cycles by Day (2006, Otis 4th order T-R cycles 1A and 1B; see Fig. 5) recording two Late Eifelian sea level events, terminated by period of sea level lowstand and platform emergence. The post-Otis lowstand removed varying amounts of the upper Otis 4th order package in the WQ-1 C98-2 Moscow Quarry core consistent with the observed erosional truncation karstification of the upper Otis strata in southeastern Iowa and northwestern Illinois (Day, 2006). Post-Otis erosion removed substantial parts of the upper Otis within the confines of the Moscow Quarry where the Otis is 8 meters thick in the Wendling Quarries WQ-1 C98-2 core (Fig. 2) and 13.8 meters thick in the IGS Moscow Core (Fig. 4).

Pinicon Ridge Formation

The Kenwood, Spring Grove and Davenport members of the Pinicon Ridge makes up the majority of the exposure in the Moscow Quarry highwall (Figs. 2 and 3). The Kenwood Member oversteps the edge of the Otis Formation, and it unconformably overlies eroded Ordovician and Silurian strata across most of its extent (Iowa, northeast Missouri, northwest Illinois). The Kenwood Member (also called the Kenwood Shale) is dominated by unfossiliferous argillaceous to shaly dolomite, in part silty to sandy, with lesser interbeds of gray to green shale, in part silty to sandy (Fig. 3). Silt and sand grains are composed of quartz and chert. Some dolomite beds are irregularly laminated to mottled. Intraclastic and brecciated beds are common, although not common in the WQ-1 C98-2 core section (Fig. 2). Concretionary masses of chalcedony and chert after gypsum or anhydrite are seen in many sections, and some dolomite beds are siliceous. The Kenwood Member includes gypsum and anhydrite evaporite units at localities southeastern Iowa, and economic gypsum deposits are extracted from the upper Kenwood in subsurface mines near Sperry, Iowa (Fig. 3) see Witzke and Bunker, 2006b, Sperry Mine section, fig. 2).

In the Moscow Quarry the Spring Grove Member is mostly dolomitized although is limestone in most sections to the east and appears to be generally unfossiliferous, but burrows, stromatolites, and ostracodes, indeterminate medusoid forms, and placoderms have been noted (Witzke et al., 1988; Hickerson, 1994), from a single locality (Milan Quarry, Illinois). Minor breccias and intraclastic units are seen at some localities (Figs. 2 and 3). Giraud (1986) observed nodular to mosaic anhydrite in the Spring Grove within evaporite-bearing Wapsipinicon successions in southeastern Iowa, and gypsum-anhydrite calcite and chert void fills occur in the lower Spring Grove in the Moscow Quarry core section as well as other localities in southeastern Iowa.

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.

The Davenport Member (Figs. 2 and 3) 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

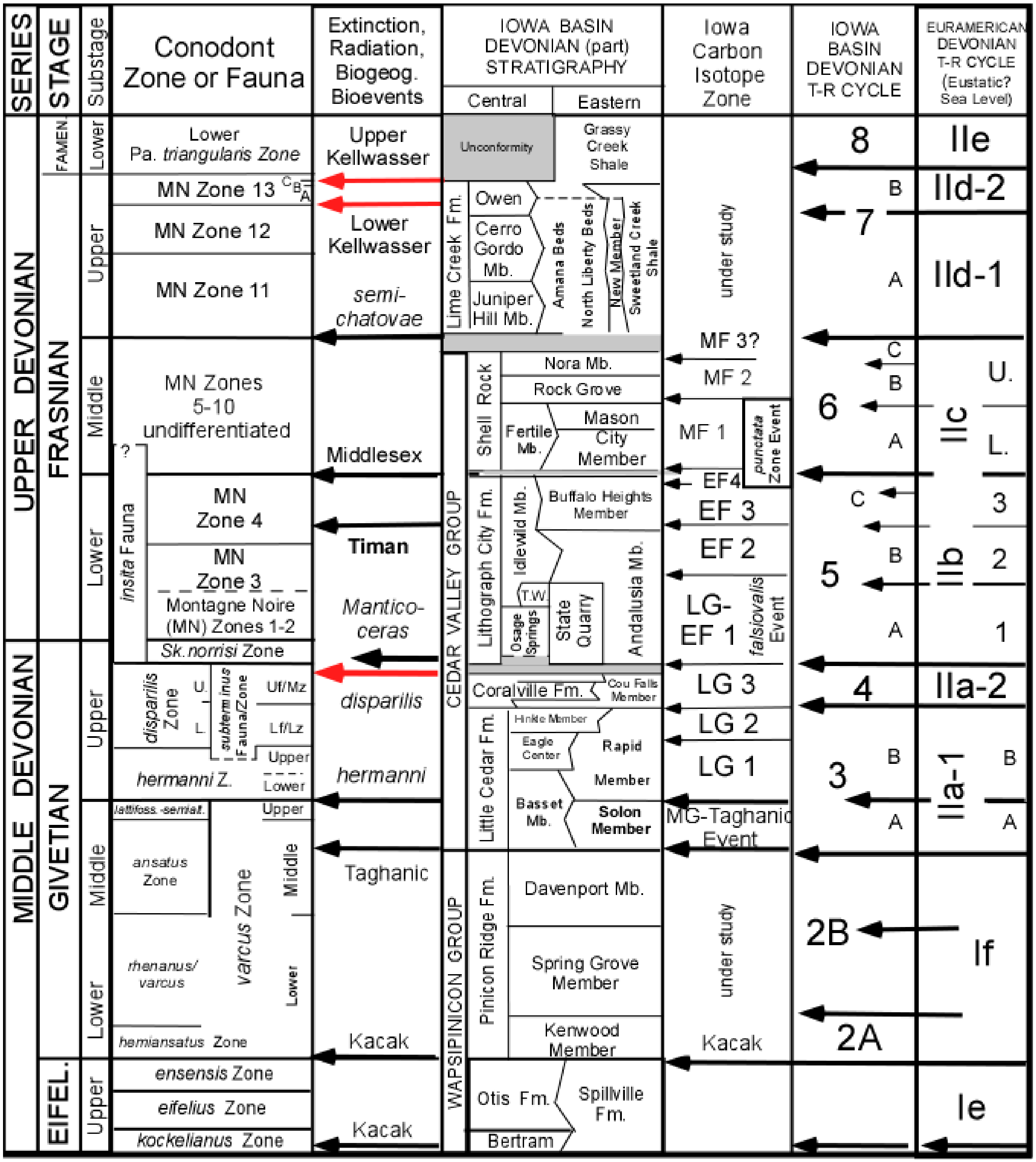

Figure 5.—Stratigraphic and biostratigraphic framework for the Middle-Late Devonian (late Eifelian-early Famennian strata of the Iowa Basin showing relationships between: the qualitative eustatic T-R cycles of Johnson et al. 1985), Johnson and Klapper (1992), Day et al. (1996), Day (1998), Whalen and Day (2008); and Iowa Basin Devonian T-R cycles of Witzke et al. (1989), Bunker and Witzke (1992), and Witzke and Bunker (1996, 2006a). 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, 2010), and Over (2002, 2006), Frasnian conodont zones after Klapper (1989). Iowa Basin Devonian stratigraphy after Witzke et al. (1989), Witzke and Bunker (1992, 1996), Day (1997), Day et al. (2008). Major Extinction bioevents shown by red arrows. Modified from fig. 3 of Day (2006) and Day et al. (2008), after fig. 2 of Day et al., in preparation. Abbreviations: Bert. = Bertram Fm. = Formation, Mb. = Member, L. = Lower, M. = Middle, U. = Upper.

limestones are dominantly mudstones, but pelletal and intraclastic units are also commonly present. Rare oolitic packstone-grainstone beds are noted. A few limestone beds display calcite-filled fenestral and 'birdseye' fabrics and gypsum crystal molds. 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. 3). Thin shales (in part silty to sandy) and argillaceous to shaly units are observed in many sections. The Davenport Member is dominated by evaporite facies in some areas of southeastern Iowa and bedded gypsum is present in the upper Davenport in the IPSCO #3 core section described by Day (in Ellwood and Day, 2006, fig. 4). Giraud (1986) also notes where nodular, mosaic, and massive gypsum-anhydrite units are observed to interbed with limestone and dolomite strata in the Davenport Member.

The Davenport Member is best known for its well developed limestone breccias, a characteristic feature in most sections across its geographic extent in the Iowa Basin (Figs. 2 and 3). 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, some with shale matrix (see Fig. 2, Unit 22). The Davenport breccias have been interpreted to have formed by solution-collapse processes (Sammis, 1978; Witzke and others, 1989, Witzke and Bunker, 2006b, Day, 2006). 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 of the basal Little Cedar Formation seen in the upper part of Unit 30 of the WQ-1 C98-2 Core (Fig. 2, unit 30) and highwall exposures in the Moscow Quarry, and across much of central and eastern Iowa (Figs. 3 and 4).

CEDAR VALLEY GROUP STRATIGRAPHY

Overlying the Davenport Member of the Pinicon Ridge Foramtion throughout the Iowa Basin is the Little Cedar Formation of the lower Cedar Valley Group (Figs. 1 to 3). The Cedar Valley Group in southeastern Iowa consists of the Little Cedar, Coralville, and Lithograph City formations (Figs. 4 and 5; Witzke et al., 1989; Witzke and Bunker, 2006a; Day, 2006, Day et al., 2008). The Cedar Valley Group in this region consists of five major disconformity-bounded packages of subtidal middle shelf facies representing five major 3rd order Iowa Devonian T-R cycles signaling a major change from restricted, to open marine conditions in this part of the Iowa Basin (Figs. 4 and 5). Well developed erosional hiatuses separate the Wapsipinicon and Cedar Valley groups, and the Coralville and Lithograph City formations of the Cedar Valley Group, indicating withdrawal of epeiric seas from the Iowa area in the early (pre-Middle *varcus* Subzone) and late Givetian (Upper *subterminus* Fauna = approximately Upper *disparilis* Zone), respectively (see Fig. 5). The timing of these withdrawals in Iowa corresponds to regressive events in the central and western Canadian platforms as well (Day et al., 1996). Pre-Lime Creek period of emergence also terminated Shell Rock Formation during the Middle Frasnian but is not discussed further here (Iowa T-R cycle 6, Fig. 5).

Little Cedar Formation

Across the Cedar Valley Group middle shelf facies tract in Johnson, Muscatine and Scott counties (Figs. 1, 2 and 4) the Little Cedar Formation in divided into the Solon and Rapid members. The Solon and Rapid make up the larger Iowa Devonian T-R sequence 3, but the Solon also comprises its own shallowing-upward succession and it represents a recognizable T-R subcycle (T-R cycle 3A of Witzke and Bunker, 1994, 1996; Day, 2006). 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. Southeastward from Johnson County, the Solon Member becomes significantly thinner, locally as thin as 2 m or less (Fig. 4, see the Lafarge Corporations' Buffalo Quarry, stop 3 of Day, 2006). The lower Solon ("*independensis* beds") in Johnson, Muscatine, and Scott counties in Iowa and Rock Island County in Illinois is characterized by slightly argillaceous fossiliferous limestone (wackestone and packstone) with a diverse marine fauna (brachiopods, crinoid debris, bryozoans, etc.). A widespread submarine hardground surface occurs near the top of the Solon (Witzke and Bunker, 2006a, 2010; Day 2006).

The Rapid Member comprises the remainder of the Little Cedar Formation above the Solon Member, and at the Moscow Quarry, the lower one third to half of the Rapid Member is preserved below the Pleistocene unconformity and overlain by glacial and fluvial deposits. Across eastern Iowa (Fig. 4) the Rapid Member forms a succession of distinctive middle shelf subtidal carbonate lithofacies interpreted to represent the upper Little Cedar subcycle within the larger Little Cedar T-R sequence (Iowa Devonian T-R cycle 3B, Witzke and Bunker, 1994, 2006a; Day, 2006). As with the Solon Member, the Rapid Member is also defined from localities in Johnson County, Iowa (Fig. 1), where it averages about 16 m thick (Fig. 4). The Rapid Member in the region is dominated by argillaceous skeletal mudstones and wackstones with scattered skeletal material and locally with major skeletal lag beds, and some intervals of concentrated skeletal packstones, especially in the upper part of the member. The Rapid contains an extremely diverse marine fauna including rugose and tabulate corals, bryozoans, brachiopods, echinoderms, gastropods, rostroconchs, and stromatoporoids. The base of the Rapid coincides to a major marine flooding surface marking a major expansion of the epeiric seaway locally and across North America during the *hermanni* Zone (Fig. 5; Witzke et al., 1988; Day et al., 1996; Day, 2006, 2010), marking the onset of Iowa Devonian T-R cycle 3B (Witzke and Bunker, 2006a; Day, 2006) in the upper part of Devonian eustatic T-R cycle IIa-2 of Day et al. (1996). The contact of the Rapid Member and overlying Coralville Formation is a prominent burrowed discontinuity surface seen across eastern and southeastern Iowa.

MOSCOW QUARRY CORE (WQ-1 C98-2) DESCRIPTION

Location: no detailed GPS or map coordinate location was provided by Wendling Quarries Inc. for the split of the WQ-1 C98-2 core recently donated to the Iowa Geological the Iowa. Geological Survey GEOSAM data base and Iowa Department of Transportation core record cites the quarry location as T. 78 N. R. 2 W., Section 8, Muscatine Co., Iowa.

Described: By J. Day, October 10-12, 2011, and section shown in Figure 2.

SILURIAN SYSTEM-SCOTCH GROVE FORMATION

Medium-coarse grained dolomite, skeletal moldic porosity, abundant echinoderms & brachiopods.

MIDDLE DEVONIAN

WAPSIPINICON GROUP (63.8-153.6 ft., total thickness 89.8 ft./27.37 m)

BERTRAM FORMATION (154.6-153.6 FT., 2.0 FT./0.61 M)

Unit 1 **(153.6-154.6 ft., 1.0 ft./0.3 m): Dolomitic Conglomerate,** reworked angular to rounded gravel (granule-to-pebble) Silurian dolomite and fine grained dolomite clasts, in fine grained sandy-silty dolomite matrix.

Unit 2 **(152.6-153.6 ft., 1.0 ft./0.3 m): Dolomite,** fine grained granular dolomite, wavy to stromatolitic (in lower 0.6 ft.) laminated to thin bedded, irregular open solution vugs in upper 0.5 foot.

WAPSIPINICON GROUP-OTIS FORMATION

Coggon Member (127.35-153.6 ft., total thickness = 26.25 ft./8.0 m)

Unit 3 **(151.1-152.6 ft., 1.5 ft./0.46 m): Dolomite,** medium grained friable sucrosic porous dolomite, medium gray brown, brachiopod molds and open small solution vugs, fractured in upper 0.3 ft.

Unit 4 **(147.1-151.1 ft., 4 ft./1.22 m): Dolomite,** fine-medium grained, light brown, open solution vugs of sand to granule size, brachiopod (*Emanuella* sp.) and echinoderm skeletal molds, vuggy horizon at 149.6’, upper contact with unit 5 a stylolitic bedding surface.

Unit 5 **(144.6-147.1 ft., 2.6 ft./0.79 m): Dolomite,** fine-medium grained, light brown, relict thin fore-set cross beds with open solution vugs of sand to granule size, brachiopod (*Emanuella*) and echinoderm skeletal molds.

Unit 6 **(142.35-144.6 ft., 2.25 ft./0.68 m): Dolomite,** medium grained, light brown, open solution vugs, with prominent open solution vugs up to 1 cm intervals from 144.45-144.6 and 142.85-143.3 ft., stylolitic bedding in upper 0.1 ft, capped by thin dark gray clay concentration on top of stylo-bedding surface.

Unit 7 **(131-142.35 ft., 11.35 ft./3.46 m): Dolomite,** medium-light brown, with pink spar mottles, oncoidal grainstone to thromboidal bafflestone, stromatolitic, open platey vugs at 138.3 ft., thromboidal at top 0.5 ft.

Unit 8 **(127.35-131 ft., 3.65 ft./1.11 m): Dolomite,** fine-medium grained, thrombolites, brachiopods (*Emanuella*? sp.), and gastropods in lower 0.4 ft., open and spar-filled solution vugs (5-8 cm) from 130-130.5 ft., large spar-lined vugs from 128.8-129.45 ft., small open vugs and laminated to thin bedded in upper 1.0 ft.

PINICON RIDGE FORMATION (63.8-127.5 ft., total thickness = 63.7 ft./19.41 m)

Kenwood Member (113.4-127.5, 14.1 ft., 4.3 m)

basal contact with the Bertram Formation features closely spaced stylolitic bedding at top of unit 8 with a 2-4 cm thick shale at base of unit 9 of Kenwood (Fig. 2).

Unit 9 (126.35-127.5 ft., 1.15 ft./0.35 m): Dolomite, fine-medium grained, laminated, lamina distorted around irregular ellipsoidal calcite spar-filled solution cavities (formerly gypsum/anhydrite nodules) in lower 0.4 ft., stromatolitic laminated dolomite from 126.9-127.1, overlain by 0.6 ft. of laminated dolomite with lamina distorted around bedded irregular ellipsoidal calcite spar-filled solution cavities (formerly (gypsum/anhydrite nodules) **.**

Unit 10 (124.6-126.35 ft., 1.75 ft./0.53 m): Agrillaceous Dolomite & laminated-dolomitic mudshale, with low amplitude stromatolitic lamina, small scattered mud intraclasts.

Unit 11 (123.45-124.6 ft., 1.15 ft./0.35 m): Dolomite, laminated dolomite with lamina distorted around bedded irregular ellipsoidal calcite spar-filled solution cavities (formerly (gypsum/anhydrite nodules) **.**

Unit 12 (119.85-123.45 ft., 3.6 ft./1.1 m): Basal 4 cm dark gray shale, overlain by dolomite, argillaceous laminated mudstone, horizontal and disrupted/distorted lamina, scattered small intraclasts, teepee structures in lower 0.4 ft. of dolomite above basal shale.

Unit 13 (115.4-119.85 ft., 4.45 ft./ 1.36 m): Mudshale, dolomitic, horizonatal and disrupted/distorted laminae, scattered small intraclasts, intervals of irregular light gray chert nodules (formerly gypsum/anhydrite nodules) 119.6. 119.4, 118.85, 118. 5-118.6, and 117.5-117.8 ft., thin laminated dark gray shales at 119.85. 118.65. Thin shale with chert nodules at 115.9-116 ft.

Unit 14 (114.8-115.4 ft., 0.6 ft./0.18 m): Limestone, mudstone with irregular base with argillaceous laminations.

Unit 15 (113.4-114.8 ft., 1.35 ft./ 0.41 m): Dolomite, laminated in two beds separated by1 cm shale at 114 ft, lower 0.3 ft. with lamina distorted around bedded irregular ellipsoidal calcite spar-filled solution cavities (formerly (gypsum/anhydrite nodules), upper 0.3 ft. fractured, with 2 cm offset. One cm dark gray shale caps unit at contact with the Spring Grove.

Spring Grove Member (113.4-98.75 ft., 14.65 ft., 4.46 m)

Unit 16 (111.25-113.4 ft., 2.15 ft./ 0.65 m): Mudstone-laminated-thin bedded lime mudstone, lamina distorted and partially brecciated in lower 0.8 ft., dolomitic in upper 0.1 ft.

Unit 17 (110-111.25 ft., 1.25 ft./0.38 m): Dolomite, stromatolitic bindstone, fractured and vuggy in lower 0.5 ft.

Unit 18 (100.5-110, 9.5 ft./2.9 m): Dolomite, light brown, fine-medium grained sucrosic, laminated with dark gray argillaceous partings, mm-scale solution vugs from 103-110.9 ft.

Unit 19 (98.9-100.5 ft., 1.6 ft./0.49 cm): Limestone, laminated with black-dark gray argillaceous partings.

Davenport Member

Unit 20 (98.9-99.0 ft., 0.2 ft., 0.06 m): Shale, thin wavy lamina, carbonate mudstone lenses in shale with stylolitic surfaces.

Unit 21 (94.25-99.0 ft., 4.75 ft., 1.45 m): Limestone, mudstone-laminated, irregular solution vugs filled with shale and calcite spar in lower 0.5 ft., sub-vertical spar-filled fractures, stromatolitic from 95.6-96.4 ft.

Unit 22 (93.5-94.25 ft., 0.75 ft./0.23 m): Limestone Collapse Breccia, laminated lime mudstone pebble-granule lithoclast breccia, shale matrix.

<u>Unit 23</u> (87.4-93.5 ft., 6.1 ft./ 1.86 m): Limestone, mudstone-laminated, stromatolitic in lower 0.5 ft., brecciated 92.8-93 ft., fenestral fabric 89.3-90.2 ft., fractures, irregular solution vugs filled with shale and calcite spar in lower 0.5 ft., sub-vertical spar-filled fractures, stromatolitic from 95.6-96.4 ft.

<u>Unit 24</u> (86.3-87.4 ft., 1.1 ft./0.33 m): Limestone Collapse Breccia, laminated lime mudstone pebble-granule lithoclast breccia, limestone matrix.

<u>Unit 25</u> (81.55-86.3 ft., 4.75 ft., 1.49 m): Limestone-bindstone-laminated, stromatolitic.

<u>Unit 26</u> (78.4-81.55 ft., 3.15 ft./ 0.96 m): Limestone Collapse Breccia, laminated lime mudstone pebble-granule lithoclast breccia, limestone matrix.

<u>Unit 27</u> (75.4-78.4 ft., 3 ft./0.91 m): Limestone-mudstone, wavy faint thin beds to laminated.

<u>Unit 28</u> (74-75.4 ft., 1.4 ft./0.43 m): Limestone Collapse Breccia-laminated lime mudstone pebble-granule lithoclast breccia, carbonate sand-mud matrix.

<u>Unit 29</u> (71.8-74 ft., 2.2 ft./0.67 m): Limestone, mudstone, very thin bedded.

<u>Unit 30</u> (68.3-71.8 ft., 3.5 ft./1.07 m): Limestone Collapse Breccia-laminated lime mudstone pebble-granule lithoclast breccia, admixed skeletal packstone clasts of Solon Mb.- in upper 0.5 ft., thin angular pebble rubble in shale in upper 0.1 ft. at Solon contact.

CEDAR VALLEY GROUP-LITTLE CEDAR FORMATION

Solon Member (58-68.3 ft., 10.3 ft./3.14 m)

<u>Unit 31</u> (66.9-68.3 ft., 1.4 ft./0.43 m): Skeletal packstone, burrowed, fine grained skeletal grains with brachiopods and echinoderms, disrupted and partially brecciated in lower 0.3-0.4 ft., upper contact irregular hardground with 0.2 ft. of local relief.

<u>Unit 32</u> (66.9-66.5 ft., 0.4 ft./0.12 m): Skeletal packstone and wackestone, burrowed, in two thin beds, separated by irregular hardground surfaces, upper contact with unit 33 is a hardground surface.

<u>Unit 33</u> (65.1-66.5 ft., 1.4 ft./0.43 m): Skeletal wackestone-packstone, echinoderms and brachiopods, including *Elita* sp., *Gypidula* sp., *Desquamatia* (*Independatrypa*) *independensis*, *Spinatrypa* sp., shale parting at upper contact.

<u>Unit 34</u> (61.7-65.1 ft., 3.3 ft./1 m): Skeletal wackestone-packstone, burrowed, medium to thick bedded with echinoderms and brachiopods, *D.* (*I.*) *independensis*, *Gypidula* sp. and *Schizophoria* sp., in lower 2.0 ft. bed, with echinoderm concentration in lower 0.1 ft., argillaceous lamina 64.45 ft. Upper 1.3 ft. bed of wackestone-packstone, with argillaceous laminated contact with unit 35.

<u>Unit 35</u> (60.66-61.7 ft., 1.04 ft./0.32m): Skeletal wackestone-packstone, burrowed, wackestone in lower 0.7 ft., upper 0.4 ft. packstone, with brachiopods and echinoderms.

Unit 36 (58-60.7 ft., 2.7 ft./0.82 m): Skeletal wackestone-packstone, burrowed, with brachiopods and echinoderms. Solon-Rapid contact is at 1 cm shale at top of unit 36.

Rapid Member (42-58 ft., 16 ft./4.88 m)

<u>Unit 37</u> (54-58 ft., 4 ft./1.22 m): Skeletal packstone & argillaceous skeletal mudstone, basal packstone in lower 0.3 ft., argillaceous burrowed mudstone with chert nodules filling burrows from 55.1-55.4 ft., echino plate filled burrow at 54.4 ft., capped by thin shale from 54-54.1 ft.

<u>Unit 38</u> (52-54 ft., 2 ft./0.61m): Skeletal mudstone, burrowed, argillaceous with brachiopods and echinoderms.

<u>Unit 39</u> (51.1-52 ft., 0.9 ft./0.27 m): Skeletal packstone, burrowed, argillaceous with brachiopods and echinoderms.

<u>Unit 40</u> (49-51.1 ft., 2.1 ft./0.64 m): Skeletal mudstone & wackestone, burrowed argillaceous mudstone with brachiopods and echinoderms, thin skeletal wackestone beds at 50.85, 50.6, 49.5, upper 1.0 ft. is skeletal wackestone, with thin one cm shale at top of unit.

<u>Unit 41</u> (45-49 ft., 4 ft./1.22 m): Skeletal mudstone-wackestone, burrowed argillaceous with brachiopods and echinoderms, in three medium beds, separated by thin argillaceous partings, lower 0.9, middle 1.6, and upper 1.05 ft., and uppermost 0.4 ft. bed, *Spinatrypa bellula* in third bed, branching trepostone bryozoans in upper bed.

<u>Unit 42</u> (41.85-45 ft., 3.0-3.15 ft./0. 96 m): Skeletal wackestone & packstone, burrowed argillaceous with brachiopods and echinoderms, in three beds, separated by thin argillaceous partings, lower 1.1, middle 0.9, and upper 1.15 ft. bed, *Schizophoria* sp. in lower bed, *Strophodonta* sp. in middle bed, upper unconformity-erosional surface with up to 0.2 ft. of relief.

PLEISTOCENE-Undifferentiated.

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Map of northwestern Muscatine County showing location of the Moscow Quarry