35th ANNUAL GREAT-LAKES SECTION - SEPM
74th ANNUAL TRI-STATE GEOLOGICAL FIELD CONFERENCE

GUIDEBOOK

The Devonian-Carboniferous Boundary in the Type Area of the Mississippian

September 28-29, 2019

Iowa Geological Survey **Guidebook Series 30**

Cover Photograph: Exposure of Kinderhookian succession at Starr's Cave Park and Preserve, Des Moines County, Iowa; Field Trip Stop 6.

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Edited by Bradley D. Cramer

THE DEVONIAN-CARBONIFEROUS BOUNDARY IN THE MISSISSIPPI RIVER VALLEY OF IOWA, ILLINOIS, AND MISSOURI

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INTRODUCTION

The excellent exposures of late Paleozoic strata along the bluffs of the Mississippi River Valley of the upper and central Midcontinent have been studied for well over a century. The original designation of the Mississippian System (now Mississippian Subsystem) was proposed for these strata exposed between Burlington, Iowa, and southern Illinois, and as a result, this is a critical region to any investigation of potential revisions to the Devonian-Carboniferous Boundary (D-C boundary). Shortcomings of the current Global Boundary Stratotype Section and Point (GSSP) for the base of the Carboniferous System at La Serre, France, combined with the identification of a major biogeochemical event known as the Hangenberg Event, have been the impetus for renewed research and global investigation of the D-C Boundary over the past decade. Currently, the International Subcommissions on Devonian and Carboniferous Stratigraphy have a working group to evaluate the best path forward for redefinition of the base of the Carboniferous System.

UPPER DEVONIAN – MISSISSIPPIAN STRATA

Upper Devonian through Mississippian strata have been the subject of a series of excellent guidebooks to field excursions published by the Iowa Geological Survey and the Illinois Geological Survey during the past two decades (e.g. Witzke & Bunker, 2001; Heckel, 2001; Witzke et al. 2002) and anyone interested in a thorough discussion of the history, detailed stratigraphy, and regional synthesis of Devonian-Carboniferous Boundary strata throughout the region should certainly consult those resources. We will not reproduce those documents here, however, we will utilize several key illustrations, stratigraphic columns, and outcrop descriptions. Our primary objective with this field guide and excursion is to highlight the results of recent and ongoing work in the region as it pertains to our understanding of the D-C boundary in the region.

Regionally, the transition from Upper Devonian to Mississippian sedimentation is marked by a transition from a predominantly shale and clastic environment to an expansive carbonate platform known as the Burlington Shelf, named for the Burlington Formation. The transition between the two spans the D-C boundary and corresponds to the Kinderhookian Regional Series. The Glen Park, Horton Creek, Hannibal, Choteau, McCraney, Prospect Hill, Starr's Cave, and Wassonville formations traditionally comprise the Kinderhookian in western Illinois, eastern Missouri, and southeastern Iowa (Fig. 1), whereas the overlying Meppen, Fern Glen, Unit 1 of Baxter, and the Burlington formations comprise the majority of the Osagean. The Louisiana Formation, which underlies the Hannibal Shale and Prospect Hill formations has been variably assigned to the Devonian as well as the Carboniferous over the past century and has an even longer history of (mis)correlation with the McCraney and/or Crapo formations throughout the region (see discussion in Witzke & Bunker, 2002). The major focus of recent research in the region has centered upon the quest to define the D-C boundary as well as an improved correlation of the stratigraphic units in the classical type areas around Hannibal, MO, with the classical type areas around Burlington, IA.

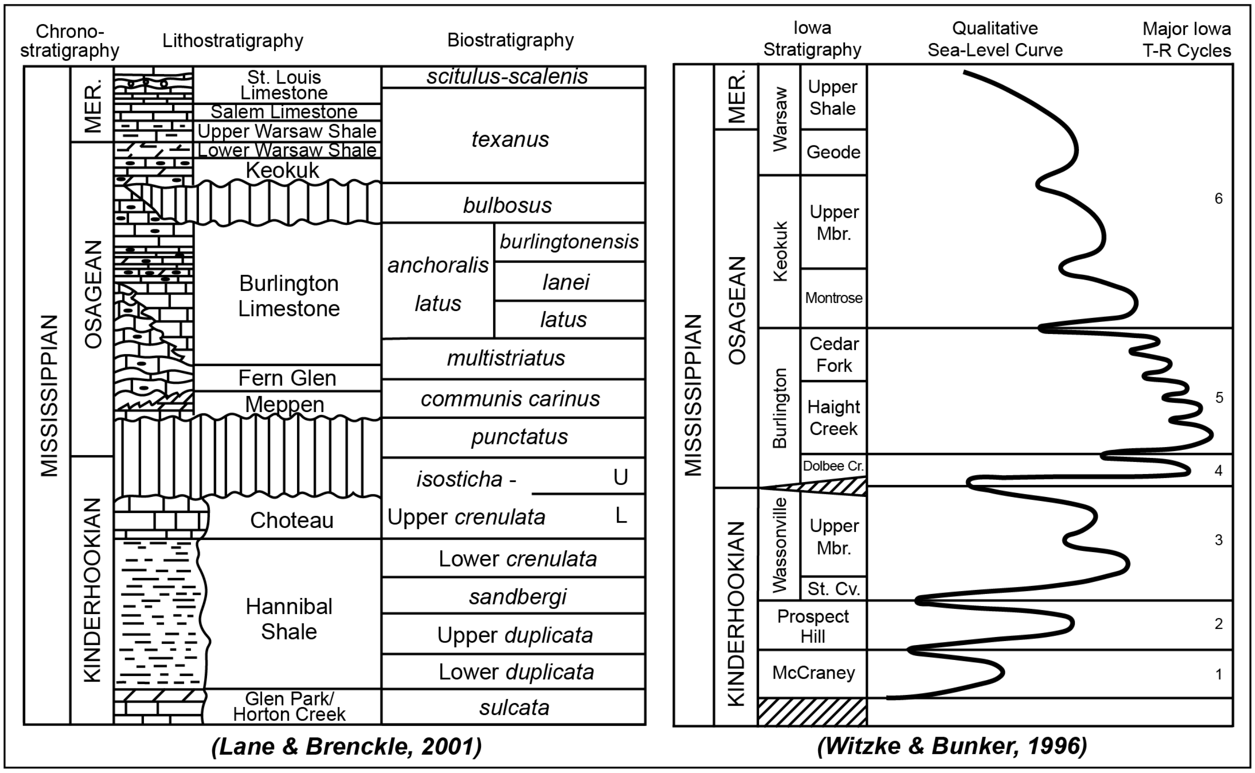

Figure 1: Chronostratigraphy, lithostratigraphy, and conodont biozonation of the classical type Mississippian area of Missouri and Illinois from Lane & Brenckle, 2001 compared to the chronostratigraphy and eustatic signal from the classical type Mississippian area of southeastern Iowa from Witzke & Bunker, 1996.

DEPOSITIONAL SETTING

Upper Devonian through Mississippian strata in the Iowa, Illinois, Missouri tri-state area were deposited on a broad epicontinental platform that extended across much of the North American continental interior during the middle Paleozoic. The regional setting included a generally NW-SE dipping platform with shallow peritidal and inner platform deposition in northwestern and central Iowa, a central Middle 'Starved' Shelf in southeastern Iowa and northwestern Missouri and a Middle-Outer Shelf break in southern Illinois and southeasternmost Missouri (Fig. 2). The Mississippian outcrop belt extends from north-central Iowa southeast towards the southeastern corner of Iowa extending down the Mississippian River Valley to southern Illinois and southeastern Missouri. Additional Mississippian strata surround the Ozark Uplift extending from north-central to the south-western edge Missouri. The focus of this field conference will be on the strata along the Mississippi River Valley from Louisiana, Missouri to Burlington, Iowa.

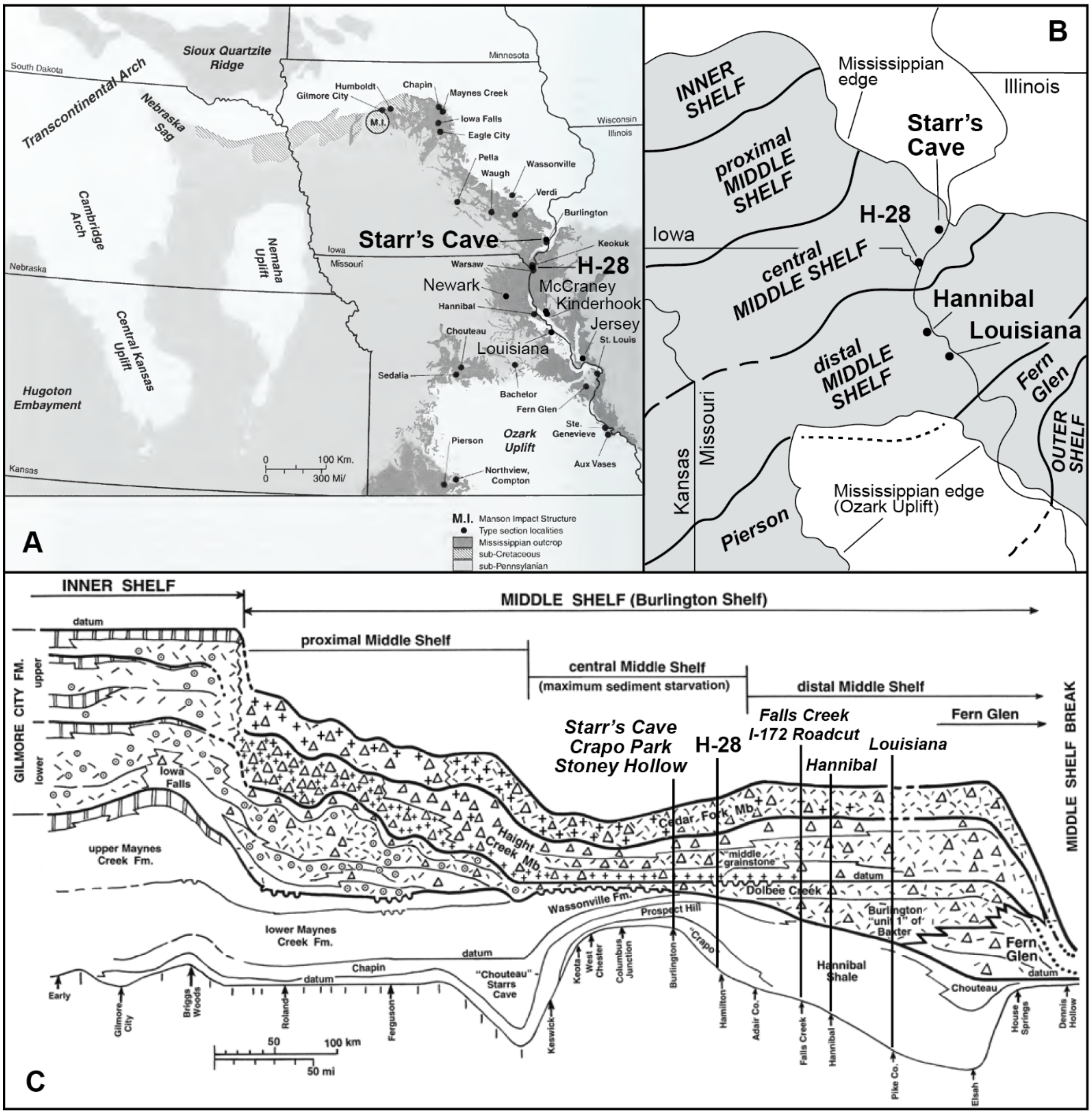

Figure 2: A) Mississippian subcrop and outcrop map showing type localities for Mississippian lithostratigraphic units (modified from Witzke & Bunker, 2001). B) Geometry of the Burlington Shelf during the early Mississippian including locations of some of the stops on the field trip. The central Middle Shelf is largely a starved shelf with the thicknesses of units expanding both upramp and downramp (modified from Witzke & Bunker, 2002). C) Cross-section of early Mississippian strata from north-central Iowa to eastern Missouri. Notice the thinness of strata along the central Middle Shelf and how section is gained moving downramp towards southern Illinois (modified from Witzke & Bunker, 2002).

The classical localities in southeastern Iowa, particularly Starr's Cave Park and Preserve, exhibit an extremely condensed and truncated Kinderhookian succession. Kinderhook strata expand in both upramp and downramp directions from the central Middle Shelf. Figure 2 illustrates the incoming of additional strata below the sub-Burlington unconformity as you move downramp towards southern Illinois. The exact duration and extent of the timing above and below the sub-Burlington unconformity remains poorly constrained throughout the study area. What is clear is that the Kinderhookian succession expands tremendously over the short distance from the city of Burlington, Iowa, to the southeasternmost tip of the state of Iowa where a series of cores (e.g. H-28, H-32) are available through the Iowa Geological Survey (Fig. 3).

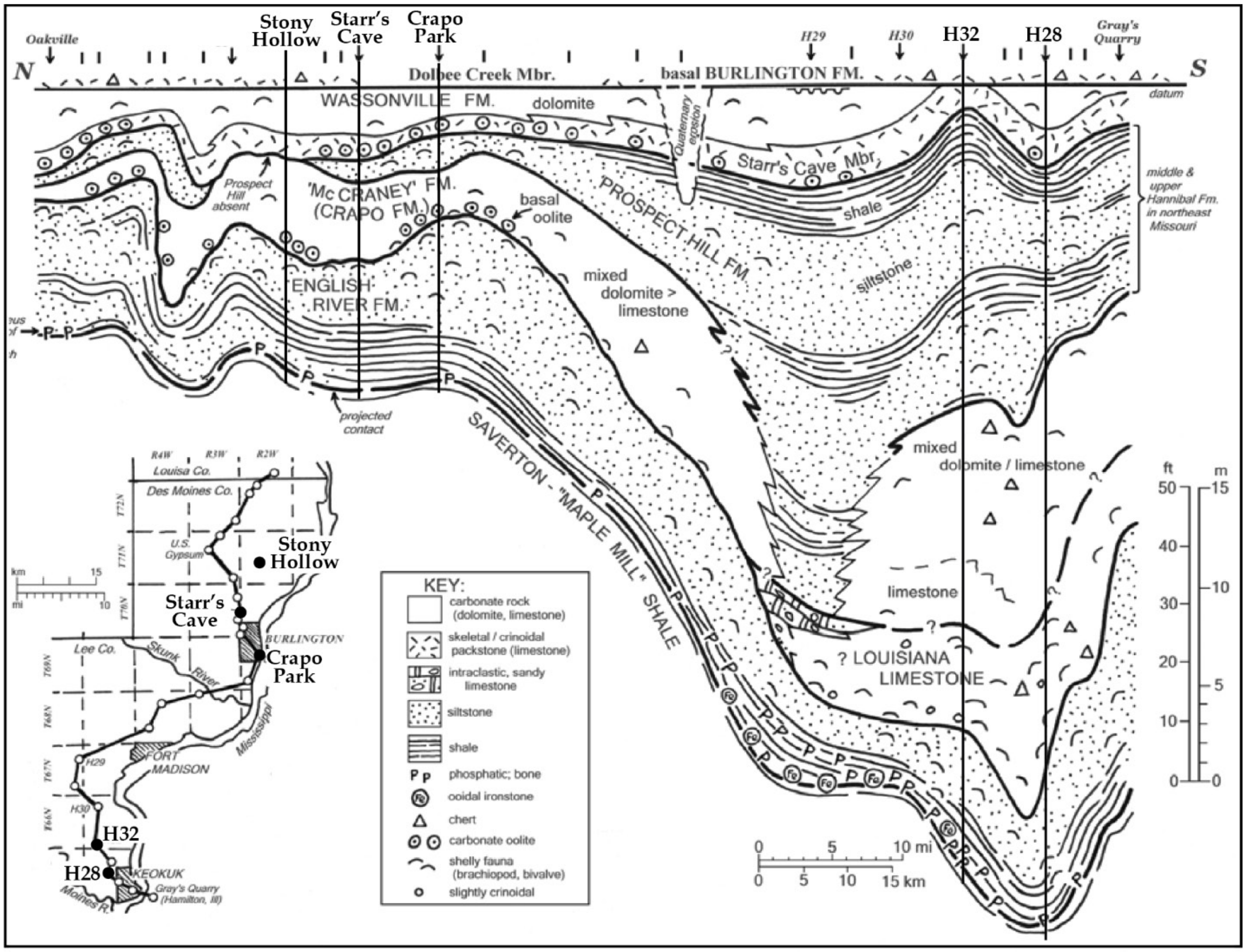

Figure 3: Schematic cross section of Kinderhookian strata in southeastern Iowa (modified from Witzke & Bunker, 2002). The three section we will visit around the city of Burlington are among the most truncated sections in the region. By comparison, the southeast Iowa cores H-28 and H-32 contain more than twice as much Kinderhookian strata.

The sub-Burlington unconformity is a regionally significant horizon that removes a variable amount of Kinderhookian strata. Similarly, the age of strata overlying this unconformity is also variable providing a complex problem for precise correlation. This surface marks the Kinderhookian-Osagean boundary (Fig. 1) and appears to contain a fairly significant interval of time. The carbonate carbon isotope ($\delta^{13}C_{carb}$) record of the early Mississippian contains a large global biogeochemical event and positive $\delta^{13}C_{carb}$ excursion known as the Kinderhook-Osage Boundary Excursion (KOBE) by Saltzman et al. (2004). This positive excursion exceeds +6.0‰ in some localities and has been identified in Belgium, Nevada, Wyoming, and Montana (Saltzman et al., 2004; Oehlert et al., 2019). Recent carbon isotope study by Stolfus (2018) illustrated that this positive excursion is not recorded in the H-28 drill core in southeastern Iowa likely due to erosion and/or non-deposition at the sub-Burlington unconformity.

The Burlington Formation itself is subdivided into three members, in ascending order the Dolbee Creek, Haight Creek, and Cedar Fork. The I-172 roadcut east of Hannibal, Missouri, in Illinois (stop 10), contains one of the most complete exposures of the Burlington Formation in the region. Stop 9, Fall Creek Scenic Overlook (incorrectly referred to as Falls Creek in Witzke & Bunker, 2002, and Fig. 2 above) exposes what is referred to as Unit 1 of Baxter & Haines (1990), which is a unit of the basal Burlington that is not present upramp in the central Middle Shelf. Farther downramp into the distal Middle Shelf of eastern Missouri and western Illinois, the Meppen and Fern Glen formations sit atop the sub-Burlington unconformity (Figs. 1 & 2) recording early Mississippian time not represented in southeastern Iowa.

From the Middle Shelf to the Inner Shelf throughout central Iowa the lithology and thickness of the Burlington Formation are fairly consistent (Fig. 4) and do not contain the level of variation seen in the underlying Kinderhookian strata. However, the transition to the shallowest strata of the Inner Shelf of northwestern Iowa includes a name change to the Gilmore City Formation that belies the transition to peritidal strata temporally equivalent to the Burlington Formation to the southeast.

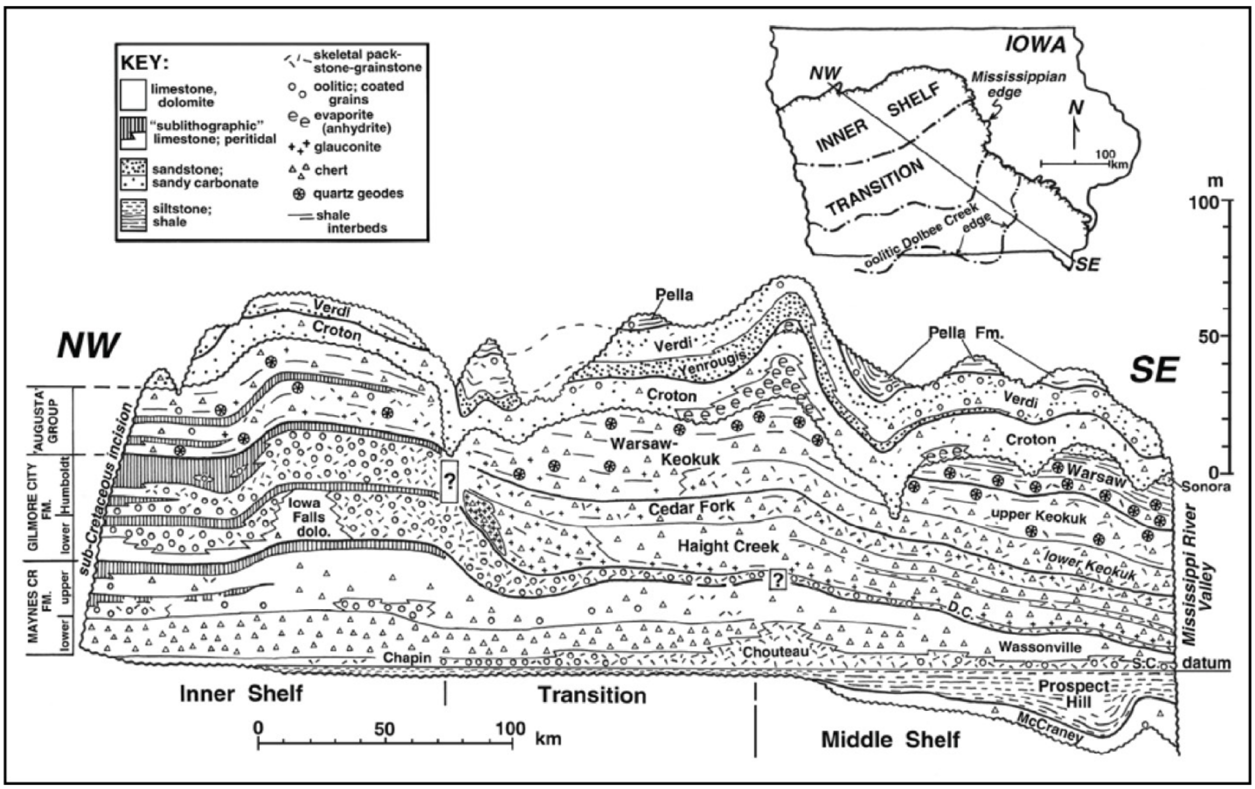

Figure 4: Schematic cross-section of Kinderhookian, Osagean, and Meramecian strata across the Inner and Middle Shelf of Iowa (from Witzke & Bunker, 2002). The transition from the Burlington Formation to the Gilmore City Formation remains underevaluated. Cross section largely generated from drill core penetrations.

THE HANGENBERG EVENT AND THE BASE OF THE CARBONIFEROUS SYSTEM

Several excellent reviews of the current and future status of the Devonian-Carboniferous Boundary as well as the global Hangenberg Crisis were recently published in a Special Volume of the Geological Society of London (Becker et al., 2016; Kaiser et al., 2016) and the reader is referred to those publications for an exhaustive discussion of the current status of the boundary interval and the Hangenberg Crisis. Here we include a few brief points of discussion regarding the conodont and carbon isotope bio-chemostratigraphy of the boundary interval as they pertain to recent restudy of the Mississippi Valley Region. Both conodonts and carbon isotopes will be critical in the revised position of the D-C Boundary.

Conodont Biostratigraphy

The review by Hogancamp et al. in the front of this volume provides a convenient overview of the changes to the conodont biostratigraphy since the seminal work of Sandberg et al. (1978). Of particular importance are the additions of several new biozones, the retirement of the name *Siphonodella hassi* (see discussion in Becker et al. 2016), the re-evaluation of existing literature and legacy collections of the tri-state area, as well as the collection of new samples in the area.

In reference to the discussion of the replacement of *S. hassi* with *Siphonodella jii* included in Becker et al. (2016), it should be pointed out that whereas yes, the designation of *S. hassi* by Ji (1985) was an invalid junior synonym of *Siphonodella cooperi hassi* (Thompson & Fellows, 1970), what was omitted from the discussion of Becker et al. (2016) was that many of the specimens originally designated as *Siphonodella cooperi hassi* were synonymized with *Siphonodella isosticha* by Klapper (1971). The result is that the name *hassi* has therefore been applied to various species in the literature that range from what was the upper *duplicata* zone to the *isosticha* zone of Sandberg et al. (1978). This interval is nearly the entire Kinderhookian. This is the basis for our use of *cooperi* as the zonal designator in our revised zonation used throughout this text. The reader should refer to the chapter by Hogancamp et al. at the front of this volume for a more complete discussion of the zonation utilized herein. However, this zonation barely differs from the latest zonation utilized in Becker et al. (2016) and Kaiser et al. (2016). Unfortunately, we have not yet extensively resampled intervals in the Mississippi Valley Region that can demonstrate the *costatus-kockelli* interregnum.

Taxonomic note: There have been several reports of species belonging to the genus *Gnathodus* in Kinderhookian strata in the tri-state area over the past 50 years. Most notably in a field guide by Scott & Collinson (1961) as well as by Straka (1968). We have re-illustrated a copy of the specimens from the original published plates by Scott & Collinson (1961) and Straka (1968) below as Figure 5. Originally designated by Scott & Collinson (1961) as *Gnathodus* cf. *Gnathodus commutatus* in their text (species list on pg. 113) and then simply as *Gnathodus commutatus* in the plate caption to their Plate 1 on pg. 137, the specimens illustrated belong to two different species of *Protognathodus* (see recent reviews by Corradini et al., 2011, 2017). Specimen 26 in Figure 5 below was described in Scott & Collinson (1961) as "*specimen 4P3014 with smooth unornamented platform*". This specimen with an enlarged basal cavity and lack of ornamentation on the upper surface of the cup clearly belongs to *Protognathodus meischneri*. Image 23 and 24 (original labels from Scott & Collinson, 1961) are the oral and aboral views of the same specimen originally described as "*There is a single low node on the upper surface of the platform*". This specimen is identified herein as *Protognathodus collinsoni*. Image 28 was originally identified as *Protognathodus kockelli* by Scott & Collinson (1961). All of these specimens illustrated in Figure 5 are from the Louisiana Limestone at Teneriffe School, Jersey County, Illinois.

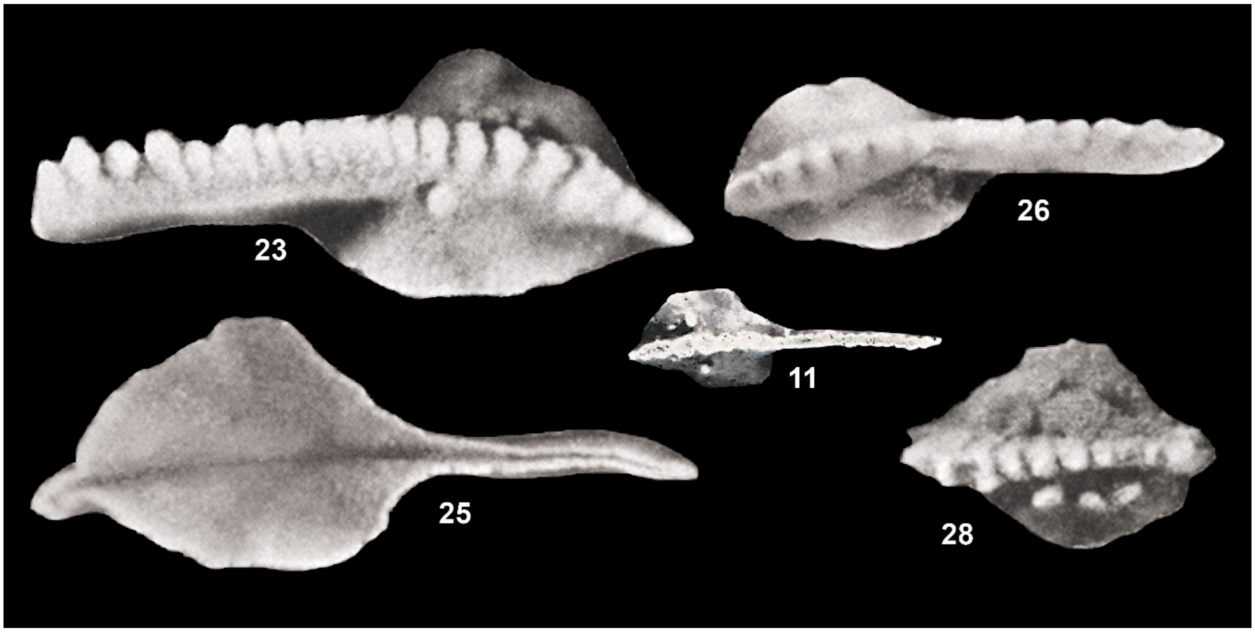

Figure 5: Plate of original images from Scott & Collinson (1961) and Straka (1968). Specimen numbers reflect their original designations. Figures 23, 25, 26, and 28 are from Scott & Collinson (1968), Plate 1, images are 40x. Figure 11 is from Straka (1968), Plate 7, image is 58x

Straka (1968) also reported a single specimen of *Gnathodus* from Kinderhookian strata in Iowa. The specimen was recovered from the Wassonville Formation at the Maple Mill Locality, Washington County, Iowa. A copy of the original image is reproduced above in Figure 5. Straka's (1968) specimen 11, plate 7, is housed at the University of Iowa Paleontological Repository as SUI 125484 and was re-examined by B.D. Cramer and B.M. Stolfus in 2018. As shown in the image above, the specimen clearly has a single node on each side of the platform and should be identified as *Protognathodus collinsoni*. Collectively, these re-identifications demonstrate that the entire succession of *Protognathodus*, including the base of the *Pr. kockelli* Zone, occurs within this succession in the tri-state area.

Carbon Isotope Chemostratigraphy

The Hangenberg Crisis was also marked by a major perturbation to the global carbon cycle that is manifest in the carbonate ($\delta^{13}C_{carb}$) and organic ($\delta^{13}C_{org}$) carbon isotope record as a major positive excursion of magnitude greater than +6.0‰ (Kaiser et al., 2006; Cramer et al. 2008; Kaiser et al., 2016). Due to the nature of sea-level and facies changes across this interval, particularly with respect to the organic-rich interval typical of the Hangenberg Black Shale, it has been exceedingly difficult to find any section in the world where both organic and carbonate carbon isotope chemostratigraphy can be carried out. As a result, we have two different records that may or may not be precisely synchronous. What is clear however is that a major positive excursion began within the uppermost Famennian and extends across the D-C boundary into the Kinderhookian (Fig. 6).

The carbonate carbon isotope ($\delta^{13}C_{carb}$) record from the tri-state area was first investigated by Cramer et al. (2008) who demonstrated that the Hangenberg Excursion occurs in nearly 20 meters of strata within the Mississippi River Valley. The apparent completeness of the carbonate carbon isotope record of the Hangenberg positive carbon isotope excursion in the Mississippi River Valley, combined with the

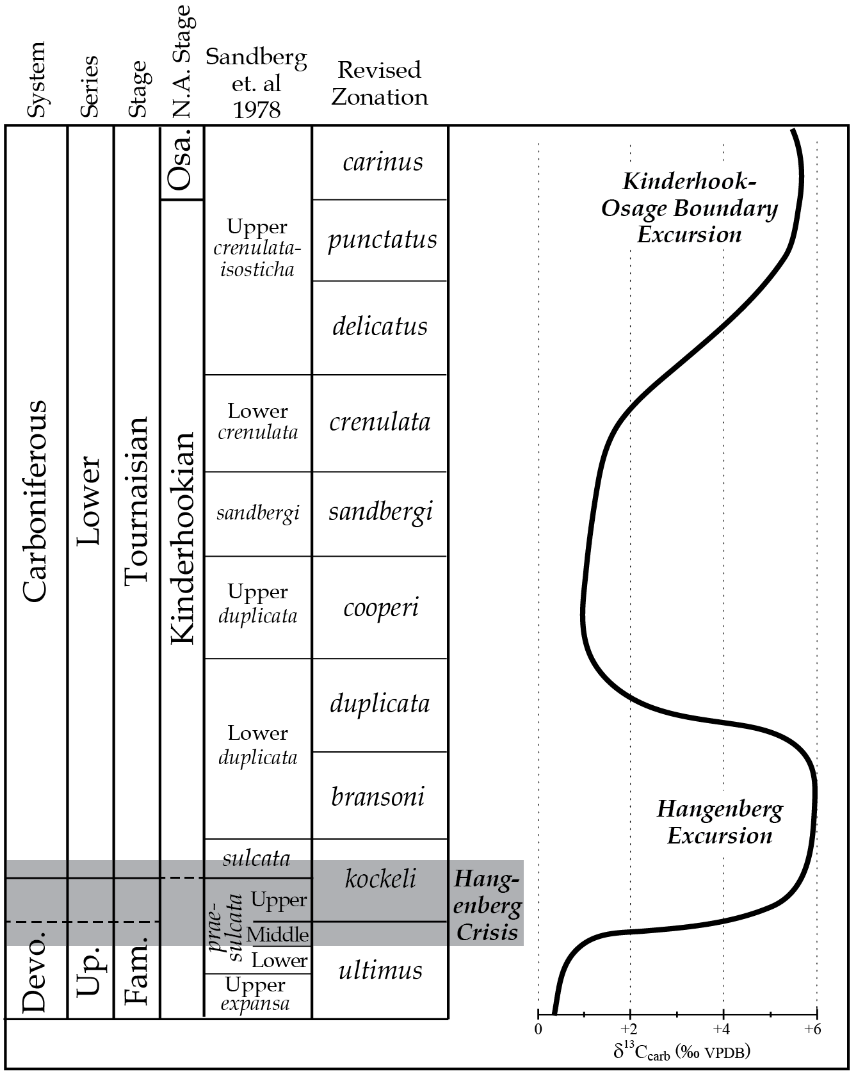

Figure 6: Conodont zonation and generalized carbonate carbon isotope curve for the Devonian-Carboniferous Boundary Interval.

exceptional magnitude of the excursion (greater than +6.0‰) demonstrates that this region has one of the most expanded records of the Devonian-Carboniferous Boundary interval in the world.

The exact position of the end of the Hangenberg Excursion with respect to the Kinderhookian conodont zonation remains to be demonstrated. However, it appears that carbon isotope values returned to near baseline levels within the *Si. duplicata* Zone (Stolfus, 2018).

The position of the overlying Kinderhook-Osage Boundary Excursion (e.g. Saltzman et al., 2004) within either the Mississippi Valley Region or the revised conodont biozonation utilized here have yet to be demonstrated. Saltzman et al. (2004) illustrated that the excursion has peak values essentially at the Kinderhookian-Osagean Boundary at the transition between the *Siphonodella isosticha* and *Gnathodus typicus* conodont zones. However, this interval in the evolution of the Tournaisian conodonts is in need of taxonomic revision and a revised global zonation of late Siphonodellids and early Gnathodids. The revised zonation of this interval utilized herein is a first step towards that re-evaluation. What is clear however is that the Kinderhookian-Osagean Boundary Excursion has yet to be identified within the Mississippi Valley Region due to the sub-Burlington unconformity. It is likely present, however, is yet to be recognized.

RECENT ADVANCES IN REGIONAL CHRONOSTRATIGRAPHIC CORRELATION

Much of the recent work surrounding the D-C boundary interval in the tri-state region has focused on the age and correlation of two nearly identical lithological units that outcrop throughout the Mississippi Valley. The Louisiana and McCraney formations are both sub-lithographic limestones with thin (typically <1cm) brown dolomitic partings between beds. Both of these units are notoriously lacking in body fossils and microfossils have been exceptionally rare and difficult to produce. Often a 10kg sample will only yield a few scattered conodont specimens, and those are typically long-ranging species that are not biostratigraphically useful. Whereas there is a long history of correlation and separation of these two units (e.g., Weller, 1900, 1906; Williams, 1943; Stainbrook, 1950; Workman & Gillette, 1956; Scott & Collinson, 1961), improved conodont biostratigraphic information from these two units (Chauffe & Nichols, 1995; Chauffe & Guzman, 1997) and revised regional chronostratigraphic correlation (Heckel, 2001; Witzke et al., 2002) demonstrate that these are two temporally distinct units that sit in different chronostratigraphic positions throughout the region. Witzke & Bunker (2002) provided an excellent overview of the history of this issue and a recent B.S. thesis at the University of Iowa (Stolfus, 2018) provided the latest update to our understanding of this issue.

The Louisiana Formation is typically underlain by the English River or the Saverton and is typically overlain by the Prospect Hill in Iowa or the Hannibal Formation in Missouri and Illinois. The type McCraney Formation is *underlain* by the Hannibal in western Illinois. Based on the conodont data provided by Chauffe & Nichols (1995), Chauffe & Guzman (1997), and Stolfus (2018), the Louisiana contains a *Protognathodus* fauna that is devoid of *Siphonodella*. However, the McCraney contains a clearly Kinderhookian *Siphonodella* fauna that is high in the Kinderhookian just below the sub-Burlington unconformity. The major impact to regional stratigraphy thusfar has been that the classical outcrops in southeastern Iowa that contained strata assigned to the McCraney, such as Starr's Cave, actually contain the Louisiana Formation instead (Stolfus, 2018).

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A REVISED CONODONT ZONATION OF THE TOURNAISIAN (KINDERHOOKIAN TO LOWER OSAGEAN) AND IMPLICATIONS FOR STRATIGRAPHIC CORRELATIONS IN NORTH AMERICA

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INTRODUCTION

The Tournaisian (Lower Mississippian) strata of North America has been subdivided into several conodont-based biostratigraphic zonations by different workers based on a variety of criteria. Most of the first Tournaisian conodont studies were focused on systematic descriptions of faunas, typically from within a single formation, and a majority of the currently recognized Mississippian species were first described therein (Bassler, 1925; Ulrich & Bassler, 1926 describe a large number of the ramiform genera and families; Roundy, 1926; Holmes, 1928; Huddle, 1934; Branson 1934; Branson & Mehl 1934; Cooper 1939; Branson & Mehl 1941a; 1941b; Cooper and Sloss 1943; Youngquist & Patterson, 1949). W. H. Hass was the first the define Tournaisian conodont zones, typically associated with work around the Devonian Mississippian boundary and lower Mississippian strata (Hass, 1947, 1950, 1951, 1953, 1956; Cloud et al., 1957; Hass 1959). Hass typically named the zones after the formation they were described from and provided systematic record keeping of the stratigraphic distribution of species. This formation-level record keeping of conodont species allowed for some of the first conodont-based biostratigraphic correlations between Devonian-Mississippian strata from different regions of North America. Cloud et al. (1957) changed zonation nomenclature style and instead named Devonian-Mississippian zones with roman numerals I-VI. Subsequent work also used different nomenclature practice to name Devonian-Mississippian strata including the "*Siphonodella* Zone" of Mehl (1960) and the Zone C, D, and E of Beach (1961).

Collinson et al. (1962) provided a comprehensive zonation of the entire Mississippian that compiled the formation-named zones with many of the alpha-numeric named conodont-assemblage based zones by placing a stratigraphic column of the Mississippi Valley strata along-side their proposed conodont zonation, but naming their zones based on conodont species. Regarding the Tournaisian interval, five zones are identified in the Kinderhookian including from oldest to youngest, the *Gnathodus* n. sB – *G. kockeli* Zone, the *Siphonodella sulcata* Zone, the *S. duplicata* s.s. Zone, the *Siphonodella quadruplicata* – *S. crenulata* Zone, the *S.* n. sA (=*S. isosticha*) – *S. cooperi* Zone, and the lower Valmeyeran Zones include the *Gnathodus semiglaber* – *Pseudopolygnathus multistriata* Zone, and the *Bactrognathus* – *Polygnathus communis* Zone. These zones were identified as assemblage zones utilizing 'earliest common occurrences' of species. Straka (1968) described the conodont zonation of Washington County Iowa by recognizing the zones of Collinson et al. (1962) and then tied them to the German zonation of Voges (1959) which was the frequently used global standard for the Devonian Carboniferous boundary strata and was built by combining conodont ranges with ammonoids. Klapper (1966) also used the German standard in identifying Tournaisian conodont zones in the western United States. Thompson & Fellows (1970) did a thorough report of the

Kinderhookian and Osagean conodont biostratigraphy from the southwestern Missouri region and described five conodont zones from the Tournaisian interval including from oldest to youngest, the *Siphonodella sandbergi* - *S. duplicata* Zone, the *S. lobata* – *S. crenulata* Zone, the *Gnathodus delicatus* – *S. cooperi cooperi* Zone, the *G. punctatus* – *S. cooperi hassi* Zone, and the *G. semiglaber* – *Polygnathus communis communis* Zone. These zones were also assemblage zones and could be defined by 'common occurrences' of species, or in some cases multiple species. Soon after this study, Collinson et al. (1971) provided a summary of Mississippian conodont studies and proposed a revised Mississippian zonation for North America. Their Kinderhookian to Valmeyeran zones combined information primarily from the previous zonations of Collinson et al. (1962) and Thompson & Fellows (1970) and placed both zonations together against the Mississippi Valley lithostratigraphic column. Lane (1974) defined distinct 'faunal units' for biostratigraphic correlation in New Mexico.

CHALLENGES ASSOCIATED WITH EARLY ATTEMPTS AT TOURNAISIAN ZONATIONS

Assemblage zones and lithostratigraphic zones (i.e. the Hannibal Shale fauna) were useful in recognizing major changes in the conodont faunas in a particular region and to constrain formation-level lithostratigraphic correlation between different regions. However, three significant challenges were lurking in the data and would prove challenging in future work interested in higher resolution stratigraphic correlations. The first involving the nature of assemblage zones and relying on abundances and common occurrences of taxa. Within a particular region this may work well, but paleogeographic and paleoenvironmental conditions are inevitably going to impact the relative species abundances, thus making the application of these zones difficult or impossible to identify in other regions. Also, there is a high probability of significant diachroneity, such as an instance where the same abundance event may occur at different times in different places, or represent different events entirely.

The second challenge is one of communication where unnecessary complications can arise from the practice of using the same species names, or combinations of species names, to label zones identified by different criteria from different places. The third major challenge with these zones is when multiple taxa are used as markers with no priority provided to guide another worker where to place the zonal boundary when more than one diagnostic criteria occur at different stratigraphic positions. Therefore, if two authors mark a zone boundary in their stratigraphic section it may be based on the FAD, LAD, or abundance occurrence datums of different species and not representing the same biostratigraphic event (Fig. 1). For example, in Thompson & Fellows (1970) the top of the *S. sandbergi* – *S. duplicata* Zone is defined as "the first appearance of *S. crenulata* and *S. lobata*, and the highest occurrence of *S. duplicata, S. sandbergi,* and *S. sexplicata*". The same boundary is described again in the description of the overlying *S. lobata* – *S. crenulata* Zone but this time is defined as "the disappearance of *S. duplicata* and most *Pseudopolygnathus dentilineatus* and *marginatus*, and by the lowest common occurrence of *S. crenulata* and *S. lobata*". The same multi-zone boundary defining criteria appears in Collinson et al. (1962) where the Tournaisian assemblage Zones are defined by the "abundant occurrence of" particular species. For example, the limits of the *S. quadruplicata* – *S. crenulata* Assemblage Zone are defined as "the uppermost abundance of *S. crenulata* and the uppermost occurrence of *S. quadruplicata*. The bottom of the assemblage zone is marked by the lowermost common occurrence of *S. quadruplicata* and the uppermost abundant occurrence of *S. duplicata*".

In all of these examples, the same zone boundary level is recognized by multiple species of various abundances and inevitably could be picked in multiple places in any stratigraphic section unless all these events happen at the exact same stratigraphic position. Without clear criteria of why zone boundaries are placed where they are in a stratigraphic section it can create uncertainty in cross-basinal correlations because if two different workers correlate a zone boundary label, the criteria used may be based on two different fossil datums and may not be stratigraphically-equivalent impacting intra- and interbasinal correlations. More rigorous definitions of these zones was necessary to allow for the identification of higher resolution biostratigraphic information and consistency in zone boundary placement.

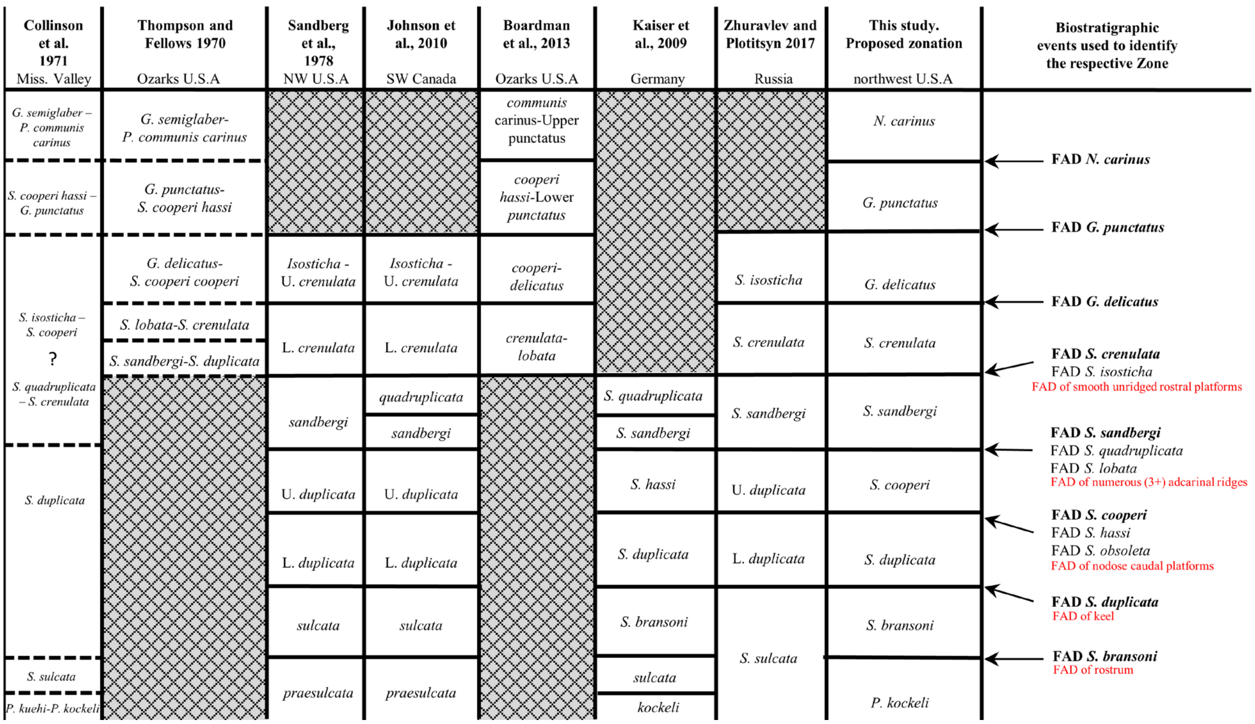

Figure 1: Comparison of conodont zonations for the Tournaisian from 1970 to the present study. Biostratigraphic events utilized in the current field guide are shown at the far right.

REVISIONS TO THE CURRENT TOURNAISIAN ZONATION

The *Siphonodella* based zonation of Sandberg et al. (1978) represents a major step-change in the zonation of lower Mississippian rocks because it stops using assemblages, multiple species datums and lithostratigraphic formation labels. The Sandberg et al. (1978) zonation uses single-taxon first appearance datums (FADs) within the evolutionary sequence of *Siphonodella* to define zone boundaries, with the exception of one last appearance datum (LAD) marking the upper limit of the *isosticha*-Upper *crenulata* Zone. Because these zone criteria are framed within an interpreted phylogenetic sequence their order of appearance should be consistent and always allow for confident relative age dating. These zone criteria lend themselves to correlation outside particular regions as siphonodellids are a common globally distributed Tournaisian group of species and have previously been globally used to define most Tournaisian zones from different basins. With this zonation, every zone boundary is defined by the same fossil datum regardless of its relative abundance or other associated species.

Another common phenomena in both older and more recent early Mississippian conodont zonations is that they did not span the entire Tournaisian as shown in Figure 1. Soon after Sandberg et al. (1978) proposed their FAD-based zonation for the lower Mississippian that spanned most of the Tournaisian, Lane et al. (1980) built from the Sandberg et al. (1978) zonation by adding younger zones defined by other taxa in their "post-*Siphonodella* zonation". When these are stitched together, the entire Tournaisian can be subdivided into a FAD-based zonation (Fig. 2). The post-*Siphonodella* interval still requires significant work due to taxonomic uncertainties with *Gnathodus,* the primary index genera for that interval (Thompson & Fellows, 1970; Lane et al., 1980; Lane & Brenckle, 2001; Boardman et al., 2013).

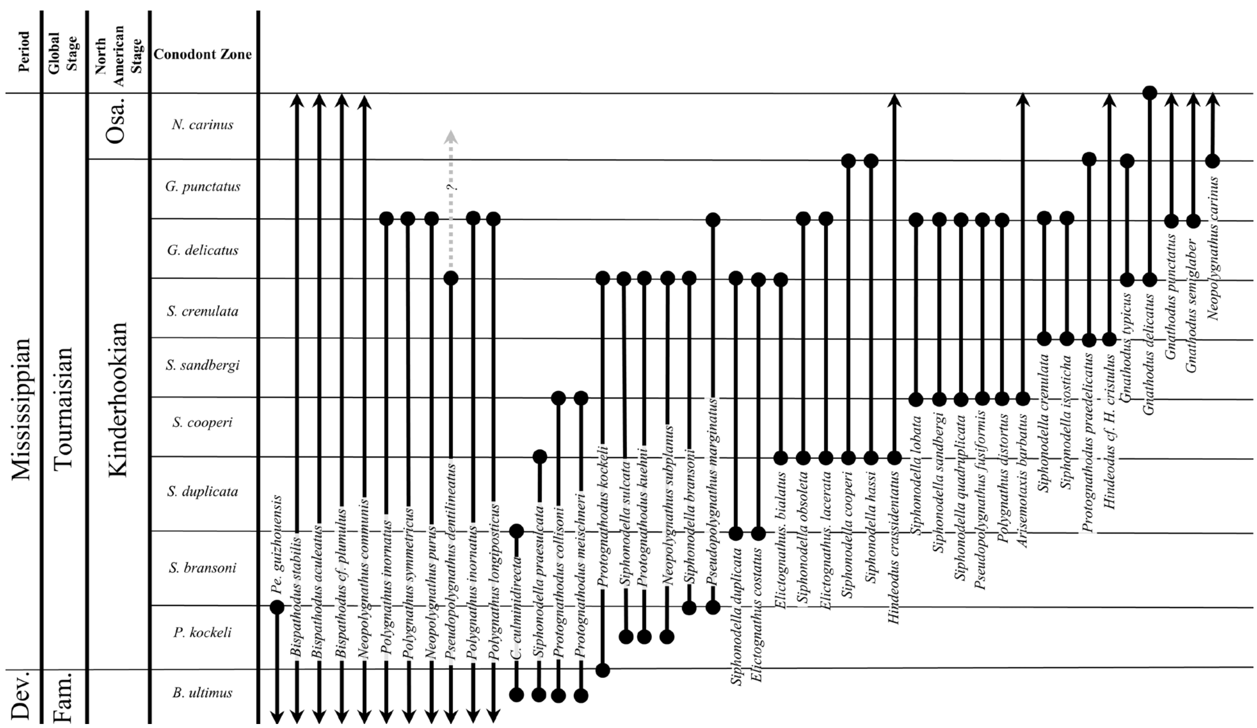

Figure 2: Ranges of taxonomically important conodont species shown against the revised zonation presented here.

The revised zonation proposed here (Fig. 2) builds from the FAD-based zonation of Sandberg et al. (1978) and many of the same species and zonation definitions still apply. This revised FAD-based zonation differs by extending beyond the range of *Siphonodella* to encompass the entire Tournaisian and by incorporating the last forty-one years of changes in conodont ranges and taxonomy. For example, significant taxonomic revision has since occurred for some *Siphonodella* species (Ji, 1985; Kaiser & Corradini, 2011; Zhuravlev & Plotitsyn, 2017), and the ranges for other Tournaisian species are now better understood with some being recognized as useful biostratigraphic markers to supplement the *Siphonodella* species. The conodont ranges and the zonation proposed here incorporate previously determined biostratigraphic information with more recent observations from ongoing work by the authors. To allow for the consistent application of this zonation in future work across different regions, each zone is defined by a direct single taxa-FAD, with other taxa FAD's considered as supplementary. Therefore, if three species FAD's occur at different stratigraphic levels, the primary zone-bearer interval is where the zonal boundary is placed. This single taxon FAD-based Tournaisian zonation follows the same practices applied in the Famennian zonation of Spalletta et al. (2017) and the two can be easily merged together to allow for continuous biostratigraphic practice above and below the Devonian-Mississippian boundary. This revised FAD-based zonation can be readily applied to historical data and new data, while also providing a simple set of rules that can continue to be tested in other areas. Particular intervals in this zonation correspond with other larger-scale changes in the conodont faunas and these broad generalized changes are described here in order to provide additional context of some of the broad scale generalized changes in conodonts.

REVISED ZONAL BOUNDARIES

Protognathodus kockelli **Zone**

Base. – FAD of *Protognathodus kockeli*

Remarks. – This zone represents the first appearance of *Protognathodus* with well-developed transverse ridges on the platform (i.e. *kockeli* and *kuehni*). The morphologically diverse early siphonodellids including *S. praesulcata* and *S. sulcata* and the numerous morphotypes attributed to those species proposed by Kaiser & Corradini (2011) are commonly found in this zone. Regardless of the platform shape and platform structure diversity, these *Siphondella* all represent the first species of the genus and all share a pseudokeel and an adcarinal ridge region that does not constrict and elongate to form the rostrum diagnostic of all the later species.

Siphonodella bransoni **Zone**

Base. – FAD of *Siphonodella bransoni*

Remarks. – This zone represents the first appearance of a well-developed rostrum on *Siphonodella* with a pseudokeel, and transverse ridges on both sides of the platform. Earlier *Siphonodella* species including the *S. praesulcata* - *S. sulcata* plexus first appear below this Zone and lack the well-developed rostrum.

Siphonodella duplicata **Zone**

Base. – FAD of *Siphonodella duplicata*

Remarks. – This zone represents the first appearance of a keeled underside in *Siphonodella*. In this zone all *Siphonodella* species still only have two adcarinal ridges and transverse ridges on both sides of the platform. The lowest reported occurrence of *Elictoganthus, E. costatus,* is also from this zone.

***Siphonodella cooperi* Zone**

Base. – FAD of *Siphonodella cooperi*

Remarks. – This zone represents the first appearance of the nodose *Siphonodella*, a term used to describe the group of *Siphonodella* with a keeled underside and nodes on the inner platform including *S. hassi*, *S. cooperi*, and *S. obsoleta*. This zone also represents the ontogenetic development of more than two adcarinal ridges on *Siphonodella* as observed with large specimens of *S. cooperi* that can develop an additional adcarinal ridge on the rostral side. *Hindeoudus crassidentatus* is another biostratigraphically useful species that appears in this Zone in Iowa, but has a slightly later appearance in the *S. crenulata* Zone Madison and Pahasapa limestones in the northwestern United States. The lowest reported occurrence of *E. lacerata* and *E. bialatus* are from this zone. Previous workers consider *Elictognathus* as a likely P_2 counterpart to the *Siphonodella* P_1 element, due to their similar stratigraphic range, and this similar interval of morphological diversification of both genera in this zone also supports this interpretation.

***Siphonodella sandbergi* Zone**

Base. – FAD of *Siphonodella sandbergi*

Remarks. – This zone represents the first appearance of nodose *Siphonodella* with more than three adcarinal ridges including *S. sandbergi* and *S. quadruplicata*. The lowest documented occurrence of the distinct *S. lobata* also appears at this interval but it is more typically recovered from the younger *S. crenulata* Zone. This is also the lowest documented occurrence of the species *Arisemotaxis barbatus,* a dolabrate neoprioniodian element that is easily identified, and despite occurring in relatively low numbers, is almost always reported from conodont samples of various lithologies and regions within its reported range. Further taxonomic and biostratigraphic studies may find these dolabrate neoprioniodian elements very useful for regional correlations because of their common occurrence and facies independency.

***Siphonodella crenulata* Zone**

Base. – FAD of *Siphonodella crenulata*

Remarks. – This zone represents two major morphological events in *Siphonodella*, the appearance of the wide crenulated platforms in keeled *Siphonodella* as seen in *S. crenulata* and the appearance of shortened adcarinal ridges on pseudokeeled *Siphonodella* with unornamented outer platforms as seen in *S. isosticha*. This zone is one that may require revision as *S. crenulata* is sometimes a rare species in places and has been recognized to have different FAD levels in some places, potentially due to its rarity in samples (Collinson et al., 1971; recent work by the authors). More work from other basins comparing the FAD's of *S. crenulata* and *S. isosticha* will be needed to confirm which FAD appears more reliable and how the relative position of their FAD's change within basins.

Gnathodus delicatus **Zone**

Base. – FAD of *Gnathodus delicatus*

Remarks. – This zone is identified by the appearance of *G. delicatus*, a species with a relatively wide platform with a single row of nodes on the caudal platform and scattered nodes on the outside. This zone represents the start of a major change in the Tournaisian conodonts. Starting at this zone and continuing to the end of the *G. punctatus* Zone, *Gnathodus* species become more common and diversify, while *Siphonodella* species stop diversify and most species become extinct after the *S. crenulata* Zone.

Gnathodus punctatus **Zone**

Base. – FAD of *Gnathodus punctatus*

Remarks. – This zone is identified by the first appearance of *G. punctatus*, a species with a wide platform, a concave row of nodes on the caudal platform and rows of outwardly radiating nodes on the rostral platform. This is currently the highest position *Siphonodella* is reported, with the last species, *S. cooperi* and *S. hassi* disappearing in this zone.

Neopolygnathus carinus **Zone**

Base. – FAD of *Neopolygnathus carinus*
To– FAD of *Pseudopolygnathus marginata*
Remarks. – This zone is identified by the first appearance of *Neopolygnathus carinus*, a species that differs from the older *N. communis* by the development of short convergent adcarinal ridges on the platform. This also represents the first zone of the Osagean Stage in North America.

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BRACHIOPOD SEQUENCE IN THE LATEST DEVONIAN HANGENBERG EXTINCTION AND DEVONIAN-CARBONIFEROUS BOUNDARY INTERVALS IN SOUTHEASTERN IOWA, NORTHEASTERN MISSOURI AND WESTERN ILLINOIS-CENTRAL NORTH AMERICA

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INTRODUCTION

Recent surface and subsurface paleontologic, geochemical, and paleomagnetic investigations have advanced the knowledge and understanding of the regional stratigraphy and biostratigraphy of Late Devonian and Early Carboniferous strata in the upper Mississippi Valley region that serves as the type area of the classic North American Kinderhookian Stage of the Mississippian Subperiod of the Carboniferous. The Devonian-Carboniferous Boundary is being revised and lowered to a position coinciding the position of the first appearance of the conodont *Protognathodus kockeli* whose first occurrence defined the base of the Upper Siphonodella praesulcata Zone of older biostratigraphic Zonal scheme for the upper part of the Upper Devonian Fammenian Stage. The zone will be named after the conodont whose First Appearance Datum (FAD), namely the newly adopted *P. kockeli* Zone. This position in the central North AmMerican stratigraphic successions These units include the Late Famennian English River Formation of eastern and southeastern Iowa; conformably overlain by earliest Tournaisian Louisiana Limestone in the subsurface of southeastern Iowa; overlain by the early Tournaisian Horton Creek Formation in eastern Missouri (following usage of Thompson, 1986=Glen Park Formation of Carter, 1988). These units were targeted for study because they comprise the thickest known record of the pre- and post-Hangenberg Extinction (HE) interval in Euramerica and Gondwana, and they span the position of the proposed revised Devonian-Carboniferous Boundary placed at the base of the *Protognathodus kockeli* Zone. This boundary is easily correlated because of the major faunal turnover of the HE marked by the regional extinction of eighteen of twenty English River brachiopod taxa immediately below the base of that conodont zone, coupled with the onset of maximum values of the global Hangenberg δC^{13}_{carb} Excursion (HIE) in the basal part of the overlying Louisiana Limestone at the base of the *P. kockeli* Zone. This regional extinction record of the HE is associated with accelerated rapid sea level rise and drowning of the English River shelf and the onset of carbonate platform deposition and replacement by the warm-water Louisiana carbonate platform fauna during the post-glacial warming interval and eustatic sea level rise (Fig. 2). This significant faunal turnover immediately below the base of the *kockeli* Zone, first occurrences of most Louisiana taxa, and maximum values of the Hangenberg Carbon δC^{13}_{carb} Excursion (Cramer et al., 2008, Clarke et al., 2009) easily identify and characterize the D-C boundary at this position (base *kockeli* Zone) in central North America.

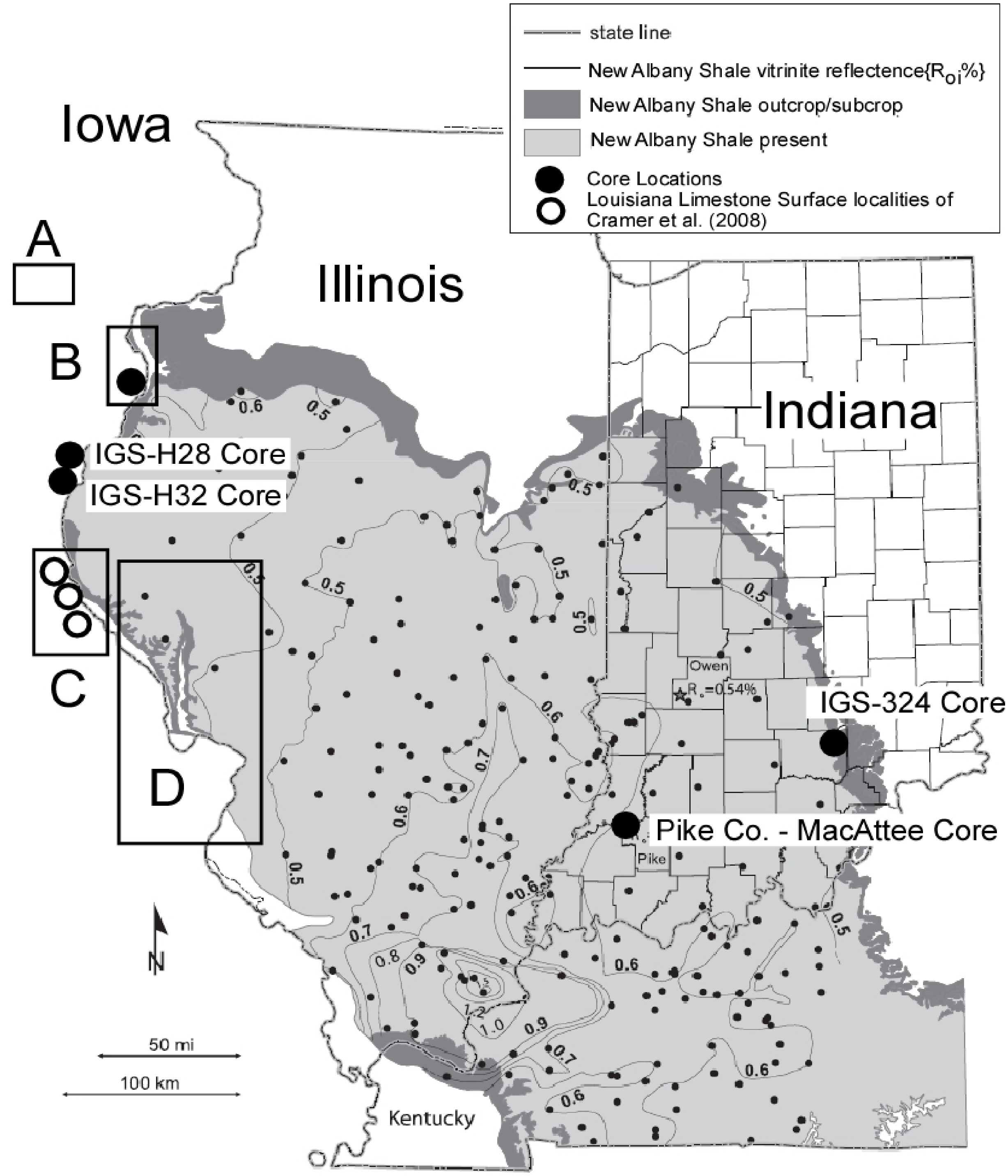


Figure 1: *Map showing Upper Devonian (Frasnian to Late Famennian) New Albany Shale and Latest Famennian-Early Tournasian deposits in the Illinois Basin. Dark gray indicates subcrop & outcrop areas, light gray with vitrinite reflectance (Ro) values shows is the distribution of the New Albany Shale in the subsurface of the Illinois Basin. **A**. English River Formation type area near the town of Kalona in Washington County, **B**. Burlington, Iowa area in Des Moines County and locations of the IGS Sullivan Slough Core and English River Fm. outcrop area; **C**. type area of the earliest Tournaisian (Kinderhookian) Louisiana Limestone; Also shown are locations of the IGS H-28 and H-32 cores. Modified from Hasenmueller & Comer (2000), and fig. 5 of Strapoc et al. (2010).*

The macrofauna impacted by the Hangenberg Extinction occurs in shale and siltstone clastic shelf facies of the English River Formation in east-central and southeastern Iowa (Fig. 1A, 1B, H-cores in Lee County), associated with conodonts spanning the interval of the *Bispathodus ultimus* Zone. Well preserved stratigraphic successions in the Iowa Geological Survey (IGS) H-cores in southeastern Iowa (Fig. 1, Fig. 2) show complete English River Formation sections conformably overlain by thick Louisiana Limestone sections in Lee County near the Iowa-Missouri border. Reports of English River Formation deposits at Kinderhook in Pike County in west-central Illinois in by Carter (1988, table 2, p. 16), cannot be confirmed, and nowhere is the English River in eastern Missouri and western Illinois (map areas of Fig 1C and 1D) observed below the Louisiana Limestone. The English River fauna consists of at least twenty species of the genera *Chonopectus*, *Mesoplica, Ovatia, Semiproductus Sentosia, Plicohonetes*?, *Leptagonia, Schuchertella*?, *Schellwienella, Schizophoria* (*S.*), *Paraphorhynhus*, *Prospira*?, *Hispidaria*?, *Eudoxina, Syringothyris, Kitakamathyris, Camarorphorella*, *Iniathyris* and *Eumetria.* Notably this fauna includes the oldest known occurrence of species of *Syringothyris* and *Leptagonia.* The brachiopod sequence records a near total turnover at the species level of the English River fauna, with only two Late Famennian English River species (*Kitakamathyris cooperensis* & *Camarophorella buckleyi*) ranging into the Louisiana (*kockeli* Zone). Five of eighteen genera known from the English River carryover into the Louisiana fauna.

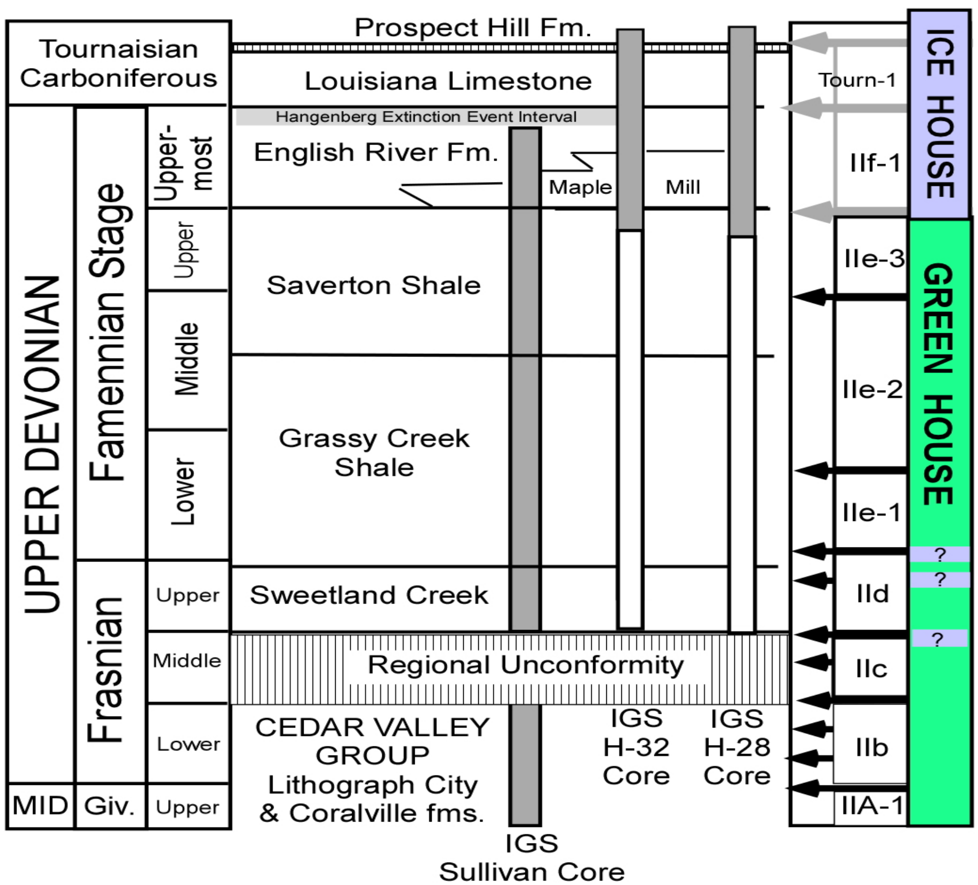


Figure 2: *Middle-Upper Devonian-Lower Tournaisian chronostratigrahy, sea level event history (black and gray arrows) in the IGS Sullivan, H-28 & H-32 Cores in subsurface of southeastern Iowa-western Illinois Basin. Gray portions of core columns show the core intervals sampled in for this investigation. The global* ***Hangenberg Extinction Event (HBE)*** *interval is positioned in the upper part of the uppemost Famennian English River Formation. Post-HBE brachiopod faunas occur in the Early Tournaisian (Kinderhookian) Louisiana Limestone.*

Rapid marine deepening drowned the English River clastic shelf and initiated Louisiana Limestone carbonate platform deposition in southeastern Iowa, eastern Missouri, and western Illinois (Fig. 1, Fig. 2). The post-Hangenberg survivor and recovery fauna of the Louisiana Limestone occurs with earliest Tournaisian conodonts of the lower *kockeli* Zone (See specimens from lower Louisiana in Collinson and Scott, 1961; and Chauff and Nichols, 1995; and discussion of conodont faunas by Cramer et al. this guidebook). Twenty or more brachiopod species known from the Louisiana Limestone are included in the genera *Anthocrania*, *Petrocrania*, *Rhipidomella*, *Schuchertella*, *Plicochonetes, Orbinaria, Cyphotalosia?, Leptolosia, Paraphorhynchus, Cyrtina, Tylothyris, Acanthospirina, Syringothyris, Parallelora, Kitakamathyris, Crurithyris*, *Lamellosathyris* and *Camarorphorella.*

In the Kinderhookian type area of northeastern Missouri and western Illinois, the Horton Creek Formation (= Glen Park Formation of Carter, 1988) immediately overlies the Louisiana (where preserved) beneath the disconformity at the base of the Hannibal Shale. Both the Louisiana and Horton Creek were eroded during an early Glacial-eustatic sea level fall that terminated Louisiana deposition and or Horton Creek deposition, followed by the interglacial sea level rise (upper *Kockeli* to *duplicata* zones) that re-established subtropical clastic shelf (Prospect Hill Formation in southeastern Iowa, and Hannibal Shale in northeastern Missouri) and carbonate platform (Wassonville Formation in southeastern Iowa) deposition in the region. The Horton Creek features a diverse (34 species, 30 genera) early Tournaisian brachiopod fauna (see Carter, 1988, table 1, locality 393) recording the diversification of moderately cosmopolitan pantropical carbonate platform faunas with close similarities at the genus and species levels to coeval faunas in the type area of the Tournaisian in Belgium and other regions of Euramerica, Gondwana, and South China. This early Tournaisian fauna include 34 species representing 32 genera.

LITHOSTRATIGRAPHY, BIOSTRATIGRAPHY AND BRACHIOPOD FAUNAS ACROSS THE D-C BOUNDARY

In the discussions below, readers are referred to the original systematic sections of studies by Rowley (1895, 1900, 1908), Weller (1914), Williams (1943), and Carter(1988) for authors of brachiopod species. We list taxa according to major Class, Order or Suborders that they are members of according the classification scheme currently in use Williams et al. (1997-2007) in the revised Brachiopoda volumes of the Treatise on Invertebrate Paleontology.

English River Formation (Uppermost Famennian)

Herein we follow Witzke and Bunker's (2002, p. 28) redefinition of the English River Formation. They proposed that the English River be redefined to include all strata of T-R cycle IIf (Johnson et al., 1985), conveniently marked at its base by a widespread phosphatic or ooidal ironstone bed. This usage removed the basal shaley strata of this cycle above the basal phosphatic bed from the upper Saverton Shale and placed these beds in the English River interval (Fig. 3). Formerly, the term English River was applied only to the siltstone-dominated portion of the depositional cycle (IIf), but the interbedded aspect of siltstone and shale strata and the gradational nature of the shale-to-siltstone transition made the formational boundary difficult to consistently define. Their lower boundary for the English River Formation, is a widely traceable stratigraphic datum in the central and eastern Iowa surface and subsurface sections.

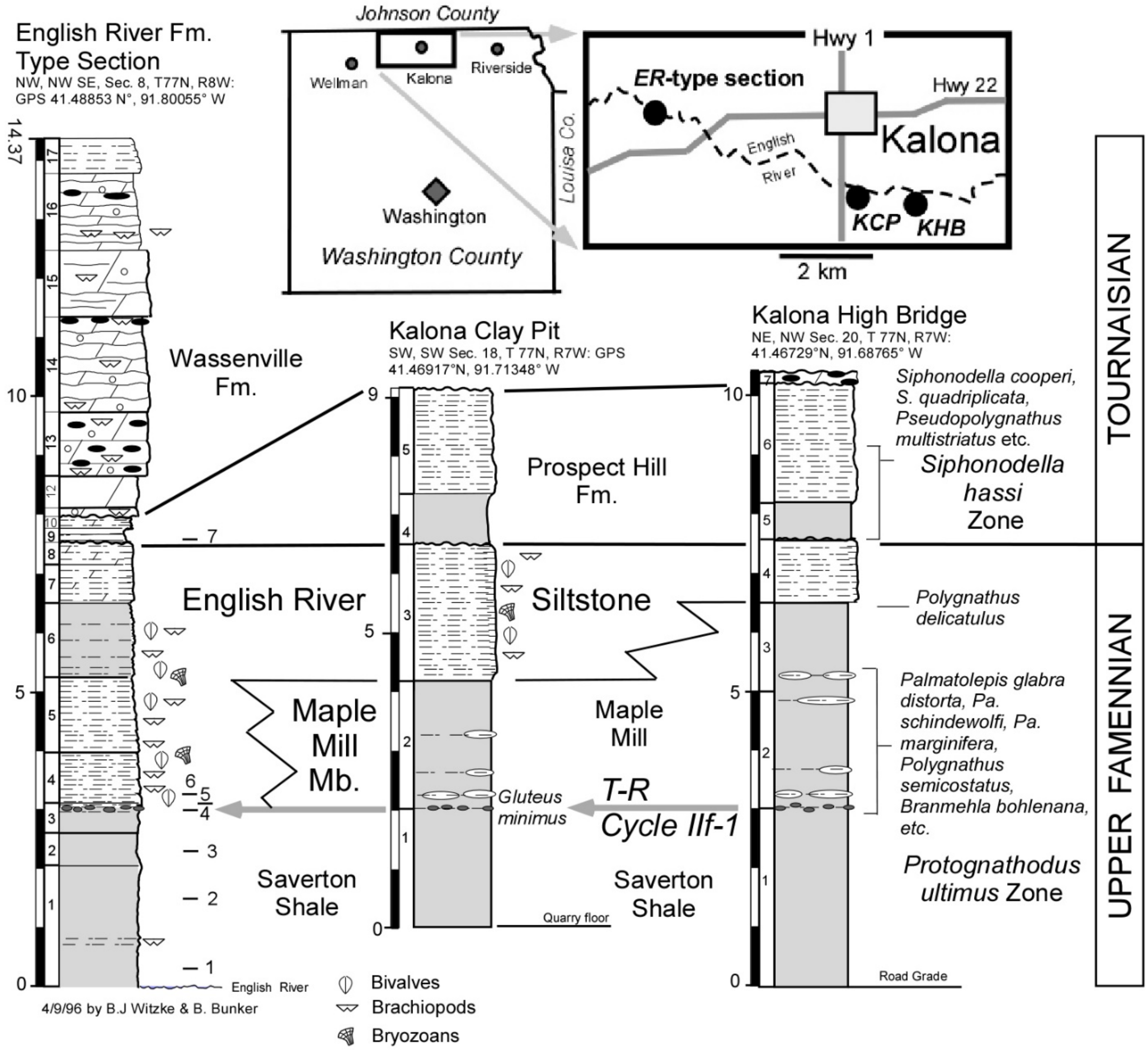


Figure 3: *Uppermost Famennian & Early Carboniferous strata in the type area of the English River Formation (Fig. 1A; see revision in Witzke & Bunker, 2001). The flooding surface-interval of Euramerican T-R cycle IIf-1 is positioned at the base of the phosphatic Gluteus minimus–bed. Most macrofossils described from the English River from the Kalona area in studies by Weller (1914) & Carter (1988) were likely collected at the type section. Units 4 and 5 yield an abundant brachiopod and mollusc faunas (Jim Preslicka and Charles Henderson's, and Day's collections at ISU). The English River is sparsely fossiliferous at the Kalona Clay Pit and High Bridge localities. English River conodonts were studied by Straka (1968) and Beinert (1968).*

As currently recognized the English River consists of : 1) a lower phosphatic lag or ooidal ironstone/phosphorite, inter-burrowed with gray shale; 2) a middle silty gray to green-gray shale, burrowed with scattered brachiopods (lingulids, *Plicochonetes*? sp.); and 3) an upper siltstone and argillaceous siltstone, commonly burrowed and with scattered to abundant moldic shelly fauna. The upper siltstone interval comprises the English River Siltstone, whereas the lower two units are generally assigned to the Maple Mill Member (Figs. 3-7).

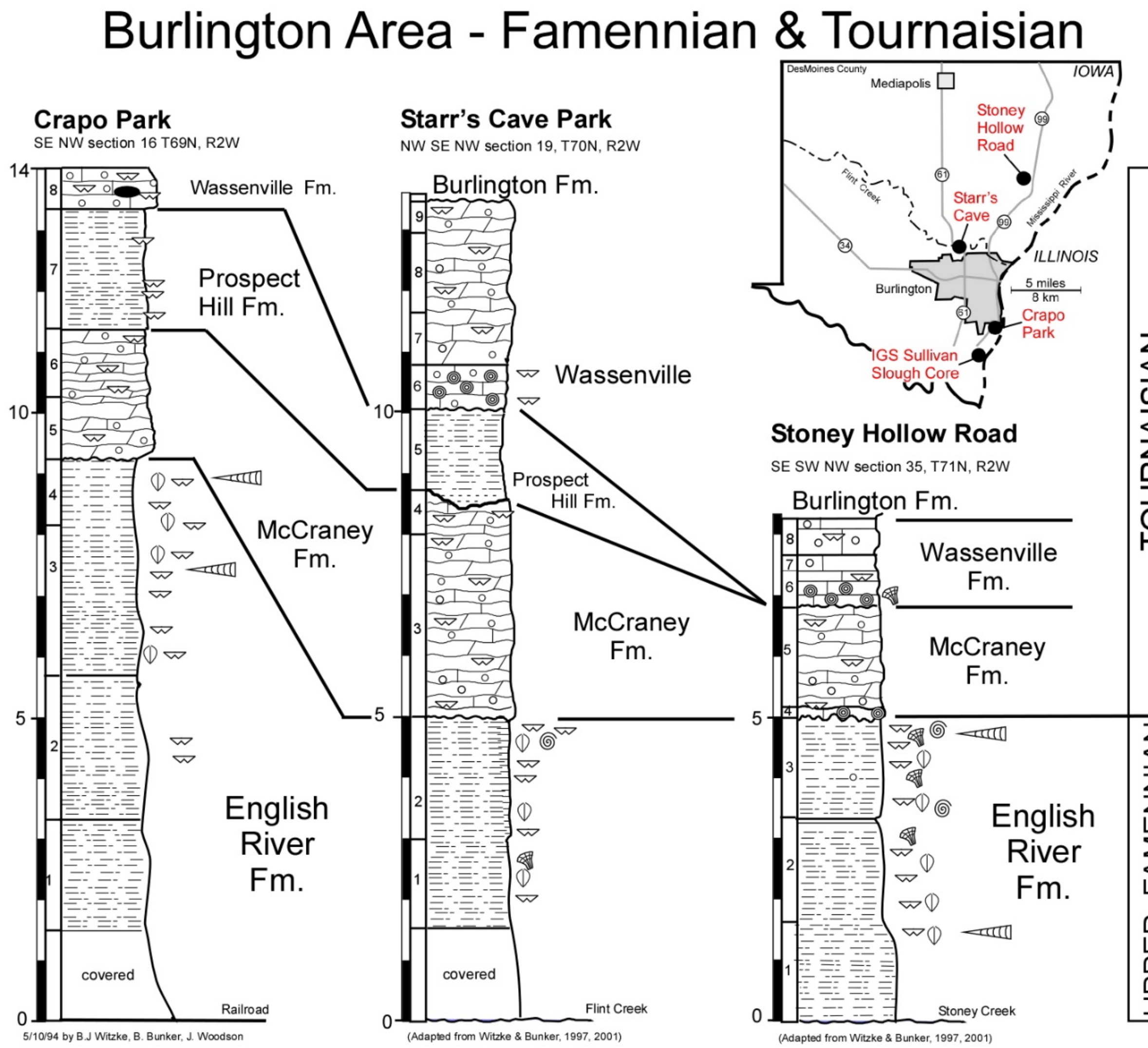
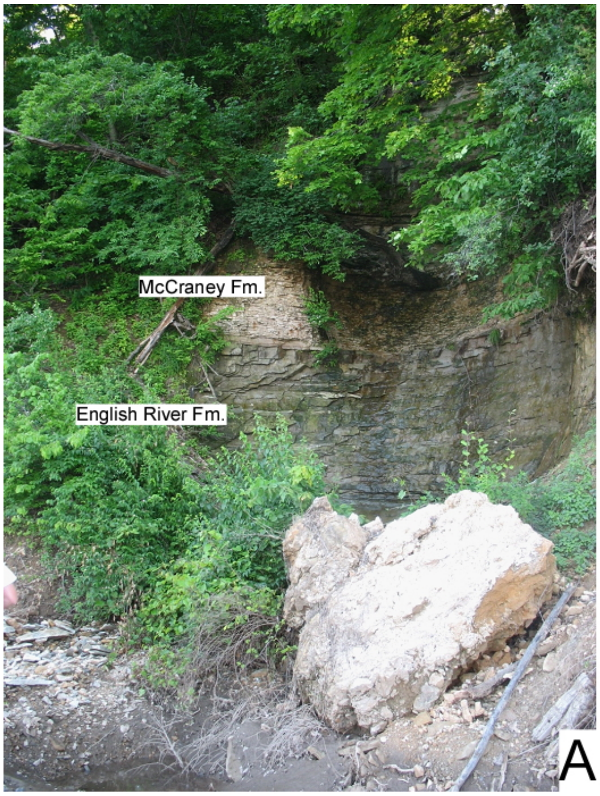


Figure 4: *Uppermost Famennian & Early Carboniferous stratigraphy in the vicinity of the city of Burlington, in Des Moines County, Iowa (Fig. 1A). The middle and upper English River Formation was sampled in the Mississippi River bluff exposures just below Crapo Park on the south side of Burlington (Figs. 1A & B; after Witzke et al. 1994), and in the outcrops along Stoney Hollow Creek north of Burlington (sections adapted from Witzke & Bunker, 1997 & 2001). Conodonts from the Saverton Shale and English River Formation were sampled in the IGS Sullivan Slough Core section drilled in the Sullivan Slough Quarry on the south side of the city of Burlington.*

The English River Formation can only be recognized in Iowa and was either never deposited or eroded in northeastern Missouri and west-central Illinois (Figs. 1 and 2). In surface sections in Washington County (Figs. 1A and 3) and in the subsurface Lee County (Figs. 1, 2, see IGS H-cores in Figs. 2) the basal phosphatic skeletal and oolitic phosphorites of English River overlay the Upper Famennian Saverton shale and is unconformably overlain by Tournaisian age Prospect Hill Formation (Fig. 3), or the "McCraney or Crapo" Formation in the Burlington area in Des Moines County area (Figs. 1B, 4 and 5). In the IGS H-28 and H-32 cores in Lee County, the English River is conformably overlain by the Louisiana Limestone.



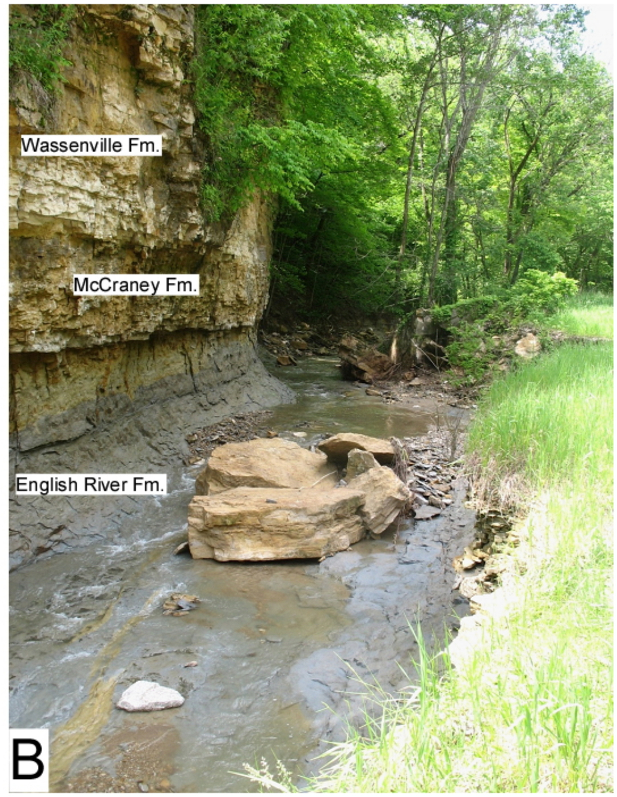


Figure 5: *Field photos (by J. Day) of Uppermost Famennian & Early Carboniferous outcrops at: A.-Crapo Park on the south side of Burlington; and B.-Stoney Hollow north of the city of Burlington, Des Moines County (Fig. 1A). Stratigraphic sections at these localities shown above in Figure 4.*

In its type area (Fig. 3) the English River is 4.5 meters thick with a basal flooding surface overlain by a basal skeletal phosphatic transgressive lag with fish teeth and presumed fish fossil *Gluteus minimus* (Davis and Semken, 1975), and conodonts. The silty units at the type section yield a diverse bivalve, gastropod and brachiopod dominated assemblage preserved as external molds and interval molds and casts. In Des Moines County near Burlington, the English River is 5-9.3 meters in surface sections (Fig. 4), and ranges between 7.16 and 17.28 meters in thickness in the subsurface in the IGS H-32 and H-28 cores, respectively, in Lee County in southeastern Iowa.

The brachiopod, conodont and ammonoid faunas clearly indicate a latest Famennian age for the English River Formation as it comprises the latest Devonian depositional sequence package that can be recognized in central and eastern Iowa outcrops and the subsurface. The macro- and microfaunas of the English River provide for biostratigraphic correlation of the English River, outlined in part above, based on the recovery of Devonian conodonts from the English River Siltstone at Burlington at the Cascade Station locality of Collinson (1961), Scott and Collinson (1961) and in the type area along the English River in Washington County (Fig. 3) by Straka (1968). The English River in the subsurface in southeast Iowa has also yielded Upper Devonian conodont faunas which Pavlicek (1986) assigned to the *Polygnathus delicatulus* Zone, now reassigned to the *Bispathodus ultimus* Zone.

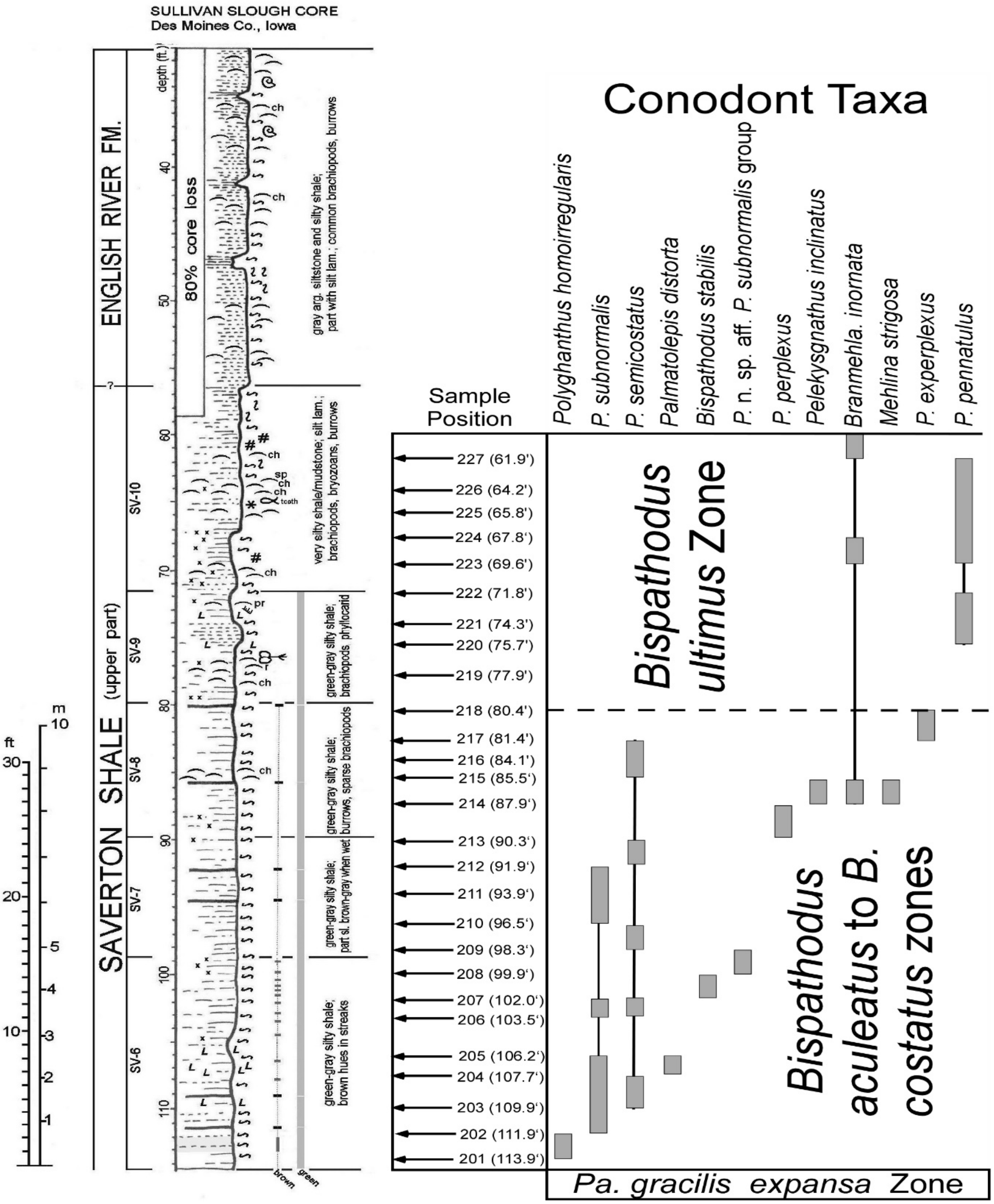


Figure 6: Upper to Upper-most Famennian conodont sequence in the Saverton Shale and lower English River Formation IGS Sullivan Slough Core in the Burlington, Iowa, area (see Fig 1B; Des Moines Co.) based on J. Day's samples and collections. Core stratigraphic section provided by Brian Witzke of the IGS-Univ. of Iowa. The English River is no older than Bispathodus ultimus Zone in age based on position above Saverton faunas of Palmatolepis expansa Zone age.

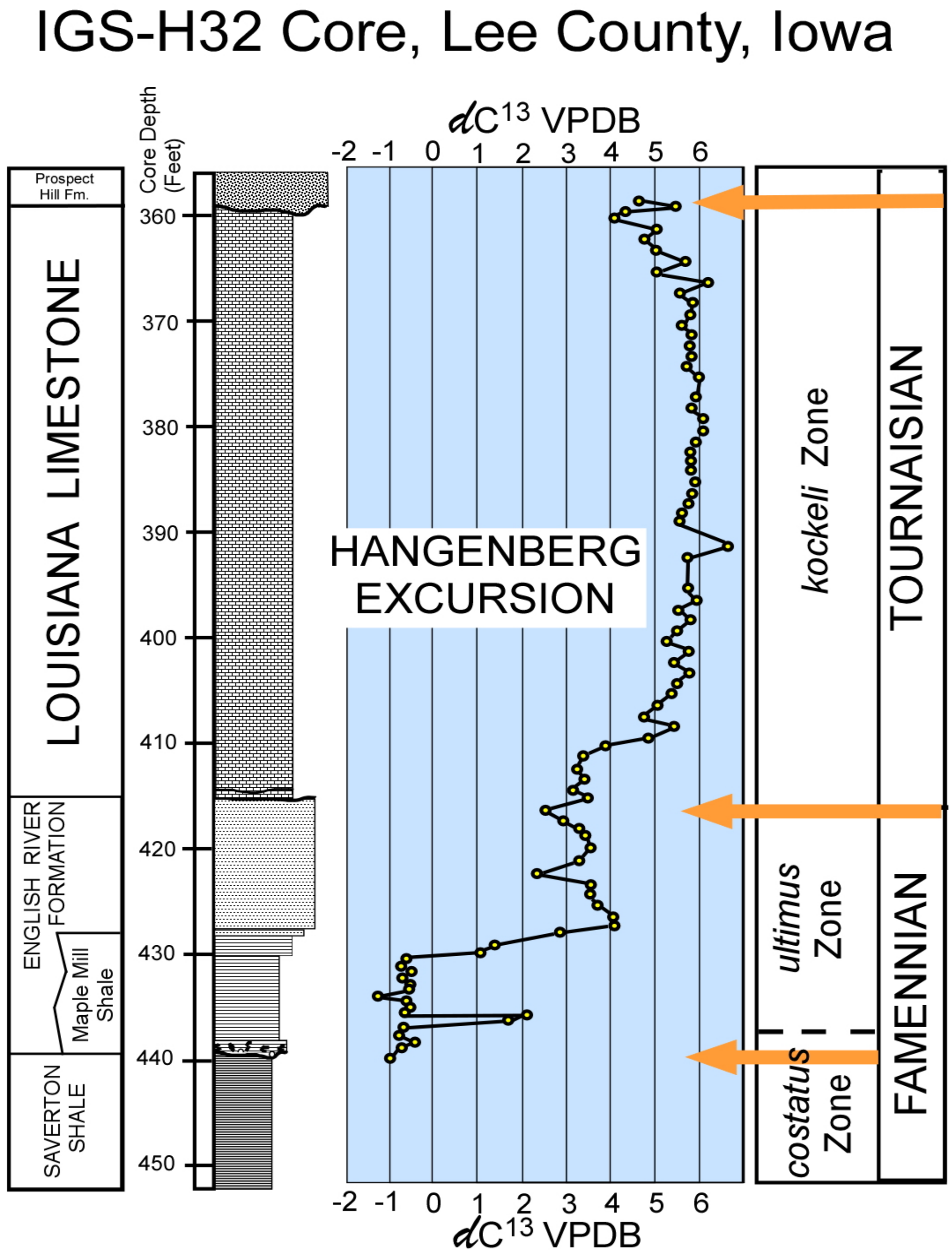


Figure 7: *Late Famennian & Early Tournaisian stratigraphy , conodont biostratigraphy, and δC^{13}_{carb} chemostratigrahy in the IGS H32 Core in the subsurface of Lee County, Iowa (Figs. 1 & 2). Conodonts from the H32 core (Day's collections) and Chauff and Nichols (1995) study of the Louisiana conodont fauna confirm first occurrence of Protognathodus kockeli in the lower meter of the Louisiana in sections in eastern Missouri (Fig. 1C) and western Illinois (Fig. 1D). The Hangenberg δC^{13} Excursion begins in the interval of the upper part of the Bispathodus ultimus Zone and reaches peak values in the interval in the lower Louisiana (basal kockeli Zone). Arrows at base of English River and Louisiana formations indicate positions of major marine flooding surfaces, and above the disconformity associated with glacial-eustatic sea level lowstand at top of the Louisiana in the Early Tournaisian. Modified from figs. 3 and 4 of Clarke et al. (2009).*

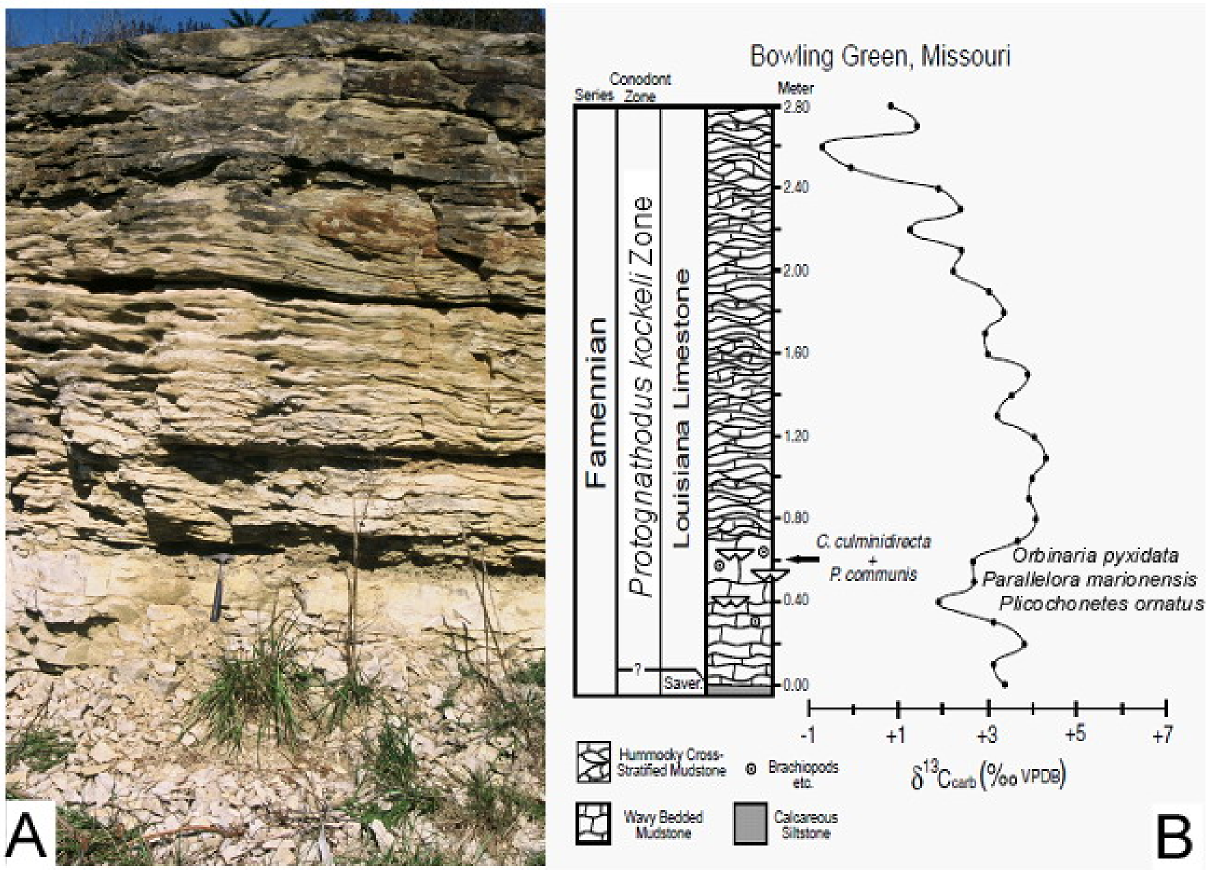


Figure 8: ***A.*** *Photograph of the US Highway 54 Roadcut of the Early Tournaisian Louisiana Limestone and its contact with the Upper Famennian Saverton Shale immediately below base of rock hammer Bowling Green section, Bowling Green, Pike County, Missouri.* ***B.*** *Carbon-isotope stratigraphy of the Bowling Green section showing hummocky cross-stratification characterizes the upper part of the Louisiana Limestone exposed here. The echinoderm–brachiopod skeletal packstone in the lower Louisiana yielded conodonts diagnostic of the Upper kockeli Zone. Brachiopods identified from the skeletal packstone are listed to the right of the carbon profile. Numbers to the right of the column indicate meters above the sampling datum (lowest exposed Louisiana Limestone bed). Fig. 8B modified from fig. 5 of Cramer et al. (2008).*

In addition, moldic specimens of clymeniid ammonoids (*Cyrtoclymenia strigata*, *Imitoceras opimum*) have also been collected from the English River in the Burlington area that clearly indicate an Upper Devonian (upper Famennian) age (House, 1962; Glenister et al., 1987). The diverse English River fauna invertebrate fauna is most abundant in the upper beds of the siltstone unit, and the lower beds are variably fossiliferous (commonly burrowed but with a sparse shelly fauna). The shelly fauna collected from exposures in Washington and Des Moines counties in and around Burlington is highly diverse, typically dominated by bivalves and brachiopods. The brachiopod fauna is listed in Figure 10 and illustrated in Figures 11-13. Most of those species were described by Weller (1914) and Carter (1988). As many as 32 species of bivalves and gastropods (21 species) are listed in Weller (1900), as well as nautiloid cephalopods, scaphopods, conularids, bryozoans.

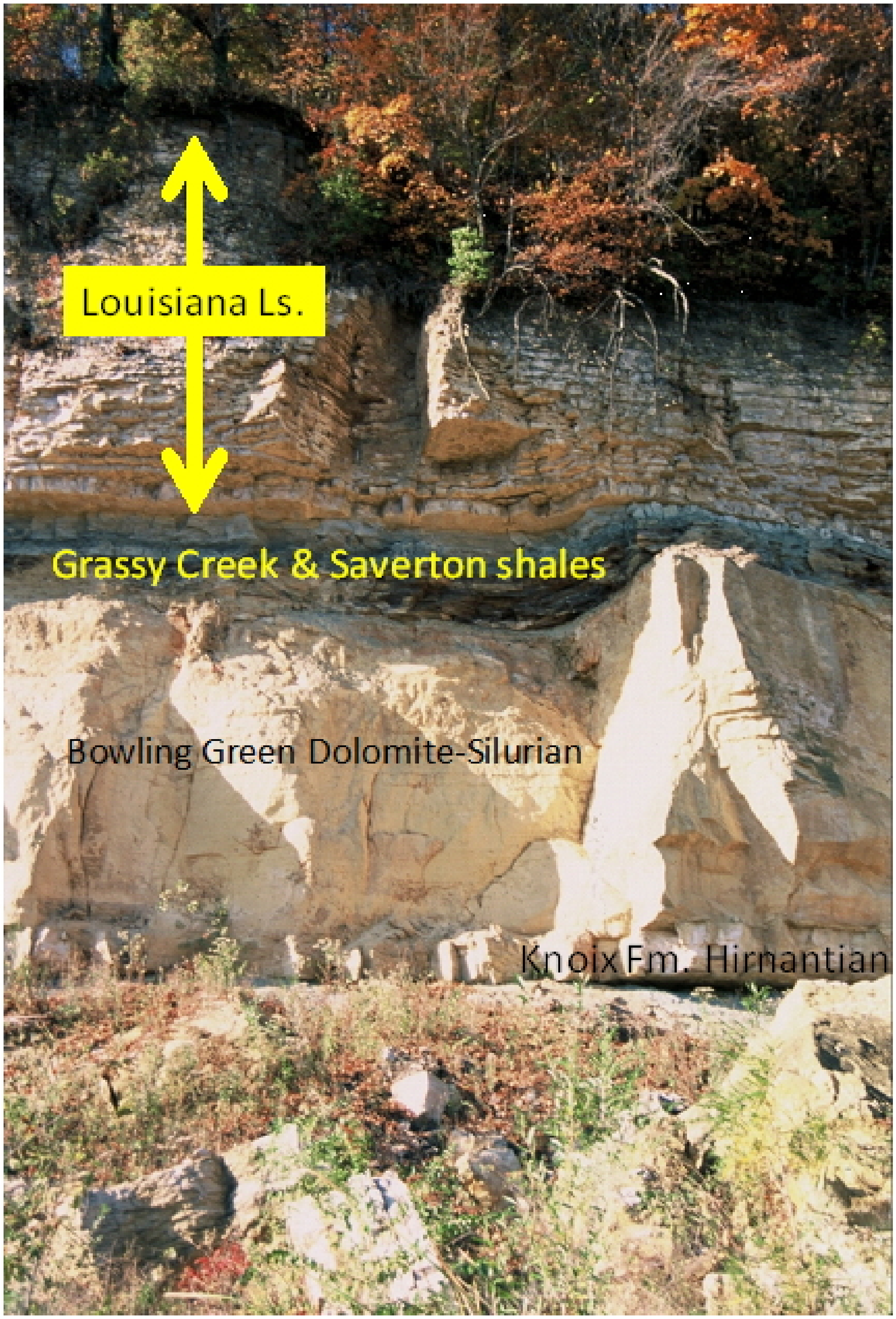


Figure 9: *Paleozoic Stratigraphy exposed in the US Highway 79 Roadcut immediately northwest of the town of Clarkesville, Pike County, Missouri. Nearly all of the brachiopods illustrated in Figures 14-17 were collected from the lower 3 meters of the Louisiana limestone at this locality by J. Day and K. Garber in 2014 and 2015. Field photograph by J. Day taken in 2008 prior to major rock falls that now cover the slope on the west side of the highway below the roadcut.*

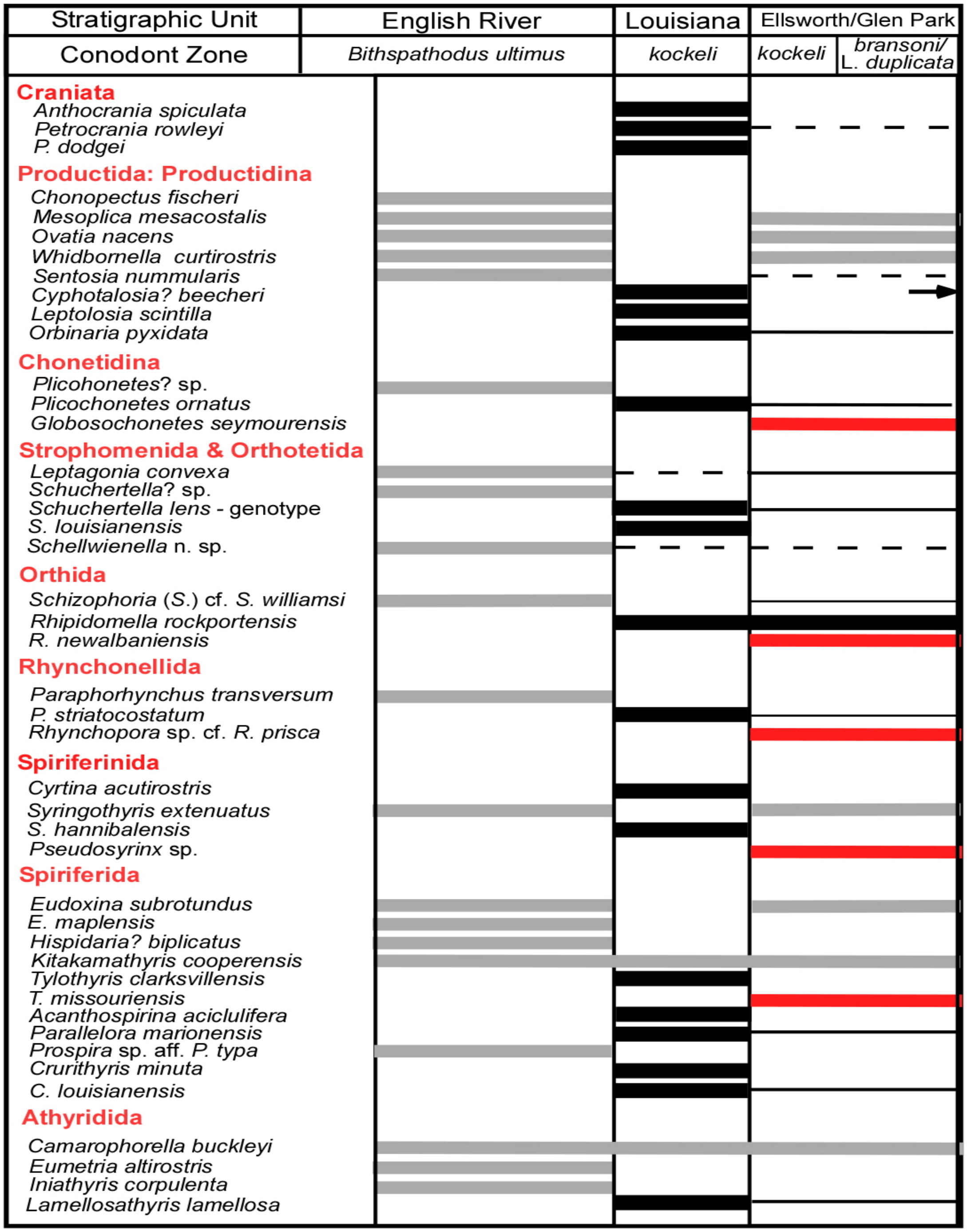


Figure 10: *Brachiopod faunas and sequence in the English River Formation and Louisiana Limestone (this study), and reported ranges of Early Tournaisian brachiopod taxa in the Glen Park Formation (Carter, 1988) or "Ellsworth Member (red range bars) of New Albany Shale in Indiana (Huddle, 1933). Blue column indicates major unconformity spanning Latest Famennian and Early Tournaisian as presently defined. HBE=horizon of Hangenberg Extinction bioevent of Walliser (1996). Red arrows show proposed positions for a new Devonian-Carboniferous Boundary. Nearly all species from the English River, Louisiana and Glenn Park faunas were described or revised in previous studies by Weller (1916), Williams (1943) and Carter (1988). New taxa or occurrences reported here are from the English River fauna that include: the strophomenid Leptagonia convexa (type English River section; Fig. 3, unit 5); the orthotetidid Schellwienella n.sp. and the spiriferid Prospira sp. aff. P. typa, both from the Stoney Hollow locality (Figs 5A & 5B).*

Despite the clear body of conodont and ammonoid evidence for correlation of the English River with Upper Famennian available at the time, Carter (1988, p. 10 and 11) considered the English River Formation of eastern Iowa as a shallow water equivalent (facies) of the early Tournaisian Glen Park Formation (Horton Creek Formation) of west-central Illinois and eastern Missouri. Witzke and Bunker (2002) clearly recognized his erroneous correlation and clearly explained the fundamental issues underlying the problem. His erroneous correlation may have stemmed from a misreading of Collinson's (1961, p. 106) discussion of the conodont faunas from English River and Kinderhookian/Tournaisian age rocks in the Burlington area in southeastern Iowa, or wishful thinking because as many as 11 English River brachiopod species reappear in the much younger Horton Creek Fauna. In either case this fundamental mis-correlation may have hindered biostratigraphic and paleobiogeographic investigations of Latest Devonian and Early Carboniferous brachiopod faunas in stratigraphic successions in North America (western Canada, Utah) and other areas (United Kingdom, Belgium, France, South China, northern Australia) where important faunas of this age are well known.

Brachiopod Fauna of the English River Formation (Figs. 10-13)

Rhynchonelliform brachiopods, representing a number of classes (Strophomenata and Rhynconellata) and orders, make up the entire described English brachiopod fauna (Figs. 10-13). The brachiopod fauna is moderately diverse and consisting of 19 known species (Fig. 10), 16 of which have been described in previous studies of the fauna in the region, the most important of those are by Weller (1914) and Carter (1988). The strophomenid *Leptagonia convexa* (type English River section; Fig. 3, unit 5); and the orthotetidid *Schellwienella* n. sp. with the spiriferid *Prospira* sp. aff. *P. typa,* from the Stoney Hollow locality are new discoveries and additions to the fauna of English River brachiopods. As discussed above, the fauna is more abundant, diverse and easily collected in the indurated siltstones and very fine-grained sandstones in the upper part (English River Siltstone) often dominated by productid brachiopods, the more abundant of those is *Chonopectus fischeri*, and hence the origin of the name "*Chonopectus* Sandstones" for the English River deposits in and around the Burlington, Iowa area. The basal and more sparsely fossiliferous Maple Mill Member (where present) yields low diversity poorly preserved moldic shelly faunas with moldic chonetid brachiopods, likely *Plicochonetes geniculatis* as shown in Figure 12.

Hundreds of specimens of well-to-poorly preserved moldic specimens of brachiopods were collected by J. Preslicka and C. Newsom from near the type section of the English River "Siltstone" in Washington County (Fig. 3, Type Section locality) and transferred to J. Day and K. Garber at ISU for study. That collection will be housed at the University of Iowa Fossil Repository after revision and systematic descriptions of the fauna are completed. New collections were made with B. Witzke, Preslicka and Newsom in the type area in Washington County, and around Burlington with Newsom and Preslicka in Des Moines County in 2012 and 2014. Additional sampling in the English River was done by J. Day with class field trip groups (2010 to present), and with then ISU student K. Garber in 2014 and 2015 at well-known sites in Des Moines County.

The English River brachiopod fauna is dominated by species included in different orders of the classes Strophomenata and Rhynchonellata. Phosphatic linguliform brachiopods have been mentioned in older reports from the English River Formation of eastern Iowa, but none have been formally named. No craniform brachiopods have been mentioned or illustrated in the previous literature, nor have any been recovered during over a decade of sampling in both the type and Burlington, Iowa areas.

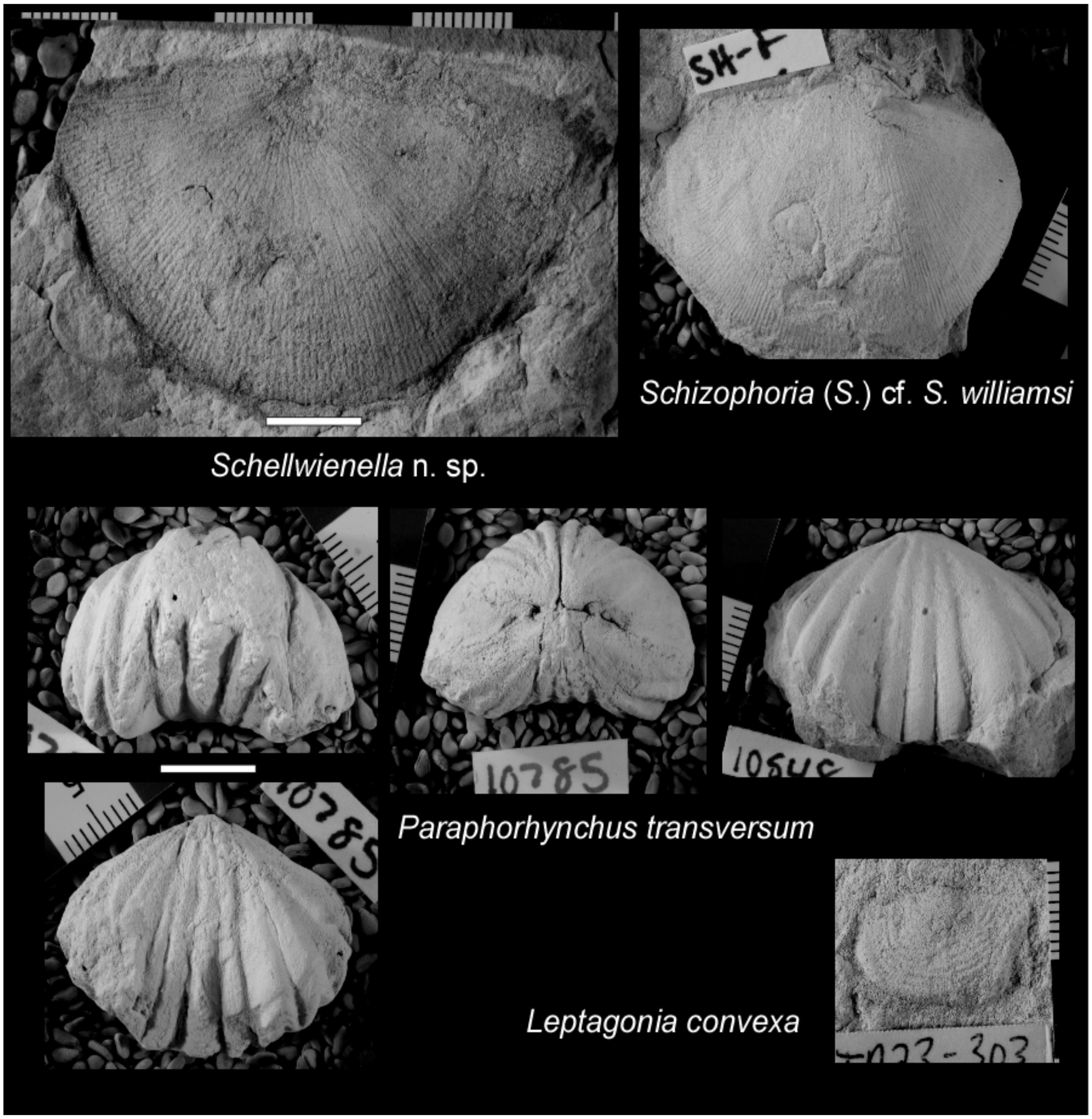


Figure 11: Common English River Formation brachiopods. Orthid: ***Schizophoria (Schizophoria)*** *cf.* ***williamsi*** *(Stoney Hollow locality, DesMoines County); Orthotetid:* ***Schellwienella*** *n.sp. (Stoney Hollow locality, DesMoines County); Strophomenid:* ***Leptagonia convexa*** *(English River Type Section locality); and Rhynchonellid:* ***Paraphorhynchus transversum*** *(Crapo Park outcrops, Burlington, Weller's 1914 specimens Field Museum of Natural History). White scale bars are 10 mm.*

Members of the Class Strophomenata includes species of the orders Productida (Suborders Productidina and Chonetidina), Strophomenida and Orthotetida. Five species of productids in our collections are rare to abundant and mostly poorly preserved as moldic fossils. These are: *Chonopectus fischeri* (Fig. 12), *Mesoplica mesacostalis,* (Fig. 12), *Ovatia nacens* (Fig. 12)*, Whidbornella curtirostris,* and *Sentosia nummularis* (Fig. 12). The only chonetid is tentatively identified as *Plicochonetes geniculatis* (Fig. 12). The strophomenide *Leptagonia convexa* (Fig. 11) was recovered from the English River at the type section in Washington County and likely the oldest known occurrence of this genus world-wide. The orthotitoids *Schuchertella* sp. and *Schellwienella* n. sp. are shown in Figure 11. *Schuchertella* is common in the upper English River in the Burlington area, and *Schellwienella* is reported here for the first time from the type English River from the type area in Washington County.

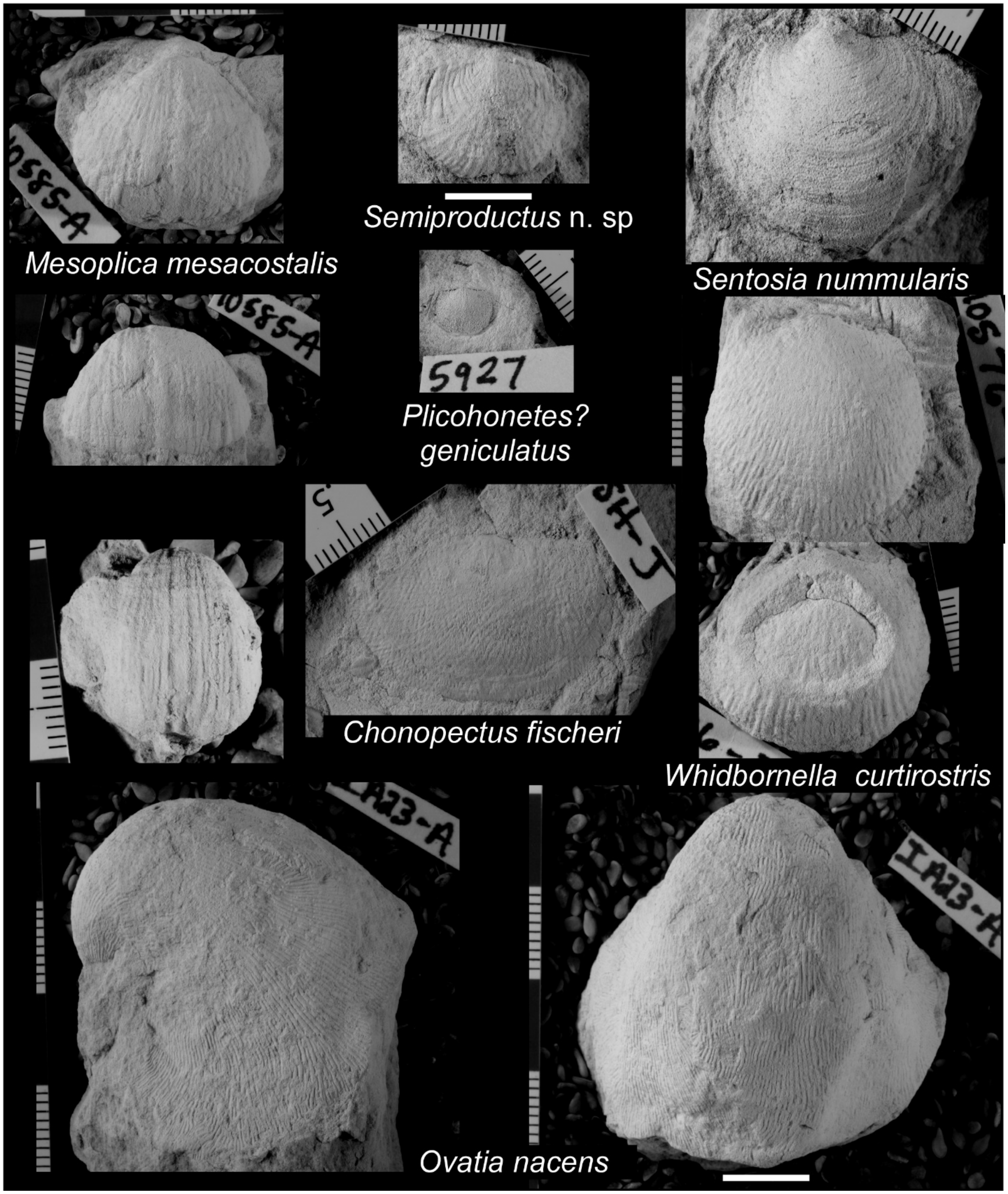


Figure 12: *Common English River Formation Brachiopods. Productidinids:* ***Mesoplica mesacostalis, Semiproductus*** *n.sp.,* ***Sentosia numularis, Chonopectus fischeri, Ovatia nacens, and Whidbornella curtirostris****. Chonetidinid:* ***Plicochonetes****?* ***geniculatus****. White scale bars are 10 mm.*

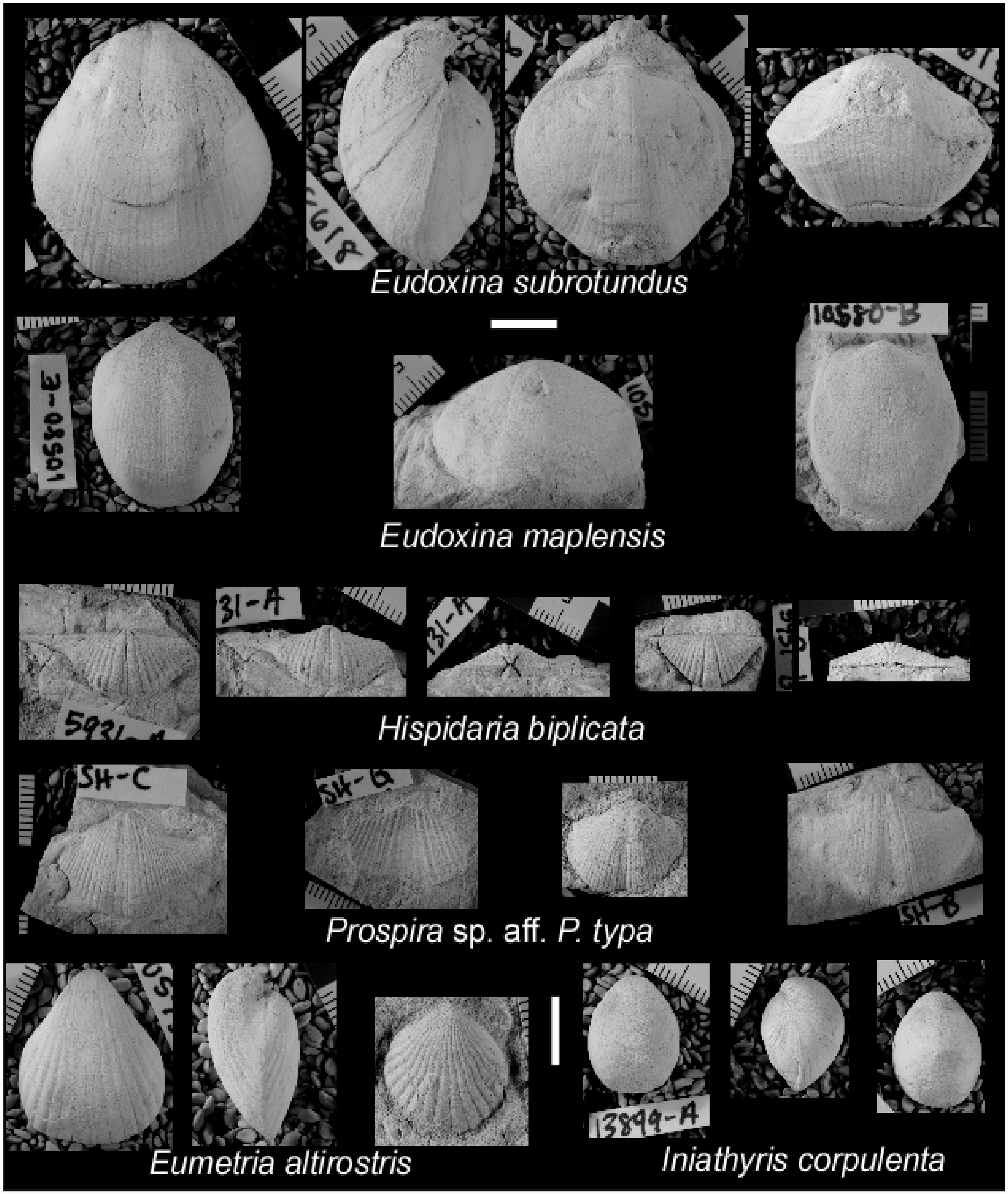


***Figure 13:** Common English River Formation Brachiopods. Spiriferids: **Eudoxina subrotundus, Eudoxina maplensis, Prospira** sp. aff. **P. typa, Hispidaria biplicatus;** athyroids: **Eumetria altirostris** and **Iniathyris corpulenta**. **Prospira** and **Eumetria** specimens in Day's collections in the Illinois State University Paleontology Laboratory; all others from Weller (1914) housed in Field Museum of Natural History, Chicago, Illinois. White scale bars are 10 mm.*

Members of the Class Rhynchonellata are dominate the English River fauna together with the productoid strophomenides discussed above. The orthide *Schizophoria* sp. cf. *S. williamsi* (Fig. 11) is a rare element of the English River fauna and larger and proportionally wider than *Schizophoria hortonensis* Carter (1988). The distinctive rhynchonellid *Paraphorhynchus transversum* (Fig. 11) is common in the English River in eastern Iowa in Washington County and sites in the Burlington area in Des Moines County (Figs. 4 and 5). The spiriferinide *Syringothyris extenuata* (not figured) is not common, and is illustrated from the English River in the Burlington area by Weller (1914). This occurrence confirms the oldest North American occurrence of *Syringothyris* is in the latest Famennian deposits (see fig. 2 of Carter, 1988).

Distinctive and common elements of the fauna are the large spiriferide ambocoeloids *Eudoxina subrotundus* (Fig. 13) and *E.* (Fig. 13) both named by Weller (1914). *Eudoxina maplensis* is more common in the exposures in Washington County, and *E. subrotundus* is the common to abundant species of the genus in the upper English River in the Burlington area. This large species occurs our collections from the English River at its contact with the "McCraney" Formation at Starrs Cave and Crapo Park (Figs. 4 and 5), and partial specimens with preserved shell material were recovered from the thin basal "McCraney" Formation shell bed with the productoid *Chonopectus fischeri* discovered during sampling in 2017 at Starrs Cave (Fig. 4). Less common are the spiriferides *Hispidaria biplicata* (Fig. 13) and *Prospira* sp. cf. *S. typa* (Fig. 13). These two species occur in the English River is the Burlington area (Figs. 4 and 5), and this is the first reported occurrence of *Prospira* in central North American Famennian marine faunas. The reticularid *Kitakamathyris clarkevillensis* is rare and we have not recovered specimens, although poorly a preserved specimen is illustrated in Weller (1914) as discussed by Carter (1988). Athyroids are common to abundant in the English River. These include: *Camarophorella buckleyi* (not figured), *Eumetria altirostris* (Fig. 13) and *Iniathyris corpulenta* (Fig. 13). *Iniathyris* is common to abundant in the English River fauna in Washington County and large numbers of specimens are in our collections from the type section (Fig. 3). We have not recovered *I. corpulenta* from exposures in the Burlington area. *Eumetria altirostris* (Fig. 13) has been recovered from exposures on English River (Fig. 3), and from the Stoney Hollow locality (Figs. 4 and 5) north of Burlington in Des Moines County.

Louisiana Limestone

The Louisiana Limestone was first named for thin-medium bedded lithographic sparsely fossiliferous skeletal mudstones with thin wavy argillaceous yellow-brown dolomitic shale interbeds exposed in the Mississippi River bluff immediately to the southeast of Clinton Spring on Missouri State Route 79 on the south side of the town of Louisiana in Pike County, Missouri. There Scott and Collinson (1961, fig. 2, locality 6) measured 23 meters of Louisiana Limestone. The Louisiana in normally much thinner 9-14 meters in thickness in other exposures in Pike County. The Louisiana has a limited geographic distribution limited to Lincoln, Pike , Ralls and Marion counties, and to the east in Jersey and Calhoun counties in western Illinois. In Iowa, relatively thick sections (17-24 m) are known only from the subsurface where occurs in the IGS H-series cores in Lee County in southeastern Iowa.

The type section is now covered, and the main reference section designated by Thompson (1993) is located in the Mississippi River Bluff just below and north of the Champ Clark Bridge where it 11.6 meters thick as measured by J. Day and B. Cramer in 2007 (see fig. 7, Motel Bluff Section of Cramer et al., 2008). Other exposures in Pike County sampled for this study and by Cramer et al. (2008) include the Missouri State Route 79 roadcut at Clarkesville in Pike County 8 miles southeast of Louisiana, and other roadcut (79 Roadcut locality of Cramer et al. 2008, fig. 7) between Louisiana and Hannibal. In and around the city of Hannibal in Ralls County it varies from 9 to 13 meters in sections in the Mississippi River bluffs where good exposures are located along State Route 79 two km south of downtown Hannibal. The Louisiana is substantially thinner in western Illinois exposures in Jersey and Calhoun counties sampled for conodonts by Scott and Collinson (1961) and Chauff and Nichols (1995).

In northeastern Missouri and western Illinois the Louisiana disconformably overlies gray shales of the Upper Famennian Saverton Shale, and conformably overlies the English River Formation in the subsurface of southeastern Iowa. Woodruff (1990) sampled the Grassy Creek (3.72 m thick) and Saverton Shale (17 cm thick) in the New Jersey Zinc DDH-04 core in Ralls County, approximately 10 km west of outcrop localities near Hannibal. Woodruff (1990, p. 48) observed an erosional disconformity at the contact between the Grassy Creek and the overlying Saverton and recovered conodonts that indicate an age no younger than the *Palmatolepis marginifera utahensis* Zone (=Upper marginifera Zone of Woodruff's report) from his highest sample in the Grassy Creek (Woodruff, 1990, p. 41) indicating a significant hiatus at the Saverton-Louisiana contact in the region (Day and Cramer, in Cramer et al., 2008). Significant erosional thinning of the Grassy Creek and Saverton shales in northern Missouri is likely due to active structural movement (uplift in Northern Missouri) along faults associated with the Lincoln Fold in this region in the Famennian. In eastern Missouri the Louisiana is disconformably overlain by thin (0-1m) sandy and oolitic to micritic skeletal carbonates of the Horton Creek Formation, or the basal gray calcareous shales of the Hannibal Shale. Significant erosional relief of up to 3-3.5 m is observed along the Louisiana-Hannibal contact in Ralls and Pike Counties in the Mississippi bluff exposures (Williams, 1943) resulting from erosion during a likely early Tournaisian sea level low prior to the rise initiating Hannibal deposition.

The basal 5-10 cm of the Louisiana is an extremely calcareous blocky yellow brown mudstone with common and diverse Louisiana brachiopods at most localities in Pike County sampled by Williams (1943, see his section descriptions p. 13-25) including the Champ Clark Bridge reference section in the town of Louisiana sampled by J. Day in 2016. The macrofauna is most abundant and diverse in the lower 3-4 meters of formation, and sparsely fossiliferous with rare scattered brachiopods, ostracodes and echinoderm skeletal plates in the overlying part of the Louisiana in most sections outside of the immediate type area in and around the town of Louisiana. Conodont-based correlations of the Louisiana Limestone in the outcrop area of northeastern Missouri and western Illinois are discussed in Scott (1961), Scott and Collinson (1961), Klapper and Philip (1971), Klapper et al. (1971), Sandberg et al. (1972), Chauffe and Nichols (1995) and Feist and Petersen (1995). Scott (1961) and Scott and Collinson (1961) illustrated most of conodont fauna and suggested a correlation of the Louisiana with the upper Famennian Wocklumeria Stufe of Germany based on the occurrence of species of form taxa assigned at that time to *Siphonodella*. Klapper et al. (1971) and Sandberg et al. (1972) indicated a latest Devonian age based on the occurrence of the conodont *Protognathodus kockeli* (Bischoff, 1957) illustrated by Scott and Collinson (1961) and later re-illustrated by Chauffe and Nichols (1995). The first occurrence of the aforementioned species defines the base of the basal Tournaisian *P. kockeli* Zone. The trilobite *Pudoproetus missouriensis* (Shumard, 1855) is associated with the brachiopod, ammonoid and conodont faunas in the lower few meters of the Louisiana and its range is restricted to the *Protognathodus kockeli* Zone (=Upper *Siphonodella praesulcata* Zone (Feist and Petersen 1995, fig. 3). Feist and Petersen (1995) further demonstrated that latest Famennian trilobites of the genus *Pudoproetus* survived the Hangenberg Extinction. House (1978) illustrated and reported the occurrence of ammonoid *Acutimitoceras* (*Stockumites*) *louisianensis* (Rowley, 1895) in the Louisiana Limestone and this occurrence is correlated with the lower part of the global *Acutimitoceras* (*Stockumites*) genozone and the *Acutimitoceras* (*Stockumites*) *porsum* Zone of Germany, spanning the *P. kockeli* Zone (Becker and House, 2000).

Brachiopod Fauna of the Louisiana Limestone (Figs. 10, 14-17)

The brachiopod fauna is moderately diverse and 10 of 19 species of calcareous craniform and rhynchonelliform brachiopods (Fig. 10) have their first appearances in the basal blocky mudstone of the lowest Louisiana based on William's collection (1943, p. 16) from the Town Branch locality, and J. Day's collection from the same basal mudstone at the Champ Clark Bridge reference section in the town of Louisiana. The fauna includes at least 19 valid species, with two cases where two names have been given to the same species. In those cases we provide the valid senior synonyms. Our new collections were made at the Clark Champ Bride reference section (basal mudstone), Clarkesville and the Bowling Green localities (Figs. 1, 8 and 9; also see Cramer et al., 2008, fig. 7). Common brachiopods collected from the lower 3 m of the Louisiana Formation at those localities, and selected specimens illustrated in Weller (1914) are shown in Figures 14 to 17.

The fauna does include phosphatic linguliforms although these are not listed in Figure 10 or illustrated in Figures 14-17. Those species are described under the genus names *Orbiculoidea* (2 species, likely valid) and *Lingula* (4 species or subspecies, status indeterminate). We did not recover any identifiable linguliform specimens permitting definitive species assignments. Species illustrated and described under the genus name *Lingula* are likely assignable to either *Barroisella* or *Langella*. Original species descriptions and illustrations of type specimens in Rowley (1908), Weller (1914), and Williams (1943) are insufficient to determine their generic affinities with any confidence without restudy of the types. *Lingula* is a late Cenozoic (Quaternary) genus and no genuine species of that genus are known from Paleozoic faunas. In the discussion below, readers are referred to the original systematic sections of studies by Rowley (1895, 1900, 1908) and Williams (1943) for authors of species.

Craniform (Class Craniata) brachiopods in the fauna include the encrusting species *Anthocrania spiculata, Petrocrania rowleyi,* and *P. dodgei.* These species occur as encrusting epibionts on a host shells of larger taxa, although none were present on shell specimens in our collections.

Rhynchonelliform brachiopods, representing a number of classes and orders, make up the majority of the Louisiana brachiopod fauna. Members of the Class Strophomenata includes species of the orders Productida (Suborders Productidina and Chonetidina) and Orthotetida. Three described strophalosid productids in our collections include extremely common and often abundant O*rbinaria pyxidata* (Figs. 14.12-14.22)*,* rare *Cyphotalosia? beecheri,* and common specimens of the encrusting micromorph *Leptalosia scintilla* (Figs. 14.9-14.11; Fig. 15.15). The latter is cemented to shell of larger species by its cicatrix like surface of its dorsal valve. It is likely that this may represent an early post-larval juvenile attached growth stage of *Orbinaria* that become detached and assume a free-lying life-style stabilizing the shell in muddy substrates by use of ventral spines as they reach adult sizes. A cicatrix is not observed on ventral umbonal regions of adult shells of *Orbinaria*. Two species of chonetids (*Plicohonetes*) are described by Williams (1943) although they are synonyms, the senior synonym is *Plicochonetes ornatus* (Figs. 14.23-14.28). Two species of Orthotetoids in the genus *Schuchertella* including the genotype *S. lens* (Figs. 14.1-14.8) and the rarer form *S. louisianensis* (not figured).

The remaining species of the fauna are included in different orders of the Class Rhychonellata (Rhynchonellida, Orthida, Spiriferida, Spiriferinida, Athyrida). The rhynchonellid *Paraphorhynchus striatocostatum* was not recovered in our collections and is not figured. The orthide *Rhipidomella*

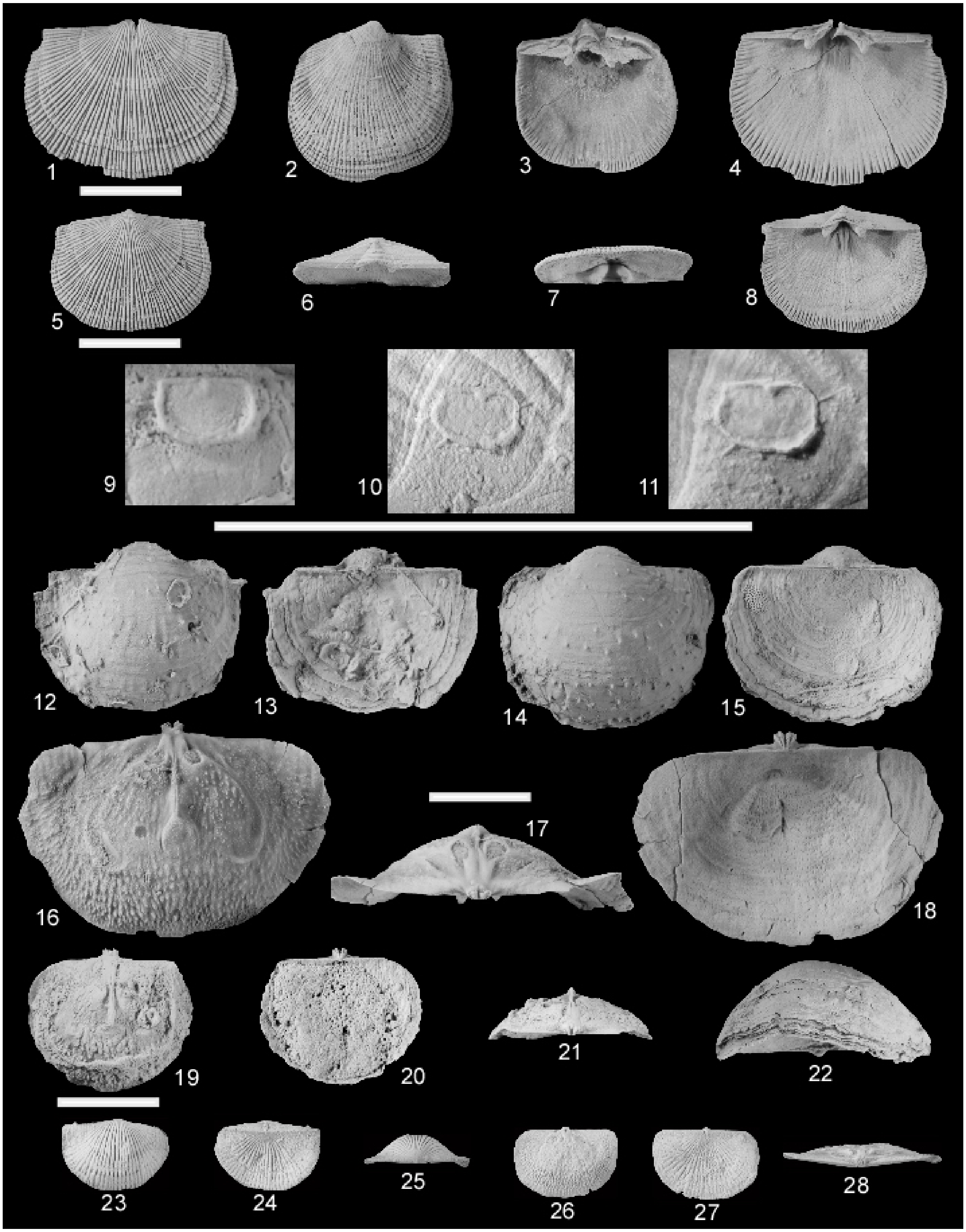


Figure 14: *Common Louisiana Limestone brachiopods. Orthotitid: Figs. 12.1-12.8* ***Schuchertella lens*** *(genotype); productidinids:* ***Leptalosia scintila (****Figs. 12.9-12.11) and* ***Orbinaria pyxidata*** *(Figs. 12.12-12.22); and chonetidinid:* ***Plicochonetes ornatus*** *(Figs. 12.23-12.25 complete shell, Figs. 12-26-12.28 isolated dorsal valve)****.*** *White scale bars are 10 mm.*

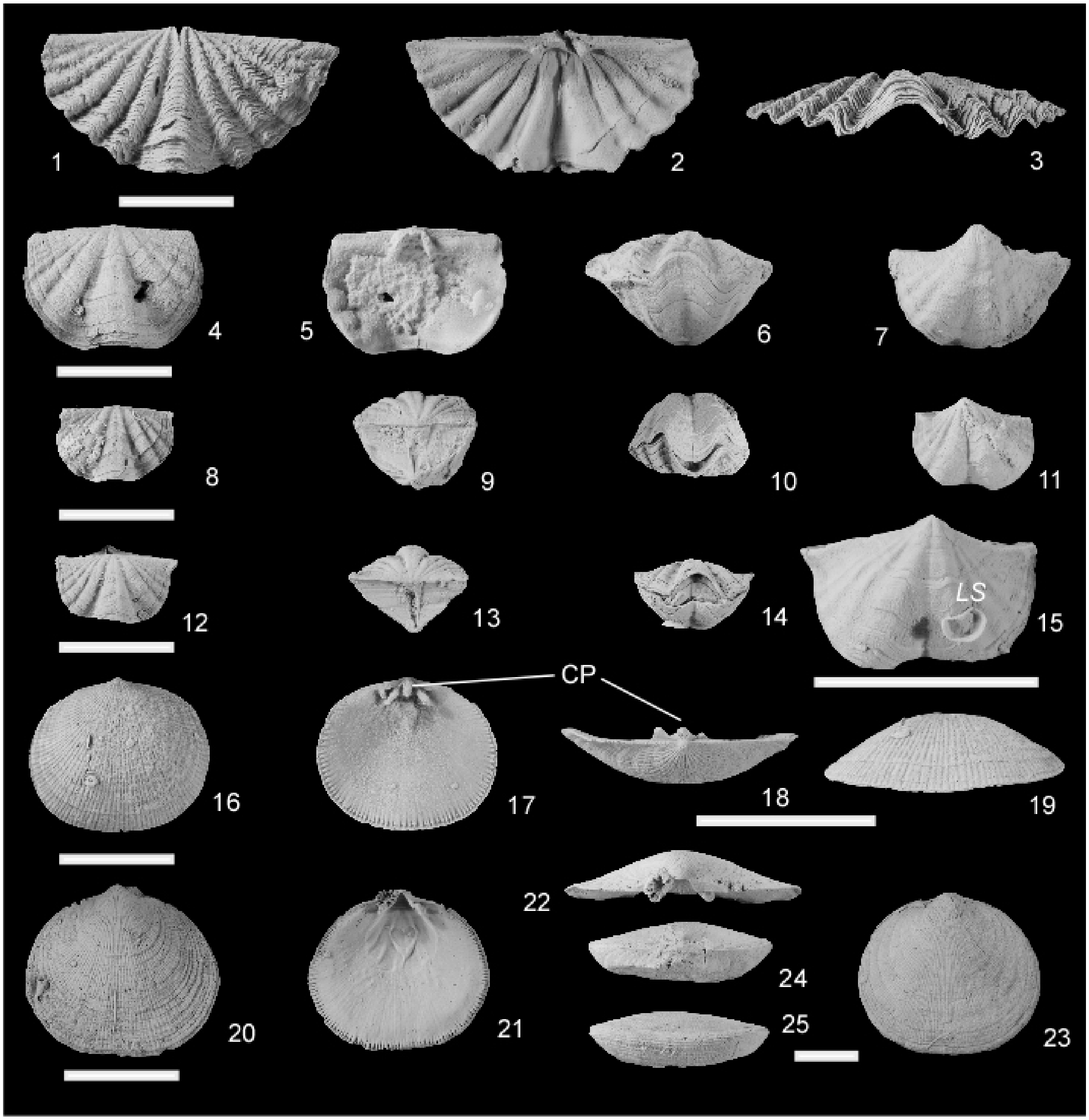


Figure 15: *Common Louisiana Limestone brachiopods. Spiriferid-Delthyrid dorsal valve of Tylothyris clarksvillensis (Figs. 13.1-13.3); spiriferinidid: Cyrtina acutirostris (figs. 13.4-13.15), note enlarged ventral view showing encrusting strophalosid productoid Leptalosia scintilla (LS); and the orthide: Rhipidomella rockportensis (Figs. 13.16-13.23; CP = cardinal process). White scale bars are 10 mm.*

rockportensis (Figs. 15.16-15.25) is a common element of the fauna and originally described under the name *R. missouriensis* that is preoccupied and unavailable. The punctate spiriferinidids *Cyrtina acutirostris* (Figs. 15.4-15.15) and large *Syringothyris hannibalensis* (Figs. 16.1-16.15) are also common. The latter is a senior synonym of S. newarkensis. Isolated valves the delthyroid spiriferid *Tylothyris clarksvillensis* (15.1-15.3) are common in the type area. Rare species of spiriferids not recovered and not figured below include: *Acanthospirina aciclulifera Crurithyris minuta, C. louisianensis. Parallelora marionensis* (Figs.

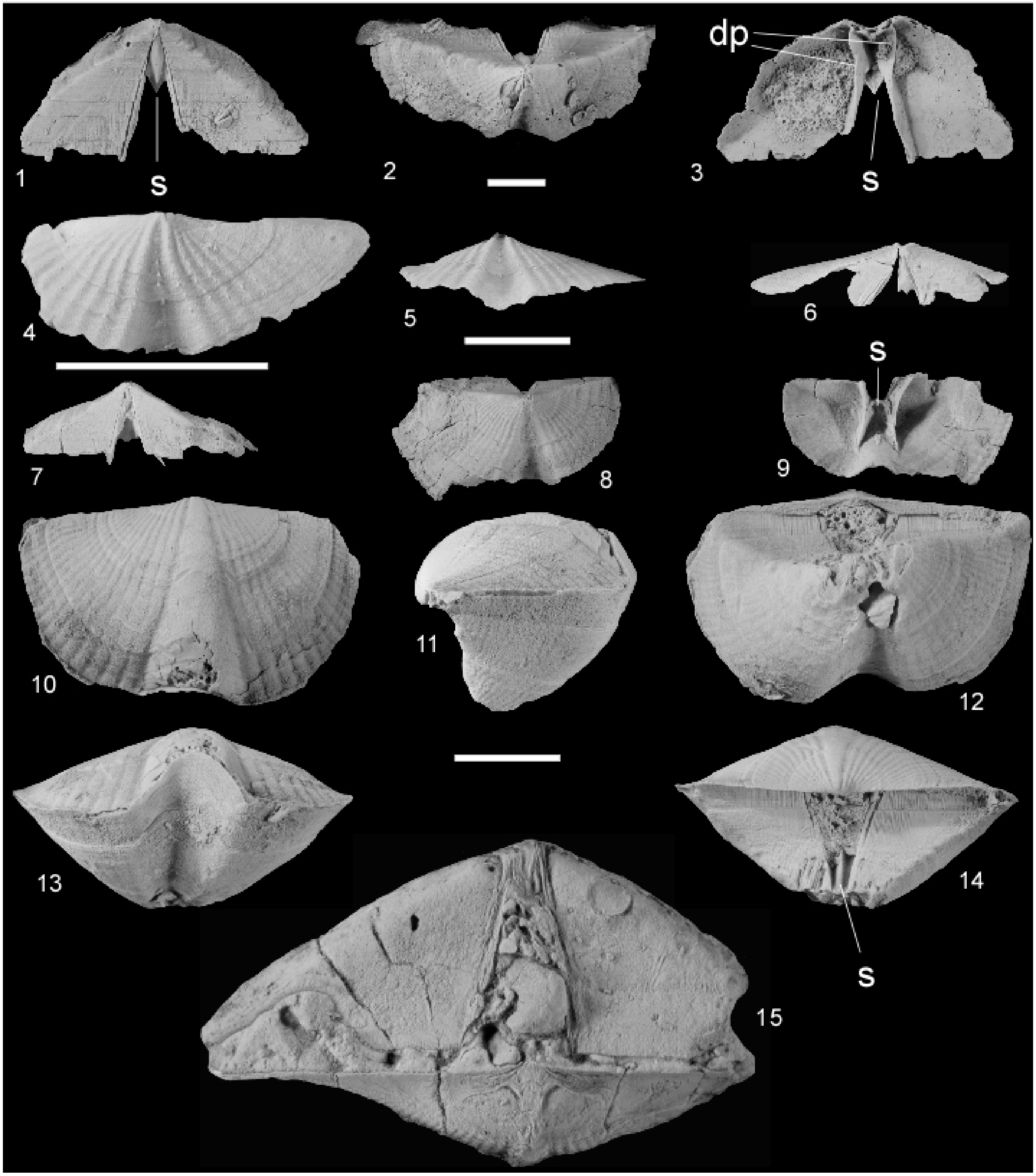


Figure 16: *Louisiana Limestone Spiriferinoid brachiopod Syringothyris hannibalensis (14.1-14.15). All collected from the Clarkesville Highway 79 road-cut locality, Pike County Missouri by K. Garber and J. Day in 2014 and 2015. Abbreviations: s= syrinx on deltidial plate, dp = dental plates. Specimen of partial ventral valve (Figs. 14.4 -14.16) enlarged in 14.4 to show micro-ornament of fine radial capillae, and spines rows in sulcus and on crests of flank plications. Specimen 15 is embedded in matrix but is the largest known specimen of this species. White scale bars are 10 mm.*

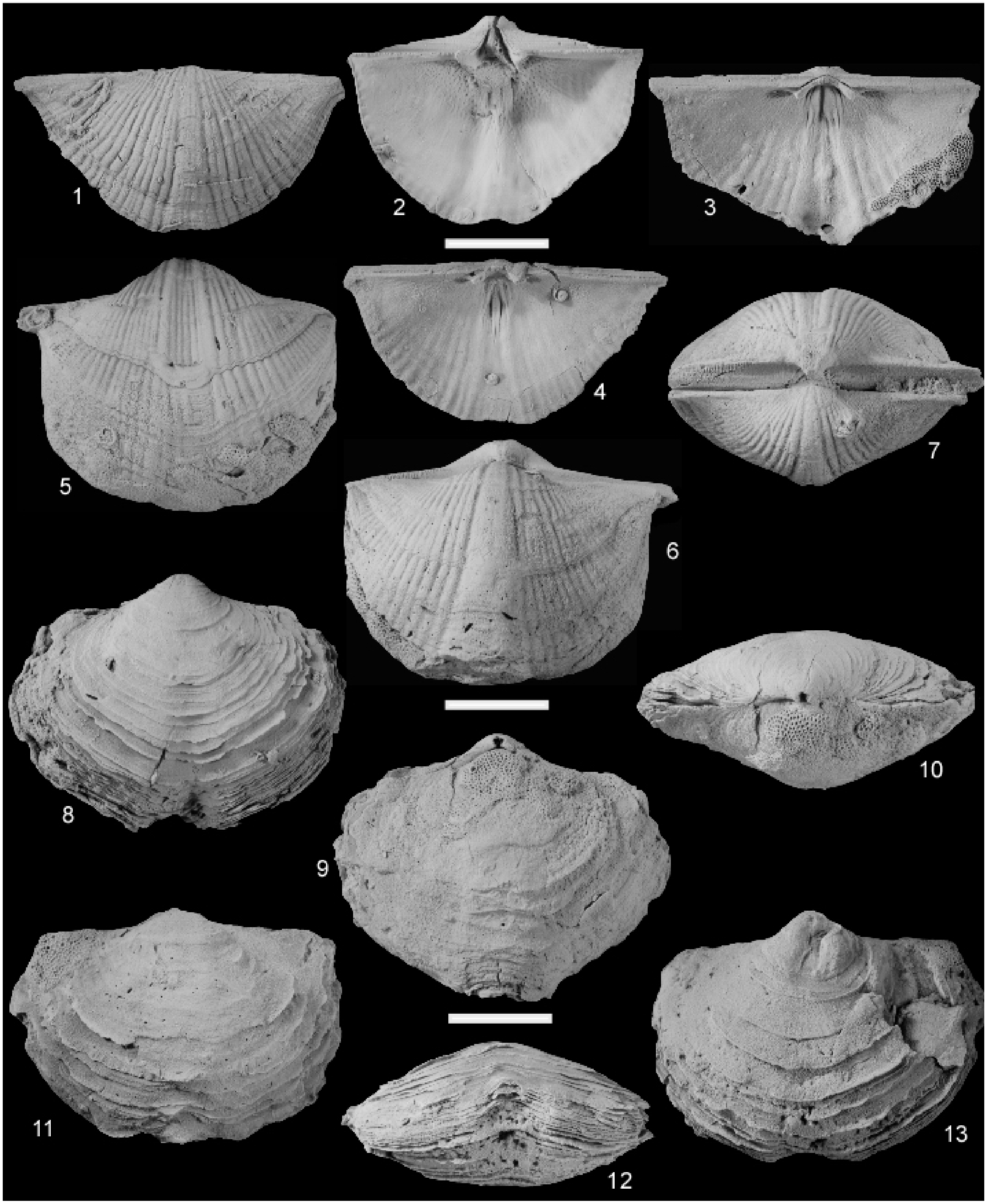


Figure 17: *Louisiana Limestone Spiriferoid & Athyroid brachiopods. Sprifieroid: Parallelora marionensis (Figs. 15.1-15.6). Athyroid: Lamellosathyris lamellosa (Fig. 15.8-12). All collected from the Clarkesville Highway 79 road-cut locality, Pike County, Missouri, by K. Garber and J. Day in 2014. White scale bars are 10 mm.*

17.1-17.7) is a common and outstanding spiriferoid in the fauna. Athyroids include *Camarophorella buckleyi* and *Lamelloathyris lamellosa* (Figs. 17.8-17.13 =*Athryis hannibalensis*). Only the latter is common in the fauna.

CONCLUDING REMARKS

The English River Formation was deposited prior to and during the Hangenberg Extinction (HE) interval. The diverse English River fauna is comprised by at least twenty species (Figs. 10-13) that includes: *Chonopectus fischeri, Mesoplica mesacostalis, Ovatia nacens, Whidbornella curtirostris, Sentosia nummularis, Plicohonetes*? sp., *Leptagonia convexa, Schellwienella* n. sp. *Schuchertella*? sp., *Schizophoria* (*S.*) sp. cf. *S. williamsi*, *Paraphorhynhus transversum, Kitakamathyris cooperensis, Eudoxina subrotundus, E. maplensis*, *Syringothyris extenuatus*, *Prospira* sp. aff. *P. typa*, *Hispidaria biplicatus*, *Camarorphorella buckleyi, Iniathyris corpulenta*, and *Eumetria altirostris*.

New occurrences in the English River fauna, not reported in earlier studies by Weller (1914; Carter, 1988) include: the Orthotetid *Schellwienella* n. sp., the strophomenid *Leptagonia convexa*, and the spiriferid *Prospira* sp. aff. *P. typa.* Only two English River taxa carryover through the Hangenberg Extinction interval and occur in the overlying Louisiana Limestone fauna. These are: *Kitakamathyris cooperensis* and *Camarorphorella buckleyi.*

Revised correlations of the English River as latest Famennian are significant in that the occurrences of the species *Leptagonia convexa* and *Syringothyris extenuata* are the oldest or first occurrences of these genera (uppermost Famennian), versus Early Tournaisian based on erroneous correlation of the English River with the Horton Creek Fauna by Carter (1988).

Rapid deepening and drowning of the English River clastic shelf system during the *kockeli* Zone initiated post-Hangenberg earliest Tournaisian Louisiana Limestone deposition along the margin of the Ozark Uplift in eastern Missouri, western Illinois and southeastern Iowa. The post-extinction survivor/recovery brachiopod fauna of the Louisiana Limestone (Figs. 10, 14-17) consists of at least 21 craniform and rhynchonelliform species. These include: *Anthocrania spiculata*, *Petrocrania rowleyi*, *P dodgei*, *Rhipidomella missouriensis*, *Schuchertella lens*, *S. louisianensis*, *Plicochonetes ornatus, Obinaria pyxidata, Cyphotalosia? beecheri, Leptolosia scintilla, Paraphorhynchus striatocostatum, Cyrtina acutirostris, Tylothyris clarksvillensis, Acanthospirina aciculifera, Syringothyris hannibalensis, Parallelora marionensis, Crurithyris minuta, C. louisianensis*, *Lamellosathyris lamellosa,* and *Camarorphorella buckleyi.*

In post-Louisiana strata of the Horton Creek Formation, nine species present in the English River fauna reappear, and an additional 25 species have their regional first occurrences as reported and described from the younger Early Tournaisian platform deposits (=Glenn Park as used in part by Carter, 1988, excluding the English River Formation) in the western Illinois Basin. A coeval fauna occurs in the deep shelf facies in eastern Illinois Basin in Indiana (Ellsworth Member of the New Albany Formation, see Day et al. 2015), and other shelf systems in eastern Eurasia, South China and subtropical Gondwana (New Zealand and Australia).

The regional signature of the Hangenberg Extinction is marked by the abrupt apparent extinctions of nearly the entire English River fauna, replaced by the Louisiana fauna during the basal *kockeli* Zone. This faunal turnover is associated with the onset within the lower English River and sudden shift to maximum values of the Hangenberg δC^{13} Excursion (HIE) within the lower Louisiana. These faunal and chemostratigraphic events can be correlated globally and clearly identify the revised D-C boundary at the base of the *Protognathodus kockeli* Zone (=former Upper *praesulcata* Zone).

ACKNOWLEDGEMENTS

The authors recognize the contributions of numerous Illinois State undergraduate students who assisted J. Day in collecting brachiopods from English River and Louisiana formations during stratigraphy and paleontology class field trips to eastern Iowa and Missouri since the early 2000s. We want to give special thanks to Mr. Jim Preslicka of Iowa City, and his good friend Dr. Charles Newsom of Department of Physics and Astronomy, University of Iowa, Iowa City (retired) for their permanent loan of their extensive collection of English River brachiopods from the type area on English River in Washington County, Iowa. Both joined J. Day to collect brachiopods near Kalona on two occasions with B. Witzke in 2011 and 2012. They also have collected English River fossils J. Day on at least two occasions at the Stoney Hollow and Crapo Park localities in Des Moines County near Burlington. Tommy Thompson (retired) of the Missouri Geological Survey was kind enough to travel from Rolla to join J. Day in the field on a number of occasions in Pike and Ralls counties in eastern Missouri to familiarize J. Day with important stratigraphic localities in eastern Missouri in the mid-1990s.

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Field Trip Road Log

Saturday, September 28th, 2019

Stop 1: Clarksville Roadcut (Grassy Creek, Saverton, Louisiana) *1 hour 10 minutes*

1) Depart Microtel Inn head south on S. 3rd Street (Hwy 57) – 11.5 miles
2) Turn right and merge onto I-172 South – 3.2 miles
3) I-172 South turns into I-72 East, continue – 5.4 miles
4) Take exit 10 for IL-96 toward IL-106/Hull/Payson turning right – 0.3 miles
5) Turn left on IL-106 East/IL-96/2421N towards Kinderhook – 2.7 miles
6) Turn right onto IL-96 South and continue to Atlas – 16.6 miles
7) Turn right onto US-54 West to Louisiana – 6.2 miles
8) After crossing the river, turn left on N 3rd Street (MO-79 South/Clinton St.) towards Clarksville – 10 miles
9) Outcrop is on the right-hand side (SSW side)!

Stop 2: Bowling Green Roadcut (Saverton, Louisiana) *25 minutes*

1) Depart Stop 1 by heading back towards Louisiana on MO-79 North – 1.4 miles
2) Turn left onto Highway N – 5.7 miles
3) Turn left onto State Highway D – 3.2 miles
4) Turn right onto Highway Ww – 5.2 miles
5) Turn right onto US-61 North – 8.7 miles
6) Outcrop is on the right side (north side)!

Stop 3: Highway 79 Roadcut (Louisiana) *40 minutes*

1) Depart Stop 2 heading northwest on US-61 North – 0.2 miles
2) Exit right onto US-54 to Mexico/Louisiana – 11 miles
3) Turn left onto South D Street – 0.2 miles
4) Turn left onto MO-79 North (Frank Ford Road) – 20 miles
    a. *Lunch stop at roadside park – Entrance is on left before we reach Stop 4*
5) Outcrop is on the right (east side)!

Stop 4: Highway 79 River Bluff Section (Louisiana) *10 minutes*

1) Depart Stop 3 heading north-northwest on MO-79 North – 10 miles
2) Outcrop is on the left (southwest side)!

Stop 5: Hannibal Type Section (Louisiana, Hannibal, Burlington) *3 minutes*

1) Depart Stop 4 heading north-northwest on MO-79 – 2 miles
2) Outcrop is on the right (northeast side)!
3) End of Day 1: Return to Microtel 200 S. 3rd Street, Quincy, IL

Sunday, September 29th, 2019

Stop 6: Starr's Cave Park (Eng. River, McCraney, Wassonville, Burlington) *1 hour 30 minutes*

1) Depart Microtel Inn head south on S. 3rd St., take first left on York St., then left on S. 4th St. – 0.4 miles
2) Turn left on Broadway Street, continue on US-24 West over the river – 5.5 miles
3) Exit right onto US-61 North to Canton, continue on US-61 North – 30.3 miles
4) US-61 North turns into MO-27 North into Iowa – 7.5 miles
5) Cross into Iowa continuing on IA-27 North – 8.9 miles
6) Turn right onto 255th Street – 7.5 miles
7) Turn left onto US-61 North – 26 miles (going through West Burlington)
8) Turn right onto Sunnyside Avenue – 0.5 miles
9) Turn left onto Irish Ridge Road – 0.7 miles
10) Turn left onto Starrs Cave Park Road – 0.5 miles
11) Exit vans in parking lot and walk on paved path to view the best Kinderhookian outcrop in the world!

Stop 7: Stoney Hollow (Eng. River, McCraney, Wassonville, Burlington) *15 minutes*

1) Depart Stop 7 on Starrs Cave Park Road – 0.5 miles
2) Turn left onto Irish Ridge Road – 1.4 miles
3) Turn right onto Golf Course Road – 1.6 miles
4) Turn left onto County Road 99/Hwy 99 – 4.6 miles
5) Turn left onto Stoney Hollow Road – 0.3 miles
6) Creek outcrop on the left side of road (south side)!

Stop 8: Crapo Park (Eng. River, McCraney, Wassonville, Burlington) *21 minutes*

1) Depart Stop 7, continuing west on Stony Hollow Road – 0.8 miles
2) Turn left at 80th Avenue (first left) – 1.2 miles
3) Turn right onto County Road 99/Hwy 99 – 5.5 miles
4) Continue onto Bluff Road/N. Main Street – 0.1 miles
5) Continue on N. Main Street – 1.6 miles
6) Turn right onto Harrison Avenue – 0.5 miles
7) Turn left onto Madison Avenue – 0.8 miles
8) Turn left into Crapo Park on S. Main Drive – 0.5 miles
9) Exit vans in parking lot and walk on gravel path to outcrops!

Stop 9: Fall Creek State Park (Hannibal, Burlington) *1 hour 40 minutes*

1) Depart Stop 8, heading back out of park on S. Main Drive – 0.5 miles
2) Turn left onto Madison Avenue – 1.6 miles
3) Turn left onto Summer Street – 2.6 miles
4) Turn left onto US-61 South – 19.4 miles
5) Turn right onto 255th Street – 7.5 miles
6) Turn left onto IA-27 South – 8.9 miles
7) Continue into Missouri on MO-27 South – 7.5 miles

8) MO-27 turns into US-61 South, continue south – 30.3 miles
9) Take right loop exit onto US-24 East/Quincy – 5.8 miles
10) Crossing the river turn right on IL-57 South/S. 3rd St./Gardner Expy – 11.9 miles
11) Take first left after crossing over I-172 onto Payson Road – 0.3 miles
12) Turn right on State Park Road and enter park
13) Exit vans in parking lot, walk ~0.4 miles down path to outcrop!

Stop 10: I-172 Roadcut (Burlington, Keokuk) *3 minutes*

1) Depart Stop 9 heading out on State Park Road, turn left on Payson Road – 0.3 miles
2) Turn right onto East 1083rd Lane – 0.2 miles
3) Turn left to merge onto I-172 North toward Mt. Sterling/Keokuk – 0.5 miles
4) Beautiful roadcut as far as the eye can see is on the right (ESE) side of the road!
5) End of Day 2: Return to Microtel 200 S. 3rd Street, Quincy, IL

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SATURDAY FIELD TRIP STOPS

STOP 1: Clarksville Roadcut

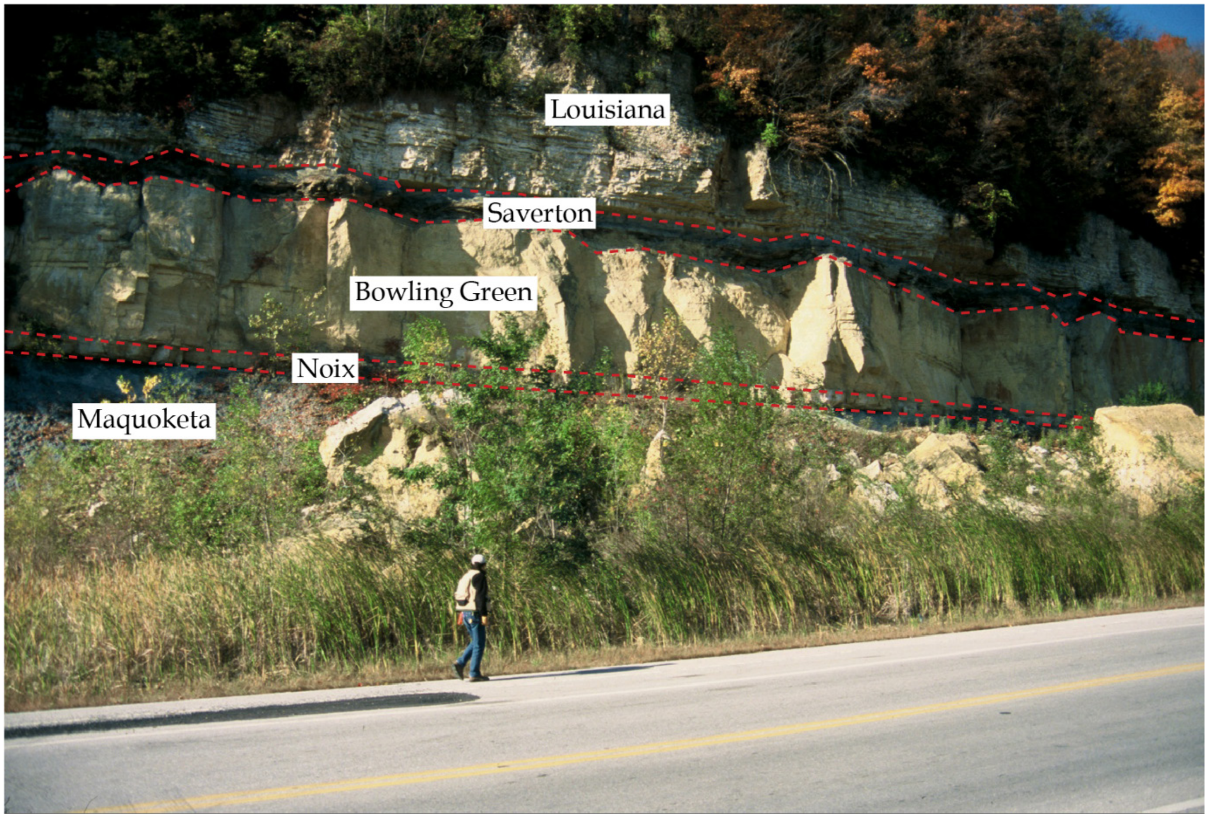

Figure 1: Clarksville Roadcut showing Ordovician through Devonian strata. The unconformity at the top of the Bowling Green Dolomite represents most of the Silurian and Devonian. Extensive deposition of both Silurian and Devonian strata outside of this immediate area demonstrate the impact of the Lincoln Fold on regional stratigraphic architecture.

The Clarksville Roadcut gives an excellent overview of the regional Paleozoic stratigraphy upon the Lincoln Fold in the area. This structural feature significantly limited the total strata deposited in this area, however, its geographic extent was limited. Expansive Silurian and Devonian deposition is recorded throughout the tri-state area and the unconformity between the Bowling Green and Saverton seen in this outcrop is not typical of the rest of the region. Here, the Bowling Green Dolomite belongs to the Llandovery Series and the Saverton and Louisiana record the upper part of the Famennian Stage. Therefore, this unconformity represents some 60 Million Years of missing time in this locality. The unconformity between the Ordovician Maquoketa Shale and the Noix Oolite is much more typical of regional stratigraphy. Throughout much of the tri-state area, particularly in Iowa, the Silurian package rests on top of the Upper Ordovician Maquoketa Shale.

Across most of the Mississippi Valley Region, the Saverton and/or English River record much of the Famennian Stage. The regional unconformity between the Silurian and Devonian throughout the upper Midwest typically extends from the upper part of the Sheinwoodian Stage of the Wenlock Series of the Silurian System through to the Eifelian Stage of the Middle Devonian Series.

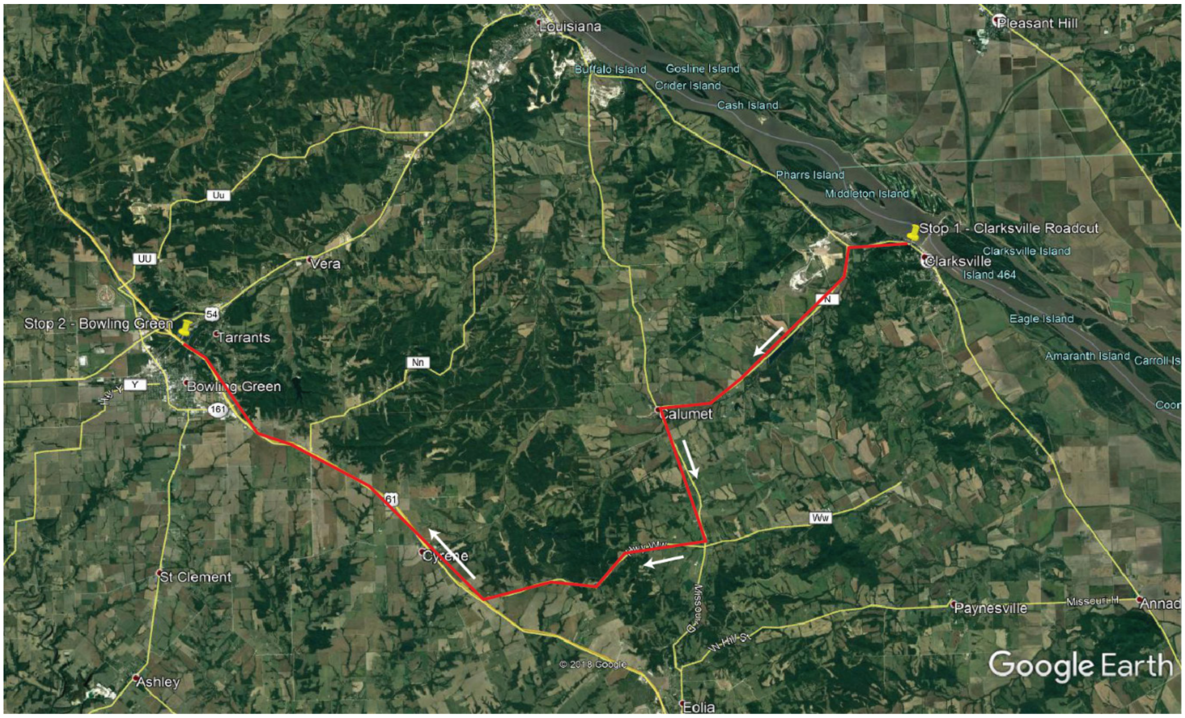

Figure 2: Travel directions between field trip stops 1 and 2.

STOP 2: Bowling Green

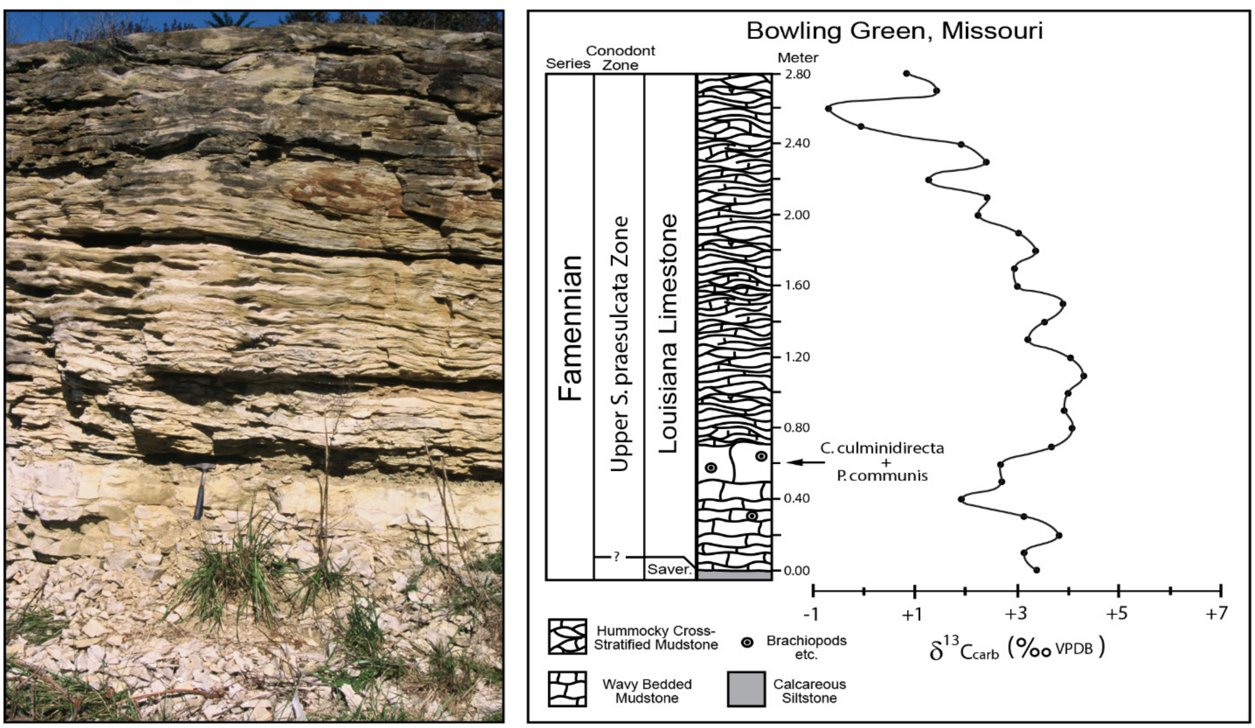

Figure 3: Bowling Green outcrop, measured section, carbon isotopes, and conodont biostratigraphy. Note falling isotope values, as well as the incoming of clastic material and HCS in the top of the outcrop (from Cramer et al. 2008).

This is the first outcrop of the Louisiana Limestone that we will get to see up close. It is quite atypical at this locality in that the isotope values are very low, there is an abundance of clastic material, and the upper part of the outcrop displays hummocky cross-stratification (HCS). With the exception of one core in Iowa (H-29), such sedimentary structures are generally not seen in the Louisiana Limestone. However, the presence of HCS in this outcrop is one of the best indicators of the apparent water depth. There has been a history of speculation as to the depth of deposition given the nearly pure carbonate mud that makes up the Louisiana with many authors suggesting an extremely shallow, restricted, and protected setting whereas other have suggested this unit represents a fairly deep, offshore environment well below fair-weather wave base. Chauffe & Nichols (1995) and Chauffe & Guzman (1997) both contain a more complete discussion of this problem. What is clear from this outcrop however is the fact that at least here, the Louisiana Limestone was deposited within storm wave base in the upper part of the outcrop exposed. Unfortunately, the isotope values, just like the HCS, demonstrate that his exposure is atypical of most Louisiana Limestone.

The underlying Saverton Formation is present at the base of this outcrop. Therefore, it appears that the Louisiana in this limited outcrop actually belongs to the lower part of the Louisiana, which is typically in the range of 20 meters in total thickness. This is puzzling given the fact that every other location where we have carbonate carbon isotope data the lower part of the Louisiana has only increasing isotope values and represents the onset of the Hangenberg Excursion. There is clearly something that we still do not understand with respect to how this section fits into the regional chronostratigraphic correlation of the Louisiana Limestone. One of several possibilities could be at play here. Either this outcrop contains some portion of the Louisiana that we normally don't find in other sections and/or that the incoming clastic source is somehow lowering the overall carbon isotope ratio of this succession; or that this section does not represent the Louisiana and instead could possibly be the McCraney instead. If the latter were true, then that would suggest that the unit at the base of the outcrop would be either the Hannibal or the Prospect Hill instead of the Saverton. At present it remains difficult to determine the correct answer without additional outcrop and core study that could connect this locality with other sections closer to the Mississippi River.

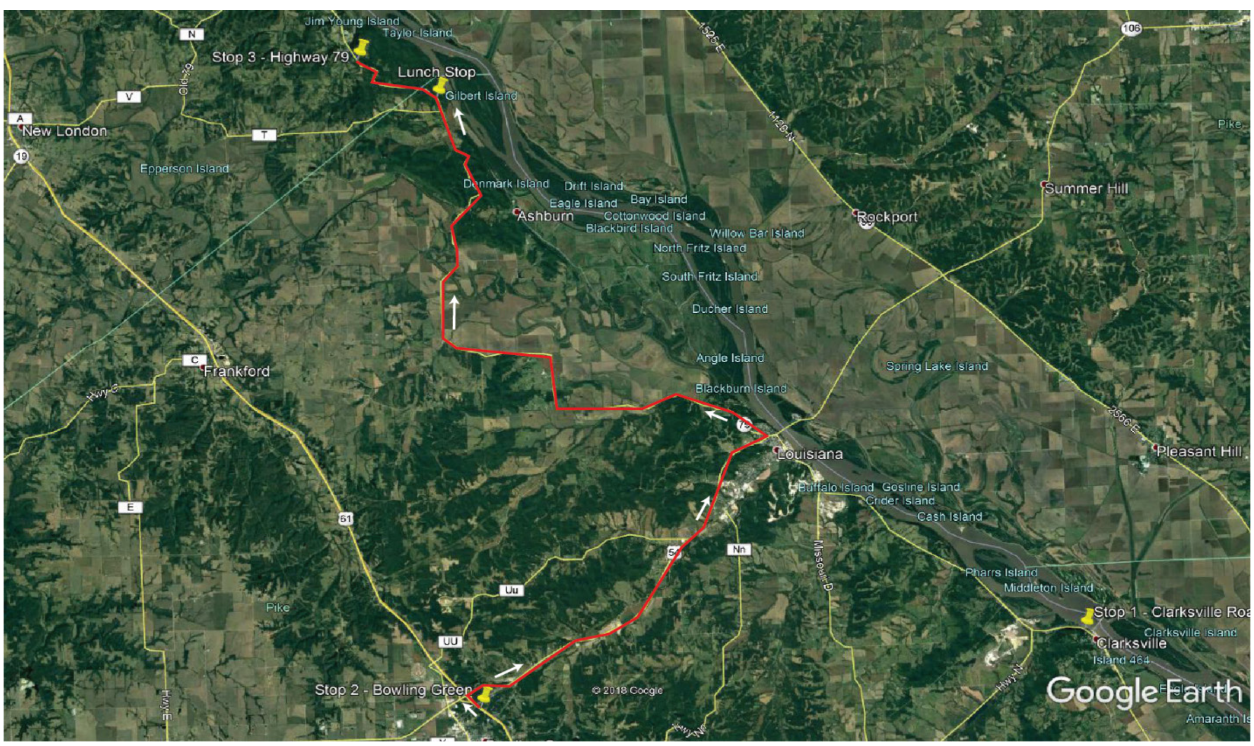

Figure 3: Travel directions between field stops 2 and 3.

STOP 3: Highway 79

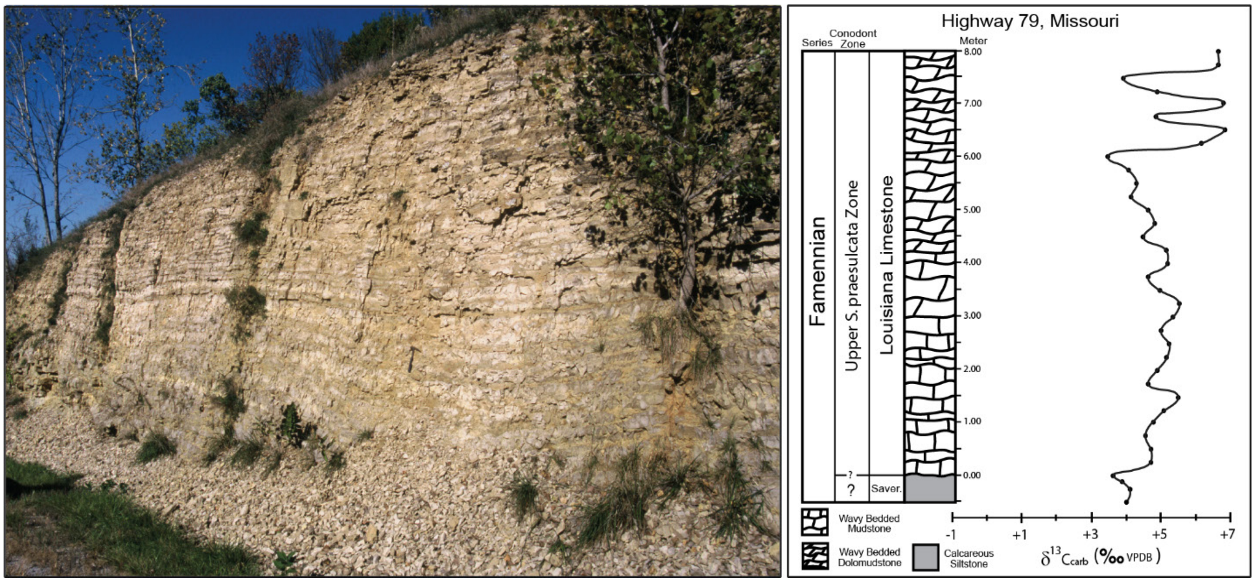

Figure 4: Highway 79 outcrop, measured section, and carbon isotope chemostratigraphy. Modified from Cramer et al. 2008.

This outcrop illustrates the typical lithology of the Louisiana Limestone. Carbonate carbon isotope values show elevated values greater than +5.0‰ typical of the Hangenberg positive excursion. Values remain elevated throughout the exposure reaching +6.8‰ near the very top of the succession. Undulatory bedding is often seen within the Louisiana throughout the region. Whereas you can often trace single beds throughout entire outcrops, they are rarely flay lying. Occasional scouring of beds and faint traces of storm influence can be seen. The Louisiana is fairly rubbly in the lower part of this outcrop with true bedding either absent or very difficult to identify.

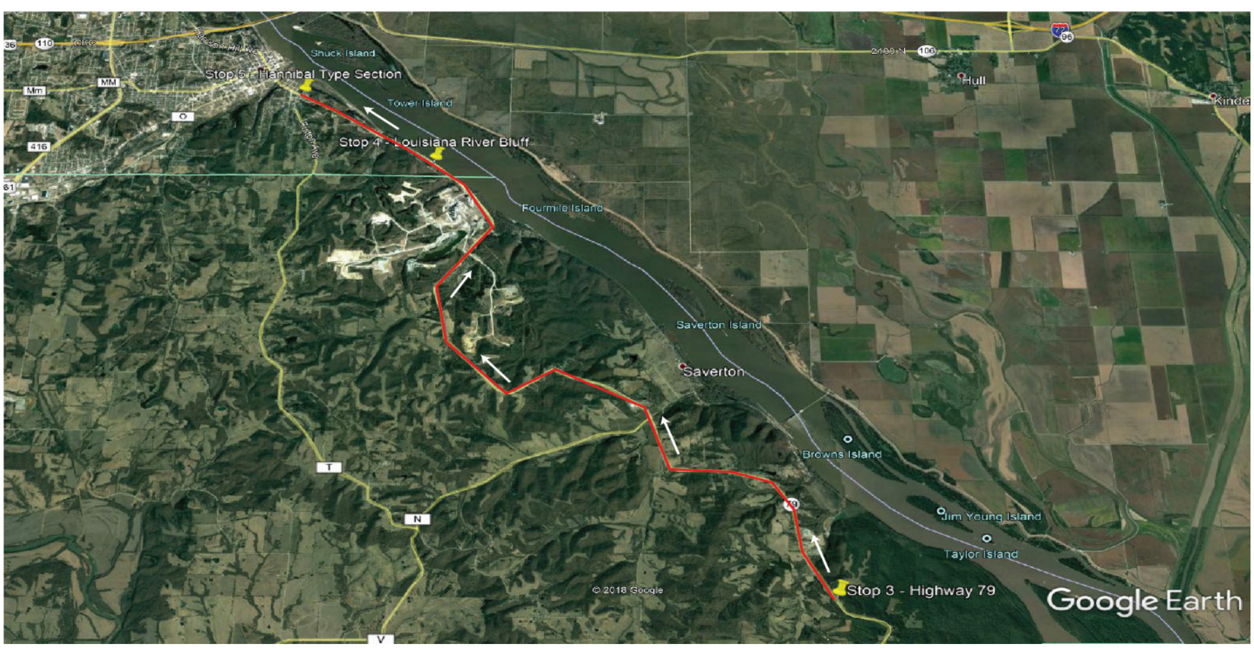

Figure 5: Travel directions between stops 3, 4, and 5.

STOP 4: 79 River Bluff

Figure 6: Outcrop photo of the Louisiana Limestone at the Highway 79 River Bluff section south of Hannibal, MO.

The Highway 79 River Bluff section includes a long exposure of the Louisiana Limestone. This section has not been sampled for either conodont biostratigraphy or carbon isotope chemostratigraphy recently and is one of the target sections that will be sampled in the near future for new integrated biochemostratigraphy. This section does include more strata above the Louisiana Limestone but it is extremely difficult to get to and is not well exposed. ***We do not suggest that anyone on the field trip try to access the upper parts of this section.***

The classical Lover's Leap section (Williams, 1943) as well as the Hannibal Shale Type Section, our stop 5, are less than two miles away from this section. At Lover's Leap, the Hannibal Shale overlies the Louisiana Limestone. This is the first area on the field trip where we can get a sense of the strata overlying the Louisiana Limestone. Williams (1943) argued that the Lover's Leap section illustrated a substantial unconformity between the Louisiana Limestone and the overlying Hannibal Shale as evidenced by more than two feet of channel erosion and downcutting at the top of the Louisiana. Scott & Collinson (1961) point out that no later authors were able to find nearly the same amount of channeling as described by Williams (1943). Elsewhere in the Mississippi Valley region there are localities where erosion and channeling at that level are easy to see, such as at Starr's Cave, in southeastern Iowa. However, those sections are substantially farther upramp than is the area around Hannibal. Our next locality exposes the very top of the Louisiana Limestone and then extends through the rest of the Kinderhookian succession.

STOP 5: Hannibal Type Section

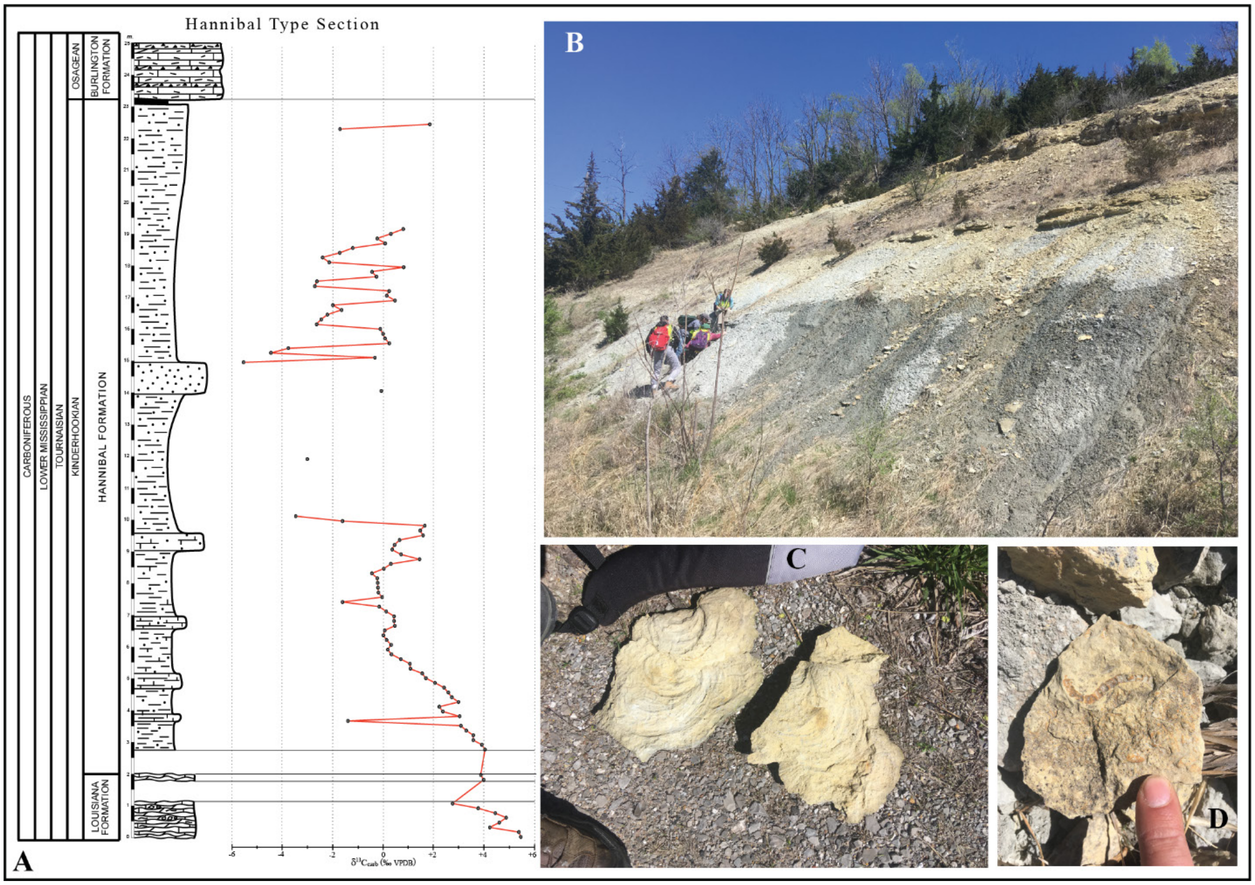

Figure 7: Measured section, carbon isotopes, and outcrop photos of the Hannibal Type Section. A) New carbonate carbon isotope data showing the end of the Hangenberg Excursion low in this section. B) Outcrop photo showing the Hannibal Shale. Note the increase in resistant sandy intervals up section. C) Zoophychus trace fossils from the middle of the Hannibal Shale. D) Scalarituba trace fossils from the middle of the Hannibal Shale at this locality.

The Hannibal Formation was erected by Keyes (1892) without a formal type section. However, it has become convention (e.g. Scott & Collinson, 1961) to consider the locality on Highway 79 just south of Hannibal, Missouri, as the Type Hannibal Shale. Here, the Louisiana Limestone underlies a thick (>20m) Hannibal Shale that progressively grades upwards into coarser and more clastic-rich facies. At the very top of this outcrop is the Burlington Formation, which we will spend more time examining on Sunday. The contact between the two is of interest at this locality due to the presence of a gummy green shale between the Hannibal and Burlington formations. This green shale is not typically exposed in other outcrops.

The lower part of the Hannibal Shale at this outcrop, far to the left of the exposure towards the city of Hannibal, was recently exposed due to a washout following major storms in the Spring of 2019. This interval was critical in sampling for carbon isotopes as well as new conodont biostratigraphy. The isotope data were available at the time of publication of this field guide (Fig. 7), however, the conodont biostratigraphy has not yet been completed. This will be part of an ongoing Ph.D. project at the University of Iowa. This is one of the best localities to collect trace fossils anywhere in the upper Midwest.

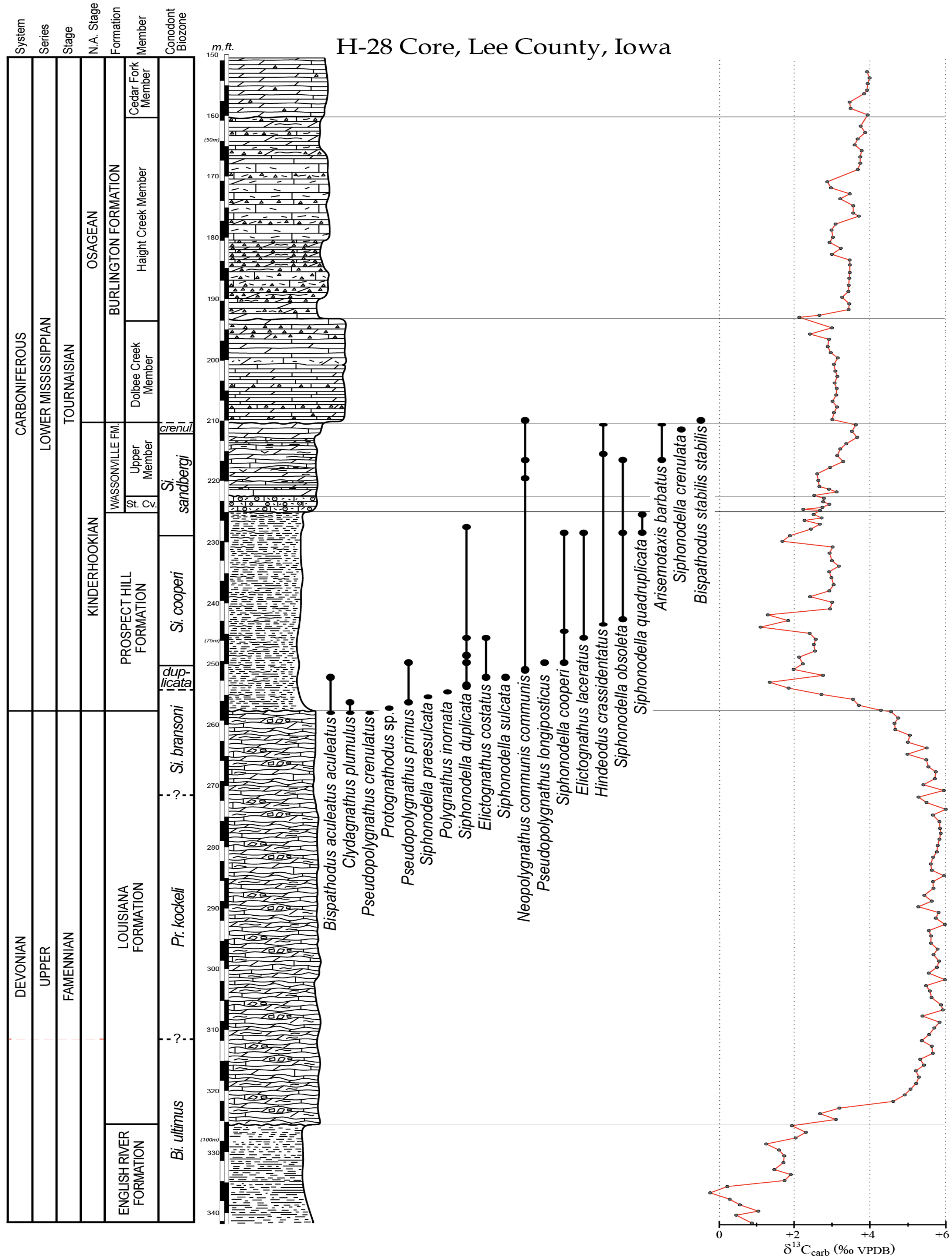

Figure 8: Litho-, bio-, and chemostratigraphy of the H-28 Core, Lee County, southeast Iowa, modified from Stolfus, 2018.

SUNDAY FIELD TRIP STOPS

STOP 6: Starr's Cave State Park and Preserve

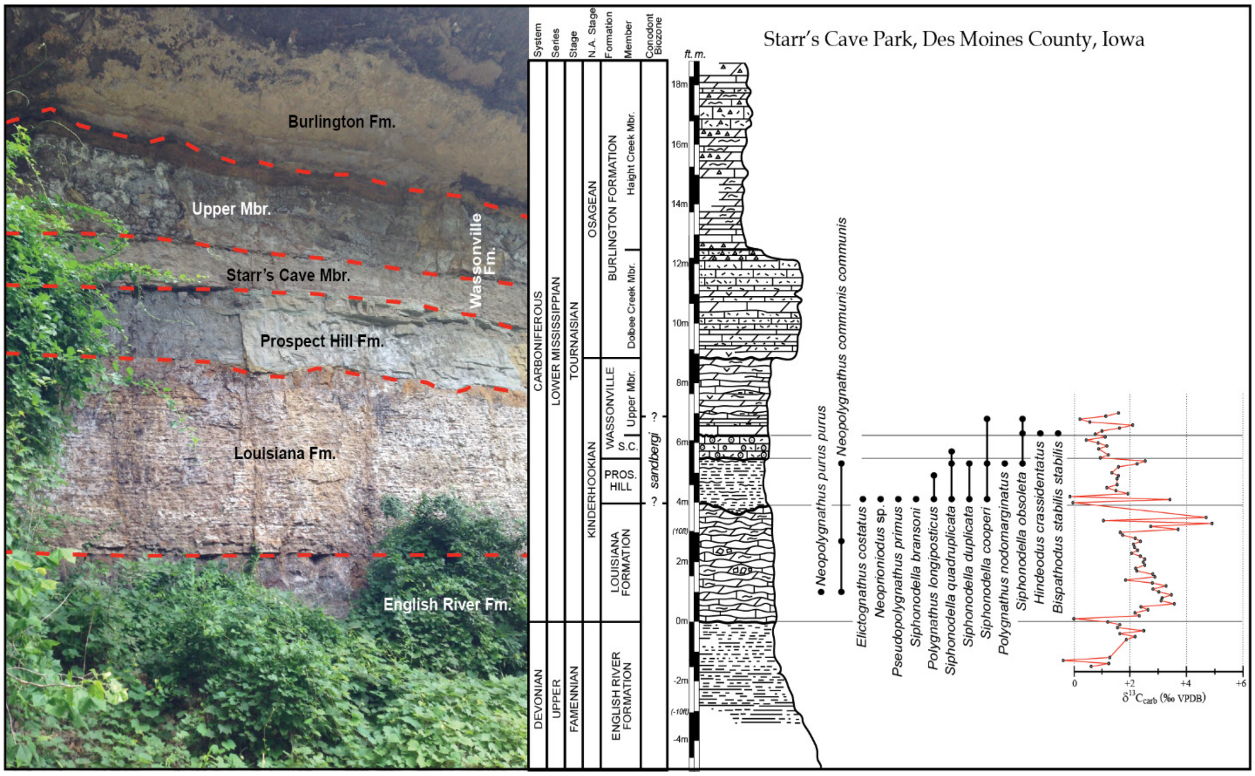

Figure 9: Outcrop photography, measured section, conodont, and carbon isotope bio-chemostratigraphy of the Starr's Cave Park and Preserve Section. What is referred to herein as the Louisiana Formation has traditionally been designated as the McCraney (e.g. Witzke & Bunker, 2002). See Stolfus (2018) and below for a discussion of why this unit is the Louisiana.

We have travelled much farther upramp to begin Day 2 of the field trip with our first stop at the Starr's Cave Park and Preserve. The H-28 drill core on the previous page illustrates a interval of stratigraphy between our previous day's stops and the morning of Day 2. Just as in the H-28 Core, the section at Starr's Cave contains the Louisiana Formation but here that unit sits below what is referred to as the Prospect Hill Formation. Elevated carbonate carbon isotope values indicative of the Hangenberg Excursion are present in the Louisiana in H-28 as well as Starr's Cave. Additionally, the unit that sits above the Louisiana in the H-28 Core has conodonts indicative of the *duplicata* and *cooperi* zones immediately above it. The biostratigraphy suggests a slightly later interval for the Prospect Hill in Starr's Cave, with the fauna there belonging to the *sandbergi* Zone. At Starr's Cave, the contact between the Prospect Hill and the Louisiana is clearly and erosive contact with some considerable relief developed on the top of the Louisiana. Farther up ramp in our next two stops you will see the Prospect Hill eventually disappear where the Wassonville Formation sits directly on top of the Louisiana Formation.

The major change to chronostratigraphic correlation of this interval in the tri-state area that has been demonstrated so far is that these units in southeastern Iowa belong to the Louisiana, nor the McCraney Formation as had been their previous assignment. The type McCraney sits at a position above the Prospect Hill and contains a considerably younger conodont fauna that is present in either the H-28 Core or the Starr's Cave Park and Preserve section.

STARR'S CAVE PRESERVE
NW SE NW and SW SW NE NW sec. 19, T70N, R2W, DesMoines Co., Iowa
section description by Brian J. Witzke and Bill J. Bunker, 11/12/1997
Originally Appeared in Iowa Geological Survey – Guidebook 23

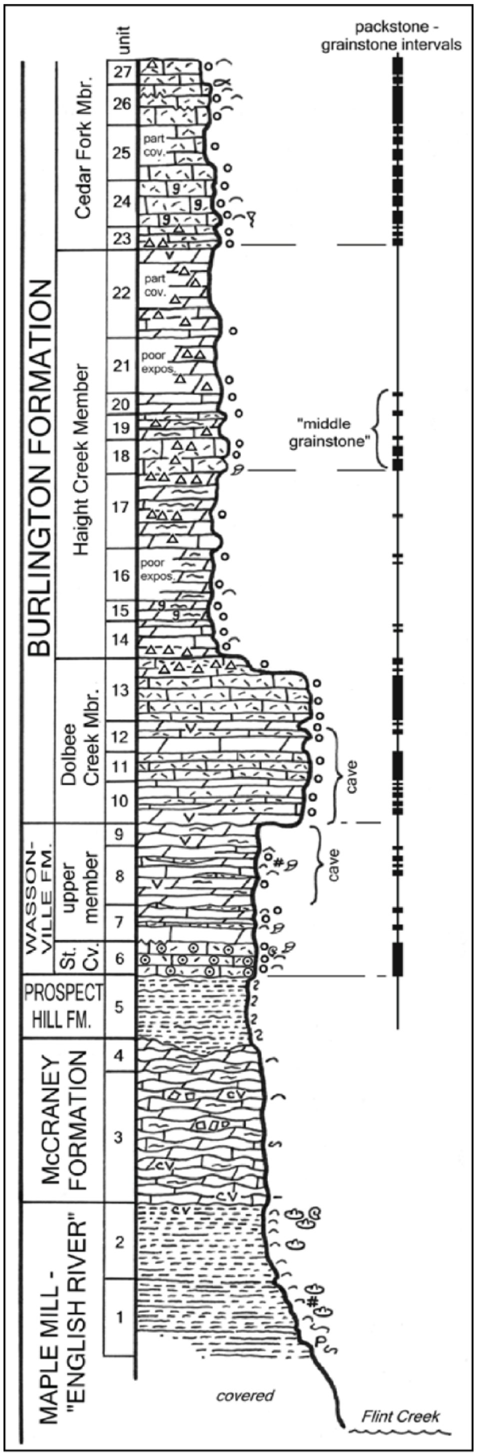

Figure 10: Stratigraphic column for Starr's Cave Park and Preserve from Witzke & Bunker, 2002. Note their McCraney Fm. is now the Louisiana

BURLINGTON FORMATION
CEDAR FORK MEMBER
Unit 27. Limestone, crinoidal packstone-grainstone; in two beds, lower 25 cm very coarse crinoidal, horn coral noted; upper 35 cm medium to coarse crinoidal, chert nodule at top, large *Spirifer grimesi*. 60 cm (2.0 ft).
Unit 26. Limestone, dominantly fine- to coarse-grained crinoidal packstone-grainstone, stylolites common in upper half; 60-76 cm above base is skeletal wackestone-packstone; upper 12 to 17 cm with silicified crinoidal debris and brachiopods, common to abundant large *Spirifer grimesi* (to 6 cm), fish bone noted at top. 92 cm (3.0 ft).
Unit 25. Limestone, crinoidal packstone-grainstone and wackestone-packstone, partly covered, basal 34 cm is wackestone-packstone ledge. 1.24 m (4.1 ft).
Unit 24. Limestone, crinoidal packstone and packstone-grainstone, traces of glauconite through most of unit; lower 28 cm forms ledge, fine crinoidal packstone at base, coarsens upward to coarse-grained crinoidal packstone, crinoid cup noted, scattered silicified crinoid debris and brachiopods; 28-60 cm above base slightly recessive fine to medium crinoidal packstone, silicified crinoid debris at base; upper 42 cm includes fine to coarse crinoidal packstone-grainstone and packstone, faint laminations concentrate glauconite, lower and middle parts with scattered large brachiopods. 1.02 m (3.35 ft).

HAIGHT CREEK MEMBER
Unit 23. Limestone and dolomite; lower 20 cm is limestone, crinoidal packstone, scattered large chert nodules (to 20 cm); 20-36 cm above base, limestone, crinoidal wackestone to packstone; top 20 cm, limestone, recessive, fine crinoidal wackestone-packstone, chert nodules. 56 cm (1.8 ft).
Unit 22. Dolomite to dolomitic limestone; lower 20 cm prominent bed, dolomitic limestone, wackestone, scattered crinoid debris, scattered chert nodules; 20-65 cm above base ledges of vuggy dolomite and calcitic dolomite, scattered crinoid debris molds, interval also includes calcitic crinoidal wackestone, chert nodules scattered through (4-15 cm diameter); 30-130 cm below top is mostly covered, float indicates dolomite with chert nodules; top 30 cm is dolomite, vuggy, part covered. Approximately 1.95 m (6.4 ft).
Unit 21. Dolomite to dolomitic limestone, poorly exposed; dolomite with scattered crinoid debris molds; scattered chert nodules in lower 40 cm, large chert nodules 45 cm below top of unit. Approximatley 1.2 m (3.9 ft).

Unit 20. Dolomite, scattered crinoid debris molds; discontinuous lenses of dolomitic limestone, crinoidal wackestone-packstone in upper part; part poorly exposed. 50 cm (1.6 ft).

Unit 19. Dolomite to dolomitic limestone, dense, recessive, faintly laminated, scattered large chert nodules; upper 16 cm is ledge former, limestone, fine to medium crinoidal packstone. 61 cm (2.0 ft).

Unit 18. Limestone, crinoidal packstone, in two beds; lower 36 cm with coarse crinoid debris, brachiopods, horn coral at base, fine to medium packstone upward, scattered chert nodules in upper part; upper 39 cm with large nodular to bedded chert, dense, smooth, faintly laminated mudstone fabrics, 5 to 20 cm thick at top and bottom of upper interval; upper interval with interbedded limestone, fine to medium crinoidal packstone. 75 cm (2.5 ft).

Unit 17. Dolomite to dolomitic limestone; basal 35 cm ledge, calcitic dolomite, scattered chert nodules; 35-65 cm above base, dolomite, faintly laminated; 65-80 cm above base, large chert nodule, white, smooth, partly a silicified crinoidal wackestone to packstone; 80-110 cm above base, dolomite to dolomitic limestone, skeletal wackestone in lower part, faintly laminated dolomite in upper part; 110-138 cm above base, dolomite, faintly laminated; top 27 cm, nodular to bedded chert, nonskeletal mudstone fabric, faintly laminated, silicified large crinoid debris on upper surface. 1.65 m (5.4 ft).

Unit 16. Dolomite, poorly exposed, lower part with scattered silicified brachiopod and crinoid debris, faintly laminated at base; upper part with scatttered skeletal debris and thinly interbedded stringers of dolomitic limestone (crinoidal packstone). 1.2 m (3.9 ft).

Unit 15. Dolomite, recessive, very finely crystalline, part faintly laminated, scattered to common fine glauconite grains (dark green) especially along laminae; glauconite content generally decreases upward. 40 cm (1.3 ft).

Unit 14. Dolomite and dolomitic limestone; basal 23 cm is crystalline dolomite interval with very large chert nodules (to 20 x 50 cm); 23-52 cm above base, dolomite and dolomitic limestone, scattered crinoid and brachiopod molds, also includes fine crinoidal packstone; 52-68 cm above base, narrow ledge, dolomite to dolomitic limestone, dense, burrowed, scattered crinoid debris molds at top (including *Platycrinites*), part with calcitic crinoid debris; top 14 cm is recessive dolomite, scattered skeletal molds, includes minor dolomitic limestone (crinoidal packstone), gradational above. 82 cm (2.7 ft).

DOLBEE CREEK MEMBER

Unit 13. Limestone, crinoidal packstone-grainstone; very coarse crinoidal packstone-grainstone in basal 15 cm, 28-40 cm above base, 55-75 cm above base; remainder is primarily fine to medium crinoidal packstone-grainstone, part slightly dolomitic; upper 40-45 cm crinoidal packstone contains very large chert nodules (70 x 25 cm; 170 x 35 cm), smooth chert, silicified skeletal mudstone to wackestone; laterally discontinuous thin dolomite, skeletal moldic, 45-50 cm below top Approximately 1.4 m (4.6 ft).

Unit 12. Dominantly dolomitic limestone; basal 33 cm dolomitic limestone, sparsely crinoidal wackestone fabric; 33-42 cm above base, limestone, very coarse crinoidal packstone-grainstone, fines upward, large-scale bedform; upper 25 cm is recessive, dolomite to dolomitic limestone, vuggy, sparse skeletal molds, scattered crinoid debris molds, top 7 cm is discontinuous crinoidal packstone lens. 67 cm (2.2 ft).

Unit 11. Limestone, crinoidal packstone-grainstone, a stacked series of graded bedforms each coarse to very coarse at the bases, fine to medium upward; succession of graded units 19, 10, 9, 8 12, and 6 cm thick; *Platycrinites* stem segments noted; prominent bedding break 47 cm above base. 65 cm (2.1 ft).

Unit 10. Dolomite and limestone; overhang at base, irregular base with up to 10 cm relief; lower 43-45 cm is dolomite to dolomitic limestone, part vuggy, scattered crinoidal molds, some calcitic crinoid debris, discontinuous thin crinoidal packstone stringers in upper 16 cm; 43-55 cm above base is limestone, part dolomitic, crinoidal packstone, laterally replaced by crinoidal wackestone, crinoid stems and columnals; upper 40 cm is limestone and dolomitic limestone, lower half with discontinuous crinoidal packstone stringers, prominent crinoidal packstone-grainstone at base, upper half is dolomitic limestone with discontinuous crinoidal wackestone-packstone lenses. 95 cm (3.1 ft).

WASSONVILLE FORMATION
UPPER MEMBER

Unit 9. Dolomite, nodular to irregular bedded aspect, “zebra-striped” appearance in part, wavy to contorted laminations best developed in lower 15 cm; scattered vugs; upper surface irregular with up to 10 cm relief locally; overhang above. 53 cm (1.7 ft).

Unit 8. Dominated dolomite and dolomitic limestone; lower 68-76 cm is dolomite, part vuggy, faint hummocky to laminated fabric; upper 60-70 cm dominantly dolomitic limestone, skeletal wackestone fabric, scattered crinoid debris and brachiopods, part moldic, interbedded with limestone, skeletal packstone lenses and discontinuous beds (to 20 cm thick), most prominently developed 68 to 106 cm above base, locally in top 10 cm; brachiopods (*Rugosochonetes*, *Unispirifer*, *Brachthyris*, *Spinocarinifera*, etc.), crinoid debris, bryozoans, cup corals. 1.3-1.38 m (4.3-4.5 ft).

Unit 7. Limestone to dolomitic limestone, locally dolomite to dolomitic limestone in upper part, increasingly dolomitic upward; dominantly a skeletal wackestone with scattered to common brachiopods (*Spinocarinifera*, *Schellwienella*, etc.), crinoid debris, scattered cup corals; argillaceous streak 13 cm above base; starved lenses and discontinuous bedforms of coarse crinoidal packstone locally noted 29-40 cm above base and top 10 cm, top packstone forms starved megaripples with 1.3 m wavelength (top of unit 0-10 cm thick); upper dolomite locally with stringers of crinoidal molds. 78-88 cm (2.6-2.9 ft).

STARR’S CAVE MEMBER (type section)

Unit 6. Limestone, oolitic and skeletal packstone to grainstone; very fossiliferous with brachiopds (*Rugosochonetes*, *Unispirifer*, *Brachythyris*, *Schellwienella*, *Rhipidomella*, etc.), crinoid debris (coarse at top), scattered gastropods, cup coral (noted at top); prominent stylolite at top of unit; silicified domains locally in upper part (not quite developed into nodular chert). 74 cm (2.4 ft).

PROSPECT HILL FORMATION

Unit 5. Siltstone, light brown gray, part tinted light green, part slightly argillaceous; 40 cm erosional incision locally at base, infills depression (channel form); basal fill, finely laminated to low-angle cross laminated, penetrated by vertical to subvertical burrows (10 cm maximum burrow penetration); remainder of unit finely laminated to low-angle cross laminated (hummocky), scattered vertical burrows penetrate across laminae; thin discontinuous light green-gray noncalcareous shale along upper surface (0-5 cm thick); thin shale parting 10 cm below top; 5-6 cm relief locally noted along upper surface. 1.45-1.85 m (4.8-6.1 ft).

LOUISIANA FORMATION

Unit 4. Dolomite, part calcitic, light brown, part with faint wavy laminations; rare rhynchonellid brachiopod molds noted; erosional upper surface displays up to 40 cm relief (over a horizontal distance of 3 m). 30-70 cm (1.0-2.3 ft).

Unit 3. Limestone and dolomite, alternations of light-colored elongate nodular limestone and darker colored dolomite create an irregular “zebra-striped” pattern on exposure, unit is approximately 2/3 limestone, 1/3 dolomite; limestone, dense, light buff, part finely laminated, laminations irregular to wavy, limestone beds displayed as elongate nodular-like bedforms, scattered stylolites, limestone is fractured in part, fractures filled with dolomite; dolomite, very fine to finely crystalline, light medium to medium brown; unit has scattered calcite void fills (to 15 cm diameter), sphalerite noted in calcite void fills at base and 50 cm below top of unit; fractured dense limestone locally brecciated, 1-5 cm limestone clasts in dolomite matrix, breccia noted 50 cm and 1.3 m below top of unit. 3.0 m (9.8 ft).

UPPER DEVONIAN (Famennian)

ENGLISH RIVER/ MAPLE MILL FORMATION (SAVERTON FORMATION)

Unit 2. Siltstone, light medium to medium gray, part slightly argillaceous, part slightly burrowed; part pyritic (oxidized to sulfate blooms on upper surface); fossil molds scattered to common, most common in upper 50 cm, brachiopod-rich lens 20 cm below top; scattered calcite void fills in upper part; brachiopods include *Chonopectus*, *Whidbornella*, *Mesoplica*, *Schizophoria*, *Syringothyris*, others; bivalves (pelecypods) scattered to common in upper part; scattered gastropods; up to 10 cm of relief locally developed on upper surface. 1.75-1.85 m (5.7-6.1 ft).

Unit 1. Siltstone and silty shale; dominantly siltstone, medium gray, slightly argillaceous to argillaceous; shale, medium dark gray to green-gray, silty to very silty, gradational with siltstone intervals, shale partings at top and 115 cm below top; shale dominated 20 to 40 cm above base with scattered phosphatic grains; pyritized burrows 50 cm above base; upper 1.15 m siltstone interval with scattered to common fossil molds including bivalves, fenestellid bryozoans, brachiopods (as in unit 2). 1.65 m (5.4 ft) thick; an additional 1.7 m (5.6 ft) covered below to level of Flint Creek, probably shale-dominated.

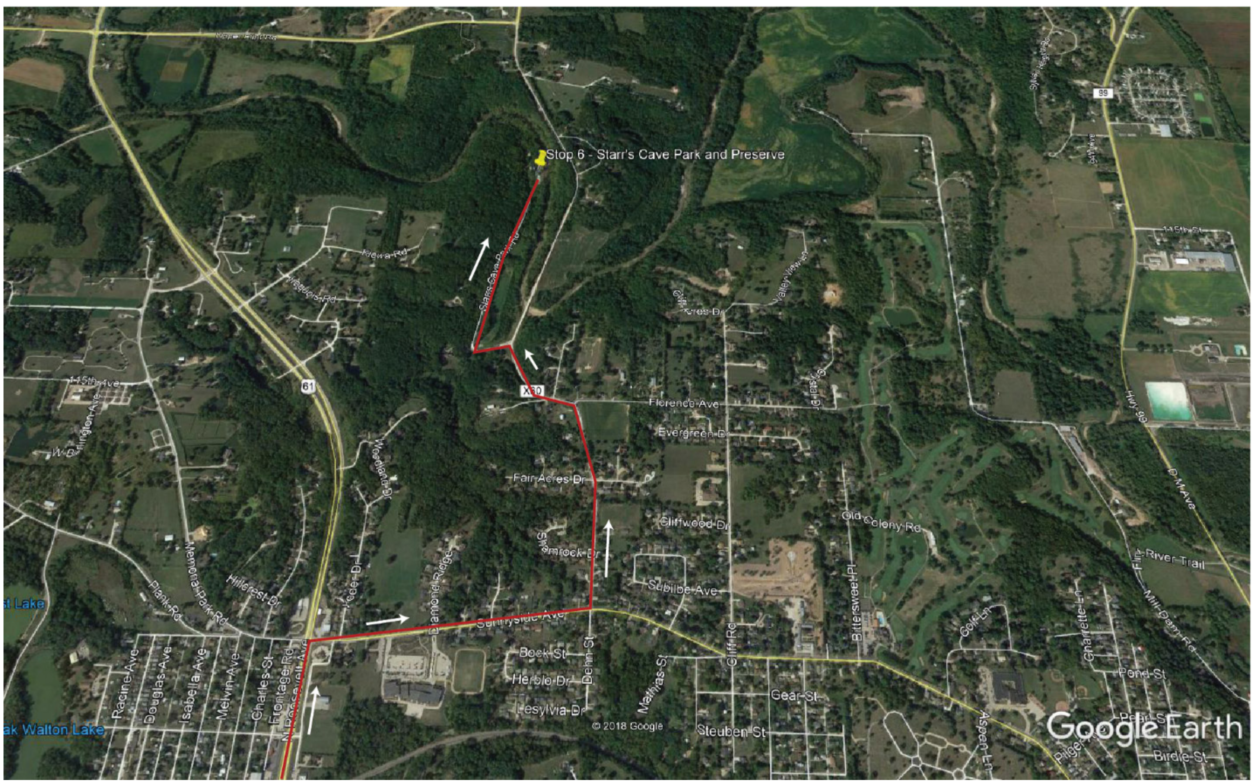

Figure 11: Driving directions to Starr's Cave coming north on U.S. 61 from Quincy, Illinois

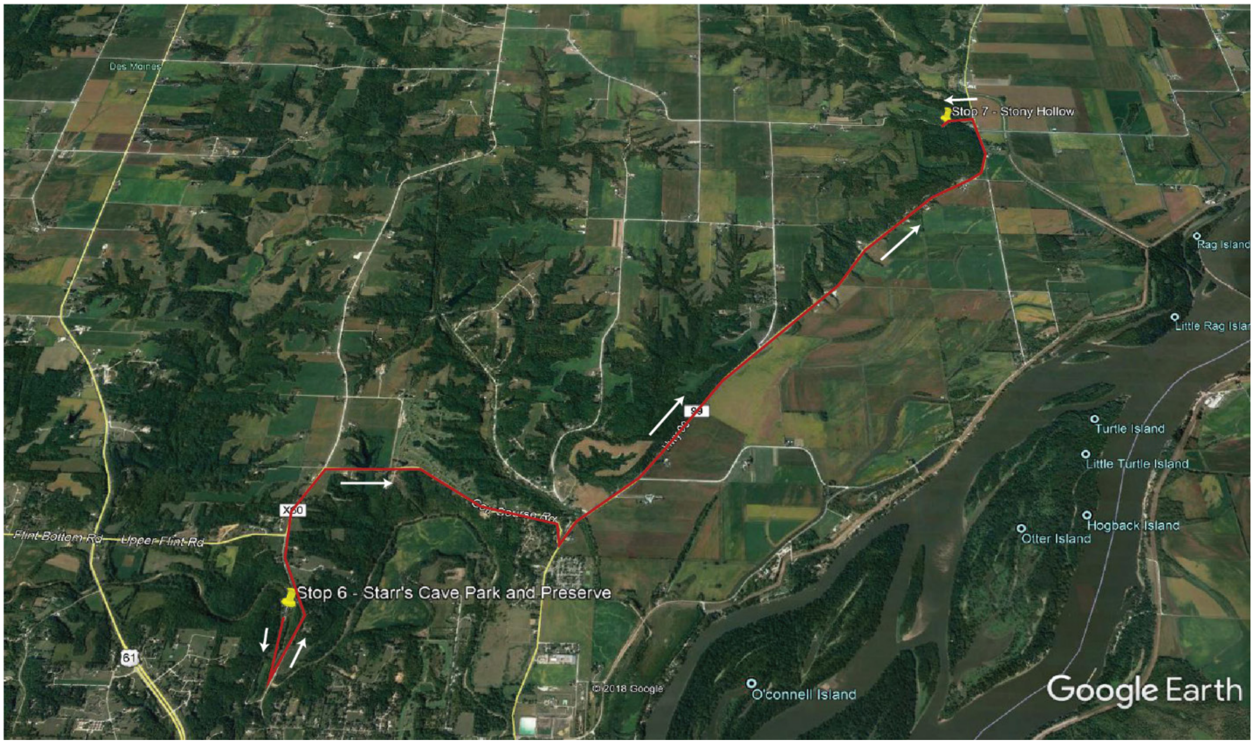

Figure 12: Driving directions from Starr's Cave (Stop 6) to Stony Hollow (Stop 7)

Figure 13: Brian Witzke and Bill Bunker comtemplating Mississipian strata exposed along Stony Hollow Road

STOP 7: Stony Hollow Road

INTRODUCTION

Ray Anderson

Originally appeared in Iowa Geological Survey Guidebook 23

Field Trip Stop 3 provides another look at the lowermost Mississippian in the area (Fig 20). Stony Hollow Road follows an unnamed tributary to Yellow Spring Creek from the uplands, through the rock bluffs, to the Mississippi River floodplain. The exposures along the unnamed creek lie on land owned by Mr. Linton Murphy, who has graciously granted permission for Tri-State participants to access the rock faces.

Please respect Mr. Murphy's property.

After we exit the buses, we will be on a gravel road that carries a fair amount of traffic.

BE CAREFUL AND RESPECT THE KINETIC ENERGY OF MOVING VEHICLES.

THE ROCKS ALONG STONY HOLLOW ROAD

The units we will see at Stony Hollow include the Devonian siltstones of the English River Fm at the base of the section, overlain by limestones and dolomites of the Mississippian "McCraney" Fm. (now Louisiana), which, are directly overlain by the oolitic limestones of the Starr's Cave Mbr. of the Wassonville Formation. This latter relationship is unusual because of the absence of the Prospect Hill Siltstone, which usually lies between the two units. Above the Starr's Cave lies the unnamed upper unit dolomites of the Wassonville Fm., the dolmites and limestones of the Dolbee Creek Mbr., Burlington Fm., and at the top of the section the cherty dolomites of the Haight Creek Member. We will travel down the road to the base of the section along the creek on the south side of the road, where siltstones of the Upper Devonian English River Fm. are exposed in and along the creek.

Moving up the creek, Mississippian rocks of the "McCraney" Fm. (now Louisiana) are exposed above the English River. Note the oolitic limestone at the base of the McCraney. Continuing up the creek, a small drainage enters the creek from the south, cascading over a meter-high ledge of English River Fm. Those climbing up the side drainage will be treated to a beautiful little grotto, a plunge pool created by intermittent high water flows cascading over resistant Burlington Fm strata.

As we move into the area of the exposure near the parked buses, a highwall of "McCraney" (now Louisiana), Wassonville, and Burlington fms is present, but only the "McCraney" is easily accessible in this area. To get close-up and personal with these units requires climbing the steep slopes on the north side of the road near the base of the exposure.

WE DO NOT SUGGEST ANYONE CLIMB THIS SLOPE!

STONY HOLLOW ROAD; roadcuts and stream cuts
SE SW NW and SW SE NW sec. 35, T71N, R2W; DesMoines Co., Iowa
measured by B. Witzke, B. Bunker, R. Anderson; 8/19/2002
top of section is a forested slope; colluvium of Burlington dolomite and chert clasts in loess-derived soil
Originally Appeared in Iowa Geological Survey – Guidebook 23

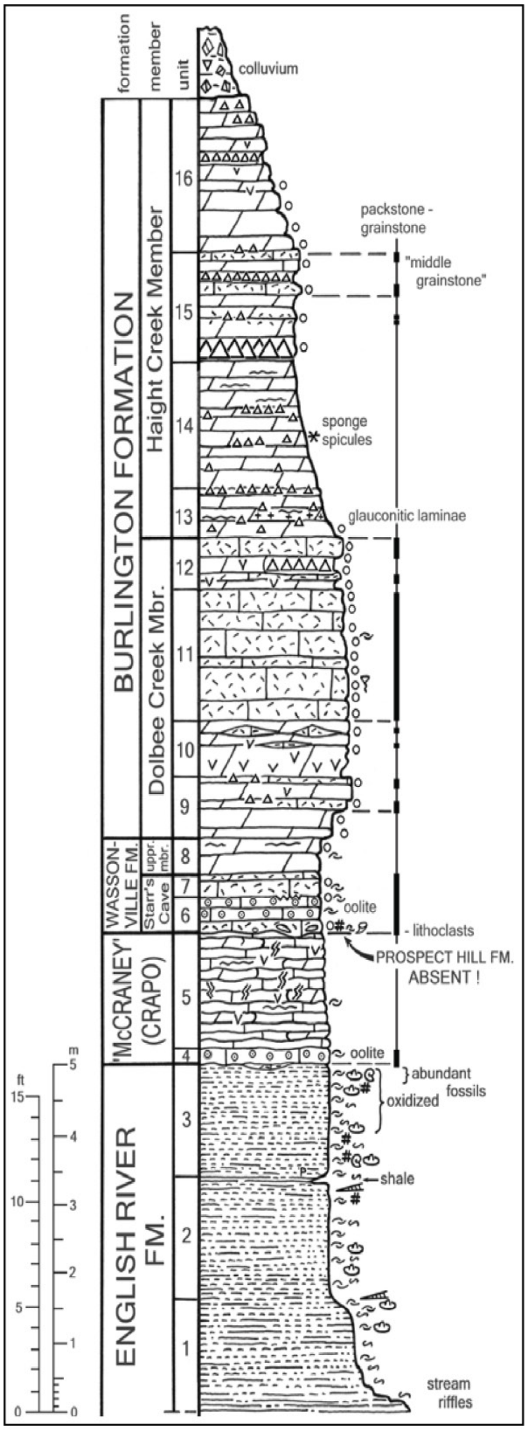

Figure 14: Stratigraphic column for Stony Hollow from Witzke & Bunker, 2002. Note the absence of the Prospect Hill Formation below the Wassonville.

MISSISSIPPIAN (Osagean)
BURLINGTON FORMATION
Haight Creek Member (lower and middle parts only)

Unit 16. Dolomite; slope former, some rock ledges, part covered; dolomite, very fine to fine crystalline with common crinoid debris molds in the lower part, poikilotopic calcite cements common, some silicification of crinoid grains; dolomite above is variably very fine and fine to medium crystalline, part with large vugs, scattered crinoid debris molds; scattered chert nodules, large chert nodules in upper 40 cm; 1.45 m above base of unit is nodular to bedded chert band to 10 cm thick. Maximum thickness 2.2 m (7.2 ft); unit is locally colluviated to absent along slope.

Unit 15. Dolomite, in ledges 10 to 25 cm thick, overhanging ledges 97 cm above base of unit; unit is dominated by dolomite and dolomitic limestone, partly skeletal moldic; interbedded with limestone, fine to medium-grained skeletal/crinoidal packstones noted at 55 cm (l-4 cm thick), 65 cm (lens 0-4 cm thick, locally chertified), 97-112 cm(packstone-grainstone), and 148-162 cm (fine to coarse crinoidal packstone) above base of unit; dolomitic limestone, sparse mudstone, at 128-139 cm above base; massive chert bed in basal 35 cm, smooth white to pale gray, includes silicified crinoidal wackestone to packstone top 1 cm; massive smooth chert bed noted 112-128 cm above base of unit; unit encompasses the "middle grainstone" interval of the Burlington Fm. 1.62 m (5.3 ft) thick.

Unit 14. Dolomite, slope former, thin to irregularly bedded, weathers into crumbly slopes, basal 25 cm is mostly covered; dolomite, very fine to fine crystalline, part is faintly and finely laminated, scattered chalcedony/silicification as pore fillings, scattered to common sponge spicule molds in part (70 cm above base of unit); nodular cherts noted at 32 cm, 60-70 cm (nodules to 8 x 35 cm), 105 cm, and 115 cm (nodules to 8 x 45 cm) above base of unit. 1.85 m (6.1 ft) thick.

Unit 13. Dolomite, slope former, ledges in upper 18 cm, vuggy re-entrant at base; dolomite, very fine crystalline, scattered silicificationi, common poikilotopic calcite cements, scattered crinoid debris molds in lower part; 30 to 40 cm above base of unit is thinly bedded to laminated, part glauconitic to very glauconitic laminae; scattered chert nodules noted 11 cm (to 4 x 15 cm), 26 cm (to 6 x 15 cm), 48 cm, and 67-75 cm (may be bedded chert band) above base of unit. 75 cm (2.5 ft) thick.

Dolbee Creek Member

Unit 12. Interbedded dolomite, limestone, and chert; lower 47 cm is dolomite dominated, fine crystalline, scattered crinoid debris molds, scattered to common vugs, scattered poikilotopic calcite cements; uppper 30-32 cm of unit is a coarse to very coarse crinoidal packstone-grainstone, *Platycrinites* columnals noted, local ledge former, skeletal moldic in upper part; 22 cm above base is 4-9 cm crinoidal packstone-grainstone forming a megaripple bedform; top of very large chert nodule noted 45 cm above base, chert nodule up to 20 cm thick x 1.5 m wide, smooth chert, white to light gray. 75 cm (2.5 ft) thick.

Unit 11. Limestone, cliff-forming ledges, dominantly a crinoidal packstone-grainstone; unit comprised of a stack of graded beds 8 to 32 cm thick, graded beds show very coarse crinoid debris, stems, scattered cups at base, grading upward into fine- to medium-grained crinoidal limestones; tops of graded beds noted at 28, 48, 75 cm, 92 cm, 124 cm, 131 cm, 139 cm, 158 cm, 166 cm, and 176 cm above base of unit; very large crinoid stems/columnals to 2 cm diameter occur in unit, scattered *Platycrinites* columnals; brachiopod noted 60 cm below top of unit. 1.9 m (6.2 ft) thick.

Unit 10. Dolomite ledges with limestone lenses, locally in overhanging ledges, locally with prominent vuggy re-entrant in basal 20 cm; dolomite, part calcitic, scattered to common small to large crinoid debris molds, locally very vuggy (especially in lower part); limestone, crinoidal packstone, part silicified, lenses noted 45 cm (coarse crinoid debris, cups) and 66 cm (discontinuous 0-7 cm thick) above base of unit. 79 cm (2.6 ft) thick.

Unit 9. Dolomite with limestone lenses, unit forms prominent overhanging ledges (especially at base, 53 cm above base, top); dolomite, calcitic, scattered to common fine to coarse crinoid debris molds (coarsest upwards), scattered small vugs (1-2 cm); limestone to dolomitic limestone, crinoidal packstone-grainstone lenses noted 40-54 cm above base and topmost 11 cm (replaced laterally by crinoid-moldic dolomite); basal contact is subtle but probably represents a disconformity. 88 cm (2.9 ft) thick.

MISSISSIPPIAN (Kinderhookian)
WASSONVILLE FORMATION
Upper Member

Unit 8. Dolomite, in 2 or 3 ledges, locally rubbly and irregularly bedded; dolomite, calcitic, poikilotopic calcite cements; fine to medium crystalline, scattered crinoid debris and brachiopod (chonetids) molds, fine laminations near top. 50 cm (1.6 ft) thick.

Starrs Cave Member

Unit 7. Limestone, medium bedded, skeletal packstone, dominantly finely crinoidal, scattered to common coarse crinoid debris, scattered brachiopods (includes chonetids, *Unispirifer*, others); unit becomes dolomitic upwards (wackestone to packstone fabrics); prominent bedding break at top. 35 cm (1.1 ft) thick.

Unit 6. Limestone, skeletal to oolitic packstone; basal 15-22 cm is a skeletal/crinoidal packstone, crinoidal (fine to coarse debris), scattered brachiopods (chonetids), scattered fenestellid bryozoans, scattered small cup corals, scattered lithoclasts (to 6 cm diameter) reworked from unit 5; upper 35-40 cm is a skeletal/oolitic packstone (ooids smaller than in unit 4, ooid diameters < 1 mm), becomes more skeletal and less oolitic upwards, stylolite near top. 50-57 cm (1.6-1.85 ft) thick; 5 to 7 cm relief on basal surface.

Note: **PROSPECT HILL FORMATION** is **absent** at this locality.

"McCRANEY" FORMATION (CRAPO FORMATION) [NOW LOUISIANA FORMATION]

Unit 5. Limestone with scattered dolomite nodules; irregular discontinuous bedding, wavy to nodular bedforms; limestone is dense, extremely finely crystalline, part faintly finely laminated, scattered fractures with internal sediment fills (limestone), other subvertical fractures filled with dolomite, low-angle cross-laminae noted 65 cm above base, scattered vugs (1-15 cm diameter), lens of small brachiopods noted 75 cm above base; dolomite nodules and fracture fills scattered through, light medium brown, fine to medium crystalline; upper contact is mostly planar, but locally shows up to 7 cm of relief. 1.63-1.7 m (5.3-5.6 ft) thick.

Unit 4. Limestone, dominantly a coarse oolite; oolitic packstone-grainstone, ooids larger than in unit 6 (> 1 mm); minor skeletal grains in oolite include brachiopods, rare crinoid debris, and scattered molds of high- and low-spire gastropods; oolite displays mega-ripple bedforms (noted wavelength of 1.3 m between crests), 17 to 24 cm thick, thin oolitic laminae interdigitate with overlying unit off bedform crests; slightly irregular basal contact with up to 5 cm of relief, basal swales infilled with brachiopod packstone (0-5 cm thick), abundant calcite fills and red-brown iron-oxide staining, abundant chonetid brachiopods (most poorly preserved). 17-25 cm (0.6-0.8 ft) thick.

DEVONIAN (Famennian)
ENGLISH RIVER FORMATION
Unit 3. Siltstone, argillaceous, generally less argillaceous upwards, medium blue-gray (unoxidized lower 50 cm), becomes increasingly oxidized upwards with hues of yellow-brown to orange-brown; lower half of unit with scattered fossil molds including brachiopods (especially chonetids), bivalves, gastropods, fenestellid bryozoans (fronds to 4 cm), horizontal burrows; unit becomes more fossiliferous upwards, especially upper 50 cm, common brachiopods (especially *Chonopectus*, also productids, spiriferids, others), scattered bivalves, gastropods (high- and low-spire), nautiloids, fenestellid bryozoans, crinoid debris molds (calcitic columnals also noted); top 10-15 cm with abundant chonetid brachiopod molds (*Chonopectus*) and other fossils; basal part (above underlying shale) with scattered phosphatic pellets (1-2 mm); sharp and slightly irregular contact at top of unit. 1.58-1.75 m (5.2-5.7 ft) thick.
Unit 2. Siltstone, argillaceous, medium blue-gray, scattered pyrite nodules (to 3 cm diameter), argillaceous to shaly streaks in upper part; scattered horizontal burrow mottles; scattered molds of brachiopods (includes spiriferids, productids, chonetids), bivalves, gastropods, fenestellid bryozoans, nautiloids (noted near top of unit); top 5-7 cm is a silty shale, medium gray, with scattered large siltstone-filled burrows (to 2.5 cm diameter). 1.75 m (5.7 ft) thick.
Unit 1. Siltstone, argillaceous, medium blue-gray; most of unit displayed as ledges (part slightly calcite cemented) and riffles in stream bed, upper part forms cascades, becomes slightly harder (more indurated) upwards; scattered pyrite nodules (to 2 cm) especially near top; basal 10-15 cm is a silty shale to shaly siltstone ("Maple Mill Shale" lithology) with faint horizontal burrow mottles; lower half of unit with scattered horizontal burrow mottles, rare brachiopod molds (includes productids); upper half of unit is more fossiliferous with scattered molds of brachiopods (spiriferids, chonetids, *Schizophoria*, others) and bivalves, nautiloids noted near top.

Figure 15: Driving directions between Stony Hollow and Crapo Park. Inset map close-up view of Burlington, Iowa.

STOP 8: Crapo Park

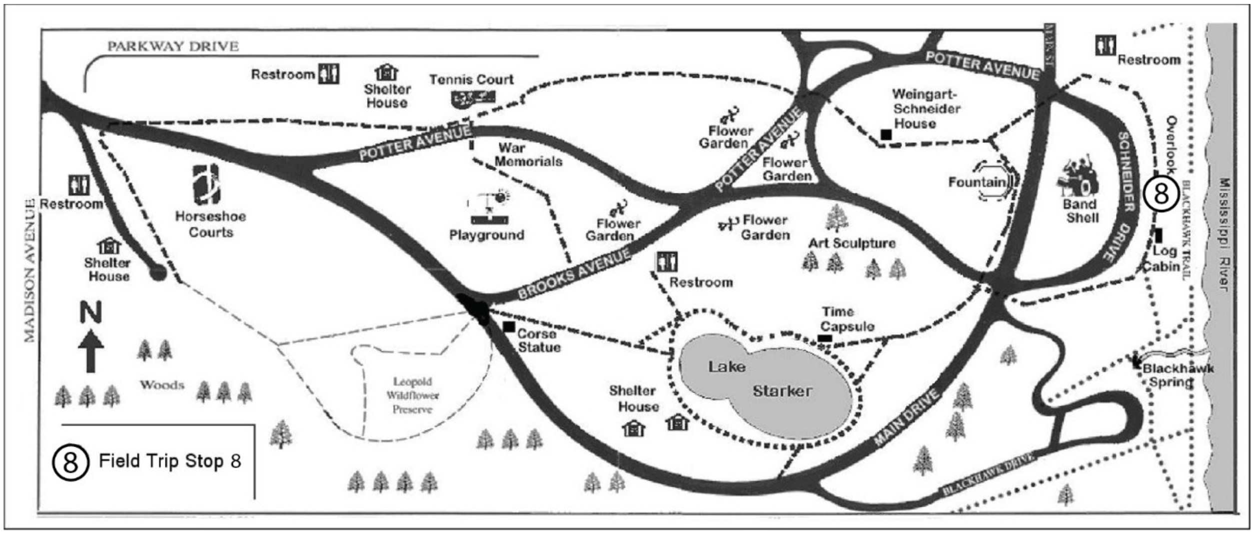

Figure 16: Map of Crapo Park showing Field Trip Stop 8 at the Mississippi River Overlook.

Figure 17: Exposures of Mississippian strata in Crapo Park, Burlington, Iowa. Left) Exposure along Black Hawk Trail of the Burlington, Wassonville, Prospect Hill, Louisiana, and English River. Right) Exposure of the Dolbee Creek Member of the Burlington Formation along the north end of Blackhawk Trail.

INTRODUCTION

Ray Anderson
Originally appeared in Iowa Geological Survey Guidebook 23

The hike to the Black Hawk Trail begins in the parking area overlooking the Mississippi River. A trail just south of the Hawkeye Pioneer Cabin leads down the bluff to the Black Hawk Spring and the cave from which it issues. The spring drains the plumbing system that is exposed in the sinkholes that we just examined. The cave from which Black Hawk Spring issues is developed in the base of the Wassonville Formation at its contact with the Prospect Hill Siltstone. Caves are developed in the same strata at Starr's Cave Preserve (Stop 6).

Leaving Black Hawk Spring, hike northeast along Black Hawk Trial just below the bluff line. Starting along the trail, exposures of the limestones of the Starrs Cave Mbr and dolomitic unnamed upper member of the Wassonville Fm. are encountered. Carbonate ooids can be observed in the rocks of the Starr's Cave, and a ledge of chert is present at the very top of the dolomite unit. For a discussion of the geology of the Wassonville Fm. and other units present at Crapo Park.

About halfway along the bluffline, the trail makes a bend around a prominent drainage. The drainage presents the best continuous exposure along the bluffline at Crapo Park. The Burlington/Wassonville contact lies about 1 meter above the trail, and below the trail the Prospect Hill and McCraney formations are exposed. Continuing north along the Crapo Park bluff line, Burlington Fm. exposures along the Black Hawk Trail progress upward through the Dolbee Creek and Haight Creek mbrs. Note the crinoidal packstone of the basal ledge of the Dolbee Creek Mbr, the chert and dolomites of the middle unit, limestones and dolomites of the upper beds.

As Black Hawk Trail works up the bluff face, the rock exposures disappear and the trail makes a sharp bend and heads up the hill. On the way up the hill note the stone restroom constructed with blocks of Proterozoic Baraboo Quartzite. This rock, among the most durable construction material on Earth, was originally deposited in fluvial and shallow marine conditions about 1.6 billion years ago. It consists of rounded, sand-size quartz grains cemented together by quartz cement. This unit is exposed near Baraboo, and other areas of central Wisconsin (where it is frequently known by local names). It is also extensively exposed in southwestern Minnesota and adjoining Iowa and South Dakota where it is called the Sioux Quartzite. Occurrences of related rocks continue below Phanerozoic strata into the subsurface of Iowa and Nebraska and probably all the way to Arizona. The unit has been extensively mined at Baraboo, as well as in southwest Minnesota, southeast South Dakota, and northwestern-most Iowa. The Iowa occurence, an old quarry at Gitchie Manitou State Preserve in northwest Lyon County, has not been mined for decades. Only one other exposure known in Iowa is in a field about 2 miles east of the preserve.

This restroom building, along with several fireplaces built from the same material, was constructed by the WPA during the depression of the 1930s. Crapo Park managers are planning to replace the structure with a more modern facility that will serve park visitors more effectively. The ultimate disposition of this structure has not yet been determined.

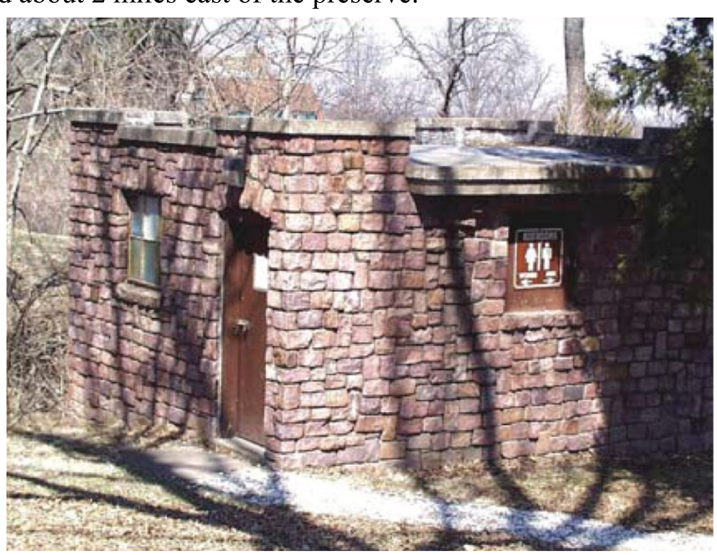

Figure 18: Original restroom facilities at Crapo Park constructed from the Baraboo Quartzite.

CRAPO PARK (CITY OF BURLINGTON)
SE NW sec. 16, T69N, R2W, DesMoines Co., Iowa
section description by B.J. Witzke, B.J. Bunker, F.J. Woodson, 5/10/1994

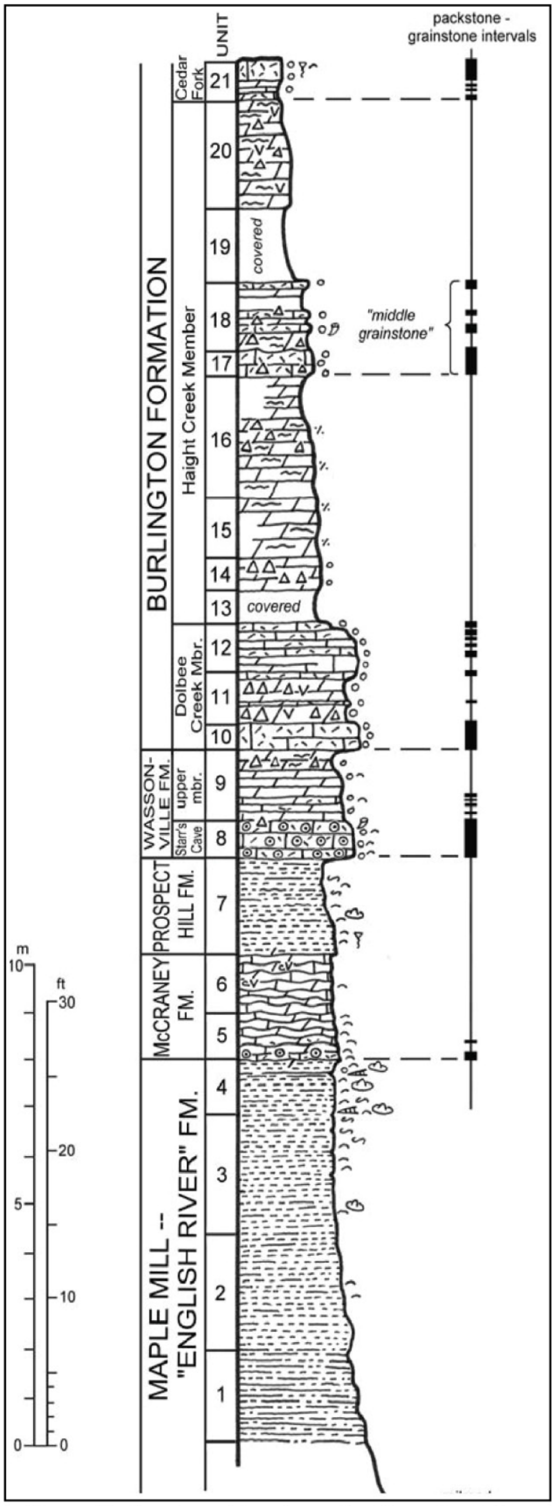

Figure 19: Stratigraphic column for Crapo Park from Witzke & Bunker, 2002.

MISSISSIPPIAN - OSAGEAN
BURLINGTON FORMATION
Cedar Fork Member

Unit 21. Limestone and dolomite; lower half is interbedded dolomite, laminated, and crinoidal packstone lenses; upper half is dominated by crinoidal packstone, minor laminated dolomite 20 cm below top; crinoid cup and large brachiopod (*Spirifer grimesi*) noted near top. 85 cm (2.8 ft).

Haight Creek Member

Unit 20. Dolomite, forms ledges, vuggy, faintly laminated, in thick beds; nodular cherts noted 85 cm, 1.15 m, and 1.65 m above base of unit. 2.2 m (7.2 ft).

Unit 19. Covered interval; some dolomite float observed. Probable dolomite unit. 1.6 m (5.2 ft).

Unit 18. Interbedded limestone and dolomite; lower 35 cm, dolomite, recessive, faintly laminated, very cherty; 35-50 cm above base, crinoidal packstone-grainstone slightly dolomitic, small cup coral noted; 50-66 cm bove base, dolomite, recessive, cherty; 66-80 cm above base, crinoidal wackestone-packstone ledge, small chert nodule at top; 80-110 cm above base, covered; 12-25 cm below top, dolomite, recessive; top 12 cm, crinoidal wackestone-packstone ledge. 1.35 m (4.4 ft).

Unit 17. Limestone ledges; lower 30 cm, crinoidal wackestone-packstone, contains large chert nodules (to 14 cm thick); upper 15-25 cm, crinoidal wackestone-packstone, coarsens upward, forms large-scale megaripple bedform. 45-55 cm (1.5-1.8 ft).

Unit 16. Dolomite, in discontinuous ledges, very finely crystalline, scattered skeletal molds, part faintly laminated; middle portion of unit with scattered large chert nodules; top 1 m is poorly exposed to covered. 2.55 m (8.4 ft).

Unit 15. Dolomite, discontinuous exposure, scattered small skeletal molds, part faintly laminated. 1.3 m (4.3 ft).

Unit 14. Dolomite, scattered to common crinoid debris molds; 25 cm above base with large chert nodule (to 20 cm thick), 50 cm above base is nodular chert band with silicified crinoid debris. 65 cm (2.1 ft).

Unit 13. Covered interval. Probably includes lower Haight Creek glauconitic dolomite. 70 cm.

Dolbee Creek Member

Unit 12. Limestone, part dolomitic, crinoidal wackestone, interbedded packstone-grainstone lenses and stringers in upper 60 cm. 95 cm (3.1 ft).

Unit 11. Dominantly dolomite and chert, minor limestone, recessive interval; dolomite, scattered crinoid debris molds, scattered large vugs; lower 35 cm, dolomite, very large smooth chert nodules locally encompass entire 35 cm interval; 60-80 cm above base with large chert nodules; 40 cm above base, discontinuous thin crinoidal packstone-grainstone; top 14 cm, crinoidal packstone-grainstone. 1.15 m (3.8 ft).

Unit 10. Limestone, ledge, in 1 or 2 beds; coarse crinoidal packstone-grainstone, very coarse lower 24-30 cm, crinoid stems to 2 cm; fines upward. 56 cm (1.8 ft).

KINDERHOOKIAN

WASSONVILLE FORMATION

Upper Member

Unit 9. Dolomite dominated, becomes more dolomitic upward, interbedded limestone and dolomitic limestone especially in lower 45 cm; pelloidal limestone noted at base; discontinuous lenses of coarse crinoidal packstone-grainstone noted 15 cm and 30-45 cm above base, lenses to 4 cm thick x 1 m; dolomitic limestone and dolomite with wackestone fabrics, moldic to calcitic brachiopods and crinoid debris scattered through; top 50 cm, dolomite, recessive interval (includes cave entrance), part with faint irregular laminations, scattered chert nodules 35-50 below top (locally to 25 cm diameter); sharp contact at top. 1.45 m (4.8 ft).

Starr's Cave Member

Unit 8. Limestone, ledge former, overhangs upward, top is cave floor; skeletal and oolitic packstone to grainstone, crinoid debris, scattered to common brachiopods (*Rugosochonetes*, *Unispirifer*, *Brachythyris*, etc.), top with scattered small silicified cup corals; nodular chert locally at top, white, chalky (nodules to 3 x 20 cm); upper contact appears gradational. 78 cm (2.6 ft).

PROSPECT HILL FORMATION

Unit 7. Siltstone, ledges, slight overhang at base, becomes more recessive upwards; base is dolomitic siltstone forming irregularly cemented bands; coarse silt noted 40 cm above base; 40 cm to 1.65 m above base is siltstone, fine to coarse silt, fines upward, gray but oxidized to light orange brown, scattered shaley partings, fine horizontal laminations scattered through interval, lower part includes molds of brachiopods (includes rhynchonellids, chonetids), bivalves, crinoid cup noted near base, upper part with scattered to common burrows, small brachiopod molds (small spiriferids, small chonetids); upper 32 cm is siltstone, green-gray to tan (oxidized), argillaceous, part laminated to platy. 1.97 m (6.5 ft).

MCCRANEY FORMATION (LOUISIANA FORMATION)

Unit 6. Irregularly interbedded pale limestone and darker dolomite; displayed as irregular elongate nodular masses forming "zebra stripes" 3 to 10 cm thick, scattered calcite void fills; limestone is pale brown, dense, sublithographic, limestone locally fractured, fractures filled with dolomite; dolomite, medium to dark brown, very fine to fine crystalline; indeterminate brachiopod noted 70 cm below top of unit. 1.35 m (4.4 ft).

Unit 5. Irregularly interbedded pale limestone and darker dolomite similar to above but higher proportion of limestone; lower 8 to 20 cm is skeletal to oolitic limestone, basal 6-8 cm is skeletal packstone, abundant chonetid brachiopods, very crinoidal; remainder of lower interval displayed as megaripple bedform, wavelengths 1.4-1.6 m, 0-14 cm thick, oolitic packstone, laminated to low-angle cross laminated, top 1 cm interfingers with overlying "zebra" stone; upper 80 cm irregularly bedded "zebra" striped, lower 15 cm (above oolitic megaripples) with common to abundant brachiopods (rhynchonellids, chonetids, productids), brachiopod-rich stringer 55 cm below top (3-10 cm thick) with common rhynchonellids and chonetids (to 3 cm), rhynchonellids common 48 cm below top, scattered large chonetids (to 3 cm) and rhynchonellids noted 35, 20, 10 cm below top and at top. 90-100 cm (3.0-3.3 ft).

UPPER DEVONIAN (FAMENNIAN)
ENGLISH RIVER/MAPLE MILL FORMATION (SAVERTON FORMATION)

Unit 4. Siltstone, argillaceous, medium blue-gray, oxidized to yellow brown upwards, locally slightly dolomitic near top; shale partings 27-35 cm above base; fossil molds generally become larger and more common upwards, scattered bivalves and nautiloids in basal 20 cm; bivalves and brachiopods scattered to common above (includes spiriferids, chonetids, *Chonopectus*), crinoid stem noted 25 cm below top (rhodocrinitid?), nautiloid 20 cm below top; irregular bioturbation especially in lower part; slightly irregular surface at top (3 cm relief). 1.2 m (3.9 ft).

Unit 3. Siltstone, medium blue gray, argillaceous, becomes less argillaceous upwards; lower interval local ledge-former, upper 1.25 m is local cliff former; bedding breaks noted 35 cm, 80 cm, and 1.25 m below top; scattered brachiopods (spiriferid) and bivalves 2.0 m below top; common molds of brachiopods (Chonopectus) and bivalves 0.8-1.2 m below top; productid brachiopod mold noted 60 cm below top; top 80 cm with scattered horizontal to subhorizontal burrows. Partly covered in lower half; approximately 2.5 m (8.2 ft) thick.

Unit 2. Siltstone, medium blue gray, argillaceous, partly covered, forms small ledges in lower part; gradational below and above; middle part of unit with scattered brachiopod molds. 2.4 m (7.9 ft).

Unit 1. Siltstone, very argillaceous to shaley, and silty shale, medium blue gray, irregular bedding; forms lower part of cascading waterfalls. 1.9 m (6.2 ft) measured thickness; base of unit lies approximately 1.5 m (4.9 ft) above railroad tracks.

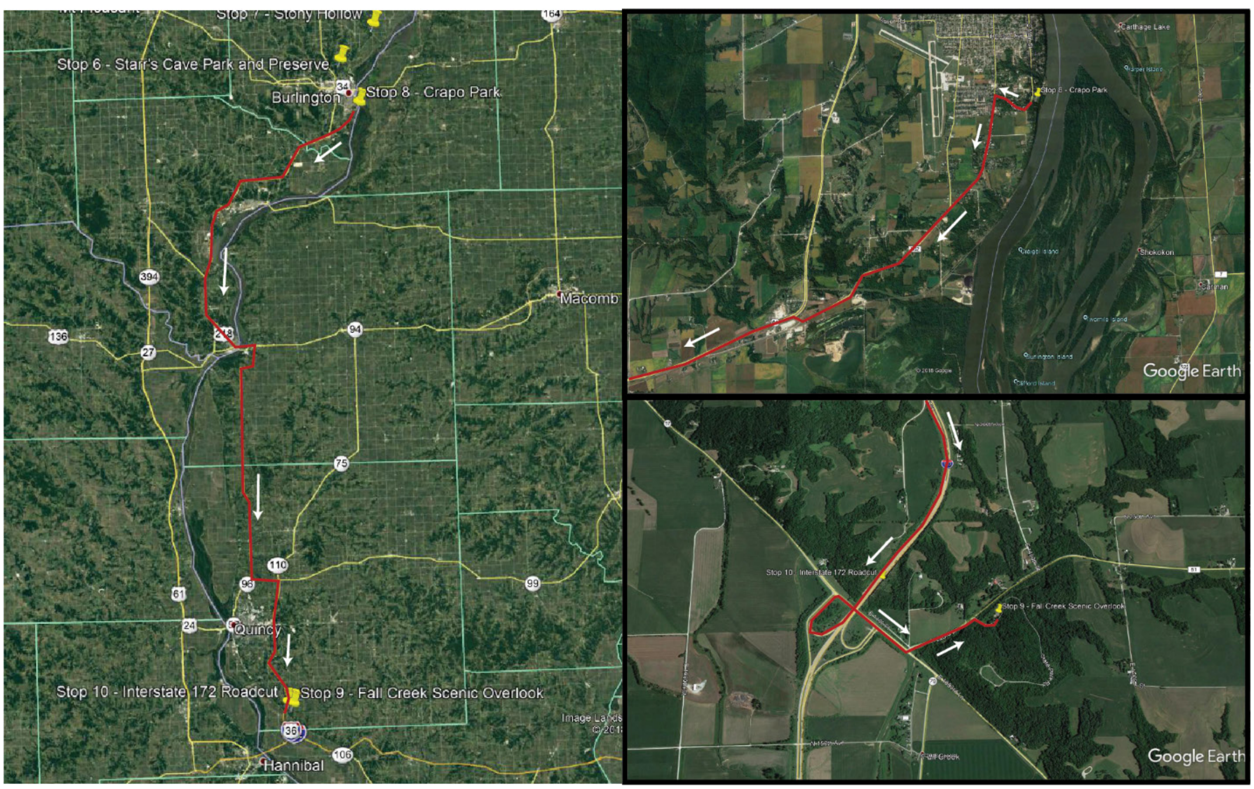

Figure 20: Driving directions between Crapo Park and Fall Creek Scenic Overlook. We will pass by the I-172 roadcut on the way to Fall Creek.

STOP 9: Fall Creek Scenic Overlook Park Section

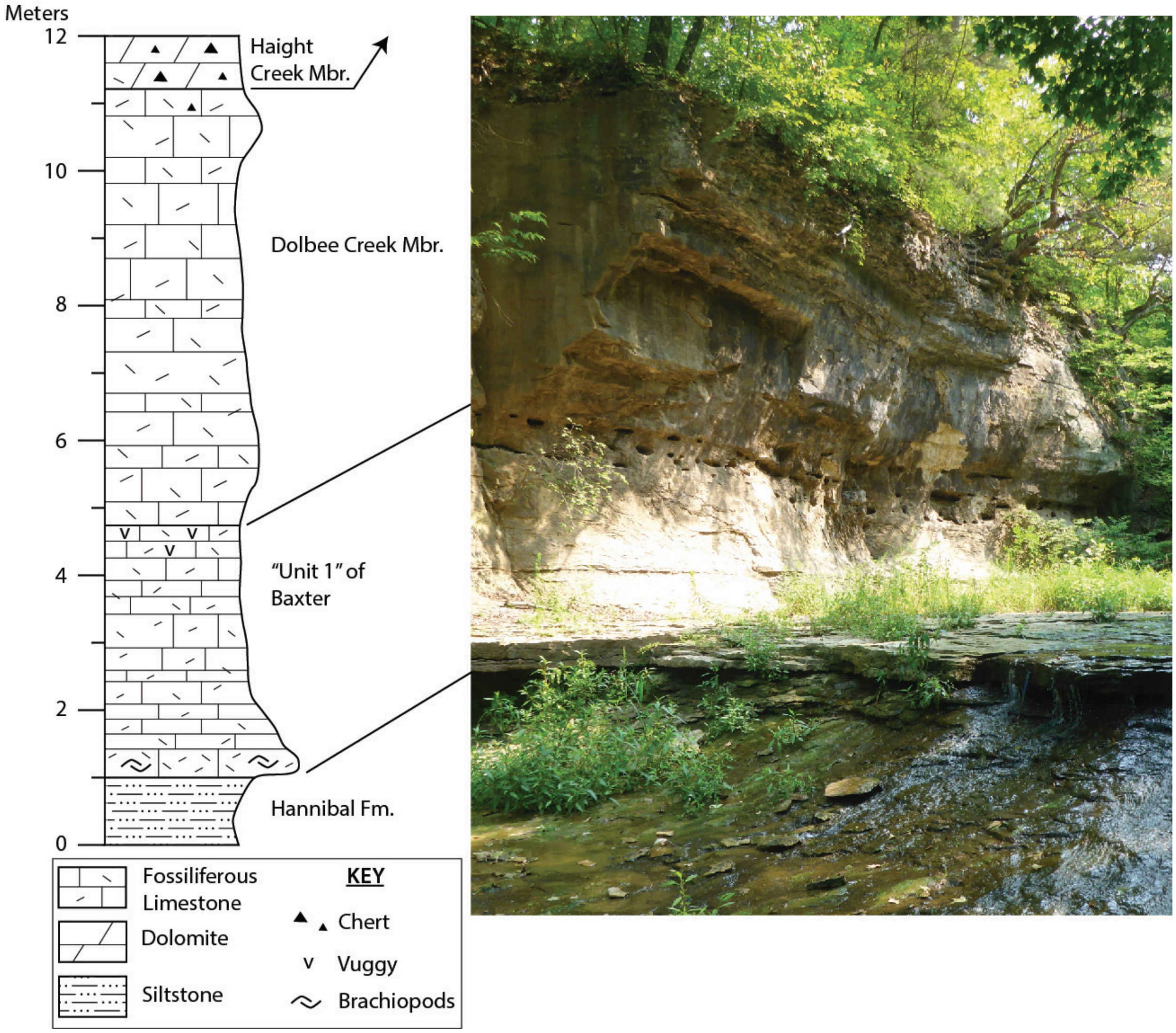

Figure 21: Generalized stratigraphic column tied to photo of the exposure at Fall Creek Scenic Overlook Park.

After a short walk down the path from the parking lot at the Fall Creek Scenic Overlook Park, participants are met with an exposure that beautifully illustrates the contact between the Hannibal Shale Formation and the overlying Burlington Formation. The Fall Creek section includes the "Unit 1" of Baxter and Haines (1990), situated below the Dolbee Creek Member, which is not present upramp in southeastern Iowa. The lower, ledge forming unit at this location displays a resistant packstone with abundant crinoid columnals and brachiopods weathering out in relief. The lithology of "Unit 1" is similar to the Dolbee Creek in that it is primarily a crinoidal packstone, however the thinly bedded nature of it weathers in contrast to the massively bedded Dolbee Creek. Of note are the abundant large voids present at the top of "Unit 1" that were likely created by chert nodules preferentially weathering out of the limestone. The Dolbee Creek is largely devoid of chert. The Haight Creek Member, which we will see up close at Stop 10, hosts abundant chert nodules, stringers, and beds.

STOP 10: I-172 Roadcut

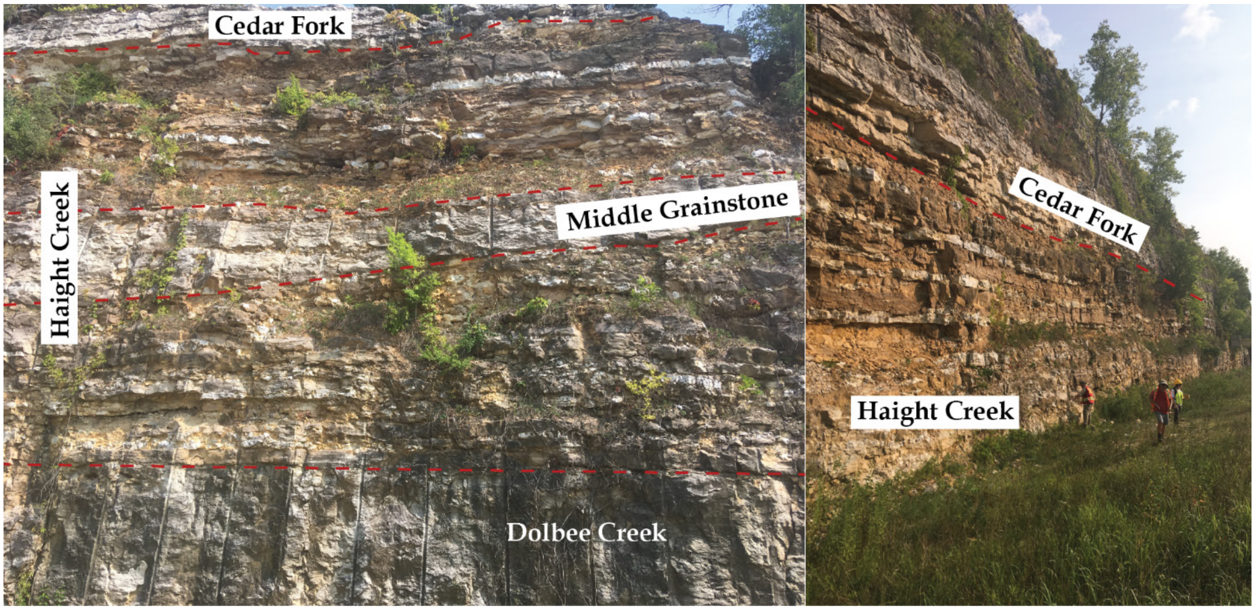

Figure 22: Annotated outcrop photographs of the I-172 roadcut. Photographs of the south side of the road showing all three members of the Burlington Formation.

The Interstate 172 roadcut exposes one of the most complete Burlington sections in the tri-state area that is not in a quarry. Here, all three members of the Burlington Formation can be clearly identified, including the regionally extensive Middle Grainstone beds of the Haight Creek Member. This section is just around the corner from our previous stop at Fall Creek, which means that Unit 1 of Baxter sits below what is exposed in this outcrop, yet above the sub-Burlington unconformity. This is curious in that there is a great difference in the Burlington Formation that sits atop the Hannibal Shale between here and the Hannibal Type Section (our Stop 5), which is only a few miles away from this locality to the southwest.

Sampling for conodont and carbonate carbon isotope chemostratigraphy of this excellent exposure began in the fall of 2018 and the analysis is ongoing. Carbonate carbon isotope samples were returned from the laboratory just before this field trip and an initial plot of the data is shown in Figure 23 below. Once again, we appear to be above the Kinderhook-Osage Boundary Excursion of Saltzman et al. (2004) as we are anticipated to be within the Osagean throughout this outcrop. Conodont processing has not yet been completed but will hopefully provide much needed age constraints to this section as well as to Fall Creek that was sampled at the same time. These samples are all part of an ongoing PhD student project at the University of Iowa.

The Keokuk Formation is exposed in the upper reaches of this section that continues up the hill of I-172 for quite some distance. Our sampling campaign for this field excursion and for the ongoing student project did not include sampling of the Keokuk Formation at this exposure. Additional information about the Burlington-Keokuk contact, as well as locality guides and stratigraphic logs for Keokuk outcrops and quarries in the tri-state area are available in several guidebooks from the Iowa Geological Survey. In particular, IGS Guidebook 23, covers many of the sections we stopped at on Day 2 as well as many more than extend well in the Keokuk Formation. Anyone who is interested in more of the Mississippian succession in the region is encouraged to check out those publications for more information.

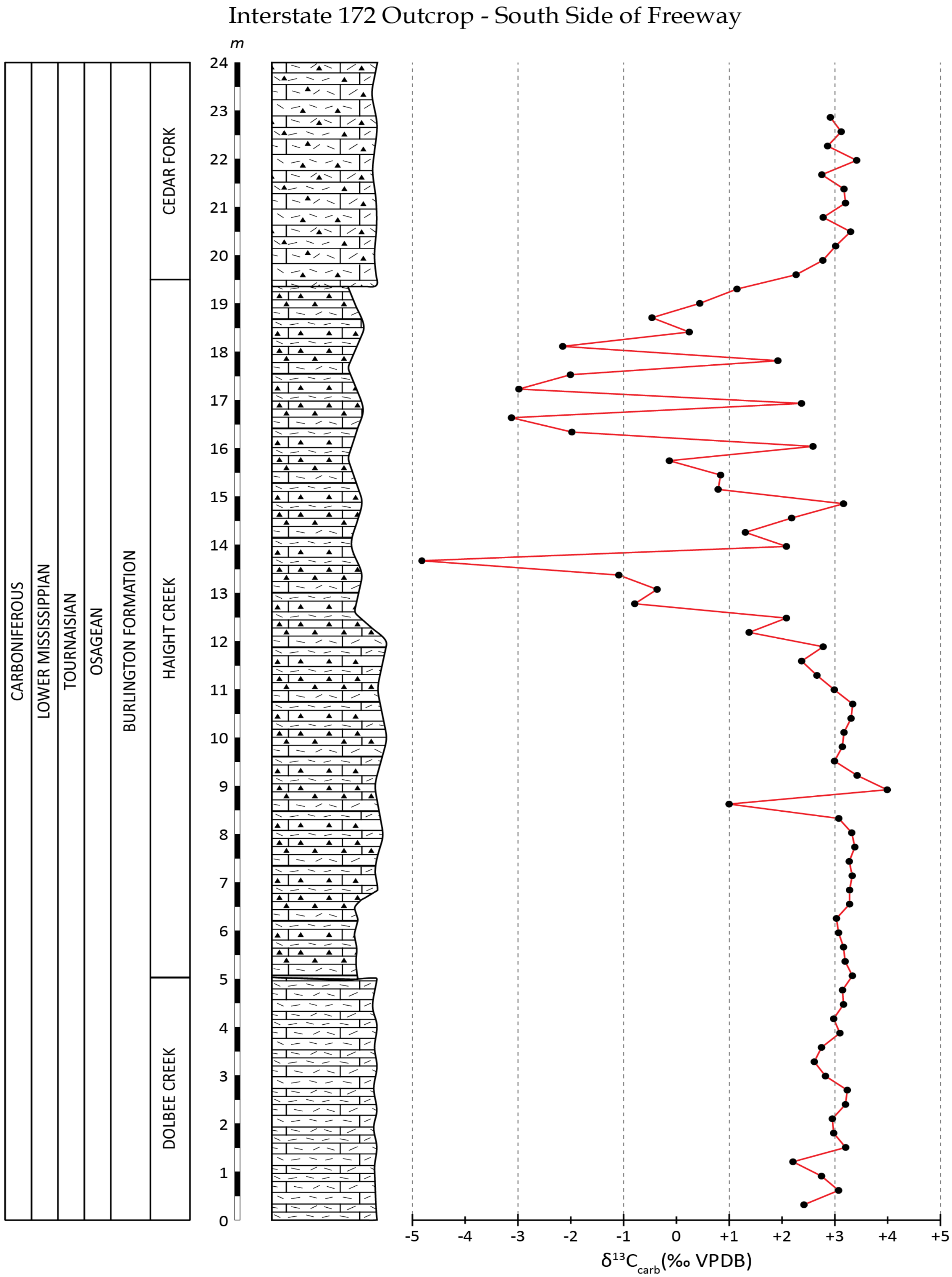

Figure 23: Initial measured section and carbonate carbon isotope values from the I-172 roadcut.

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