SUMMARY REPORT OF THE BEDROCK GEOLOGIC MAP OF THE DANVILLE (IOWA) 7.5' QUADRANGLE, DES MOINES, HENRY, AND LEE COUNTIES, IOWA

Iowa Geological Survey
Open File Map OFM-17-7
June 2017

Ryan Clark, Huaibao Liu, Stephanie Tassier-Surine, and Phil Kerr

Iowa Geological Survey, IIHR-Hydroscience & Engineering, University of Iowa, Iowa City, Iowa

IOWA GEOLOGICAL SURVEY

Iowa Geological Survey, Robert D. Libra, State Geologist

Supported in part by the U.S. Geological Survey
Cooperative Agreement Number G16AC00193
National Cooperative Geologic Mapping Program (STATEMAP)
Completed under contract with the Iowa Department of Natural Resources

INTRODUCTION

The Bedrock Geologic Map of the Danville (Iowa) 7.5' Quadrangle is the initial project aiming to refine bedrock mapping of portions of southeastern Iowa as part of the Iowa Geological Survey's (IGS) ongoing participation in the STATEMAP mapping program. Due to increased demand for groundwater resources in the region, new research into the Lower Skunk River watershed, development of additional aggregate resources, and expanding urban areas lead to the selection of southeast Iowa as the next target for geologic mapping by the Iowa State Mapping Advisory Committee (SMAC). Key societal concerns that can be aided by this mapping project include watershed management, groundwater quantity and quality assessment, flood mitigation, aggregate resource protection, and land use planning and development.

GEOLOGIC SETTING

The Danville Quadrangle occupies approximately 56 square miles of primarily agricultural land situated within the Southern Iowan Drift Plain (SIDP) landform region (Prior, 1991). This area hosts glacial deposits over 500,000 years old that contain a thick till package mantled by loess draped over upland hill slopes. Numerous rills, creeks, and rivers branch out across the landscape shaping the old glacial deposits into steeply rolling hills and valleys. The thickness of unconsolidated Quaternary deposits is variable across the quadrangle, ranging from 0 to 18 m (0-60 ft), reaching a maximum thickness of 64 m (210 ft) in the northern part of the mapping area. Mississippian bedrock units dominate the bedrock surface with some Pennsylvanian outliers. The majority of the bedrock exposures occur along the Skunk River valley in the southern portion of the mapping area.

RESEARCH HISTORY

The conundrum that is the Mississippian in Iowa has been the subject of curiosity for many previous workers. Owen (1852) and Hall (1857) were the first to recognize the abundance of bedrock exposures in southeastern Iowa and likely correlated them with those observed farther down the Mississippi River Valley. Then Van Tuyl (1923) took on the ambitious task of correlating all of the Mississippian units across Iowa. Many of their lithologic interpretations were valuable, however, the correlations were, and continue to be, subject to revision as later workers attempted to piece the Mississippian into the global stratigraphic framework. Harris and Parker (1964) provided inspirational insights into the structural context of southeastern Iowa by identifying a series of northwest-southeast trending anticlines that were later found to be superimposed on the larger northeast-southwest trending structural feature known as the Mississippi Arch (Witzke et al., 1990, p. 5). Many questions remain regarding the stratigraphic correlations within the Mississippian such as whether the "St. Louis" Formation in Iowa truly belongs in the St. Louis Formation or should some of the upper members be reassigned to the Ste. Genevieve Formation; whether the Prospect Hill Formation is an offshoot of the Hannibal Formation in Missouri and Illinois; and whether the McCraney Formation is correlative to the McCraney in Illinois or if it should become a new stratigraphic interval (as proposed by Witzke et al., 2002). Although the Mississippian bedrock in southeastern Iowa is no longer a widely used aquifer due to low yields and locally poor water quality, many of the bedrock units are highly desirable sources of aggregate, thus necessitating the continued effort to gain a better understanding of the local and regional stratigraphic characteristics and relationships of the Mississippian System in southeastern Iowa. The culmination of the diligent work of several key IGS geologists, and numerous other staff and student aides, resulted in a series of compilation geologic mapping projects, including Southeast Iowa (Witzke et al., 2004), that led to the creation of the first state-wide geologic map of Iowa using geographic information system (GIS) technology (Witzke et al., 2010). The 2010 map set the standard to which all subsequent geologic maps in Iowa are held.

Although the 2010 geologic map utilized more than a century of archived geologic data and was crafted by the hands of unquestionably the finest geologists to pass through the history of the IGS, its one defining limitation is that it was at such a large scale (1:500,000). This left room for improvement. That is where the recent IGS mapping staff has picked up, with the support of the STATEMAP program. Refining the mapping units of the 2010 map at quadrangle (1:24,000) and county (1:100,000) scales has provided users with valuable detail and insight that lacks in the state-wide map. The major refinements in the Bedrock Geologic Map of the Danville (Iowa) 7.5' Quadrangle include 1) differentiation of the Augusta Group into its three distinct formations, 2) better characterizing the extent and distribution of Pennsylvanian outliers, 3) refining the previous bedrock topography from 50' contour intervals to 25' contours, and 4) identifying the locations of known and previously unknown bedrock exposures. These factors set this map apart from all previous mapping efforts in the region and will hopefully provide a more robust and useful product for the user.

DATA SOURCES AND COMPILATION

The Bedrock Geologic Map of the Danville (Iowa) 7.5' Quadrangle was compiled using all available sources of information on the distribution and stratigraphy of bedrock units. Data were derived from a number of sources including, but not limited to the following:

- Applicable field trip guidebooks, technical reports, and publications
- Unpublished archived field notes of outcrops, road cuts, and quarry sections
- Well records from the IGS's online well database (GeoSam) including driller's logs, lithologic strip logs generated from drilling cutting samples, and core descriptions
- Iowa Department of Transportation (IDOT) bridge boring records and core
- Engineering reports
- Stratigraphic sections compiled by quarry companies
- Natural Resources Conservation Service (NRCS) county-scale soils maps
- Field observations made of outcrops, road cuts, and quarry sections as part of this mapping project

GeoSam Data

Well records constitute the largest data set and were therefore diligently scrutinized for content, quality, and accuracy. More than 180 well records were studied during the data compilation phase. Although about 120 wells already had strip logs, 40 new strip logs were created for this mapping project, the deepest one being 1,140 feet deep. Driller's logs were valued primarily for depth to bedrock information. Two bridge cores collected by the IDOT and one core from an abandoned quarry, which are stored at the IGS Oakdale Rock Library, were logged as part of this mapping project.

Locational accuracy of well points is of utmost importance, especially for those associated with lithologic strip logs. Historical plat books, county assessor records, internet resources, and personal communications with individual landowners were incorporated in refining the locations of wells in the mapping area. Once a well was accurately located, an elevation was assigned based on digital elevation models (DEM) derived from LiDAR imagery, within 2-feet accuracy.

Outcrop Data

Previous IGS geologists that conducted field studies in the mapping area cataloged their findings in archived records at the IGS. That, coupled with shallow and/or exposed bedrock areas identified in the Soil Survey of Des Moines, Henry, and Lee counties, Iowa (Brown, 1983; Seaholm, 1985; and Lockridge, 1979), provided the basis for planning the field activities for this mapping project. Geologic reconnaissance of three active quarries and two abandoned quarries were conducted during field activities, as well as 26 bedrock exposures, found mostly along the Skunk River and its tributary creeks.

METHODS AND APPROACHES TO MAPPING

ArcGIS 10.3 software and on-screen digitizing techniques developed during previous STATEMAP projects were employed for this mapping project. Drawing bedrock topographic lines and bedrock contact polygons using ArcGIS allows for rapid data processing while utilizing multiple layers of information that are all accurately projected using the Universal Transverse Mercater (UTM) North American Datum (NAD) 1983 Zone 15 coordinate system. The IGS works with the IDNR-GIS Section to generate and refine the data packages that are cataloged on the online NRGIS Library (https://programs.iowadnr.gov/nrgislibx/) and utilized for a variety of relational work products such as STATEMAP publications.

Bedrock Topography

Once the data set for all depth-to-bedrock information was compiled, a refined bedrock topographic map was generated. Drawing the bedrock topography of the mapping area incorporated well point and outcrop data, as well as using land surface topography in areas where shallow bedrock was identified. Bedrock topography for the entire state was generated as part of the Bedrock Geologic Map of Iowa (Witzke et al., 2010) using 50-foot contour intervals. The refined bedrock topography of the Danville Quadrangle was constructed using 25-foot contour intervals, which provided the basis for constructing this map. In addition to aiding in lithologic contact interpretation, the refined bedrock topographic map was also utilized to create the aesthetic effect of "hillshade" to the bedrock surface (Fig. 1), which was used a base layer for the final map.

Bedrock Structures

In general, the bedrock strata in Iowa exhibit a subtle dip to the southwest, typically less than 5°. The stratigraphic data from the well points in the mapping area reflect the regional dip, however, dip orientations varied widely within the mapping area. Harris and Parker (1964) noted that multiple large scale northwest-southeast trending anticlines were observed within the Mississippian bedrock package of southeastern Iowa (Fig. 2). These anticlines are thought to be superimposed on top of, and perpendicular to, the broader northeast-southwest trending Mississippi Arch (Witzke et al., 1990, p. 5). The well data in the mapping area does elude to possible folding, however, the areal extent of this map is too small to reflect these regional structural features on the map.

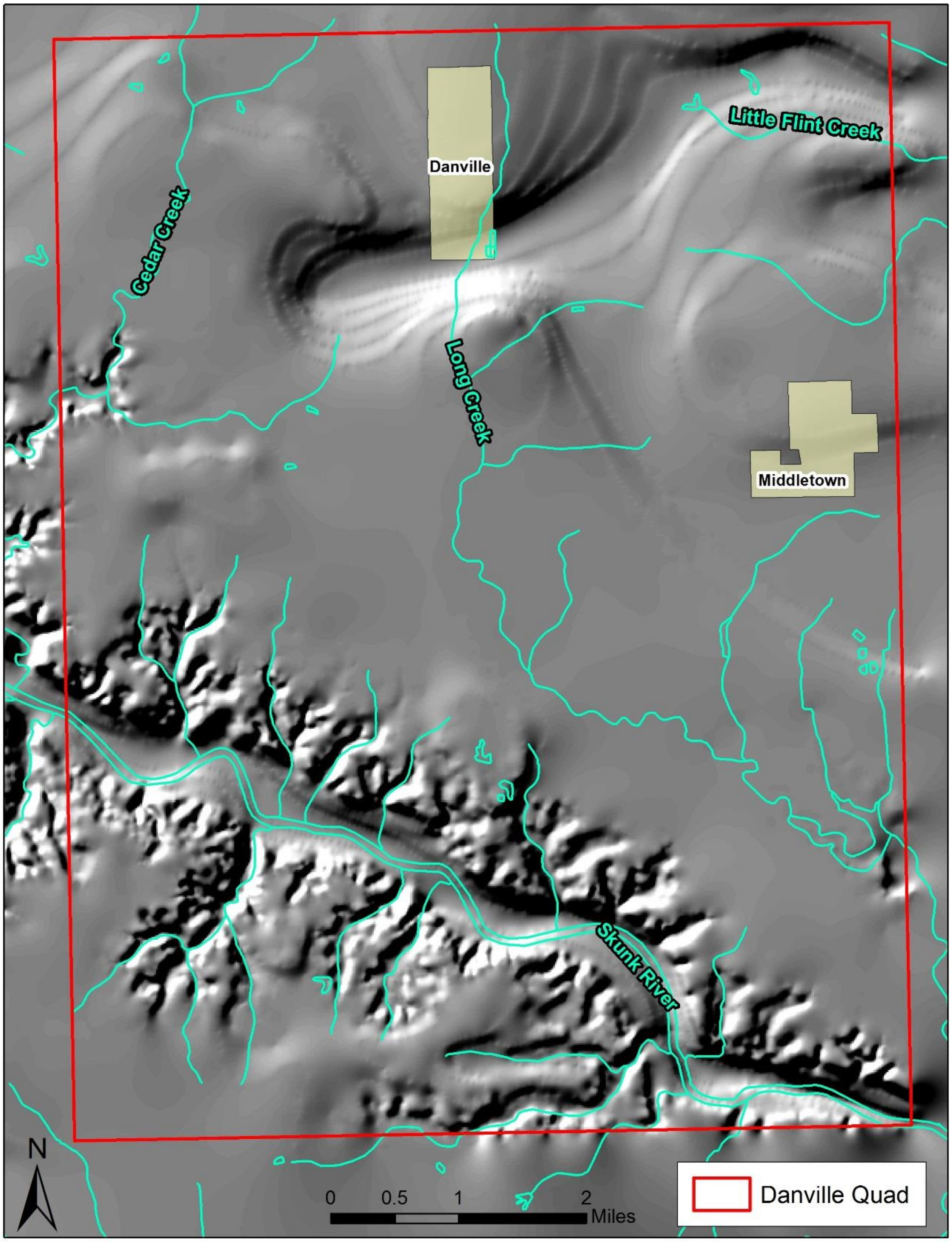

Figure 1: Raster image of the bedrock surface of the Danville 7.5' Quadrangle using a "hillshade" effect. Image generated from the bedrock topography lines drawn at 25-foot contour intervals.

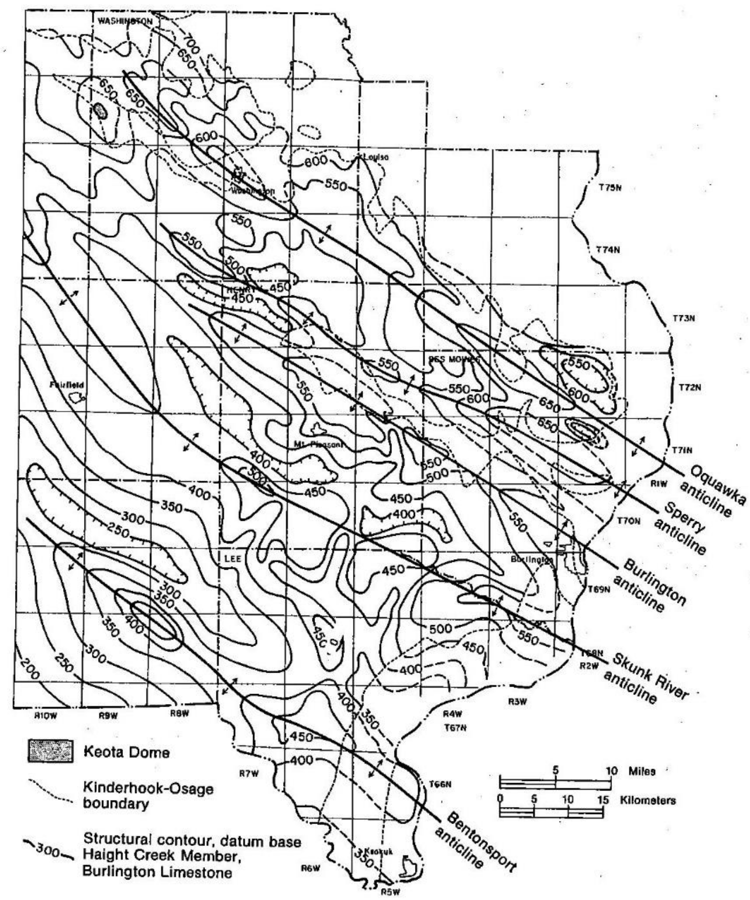

Figure 2: Structural contour map of southeast Iowa. Contours are drawn on the base of the Haight Creek Member of the Burlington Formation (Osagean Series). A number of anticlines are shown and are flanked by synclines (unlabeled). (From Harris and Parker, 1964, plate 2)

BEDROCK STRATIGRAPHY AND MAPPING UNITS

The units occurring at the bedrock surface in the Danville Quadrangle primarily include Mississippian deposits with scattered Pennsylvanian outliers. Stratigraphic units mapped on the new bedrock geologic map are summarized on the map Legend and the Stratigraphic Column and are described in further detail in the following sections. The boundaries separating the various map units were selected based on 1) prominent lithologic changes, 2) characteristic fossils, when available, and 3) major regional unconformities and/or disconformities. The bedrock stratigraphic nomenclature and correlation of the mapping units for this project follow that of Witzke et al. (2010), although the Augusta Group has been differentiated into its three distinct formations (in ascending order): the Burlington, Keokuk, and Warsaw. The thickness of each map unit was derived chiefly from well penetrations within and adjacent to the map area. Photos of lithologic features and exposures identified during field activities are included in Appendix A of this report.

Lithostratigraphic Setting

The mapping area is dominated by bedrock of the Mississippian System that was deposited in a variety of marine environments from the late Kinderhookian to early Chesterian, approximately 355 – 330 million years ago (Ogg et al., 2008). Kinderhookian strata represent a sequence of interbedded carbonates and siltstones that unconformably underlie the Burlington Formation (early Osagean) and are not exposed at the bedrock surface within the mapping area. The Burlington, Keokuk, and Warsaw formations (collectively the Augusta Group of Witzke et al., 2010) represent a relatively conformable package of marine rocks deposited during the Osagean transgressive-regressive (T-R) cycle. Interpreted as part of the central middle shelf of the Osagean sea that transgressed toward the northwest and the Transcontinental Arch, the Burlington Formation rocks were deposited across a vast subtidal epicontinental shelf that stretched from Illinois and Iowa into central Kansas and Oklahoma (Lane, 1978; Witzke et al., 1990, p. 55). The Keokuk and Warsaw formations represent the regressive phase of the Osagean T-R cycle punctuated by a stark unconformity below the overlying Pella and "St. Louis" formations, regionally displaying up to 40 m (130 ft) of erosional relief (Witzke et al., 2002). The Pella and "St. Louis" formations are mapped as one unit due to their stratigraphic complexity and questionable correlation to the type sections in Missouri and Illinois (Witzke et al., 1990, p. 23). The Pella and "St. Louis" formations were deposited in a near-shore environment as evidenced by mudflat facies rocks, evaporites and associated collapse breccias (Fig. 3), and increased terrigenous sandstone deposits, with periods of brackish and/or lacustrine deposition interpreted from coal deposits and root casts (Witzke et al., 2002).

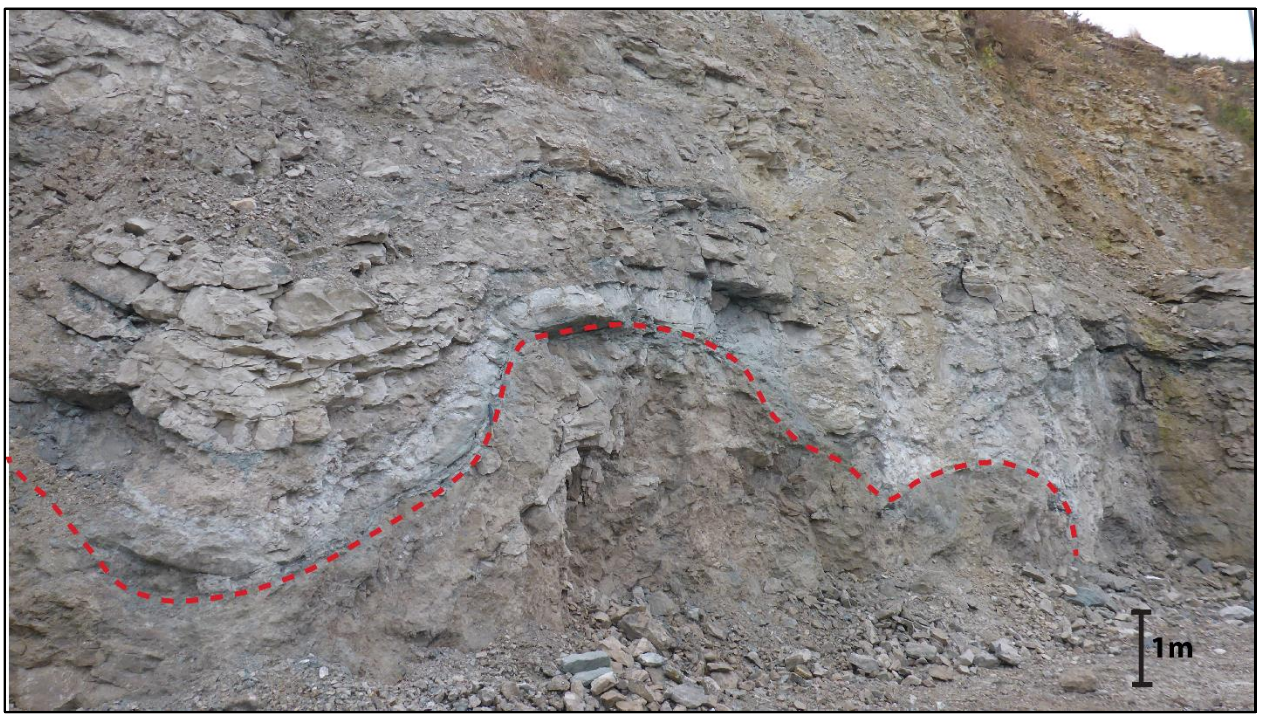

Figure 3: Disturbed bedding in the "St. Louis" Formation due to solution collapse seen in the Beach Quarry southwest of the Lowell Quadrangle. Basal dark brown dolomite is pervasively brecciated.

Mississippian strata unconformably overlie an eroded surface of Devonian shales in the mapping area. Multiple hardground surfaces, regional thinning or complete removal of units, and drastic facies changes makes correlation of Mississippian units in Iowa and surrounding states difficult. Although much research has been done in an attempt to unravel these complex relationships, more lithologic, geochemical, and biostratigraphic study will be needed to fully understand what the Mississippian bedrock sequence is telling us.

Mapping Units

Pennsylvanian Sub-System

Lower Cherokee Group – This map unit occurs as erosional outliers primarily in the central and northwestern portions of the mapping area and is usually less than 14 m (45 ft) thick. This map unit consists primarily of light to medium gray shale/mudstone, part silty to sandy and fine to medium grained sandstone, rarely conglomeratic (Photos 1 & 2). Some shales are carbonaceous to phosphatic, minor coal, and rare limestone lithologies. Only a few outcrops of this map unit were identified in the Cedar Creek valley located in the northeastern part of Geode State Park in the western portion of the mapping area.

Mississippian Sub-System

Pella & "St. Louis" formations – The Pella and "St. Louis" formations were mapped as one unit in Witzke et al. (2010) and that methodology was adopted for this mapping area as well. Although the two formations display distinct lithologic characteristics, their nature and occurrences lend them to be grouped in mapping exercises until further information becomes available to allow their differentiation. This mapping unit ranges between 12 and 27 m (40 – 90 ft) thick in the mapping area. It is dominated by limestone, sandstone, dolomitic limestone, and dolomite with minor shale (Photo 3). Limestones of the Pella Formation are typically sub-lithographic (Photo 4) with scattered to abundant fossils, primarily brachiopods, echinoderms, bryozoans, and ostracods (Photos 5 & 6). The "St. Louis" Formation is dominated by limestone, sandy limestone and dolomite, variably cherty, and partly fossiliferous with brachiopods, echinoderms, bryozoans, and several varieties of coral. Some fossils are silicified. Sandstones of the "St. Louis" Formation are typically very fine to medium, quartz sandstones that are poorly to moderately cemented with calcite or quartz (Photos 7 & 8). Lower "St. Louis" units are more dolomitic, gray to dark brown, commonly brecciated (Photos 9, 10, & 11) and sandy, with rare fossils. Brachiopods, echinoderm debris, and corals usually occur in the limestone facies and fossil molds in the dolomite facies. This mapping unit dominates the bedrock highs north of the Skunk River and are overlain by Quaternary sediments or Pennsylvanian outliers. Outcrops of this mapping unit are found along road cuts and tributaries of the Skunk River, as well as in quarries.

Warsaw Formation – The Warsaw Formation varies in thickness, reaching a maximum thickness of approximately 17 m (55 ft). This unit can generally be divided into two major lithologic groupings, a lower argillaceous dolomite sequence and an upper shale-dominated sequence. The upper shale is typically light to medium gray (Photos 12 & 13), silty, and variably dolomitic with minor chert, sand, and sparse quartz geodes. The lower dolomite, sometimes referred to as the "geode beds", is argillaceous to shaly, with scattered to abundant quartz geodes (Photos 14, 15, & 16). Minor limestone units occur locally as thin, lensatic beds with crinoidal packstone/grainstone fabrics. Brachiopods, echinoderm debris, and bryozoans are found throughout this mapping unit, although are more common in the carbonate lithologies. This unit exhibits wide variability leaving only the upper shale or lower dolomite in place, suggesting strong erosional unconformities above and below this mapping unit. Outcrops of this unit are rare due to the selective weathering of the shale creating recessive exposures beneath ledges of overlying Pella and "St. Louis" formations.

Keokuk Formation – The Keokuk Formation typically ranges from 12 to 21 m (40 – 70 ft) in thickness with a maximum thickness of 26 m (85 ft) in the mapping area. This unit is dominated by tan to gray interbedded skeletal limestones displaying packstone/grainstone fabrics (Photos 17 & 18). Nodular to bedded chert, in part fossiliferous, is common in the lower half of the sequence. Calcite-filled vugs are also common and may occasionally host sphalerite crystals as well (Photo 19). Dolomite, variably argillaceous, and thin shales also occur throughout the unit. The unit displays multiple hardground surfaces and bone beds with scattered to abundant fish debris, the most prominent of these serves as a marker bed at the base of the formation (sometimes referred to as the Burlington-Keokuk or B-K bone bed) (Photo 20). Brachiopods, crinoids, bryozoans, solitary corals, and fish bones and teeth occur throughout this unit as both abraded debris and partly articulated specimens. Molds of sponge spicules are noted in the dolomite facies. Traces of glauconite and locally abundant geodes were also observed within the mapping area. Outcrops of this unit are typically found along the Skunk River and its tributaries and in select quarries along the southeastern boundary of the mapping area.

Burlington Formation – The Burlington Formation ranges in thickness from 12 to 21 m (40 – 70 ft) with a maximum thickness of 27 m (90 ft) in the mapping area. This unit is subdivided into three members (in ascending order: the Dolbee Creek, Haight Creek, and Cedar Fork), characterized by distinct lithologic groupings. The Dolbee Creek Member is dominated by white to tan skeletal limestone displaying packstone/grainstone fabrics (Photo 21) and nodular to bedded chert that is often fossiliferous (Photos 22, 23, & 24). The Haight Creek Member is characterized by dolomite with an intermittent unit of skeletal limestone (sometimes referred to as the "middle grainstone") and thick beds of chert. A glauconite-rich zone marks the lower contact between the Dolbee Creek and can be used as a regional marker bed (Photo 25). Fossil molds are also present in the dolomite facies. The Cedar Fork Member is a pure white crinoidal packstone limestone unit which is usually differentiated from the packstones of the overlying Keokuk Formation by its white appearance. Occasional fish debris and glauconite are also observed in this member. Outcrops of the Burlington Formation are typically found along the Skunk River and its tributaries and in select quarries along the southeastern boundary of the mapping area (Fig. 4).

Kinderhookian formations – The Kinderhookian sequence ranges in thickness from 9 to 15 m (30 – 50 ft) with a maximum thickness of 23 m (75 ft) in the mapping area. This unit comprises three formations (in ascending order: the McCraney, Prospect Hill, and Wassonville), characterized by distinct lithologic groupings described below. Outcrops of the Kinderhookian are found just outside the southeastern corner of the mapping area and in the sump pit of a quarry located along the southeastern boundary of the mapping area.

The Wassonville Formation, including the basal Starr's Cave Member, consists of massive dolomite (Photo 26) that is variably cherty grading into dolomitic limestone lower in the section. The basal Starr's Cave Member is a fossiliferous limestone with packstone/grainstone fabrics and is commonly oolitic (Photo 27). Crinoids (partly articulated) are the dominant fossil type of the Starr's Cave Member. A diverse assemblage of brachiopods are present with lesser amounts of blastoids, starfish, corals, bryozoans, and trilobites reported.

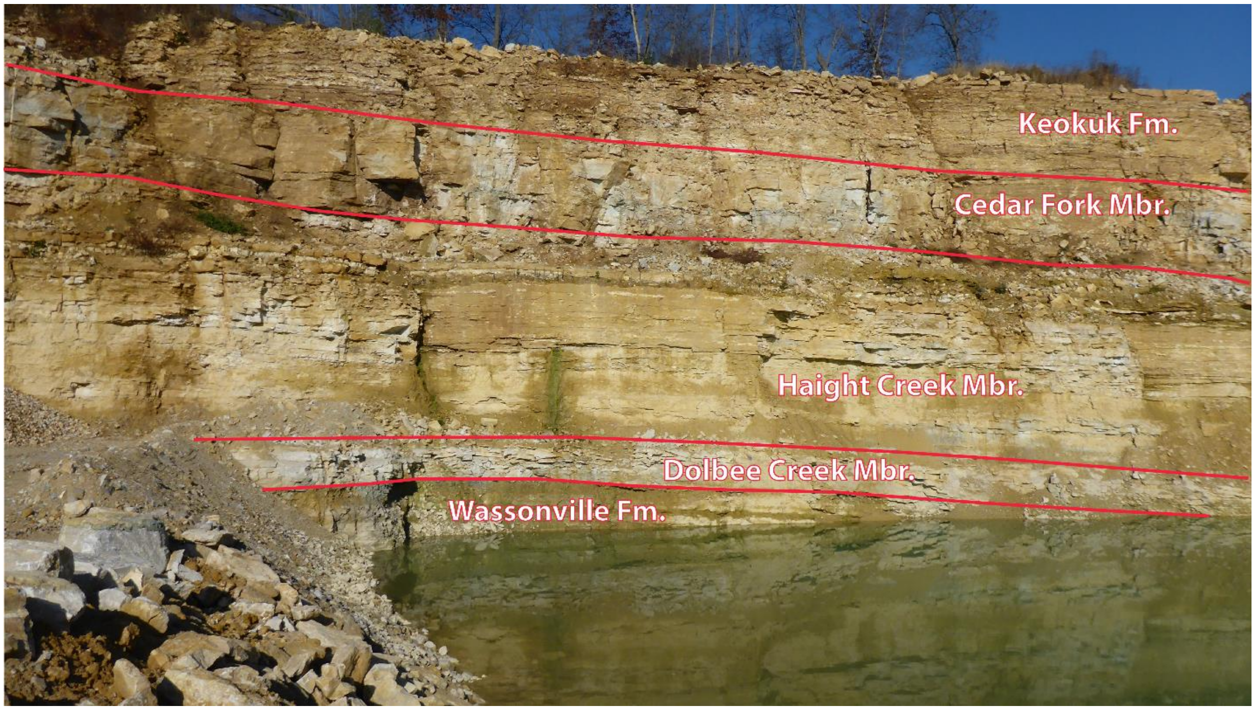

Figure 4: West wall of the Heritage Quarry showing Keokuk, Burlington, and Wassonville formations. Rocks from the Prospect Hill Formation were found around the excavated sump pit now filled with water. (Photo by Ryan Clark)

The Prospect Hill Formation is a light to medium gray, dolomitic siltstone that grades to shale in some locations (Photo 26). This unit is often laminated with vertical and horizontal burrow fabrics and faint cross stratified bedforms (Photos 28 & 29). Fossils are rare to absent although fossil molds are locally abundant.

The McCraney Formation is composed of alternating beds of sparsely fossiliferous, sub-lithographic limestone and dark brown, unfossiliferous dolomite, generating a unique "zebra striped" appearance in outcrop (Photo 30). A basal oolite is locally present.

Devonian System

English River Formation – The English River Formation is up to 6 m (20 ft) within the mapping area. This unit is dominated by gray to olive green siltstone with apparent bioturbated fabrics (Photo 30). Bivalves and brachiopods are common, especially in the upper beds, with scattered to abundant fossil molds as well. This unit appears only in the cross-section and not on the map.

Saverton Shale Formation – The Saverton Shale Formation can be up to 46 m (150 ft) within the mapping area. This unit is dominated by green-gray shale, commonly burrowed with sparse to absent macro-fossils. This unit appears only in the cross-section and not on the map.

REFERENCES

Brown, M.D., 1983: Soil Survey of Des Moines County, Iowa. U.S. Department of Agriculture, Soil Conservation Service, 199 p., 66 map sheets.

Hall, J., 1857: Observations upon the Carboniferous limestones of the Mississippi Valley. American Journal of Science, v. 23, p. 187-203.

Harris Jr., S.E. and Parker, M.C., 1964: Stratigraphy of the Osage Series in Southeastern Iowa, Iowa Geological Survey Report of Investigation No. 1, 52 p., 17 figs, 7 plates.

Lane, H.R., 1978: The Burlington Shelf (Mississippian, north-central United States). Geologica et Palaeontologica v. 12, p. 165-176.

Lockridge, L.D., 1979: Soil Survey of Lee County, Iowa. U.S. Department of Agriculture, Soil Conservation Service, 188 p., 85 map sheets.

Ogg, J.G., Ogg, G., and Gradstein, F.M., 2008: The Concise Geologic Time Scale, Cambridge University Press, 177 p.

Owen, D.D., 1852: Report of a Geological Survey of Wisconsin, Iowa, and Minnesota; and incidentally of a portion of Nebraska territory. Lippincott, Gambo and Co., 638 p.

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

Seaholm, J.E., 1985: Soil Survey of Henry County, Iowa. U.S. Department of Agriculture, Soil Conservation Service, 259 p., 63 map sheets.

Van Tuyl, F.M., 1923: The stratigraphy of the Mississippian formations of Iowa. Iowa Geological Survey, Annual Report, v. 30, p. 33-359.

Witzke, B.J., McKay, R.M., Bunker, B.J., and Woodson, F.J., 1990: Stratigraphy and Paleoenvironments of Mississippian Strata in Keokuk and Washington Counties, Southeast Iowa. Iowa Geological Survey Guidebook No. 10, 105 p.

Witzke, B.J., Bunker, B.J., Anderson, R.R., Artz, J.A., and Tassier-Surine, S.A., 2002: Pleistocene, Mississippian, & Devonian Stratigraphy of the Burlington, Iowa, Area. Iowa Geological Survey Guidebook No. 23, 137 p.

Witzke, B.J., Anderson, R.R., and Bunker, B.J., 2004: Bedrock Geology of Southeast Iowa, 1:250,000. Iowa Geological Survey Open File Map OFM-04-1.

Witzke, B.J., Anderson, R.R., and Pope, J.P., 2010: Bedrock Geologic Map of Iowa, 1:500,000. Iowa Geological and Water Survey Open File Map OFM-10-1.

Photo 1: Sandstone of the Lower Cherokee Group overlying limestone of the "St. Louis" Formation.

Photo 2: Sandstone and shale of the Lower Cherokee Group. (Rock hammer for scale)

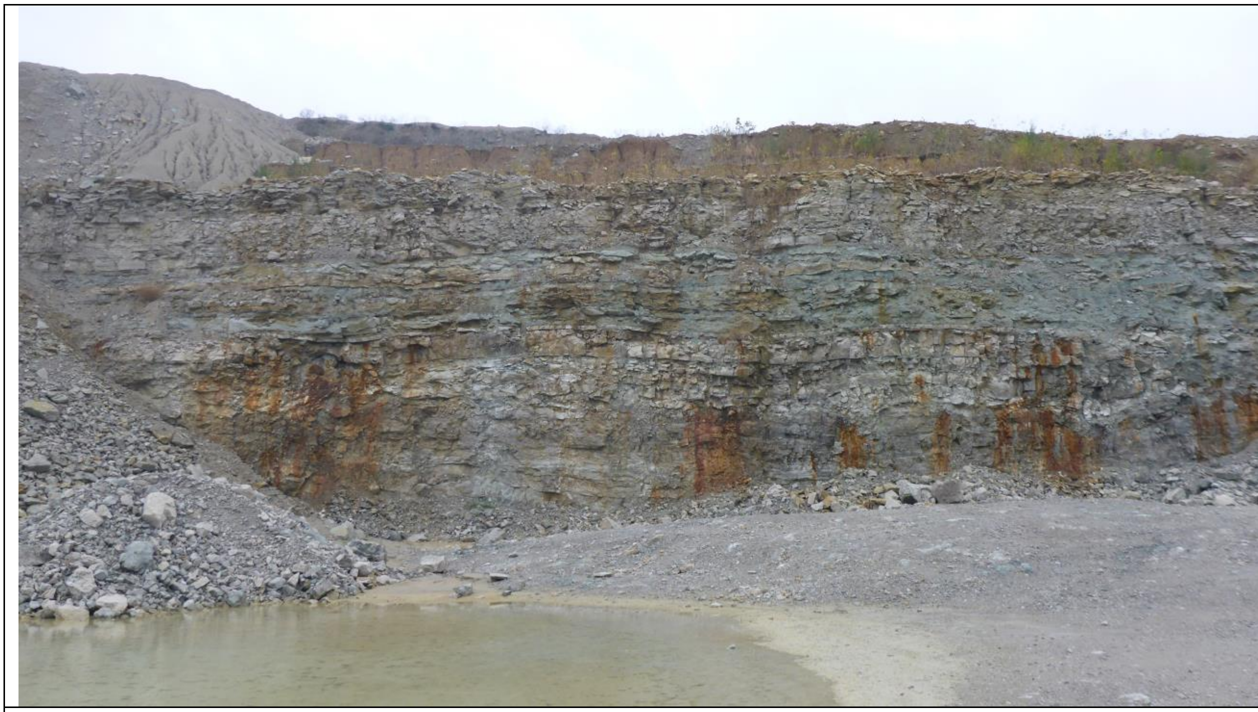

Photo 3: Interbedded limestone, dolomite, and sandstone of the "St. Louis" Formation in the Geode Quarry. Iron staining from weathering of pyrite-rich layers.

Photo 4: Sub-lithographic limestone of the Pella Formation in the Geode Quarry.

Photo 5: Limestone of the Pella Formation with solitary coral, brachiopod, and crinoid debris in the Geode Quarry.

Photo 6: Branching bryozoans from the Pella Formation in the Geode Quarry.

Photo 7: Poorly cemented sandstone of the upper "St. Louis" Formation.

Photo 8: Rock hammer sitting on sandstone underlying limestone of the "St. Louis" Formation.

Photo 9: Brecciated dolomite of the lower "St. Louis" Formation in the Beach Quarry.

Photo 10: Brecciated limestone of the "St. Louis" Formation in the Geode Quarry.

Photo 11: Limestone micro-breccia of the "St. Louis" Formation in the Geode Quarry.

Photo 12: Contact between dolomite of the overlying "St. Louis" Formation and gray shale of the underlying Warsaw Formation. (Rock hammer for scale)

Photo 13: Interbedded shale and argillaceous dolomite of the Warsaw Formation. (Rock hammer for scale)

Photo 14: Argillaceous dolomite of the Warsaw Formation. Tanner is holding a geode from this unit!

Photo 15: Argillaceous dolomite of the lower Warsaw Formation (the "Geode Beds") in the Vinsennes Quarry in southern Lee County, Iowa. (Rock hammer for scale)

Photo 16: Geode lying in place within the "Geode Beds" of the lower Warsaw Formation in the Vinsennes Quarry in southern Lee County, Iowa.

Photo 17: Rock hammer sitting on the contact between the underlying Burlington Formation and the overlying Keokuk Formation in the Augusta Quarry.

Photo 18: Gray-brown crinoidal packstone limestone from the Keokuk Formation in the Augusta Quarry. Upper part of photo shows white chert replacing the limestone fabric while maintaining the crinoid debris.

Photo 19: Same sample of Keokuk Formation packstone as in previous photo showing calcite-filled vug with sphalerite. Fish bone also present in the upper right corner of the photo.

Photo 20: Pure crinoidal packstone limestone of the upper part of the Cedar Fork Member of the Burlington Formation illustrating the “B-K bone bed”.

Photo 21: Weathered surface of crinoidal packstone limestone of the Dolbee Creek Member of the Burlington Formation. (Handle of rock hammer for scale)

Photo 22: White nodular to bedded chert within tan-brown packstone limestone of the Burlington Formation in the Heritage Quarry.

Photo 23: White-gray chert with abundant calcareous crinoid fossils from the Burlington Formation in the Heritage Quarry.

Photo 24: Silicified brachiopods of the Burlington Formation from the Nelson Quarry in northeastern Des Moines County.

Photo 25: Rock hammer sitting on the contact between the glauconitic dolomite of the overlying Haight Creek Member and bedded chert of the underlying Dolbee Creek Member of the Burlington Formation in the Heritage Quarry.

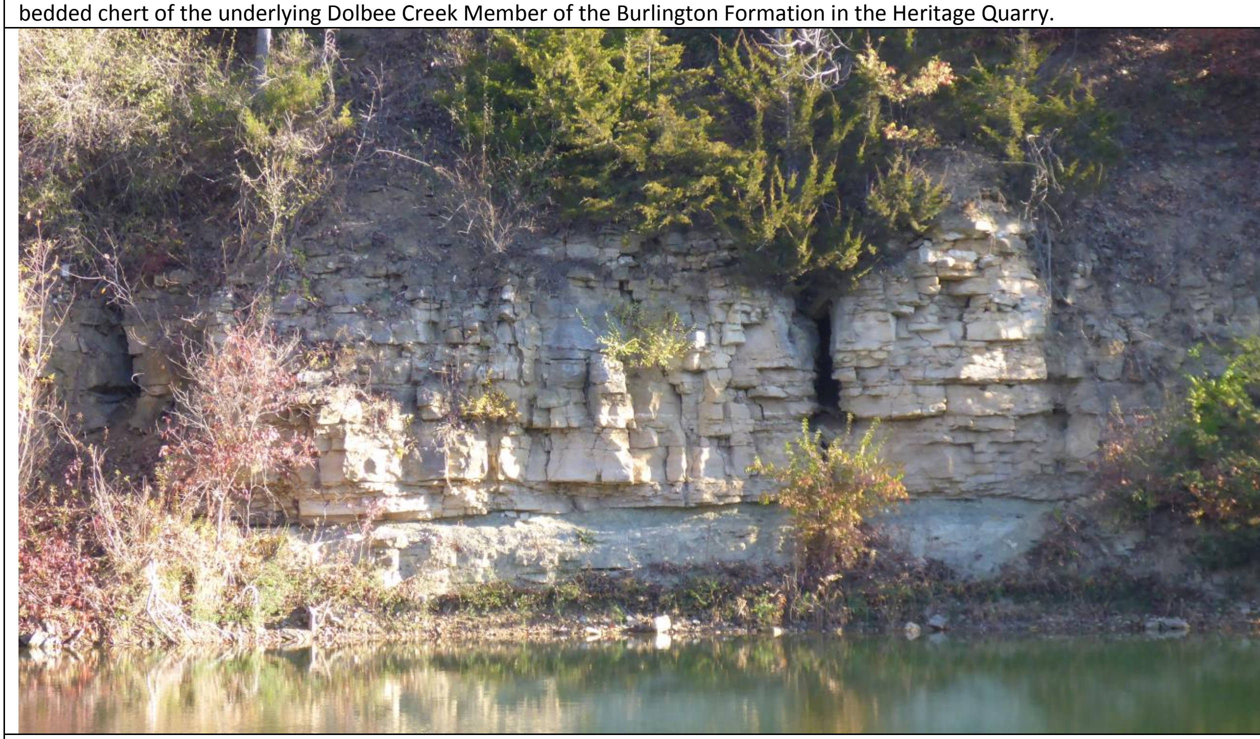

Photo 26: Contact between the overlying Wassonville Formation dolomite and the underlying gray siltstone of the Prospect Hill Formation in the former Prospect Hill Quarry (3.5 miles east of the mapping area).

Photo 27: Oolitic limestone of the Starr's Cave Member of the Wassonville Formation at an exposure along Stony Hollow Road in northeastern Des Moines County.

Photo 28: Burrows in gray siltstone of the Prospect Hill Formation in the Heritage Quarry.

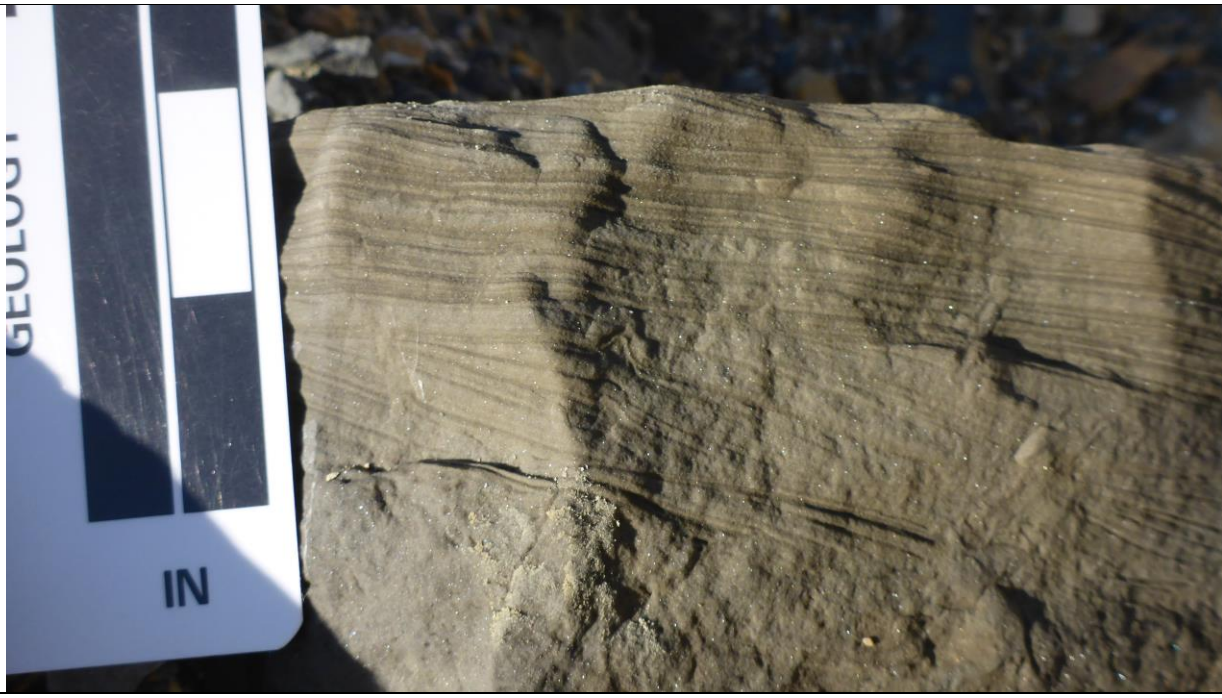

Photo 29: Cross-bedded siltstone of the Prospect Hill Formation in the Heritage Quarry.

Photo 30: Exposure of the carbonates of the overlying McCraney Formation and the siltstones of the underlying Devonian English River Formation near Blackhawk Spring at Crapo Park in Burlington, Iowa.