SUMMARY REPORT OF THE BEDROCK GEOLOGIC MAP OF MITCHELL COUNTY, IOWA

Iowa Geological Survey
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INTRODUCTION

The Bedrock Geologic Map of Mitchell County represents the culmination of three years of geologic mapping conducted as part of the Iowa Geological Survey's (IGS) ongoing participation in the STATEMAP mapping program. Recent flooding in the Cedar River watershed has generated significant interest from local government and conservation groups which led to the formation of several watershed management coalitions and protection initiatives. Additionally, increased demand on the Devonian aquifers in north-central Iowa for agricultural purposes has highlighted the need for a better understanding of the geologic setting of north-central Iowa. 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. As three 7.5' quadrangles in Mitchell County had been previously mapped (Rowden et al., 2014a & b; Clark et al., 2015), completion of a 1:100,000 scale bedrock geologic map of Mitchell County was strongly recommended by the Iowa State Mapping Advisory Committee (SMAC) and approved by the National Cooperative Geologic Mapping Program (STATEMAP).

GEOLOGIC SETTING

Mitchell County occupies approximately 470 square miles of primarily agricultural land situated within the Iowan Surface (IS) landform region (Prior, 1991) of north-central Iowa. The IS region is characterized by relatively low relief with gently rolling hills and moderately incised drainage valleys. This landform region also features common fieldstones of glacial origin known as *erratics*, which were observed in some farm fields measuring several meters in diameter. The thickness of unconsolidated Quaternary deposits is variable across the county, ranging from 5 to 15 m (15-45 ft). However, thicker deposits of Quaternary materials lie within several prominent bedrock valleys, achieving a maximum thickness of about 100 m (330 ft) in the north-south trending bedrock valley along the southeastern margin of the mapping area. In general, Quaternary cover is thinner in the western half of the county, with the exception being around the village of Little Cedar in east-central Mitchell County, where several bedrock quarries exist near the western rim of the prominent bedrock valley along the eastern side of the mapping area. The town of McIntire in northeast Mitchell County is an outlier in that it hosts one bedrock quarry exposing Lithograph City Formation rocks and hints of Cretaceous Dakota/Windrow Formation residuum. The majority of the Cedar River and its tributary creeks are incised into bedrock, thus making their valleys relatively steep-sided keeping meandering to a minimum. The Lithograph City Formation is the dominant bedrock unit exposed along these waterways with lesser amounts of Coralville and Shell Rock formation rocks exposed.

Karst Geology

Evidence of karst was apparent in shallow bedrock areas when looking at depressions on LiDAR, observing sand and gravel intermingled deep into the bedrock section while logging certain wells, and during field investigations. Several springs and seeps were noted during field activities, the most noteworthy being the spring at Osage Spring Park (Fig. 1). Sinkholes were observed primarily adjacent to the Cedar River between Osage and Mitchell. One such sinkhole was identified in the alluvial terrace on the west bank of the Cedar River in SE, SE, Section 17, R17W, T98N (Fig. 2).

Figure 1: Phil Kerr of the IGS standing beside the spring at Osage Spring Park.

Figure 2: A sinkhole along the Cedar River (Ryan Clark of the IGS for scale [1.93 m]).

RESEARCH HISTORY

Mapping of Iowa's bedrock geology dates back to 1857 when David Dale Owen conducted the first geologic reconnaissance of the Upper Mississippi Valley region, which included Iowa. Since then, several geologic maps of Iowa were produced by the IGS between 1894 and 1937. A geologic map of Mitchell County produced by Samuel Calvin, along with a detailed report of the geologic occurrences observed at the time, was included in the IGS Annual Report of 1902 (Calvin, 1902). Not until the 1969 geologic map of Iowa (Hershey, 1969) was an attempt made to incorporate the growing wealth of well data utilized in deciphering the convoluted stratigraphic relationships seen in Iowa's rock record. Hershey's map was a vast improvement on the previous attempts which set the stage for the numerous geologists at the IGS in the decades to follow. An in depth perspective on the legacy of geologic mapping of the North-Central Iowa region is given in the summary report for the Bedrock Geologic Map of North-Central Iowa (Witzke, 2001). 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 that led to the creation of the first state-wide geologic map of Iowa using geographic information system (GIS) technology, published in 2010 (Witzke et al., 2010). The 2010 map set the standard by 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 components 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 Mitchell County include 1) differentiation of the Cedar Valley Group into its four distinct formations and the Wapsipinicon Group into its two distinct formations, 2) better characterizing the extent and distribution of Cretaceous outliers, 3) refining the previous bedrock topography from 50' contour intervals to 25' contours, and 4) identifying the location of known 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 Mitchell County, Iowa 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, and core descriptions
- Iowa Department of Transportation (IDOT) bridge boring records and core
- Minnesota Geological Survey
- Engineering reports
- Natural Resources Conservation Service (NRCS) county-scale soils maps

- Passive geophysical surveys (Electrical Resistivity)
- 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 was therefore diligently scrutinized for content quality and accuracy. More than 900 well records, including 665 from within Mitchell County, were studied during the data compilation phase. 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 nearly 600 wells in and around 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. A total of 497 well records only had a driller's log and were valued primarily for their depth-to-bedrock information. There are 406 well records that have lithologic strip logs with 322 of those lying within Mitchell County. One deep research core located within the mapping area drilled by the IGS (FM-2 in Witzke and Bunker, 1985) provided a valuable reference point for correlation of lithologic units identified in the strip logs. Two bridge cores collected by the IDOT and reposited at the IGS Oakdale Rock Library were logged as part of this mapping project. Two additional cores located just west of the mapping area in Worth County were also logged.

The majority of the lithologic strip logs utilized were created as part of the recent STATEMAP projects in Worth (Liu et al., 2012), Cerro Gordo (Liu et al., 2015), Mitchell (Rowden et al., 2014a&b; Clark et al., 2015; and this map), and Floyd (Liu et al., 2016a & b) counties. However, many of the earlier strip logs, and their associated stratigraphic calls, were interpreted using the Devonian stratigraphic nomenclature that preceded the revisions made by Witzke and others (1988). That added to the already mounting task of, not only assigning stratigraphic calls to the new strip logs and updating that information in GEOSAM, but also reinterpreting the old logs and applying the current stratigraphic scheme and updating that information in the database. It was only with the assistance of a few outstanding student aides from the University of Iowa's Department of Earth and Environmental Sciences that this herculean task was completed.

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 Mitchell County, Iowa (Voy and Highland, 1975), provided the basis for planning the field activities for this mapping project. More than 90 bedrock exposures, mostly stream banks and road cuts, were accessed and studied during field activities as well as 13 rock quarries. Many of the exposures and quarries had been visited by previous IGS geologists, however one quarry, the Winters Quarry (NW, SW, Section 23, R16W, T99N), was studied for the first time as part of this mapping project. Two sand and gravel pits were accessed and studied, both located along the northern boundary of the mapping area (E, E, Section 7, R16W, T100N and NE, NE, Section 7, R18W, T100N), which provided the only presumed exposures of Cretaceous Dakota/Windrow Formation bedrock within the mapping area.

Geophysical Survey Data

There were many areas of Mitchell County that had very sparse well point and/or outcrop data coverage so geophysical technology was utilized to help fill some vital gaps in the depth-to-bedrock data.

Electrical Resistivity (ER) methods were employed at three select locations in the mapping area. In general, ER measurements are obtained by introducing direct current into the subsurface and measuring resulting voltages (http://www.iihr.uiowa.edu/igs/programs/geophysics/). The details of the results of these surveys are discussed in the following section and provided in Appendix A of this report.

METHODS AND APPROACHES TO MAPPING

ArcGIS 10.2 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 mapped by Voy and Highland (1975). 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 Mitchell County was constructed using 25-foot contour intervals (Fig. 3), which provided the basis for constructing this map. Bedrock depth in areas where subsurface data was absent was greatly improved with the use of geophysical (ER) surveys. These surveys produced models that illustrated the approximate bedrock depth in three key areas (see Appendix A). Perhaps the most important of these ER surveys was conducted a few miles north of Osage (Fig. 4) in an attempt to constrain the upper reaches of an east-west trending bedrock valley that was first mapped as a depression by Rowden and others (2014a).

A structure contour map of the top of the Coralville Formation was generated to aid in the visualization of the regional structure and attitude of bedrock units within the mapping area. The Coralville Formation was used as a reference datum because it underlies most of the mapping area. This process served as a useful way to project the lithologic contact lines in relation to the bedrock surface topography in a way that likely best mimics their natural association with the variably incised bedrock surface. 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. 5), 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, with a gradual flattening to a slight southeasterly dip in the northwestern portion of Mitchell County. Many of the quarries in the area display dipping strata exceeding 5° and in directions other than to the southwest, which highlights the variability indicative of Iowa's Devonian strata. These variations have not been studied in great detail but could be attributed to any of a number of factors, such as evaporite solution collapse, differential sediment compaction, intracratonic structural deformation, and/or diagenetic processes.

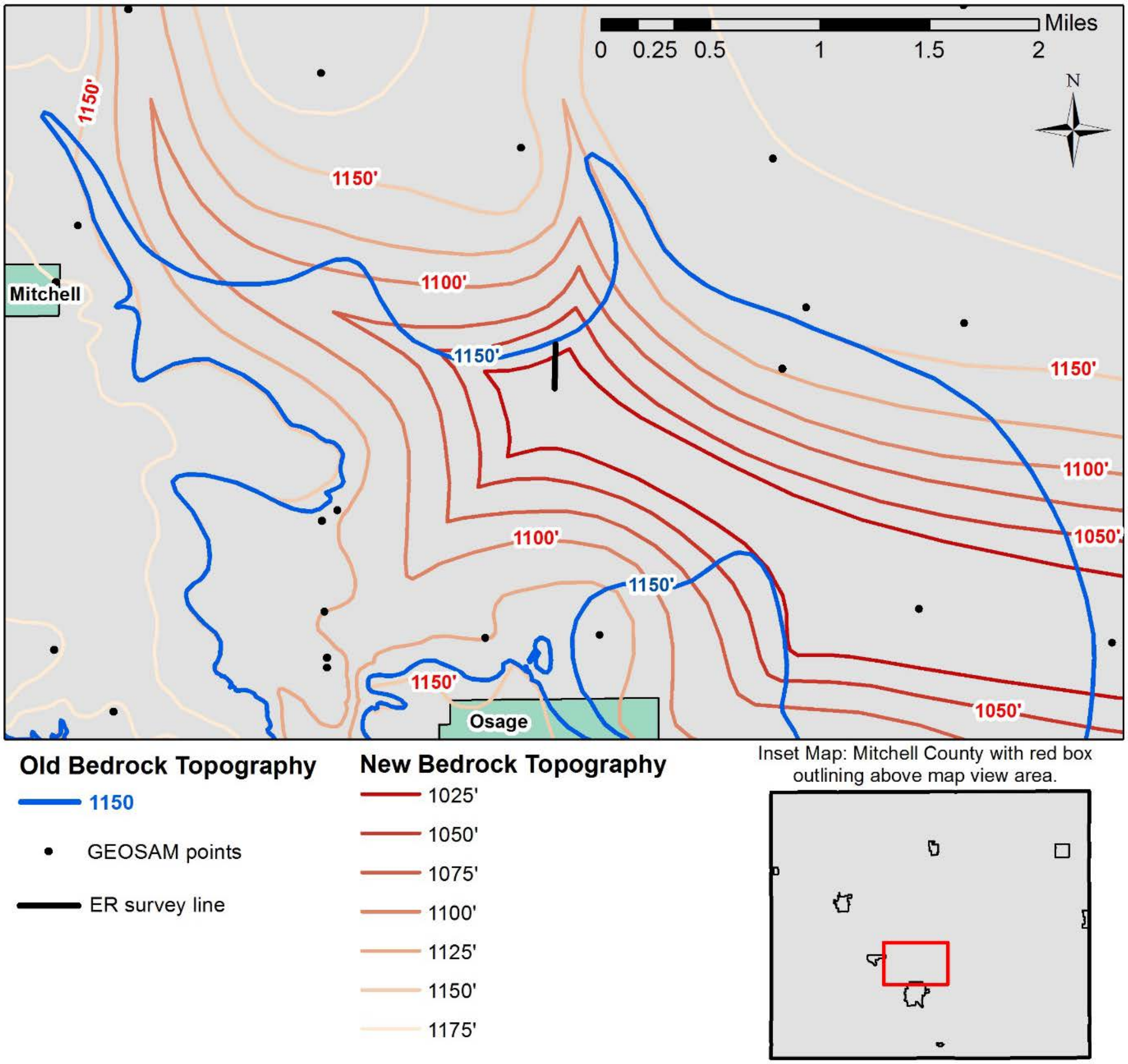


Figure 3: Comparison of a portion of the old and new bedrock topographic maps.

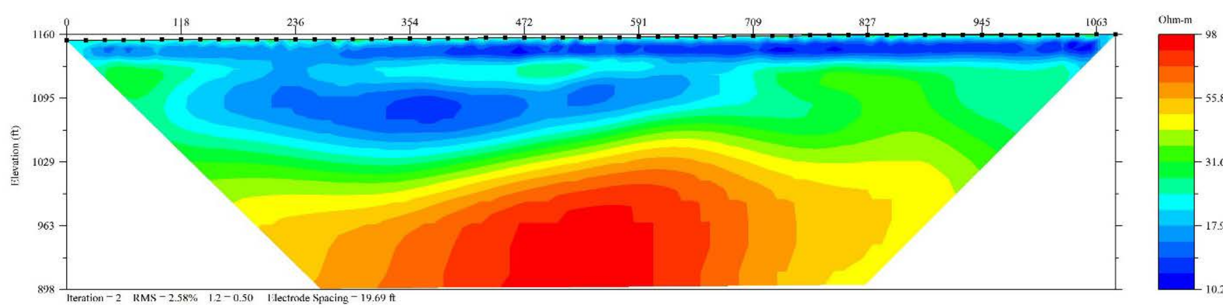


Figure 4: South (left) to north (right) cross-sectional view of the ER model from the area shown in Figure 3 (black line). Warm colors indicate competent bedrock. Depth is shown as elevation in feet above sea level on the X-axis.

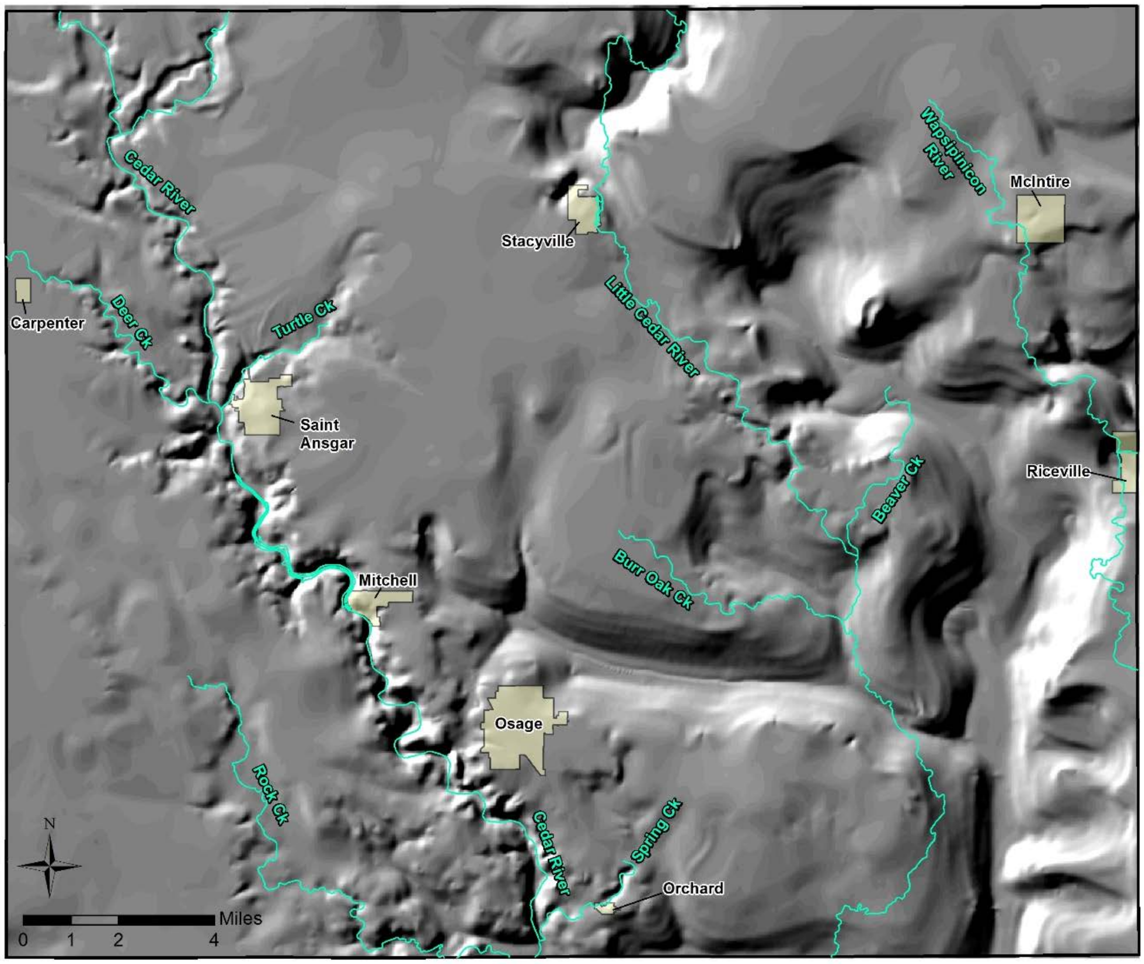


Figure 5: Raster image of the bedrock surface of Mitchell County using "hillshade" effect. Image generated from the bedrock topography lines drawn at 25-foot contour intervals.

<u>"St. Ansgar Fault"</u>

Generating the structure contour map of the top of the Coralville Formation revealed a pronounced change in elevation observed in a few wells located west of St. Ansgar (Fig. 6). This necessitated a re-examination of the strip logs in that area to verify if the modeled structure contour map was correct. After confirming the location and elevation of the well points in question (primarily wells W-73825 and W-46517), they were re-logged in greater detail. The results showed a rise in elevation of all bedrock contacts intersected by the wells of almost 100 feet over a lateral distance of less than ¾ of a mile from east to west. Bearing in mind that the average dip of bedding in the area equates to approximately 20 feet per mile, this amount of offset garnered some explanation other than typical undulation of strata observed throughout the Devonian section of north-central Iowa. Thus a fault was deemed the best way to convey the observed lithologic irregularities in this area, informally named the "St. Ansgar Fault".

Figure 7 is a magnified portion of the new bedrock map showing the fault and GEOSAM well point locations. The elevation of the top of the Little Cedar Formation illustrates the observed offset since the majority of the Coralville Formation is removed on the west (upthrown) side of the fault. Most of the wells near the northern end of the fault are too shallow to intersect the Little Cedar Formation and a lack of well points near the southern end of the fault made tracing the extent of the fault difficult, necessitating the use of an inferred fault line in those areas.

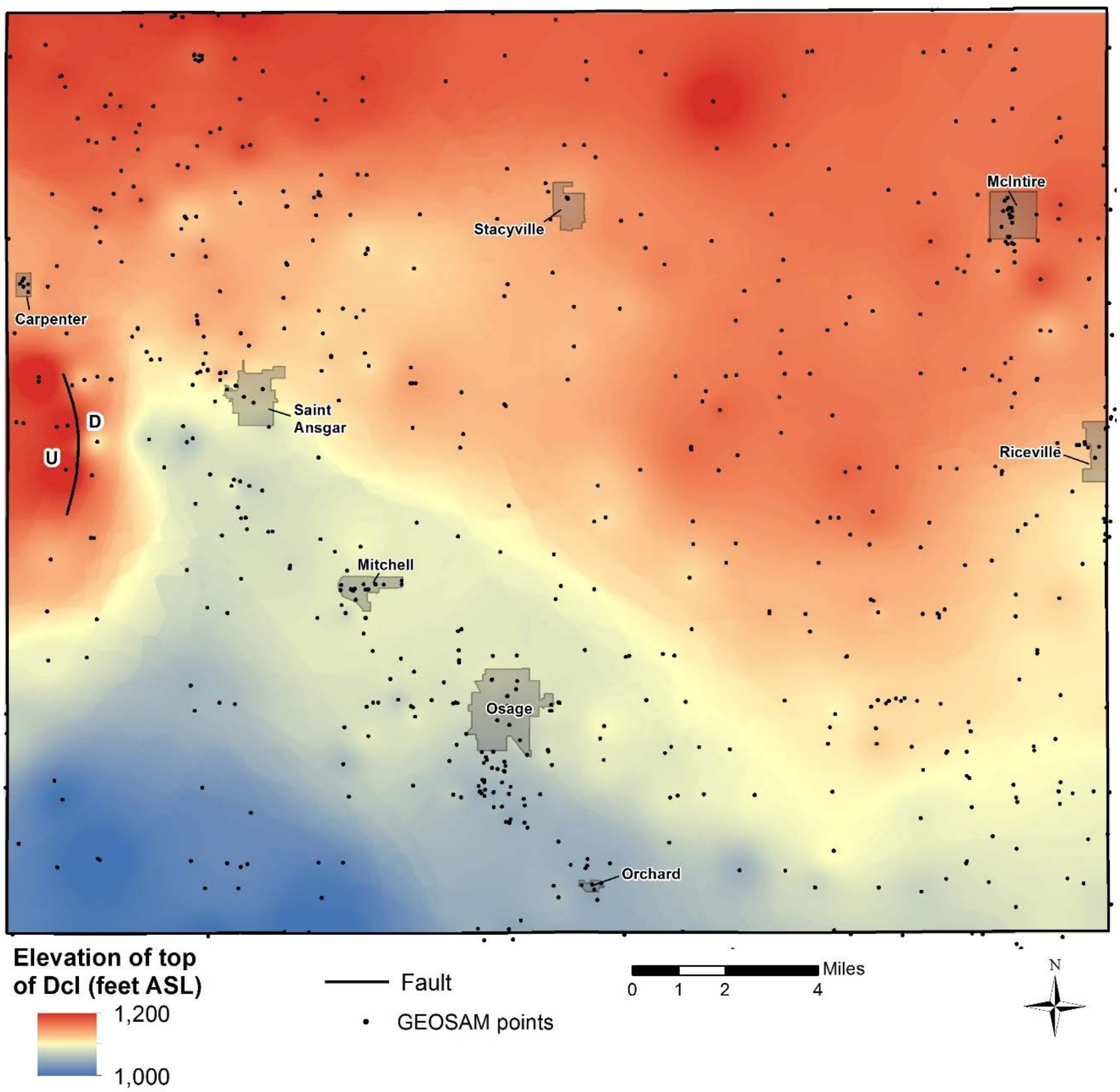


Figure 6: Raster image of the elevation of the top of the Coralville Formation. “U” and “D” indicate the upthrown and downthrown sides of the fault, respectively.

Faulting is not entirely unheard of in the region. Several Paleozoic faults were mapped by geologists with the Minnesota Geological Survey immediately north of Mitchell County in Mower County, Minnesota (Mossler, 1998). The Mower County map includes a number of faults, some with over 100 feet of displacement in the Paleozoic strata. The Mower County map also shows several folds that all plunge to the south or southwest.

The Mid-Continent Rift System (MRS) is a Precambrian feature that extends more than 1,500 kilometers from Michigan through Minnesota, entering north-central Iowa and exiting through the southwestern corner of Iowa, and continuing as far south as Kansas (Anderson, 2006). Western Mitchell County lies across the mapped boundary of the central, uplifted horst, and the east-flanking rift basin. The Thurman-Redfield Fault Zone (TRFZ), referred to as the Thurman-Redfield Structural Zone (TRSZ) in Anderson (2006), marks the boundary between the central horst and the east basin and is known to have been active through the Pennsylvanian (~300 Ma) in central and southwestern Iowa (Witzke et al., 2010). The TRFZ may well have been active during the same time period in north-central Iowa, which would lend

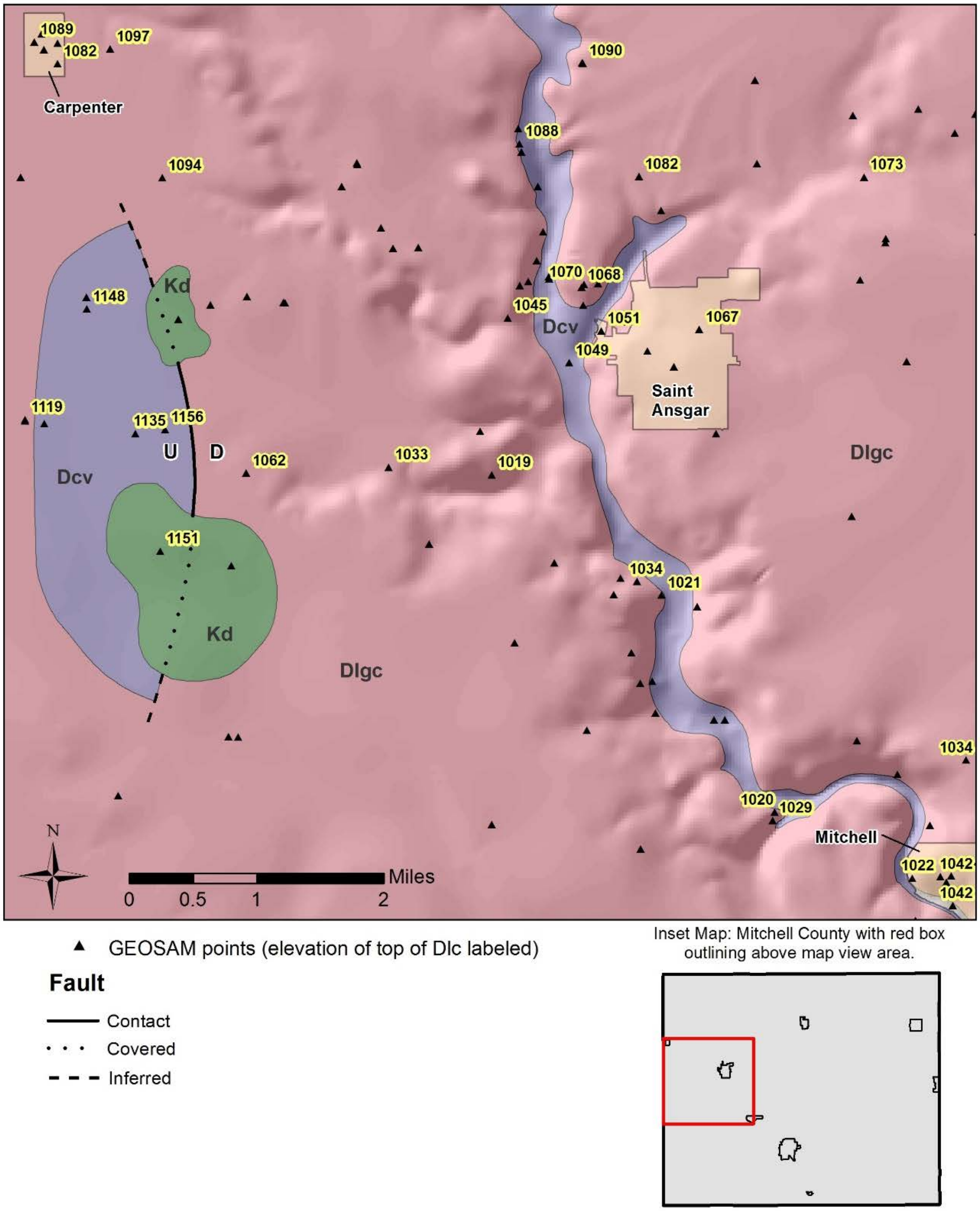


Figure 7: Portion of the bedrock geologic map showing the area of the "St. Ansgar Fault". GEOSAM well points are labeled with the elevation of the top of the Little Cedar Formation. "U" is upthrown side and "D" is downthrown side of the fault.

further credence to the presence of a fault such as the “St. Ansgar Fault” in western Mitchell County. The lack of subsurface stratigraphic data prevents a determination of whether it is a normal or reverse fault. If the “St. Ansgar Fault” is related to the TRFZ, then an argument could be made either way. Perhaps future drilling and stratigraphic information will reveal its true identity, or perhaps erase its very existence.

BEDROCK STRATIGRAPHY AND MAPPING UNITS

The units occurring at the bedrock surface in Mitchell County primarily include Devonian deposits with scattered Cretaceous 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 section. 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 Devonian for this map follow the stratigraphic framework established by Witzke and others (1988). The thickness of each map unit was derived chiefly from well penetrations within and adjacent to the map area.

Lithostratigraphic Setting

Devonian strata in north-central Iowa unconformably overlie an eroded surface of Ordovician rocks. The thick succession of Devonian strata suggests that subsidence continued in the region from the Late Givetian through the Frasnian and the consistently shallower depositional facies indicate that sedimentation kept pace with subsidence, defining the Iowa Basin as a stratigraphic basin rather than a bathymetric basin (Witzke et al., 1988). The richly fossiliferous lower Wapsipinicon and Cedar Valley group eperic carbonate platform deposits of the Iowa Basin accumulated during the interval of the Late Eifelian to Late Frasnian and provide a record of nine 3rd order and a number of other 4th order relative sea level changes (Transgressive-Regressive [T-R] cycles) (Day et al., 2006 and references therein). In Northern Iowa, quarry and outcrop exposures of Wapsipinicon and upper Cedar Valley group strata (Spillville to Shell Rock formations) of Late Eifelian to Middle Frasnian consist of cyclic sequences of middle and inner shelf facies including open and restricted-marine carbonates, evaporites, and shales. These strata were deposited during parts of seven major 3rd order relative sea level fluctuations recognized as Iowa Devonian T-R cycles 1 to 7 (Day et al., 2006, figures 1-5).

Although the Devonian stratigraphy has been definitively established through diligent field observations and biostratigraphic correlation, identification of the seven Devonian formations in the mapping area based on lithology and macro-fossils alone proved to be a challenge. The subtle nature of the 3rd order T-R cycles and associated subcycles reflected in the variation of carbonate facies throughout the Devonian section in the mapping area can be nearly impossible to differentiate when logging well chip samples at 5-feet intervals, as well as in small, isolated outcrops. In other words, when staring at a small weathered outcrop of fossil moldic dolomite, one must decide whether it belongs in the lower Lithograph City, lower Coralville, lower Little Cedar, or Spillville formations. Nonetheless, the following descriptions reflect the observations of all known bedrock exposures, core, and chip samples in and around the mapping area. All photos are provided in Appendix B of this report.

Mapping Units

Cretaceous System

Dakota/Windrow Formation – This map unit occurs as erosional outliers primarily in the northern half of the mapping area and is usually less than 12 m (40 ft) thick. The formation consists of a variety of lithologies including quartz arenite, non-calcareous shale and mudstone, and chert-pebble conglomerate; with lesser amounts of siderite occurring as granules and pellets. Commonly reddish, although yellow and brown coloration of the sandstone and conglomerate lithologies; and green, gray, and white in the shale and mudstone lithologies were observed both in well cuttings and outcrop. Sandstone and conglomerate lithologies display iron, pyrite, goethite, and chert cementation.

In the mapping area, this formation represents non-marine fluvial and pedogenic facies which are dominated by poorly indurated and weakly cemented sedimentary lithologies. The nature of these rocks lends them to be easily eroded and remobilized during Quaternary glacial and inter-glacial periods, making identification between Iowan Surface materials and Cretaceous bedrock and/or residuum very difficult. Identification of Cretaceous conglomerate facies rocks in well cutting samples was predicated on the presence or absence of igneous clasts. The identification of Cretaceous shales was relied, regrettably, on color and consistency. There were a few wells in Mitchell County that were dominated by relatively pure, weakly cemented, arenitic sandstone (up to 27 m [90 ft] in the case of W-28701). One of the primary indicators, however, of Cretaceous bedrock at or near a well location is the presence of iron-cemented sandstone clasts.

Although typically identified from well cuttings, outcrops were identified at two apparent sand and gravel pits, both located along the northern boundary of the mapping area (Fig. 8). Inspection of these pits revealed scattered pieces of iron-cemented sandstone and conglomerate (Photos 1 & 2). Abundant fine to coarse sand as well as mudstone, siltstone, and shale of varying colors were also observed, however none of the observed lithologies were confidently deemed to be in place outcrops (Photos 3 & 4). Additional exposures of Cretaceous bedrock were observed at the Aspel Quarry in northeastern Mitchell County (Fig. 8). Similar lithologies were observed in the 'overburden' piles at the quarry with possible *in situ* residuum of Cretaceous observed in a few places within the quarry (Photos 5 & 6).

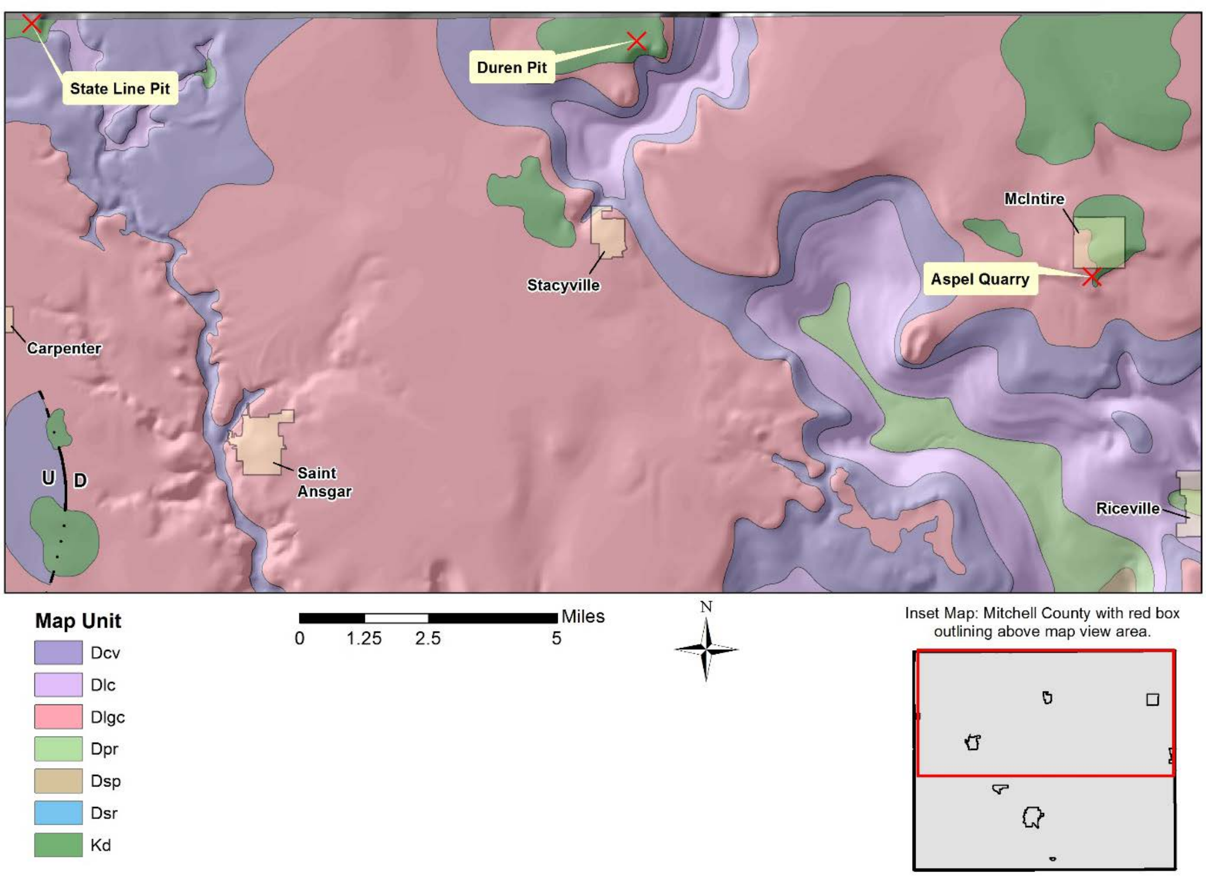


Figure 8: Portion of bedrock map showing location of Cretaceous outcrops.

Devonian System
Cedar Valley Group

Shell Rock Formation – This map unit forms the bedrock surface in the southwestern corner of the mapping area, usually with a thickness between 2 and 20 m (6-65 ft). The unit is characterized by fossiliferous limestone, dolomitic limestone and dolomite, with some gray to light green shale and/or argillaceous carbonates. Layers containing abundant subspherical and branching stromatoporoids commonly occur in the lower part of the unit. Brachiopods, bryozoans, corals, and crinoids are abundant in some intervals. Outcrops of this unit are only found along portions of Rock Creek and in a few quarries along Rock Creek.

During initial field reconnaissance of southwestern Mitchell County, the occurrence of abundant subspherical stromatoporoids was thought to be a strong indicator of lowermost Shell Rock Formation lithology, however after further consideration that was not deemed prudent as similar fossils were also observed in the upper Lithograph City Formation elsewhere in the region. However, the occurrence of abundant bryozoans (trepostome?), typically associated with stromatoporoids, in lithographic and fossiliferous limestones was accepted as lowermost Shell Rock Formation. Bryozoan-rich limestone was observed at only one location in Mitchell County, the Staff Quarry (SE, SW, Section 8, R17W, T97N), and at two locations in north-central Floyd County (Jones and Lacoste quarries) (Photos 7 & 8).

Lithograph City Formation – This map unit represents the majority of the bedrock surface in the mapping area reaching a maximum thickness of 32 m (105 ft). In the mapping area, this unit consists of two members with differing lithologies. The lower Osage Springs Member is mostly dolomite and dolomitic limestone, commonly vuggy with scattered to abundant fossil molds (Photo 9), while the upper Idlewild Member is characterized by interbeds of laminated, lithographic and sub-lithographic limestone and dolomitic limestone (Photo 10). A third intervening unit, the Thunder Woman Shale, is not recognized this far north in the Iowa Basin although both the Idlewild and Osage Springs member are variably argillaceous to locally shaly throughout the mapping area. The Osage Springs Member type section is located just south of Osage in Mitchell County (Witzke et al., 1988 and Bunker, 1995).

The Lithograph City Formation hosts the widest variety of lithologic textures and structures of any other mapping unit in Mitchell County. "Birdseye" structures, vugs, and calcite vug-fills are common, worm burrows and other heavily bioturbated fabrics were observed at most localities, stromatolitic lamination, mud cracks, stylolites, liesegang banding, paleo-karst, peloidal, intraclastic, brecciated, and hard ground surfaces were also observed (Photos 11-19).

Occasional intervals of fossiliferous and stromatoporoid-rich carbonates are present in the limestone facies, locally forming biostromes with both subspherical and branching varieties (Photos 20 & 21). A possible change in depositional environment is noted by the rapid decline of stromatoporoid fauna observed northward in Mitchell County. Fossiliferous limestone beds in the upper half of the formation are dominated by a variety of brachiopod fauna (Witzke et al., 1988; Bunker, 1995; Groves et al., 2008; and Day et al., 2013) followed in observed abundance by crinoids, stromatolites, corals, and bryozoans (Photos 22 & 23). The dolomitic facies of this formation exhibits abundant fossil molds (Photos 24), primarily of brachiopods with lesser crinoids.

Coralville Formation – This map unit is between 12 and 20 m (40-70 ft) thick in the mapping area, generally thinning to the northwest. This unit is dominated by dolomite and dolomitic limestone; in part, laminated, argillaceous, intraclastic, and bioturbated with occasional sub-lithographic limestone and mud cracks (Photos 25 & 26). A thin green-gray shale along with a green-gray, mottled, bioturbated dolomite occurs near the upper contact of the Coralville Formation at several locations (Photos 27-30). This was thought to be a marker bed however similar lithologies were observed lower in the section at the Lesch Quarry along the Cedar River south of Osage (Photo 31). Prominent breccia zones occur in the upper part of the unit (Photos 32 & 33). Brachiopods, echinoderm debris, and corals usually occur in the limestone facies and as fossil molds in the dolomite facies in the lower part of the unit (Photo 34).

Little Cedar Formation – This map unit can be up to 37 m (120 ft) thick and consists of four distinct members (in ascending order): the Basset, Chickasaw Shale, Eagle Center, and Hinkle. Since there are no known exposures of this formation within the mapping area, careful consideration of this unit was taken when creating strip logs.

The bulk of this formation, 15 to 24 m (50-80 ft), is occupied by the Bassett Member which is typified by thick bedded dolomite, argillaceous dolomite, and minor dolomitic limestone. Typically vuggy with scattered to abundant fossil molds throughout and minor chert in the upper half of the section (Photos 35 & 36). Rare occurrences of fossiliferous limestone were identified in the lower half of the Bassett in a few wells in Mitchell County which seemed to correlate with the "Salisbury Beds" of Klapper and Barrick, 1983 (Witzke et al., 1988). The fossils where mostly phosphatized (black) and consisted of brachiopods, crinoids, and bryozoans.

The Chickasaw Shale Member is a moderately continuous gray-green silty, shale, typically dolomitic that ranges from 3 to 6 m (10-20 ft) thick (Photo 37 & 38). This unit is of distinct interest because it serves as a regional confining layer between the upper and middle Devonian aquifers in north-central Iowa (Libra and Hallberg, 1984 and Witzke et al. 1988). It becomes increasingly difficult to identify in well cuttings and seems to disappear entirely, blending into the argillaceous dolomites of the Bassett northward in the mapping area.

The Eagle Center Member is typically less than 5 m (15 ft) thick and consists of dolomite, commonly vuggy with abundant fossil molds and traces of chert. Upon studying the FM-2 core (W-27275), the Eagle Center appeared to be uniquely dark, chocolate brown, with a distinctive clean, crystalline texture. These characteristics seemed to persist throughout much of the mapping area and became a useful marker bed when logging cuttings.

The Hinkle Member consists of up to 5 m (15 ft) of limestone and dolomitic limestone, partly sub-lithographic and laminated. This unit is quite difficult to differentiate in well cuttings and is presumed to coincide, in some areas, with the Eagle Center. In some cases, making stratigraphic calls between the Little Cedar and Coralville formations involved simply adding 20 to 30 feet onto the Chickasaw Shale Member.

<u>Wapsipinicon Group</u>

Pinicon Ridge Formation – This map unit ranges from 9 to 15 m (30-50 ft) in thickness and consists of unfossiliferous dolomite and limestone with minor shale. This unit displays a variety of textures and compositions including laminated, pyritic, sandy, and cherty. This unit is characterized throughout the mapping area by being heavily brecciated, mixing all lithologies. The Pinicon Ridge Formation is not exposed in Mitchell County. Although many formations encountered in wells in Mitchell County are brecciated, this unit was fairly easily identified by the presence of embedded sand and, to a lesser extent, the chert, which commonly appeared as crystalline quartz.

Spillville Formation – This map unit reaches a maximum thickness of approximately 24 m (80 ft) and is dominated by medium to thick bedded dolomite, commonly vuggy with calcite vug fills and scattered to abundant fossil molds. Sporadic fossiliferous limestone units have been observed. The basal unit, where present, is variably sandy, shaly, and/or conglomeratic with reworked Ordovician chert clasts. This unit is also not exposed in the mapping area and fewer well penetrations extend deep enough to encounter it. The relatively clean, recrystallized nature of this formation is what makes it easy to identify in well cuttings and core. This unit is quite variable due to the large unconformity between it and the underlying upper Ordovician Maquoketa Formation. The Spillville thins dramatically to the north-northwest in the mapping area to a mere 20 feet thick in some wells.

REFERENCES

Anderson, R.R., 2006: Geology of the Precambrian Surface of Iowa and surrounding area. Iowa Geological Survey Open File Map OFM-06-7.

Bunker, B.J., (ed.), 1995: Geology and hydrogeology of Floyd-Mitchell counties, north-central Iowa. Geol. Soc. of Iowa Guidebook No. 62, 169 p.

Calvin, S., 1902, Geology of Mitchell County: Iowa Geological Survey Annual Report, v. 13, p. 293-338.

Clark, R., Liu, H., Kerr, P., Tassier-Surine, S., Rowden, R., and Streeter, M., 2015: Bedrock Geology of the New Haven 7.5' Quadrangle, Mitchell County, Iowa. Iowa Geological Survey Open File Map OFM-15-3.

Clark, R., Liu, H., Kerr, P., Tassier-Surine, S., Rowden, R., and Streeter, M., 2016: Bedrock Geologic Map of Mitchell County, Iowa. Iowa Geological Survey Open File Map OFM-16-1.

Day, J., 2006: Overview of the Middle-Upper Devonian sea level history of the Wapsipinicon and Cedar Valley Groups, with discussion of new conodont data from the subsurface Cedar Valley Group of southeastern Iowa. *in* Day, J., Luczaj, J., and Anderson, R., (eds.), New Perspectives and Advances in the Understanding of Lower and Middle Paleozoic Epeiric Carbonate Depositional Systems of the Iowa and Illinois Basins. Iowa Geological Survey Guidebook Series No. 25, p. 3-21.

Day, J., Witzke B., and Lundy, S., (eds.), 2013: Aspects of the Paleozoic history of epeiric seas of the Iowa basin. Iowa Geological and Water Survey Guidebook No. 29, 118 p.

Groves, J.R., Walters, J.C., and Day, J. (eds.), 2008: Carbonate platform facies and faunas of the Middle and Upper Devonian Cedar Valley Group and Lime Creek Formation, northern Iowa. Iowa Geological Survey Guidebook No. 28, 96 p.

Hershey, H. G., 1969: Geological map of Iowa showing the indurated rocks exposed immediately beneath the glacial deposits. Iowa Geological Survey M-9.

Libra, R.D., Hallberg, G.R., Ressmeyer, G.G., and Hoyer, B.E., 1984: Groundwater quality and hydrogeology of Devonian-Carbonate aquifers in Floyd and Mitchell counties, Iowa. Iowa Geological Survey Open File Report 84-2, p. 1-106.

Liu, H., McKay, R., Rowden, R., Quade, D., Tassier-Surine, S., and Giglierano, J., 2012: Bedrock Geology of Worth County, Iowa. Iowa Geological and Water Survey Open File Map OFM-12-1.

Liu, H., Clark, R., Fields, C., McKay, R., Rowden, R., Tassier-Surine, S., Kerr, P., and Streeter, M., 2015: Bedrock Geology of Cerro Gordo County, Iowa. Iowa Geological Survey Open File Map OFM-15-1.

Liu, H., Clark, R., Streeter, M., Kerr, P., and Tassier-Surine, S., 2016a: Bedrock Geology of the Charles City 7.5' Quadrangle, Floyd County, Iowa. Iowa Geological Survey Open File Map OFM-16-5.

Liu, H., Clark, R., Kerr, P., Tassier-Surine, S., and Streeter, M., 2016b: Bedrock Geology of the Orchard 7.5' Quadrangle, Floyd and Mitchell Counties, Iowa. Iowa Geological Survey Open File Map OFM-16-3.

Mossler, J. H., 1998: Bedrock Geology of Mower County, Minnesota. Mower County Board of Commissioners and the Minnesota Department of Natural Resources, Division of Waters, County Atlas Series C-11, Part A, Plate 2.

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

Rowden, R., McKay, R., Clark, R., Liu, H., Tassier-Surine, S., Quade, D., Galer, R., and Streeter, M., 2014a: Bedrock Geology of the Osage 7.5' Quadrangle, Mitchell County, Iowa. Iowa Geological Survey Open File Map OFM-14-7.

Rowden, R., McKay, R., Clark, R., Liu, H., Tassier-Surine, S., Quade, D., Galer, R., and Streeter, M., 2014b: Bedrock Geology of the St. Ansgar 7.5' Quadrangle, Mitchell County, Iowa. Iowa Geological Survey Open File Map OFM-14-5.

Voy, K.D. and Highland, J.D., 1975: Soil Survey of Mitchell County, Iowa. U.S. Dept. of Agriculture, Soil Conservation Service, 125 p. with 70 map sheets.

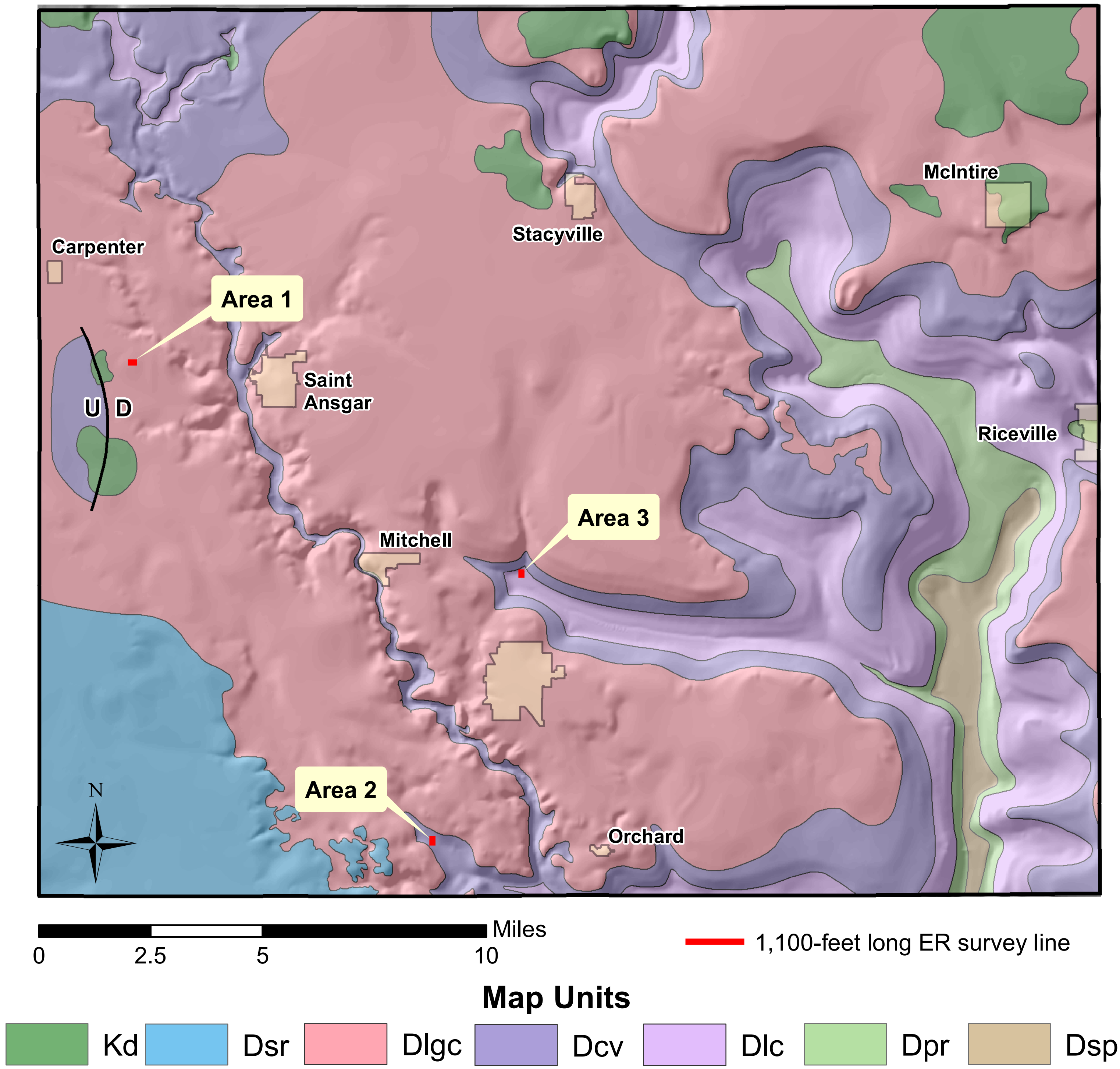
Witzke, B.J. and Bunker, B.J., 1985: Part 2. Stratigraphic framework for the Devonian aquifers in Floyd and Mitchell Counties, Iowa. Iowa Geological Survey Open File Report 85-2, p. 21-32, 6 figs.

Witzke, B.J., Bunker, B.J., and Rogers, F.S., 1988: Eifelian through lower Frasnian stratigraphy and deposition in the Iowa area, central midcontinent, U.S.A. *in* McMillan, N.J., Embry, A.F, and Glass, D.J. (eds.): Devonian of the World, Canadian Soc. of Petroleum Geologists, Memoir 14, vol. I, p. 221-250.

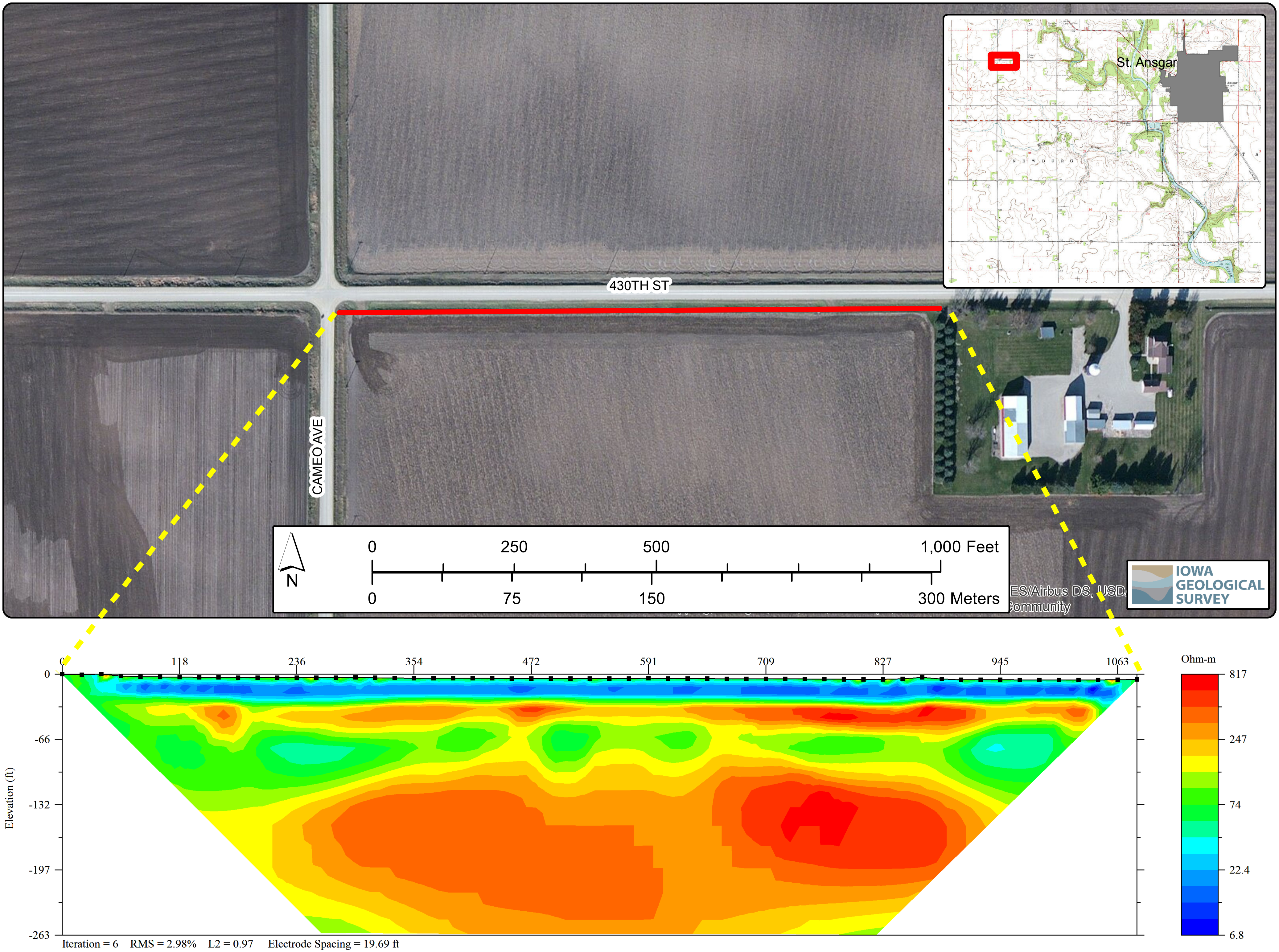
Witzke, B. J., Anderson, R. R., Bunker, B. J., Ludvigson, G. A., and Greeney, S., 2001: Bedrock Geology of North-Central Iowa. Geological Survey Bureau Open File Map OFM-01-3.

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.

Appendix A - Location Map of Geophysical Surveys

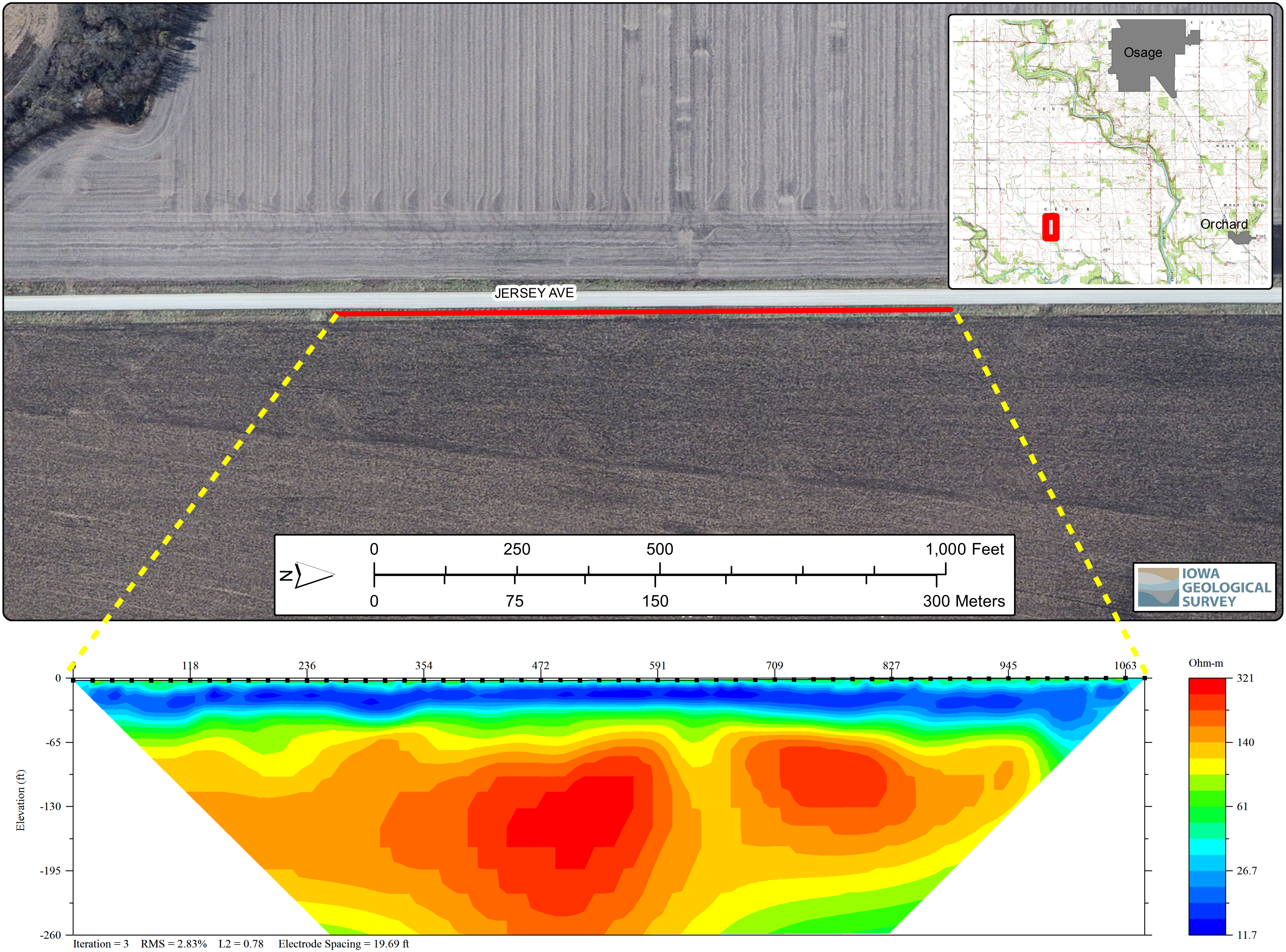


Area 1



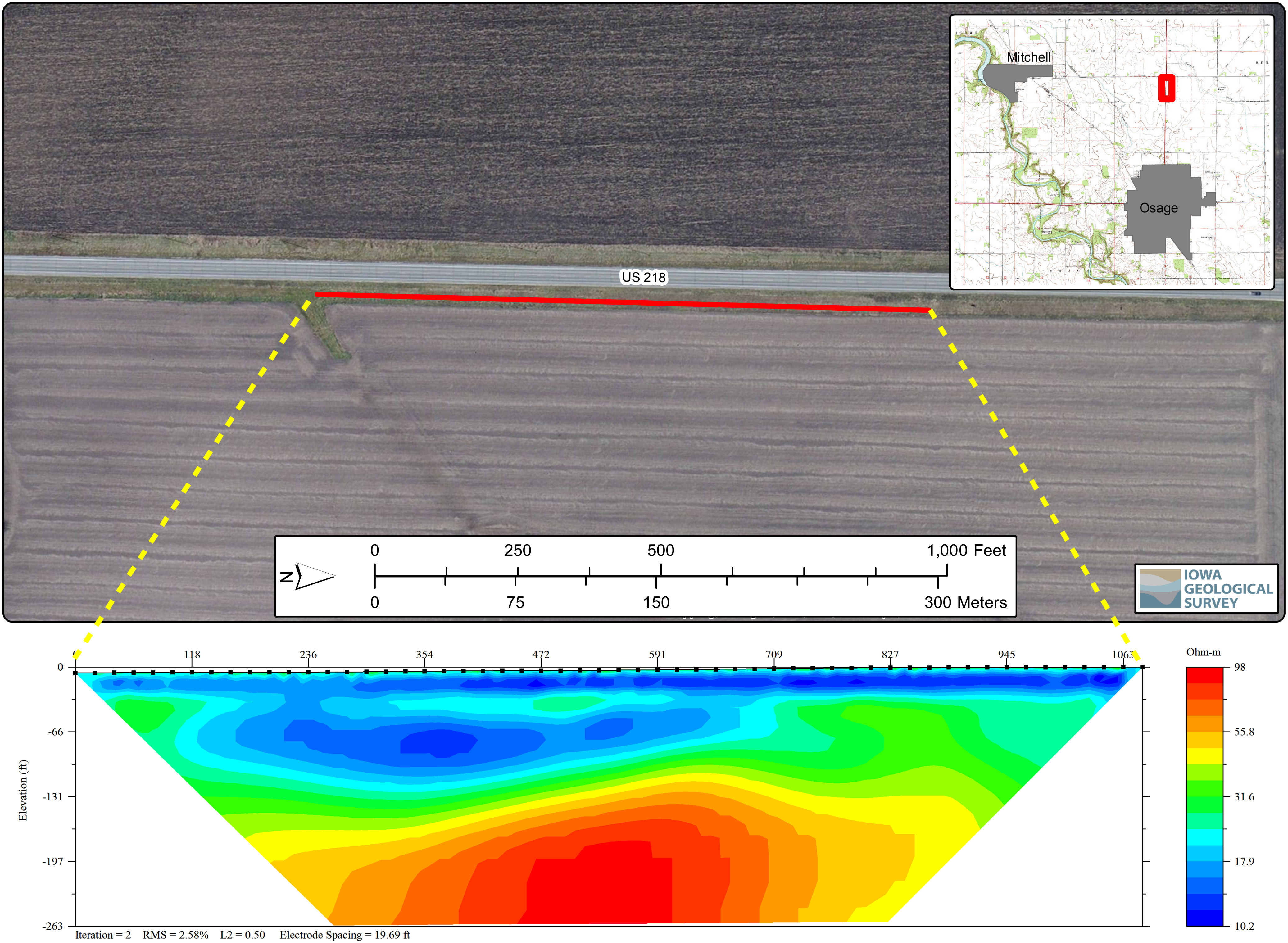
St. Ansgar
430TH ST
CAMEO AVE
N
0
250
500
1,000 Feet
0
75
150
300 Meters
IOWA GEOLOGICAL SURVEY
0
118
236
354
472
591
709
827
945
1063
0
-66
-132
-197
-263
Elevation (ft)
Ohm-m
817
247
74
22.4
6.8
Iteration = 6 RMS = 2.98% L2 = 0.97 Electrode Spacing = 19.69 ft

Area 2



Osage
Orchard
JERSEY AVE
N
0
250
500
1,000 Feet
0
75
150
300 Meters
IOWA GEOLOGICAL SURVEY
0
118
236
354
472
591
709
827
945
1063
Elevation (ft)
0
-65
-130
-195
-260
Ohm-m
321
140
61
26.7
11.7
Iteration = 3 RMS = 2.83% L2 = 0.78 Electrode Spacing = 19.69 ft

Area 3



Mitchell
Osage
US 218
N
0
250
500
1,000 Feet
0
75
150
300 Meters
IOWA GEOLOGICAL SURVEY
0
118
236
354
472
591
709
827
945
1063
0
-66
-131
-197
-263
Elevation (ft)
Ohm-m
98
55.8
31.6
17.9
10.2
Iteration = 2 RMS = 2.58% L2 = 0.50 Electrode Spacing = 19.69 ft

Photo 1: Iron-cemented sandstone (near rock pick handle) encrusted over white shale and abundant chert pebbles at the "State Line Pit" (NE, NE, Section 7, R18W, T100N). (rock pick for scale).

Photo 2: Iron-cemented chert pebble conglomerate from the "Duren Pit" (E, E, Section 7, R16W, T100N). (rock pick for scale)

Photo 3: View looking northeast from inside the "State Line Pit". Note the white and pink colored mudstone intermingled with the orange-brown sandstone in the pit wall. (truck for scale)

Photo 4: View looking southeast inside the "Duren Pit". Note the white blobs of mudstone mixed with apparent glacial erratics and sand deposits.

Photo 5: Brick red Cretaceous mudstone mixed with abundant chert pebbles lying on top of limestone of the Lithograph City Formation at the Aspel Quarry (NE, NE, Section 3, R15W, T99N). (rock pick for scale)

Photo 6: Partially iron-cemented chert pebble conglomerate and sandstone in a rock pile at the Aspel Quarry. (rock pick for scale)

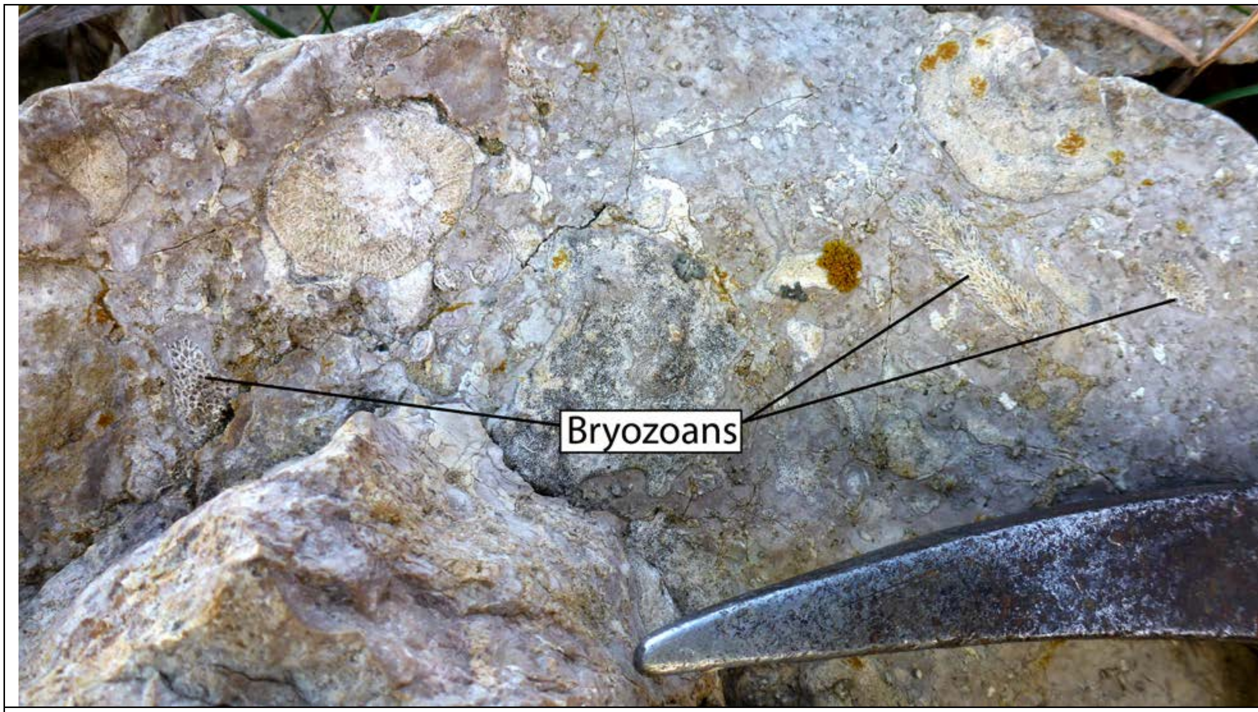


Photo 7*: Bryozoan fossils (trepostome?) in fossiliferous limestone of the lower Shell Rock Formation from the uppermost bed in the Jones Quarry in north-central Floyd County. (rock pick for scale)

Photo 8: Fossiliferous limestone with bryozoan fossils (trepostome?) of the lower Shell Rock Formation from the uppermost unit in the Staff Quarry (SE, SW, Section 8, R17W, T97N). (rock pick for scale)

Photo 9: Calcite-filled vugs in dolomite of the Osages Springs Member of the Lithograph City Formation as seen in the upper beds of the Winters Quarry (NW, SW, Section 23, R16W, T99N). (rock pick for scale)

Photo 10: Looking northeast from inside the Duenow Quarry (NW, SE, Section 8, R17W, T99N) at a ledge of Lithograph City Formation. (Ryan Clark for scale)

Photo 11: Concoidal fracture patterns in lithographic limestone from Jones Quarry in Floyd County. (ruler for scale)

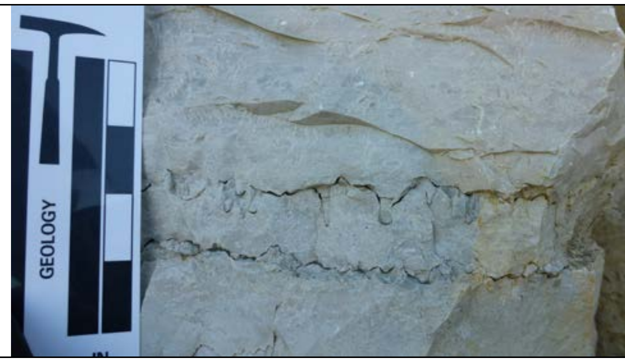


Photo 12: Stylolites in limestone from Jones Quarry in Floyd County (ruler for scale)

Photo 13: "Birdseye" structure with open cavities in lithographic limestone of the upper Lithograph City Fm. in the Staff Quarry. (rock pick for scale)

Photo 14: Burrows found on the underside of a ledge at the base of the Osage Springs Member from the Winters Quarry (NW, SW, Section 23, R16W, T99N). (ruler for scale)

* Indicates photo modified to enhance detail.

Photo 15*: Peloidal limestone of the Lithograph City Formation from the Lacoste Quarry in Floyd County. (ruler for scale)

Photo 16*: Brecciated limestone in the Lithograph City Formation at the Koster Quarry (NW, NE, Section 35, R18W, T99N). (rock pick handle for scale)

Photo 17: Heavily brecciated section of Lithograph City Formation in the Duenow Quarry. (rock pick for scale)

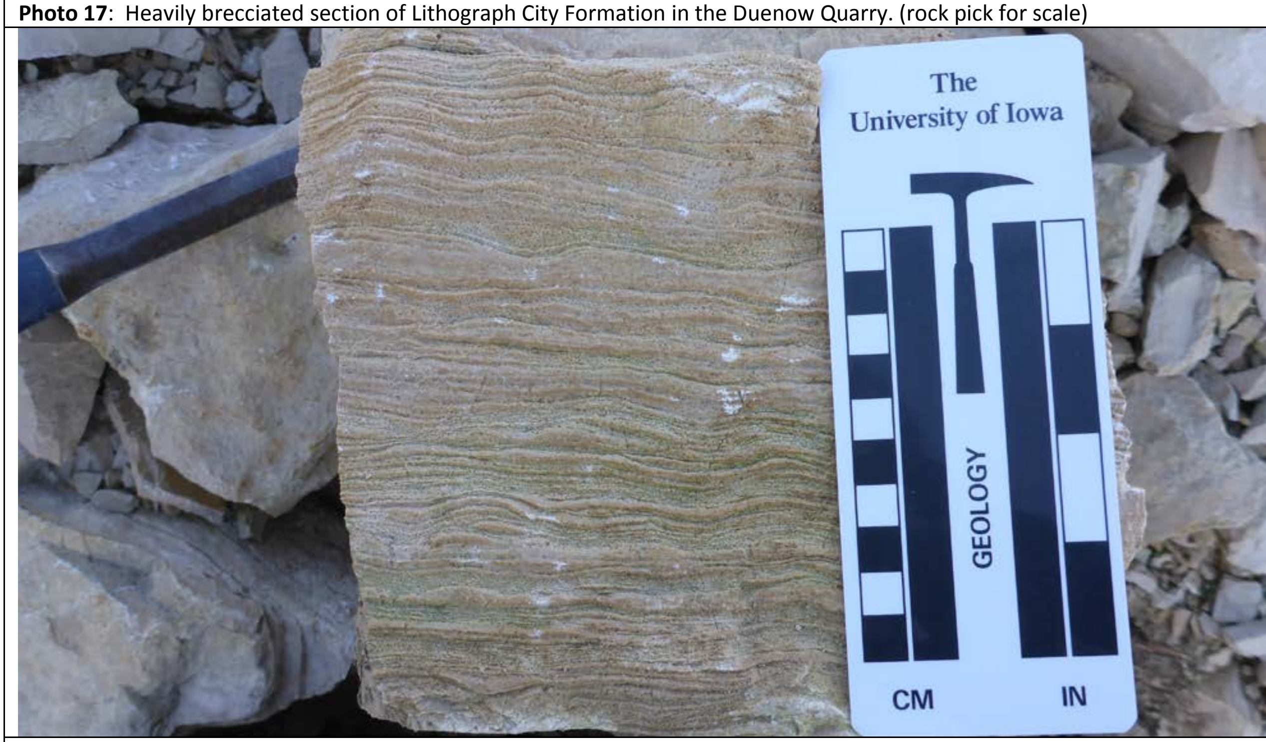


Photo 18: Stromatolitic lamination in limestone of the Lithograph City Formation from the Wagner Quarry (SW, NW, Section 29, R16W, T98N). (ruler for scale)

Photo 19: Mud cracks in the Lithograph City Formation at the Lacoste Quarry in north-central Floyd County. (rock hammer for scale)

Photo 20: Subspherical stromatoporoids in limestone of the Lithograph City Formation (SW, SE, SE, Section 15, R18W, T98N). (ruler for scale)

Photo 21: Branching stromatoporoids in the Lithograph City Formation at the Cedar Quarry (NE, SW, Section 35, R17W, T98N). (rock hammer for scale)

Photo 22: Abraded brachiopod and crinoid debris in fossiliferous limestone of the Lithograph City Formation in the Wagner Quarry. (ruler for scale)

Photo 23: Brachiopods fossils in lithographic limestone near the top of the Lithograph City Formation in the Staff Quarry. (ruler for scale)

Photo 24: Brachiopod fossil molds and calcite-filled vugs in dolomite of the Osage Springs Member in the Dynes Quarry (SE, SW, Section 30, R15W, T99N). (ruler for scale)

Photo 25: Mud cracks in sub-lithographic limestone near the top of the Coralville Formation at the Mitchell Dam (NE, SW, Section 8, R17W, T98N). (rock pick for scale)

Photo 26: Laminated dolomite in the Coralville Formation at the Winters Quarry. (ruler for scale)

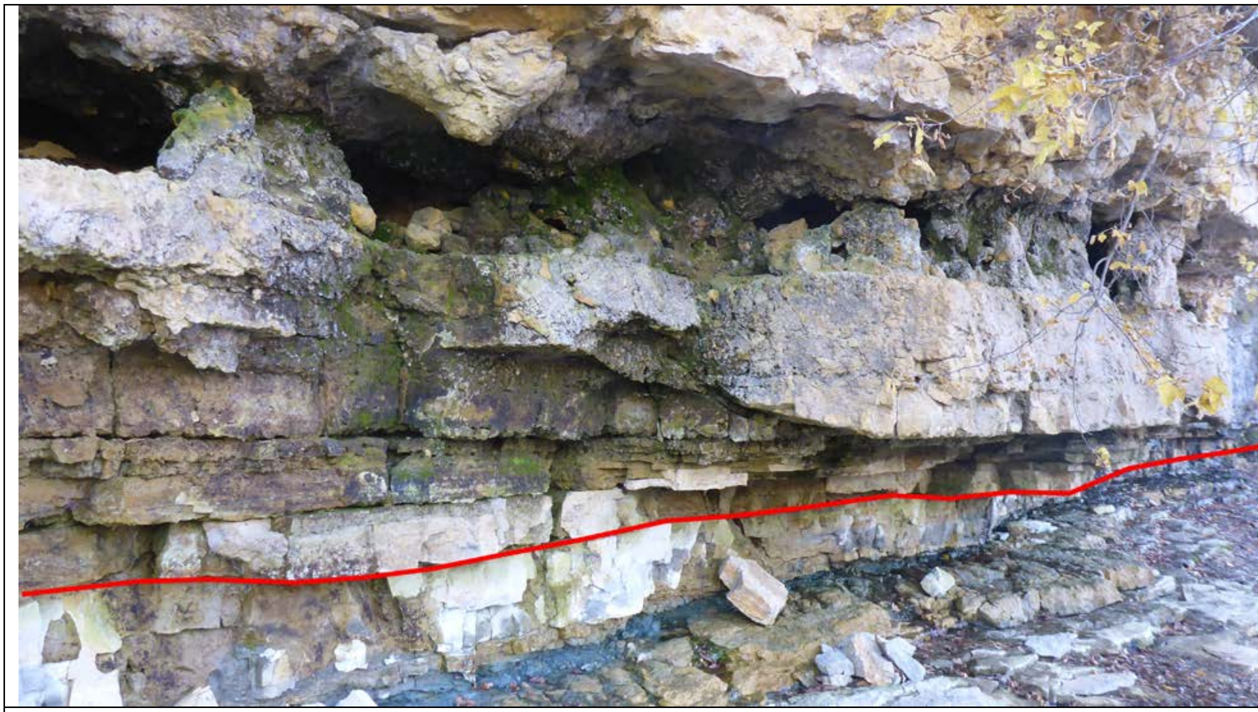


Photo 27: Exposure of the contact (red line) between the Lithograph City Fm. (above) and the Coralville Fm. (below) at the Mitchell Dam along the west bank of the Cedar River. Note the thin green-gray shale about 1 m below the contact.

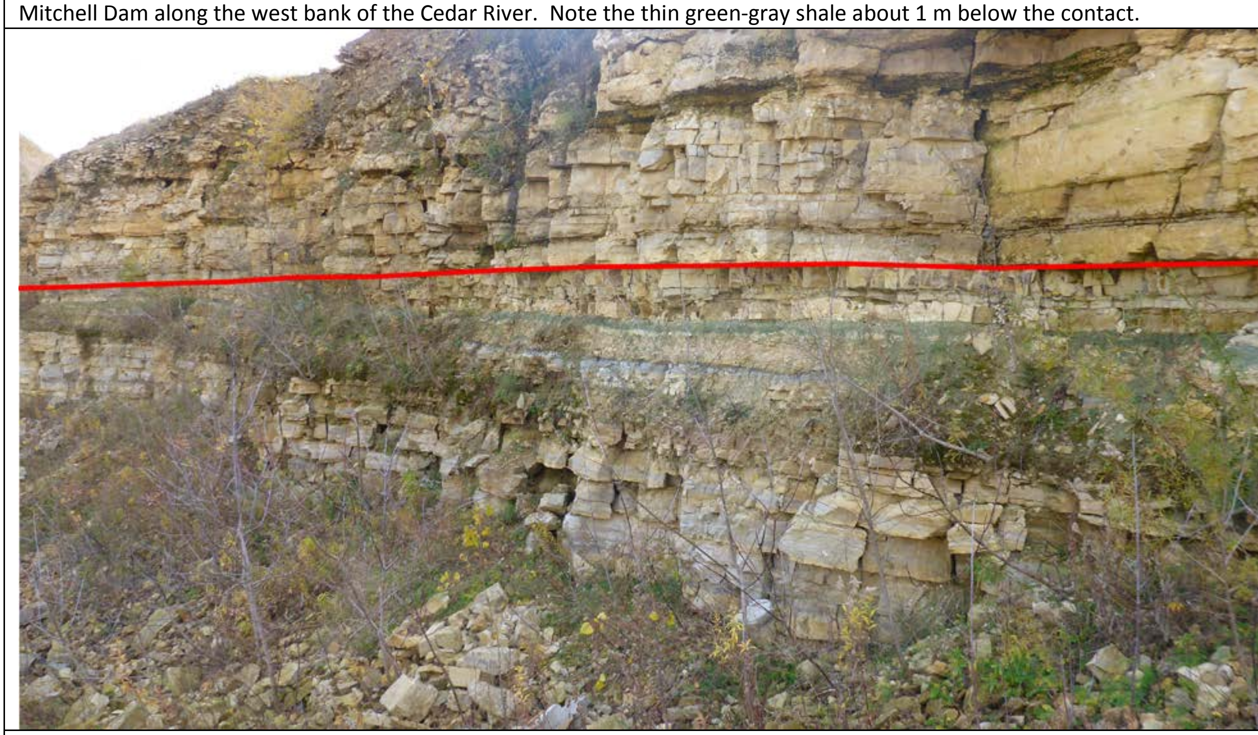


Photo 28: Exposure of the contact (red line) between the Lithograph City Fm. (above) and the Coralville Fm. (below) at the Winters Quarry. Note thin green shale about 1 m below the contact.

Photo 29: Mottled, bioturbated fabric in dolomite near the top of the Coralville Formation at the Mitchell Dam. (rock pick for scale)

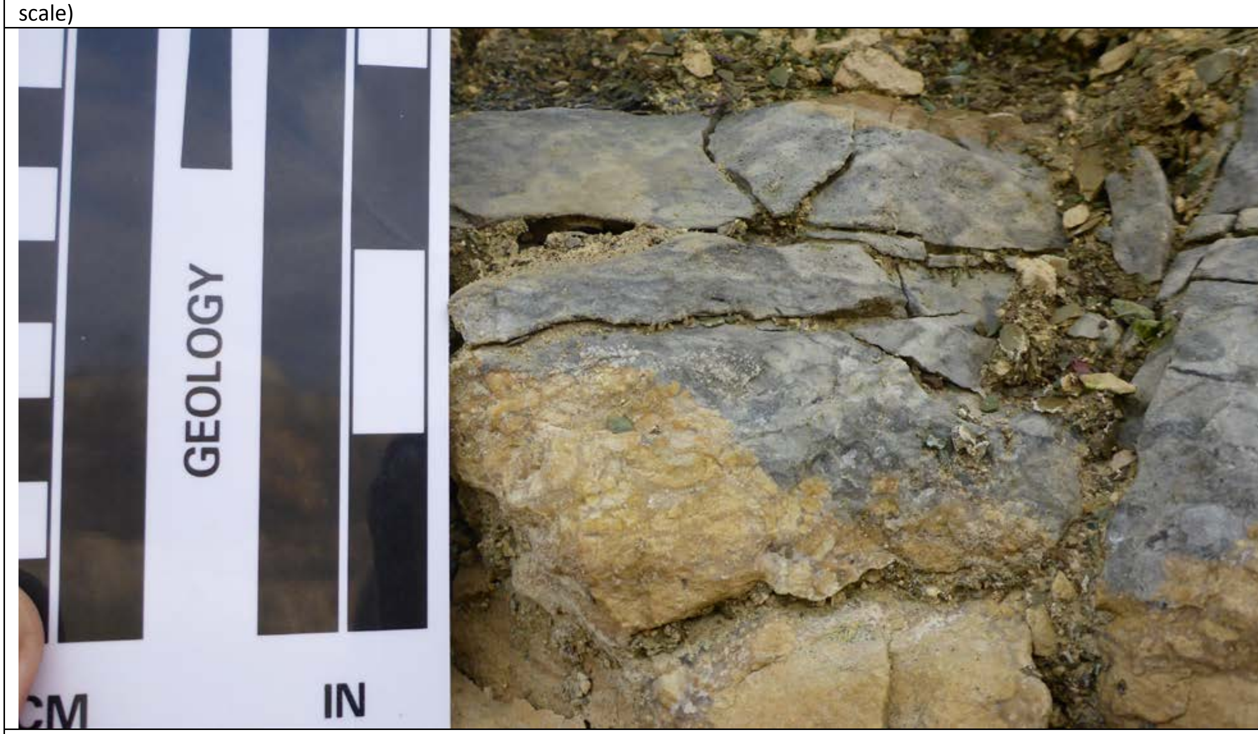


Photo 30: Mottled, bioturbated fabric in dolomite near the top of the Coralville Formation at the Winters Quarry. (ruler for scale)

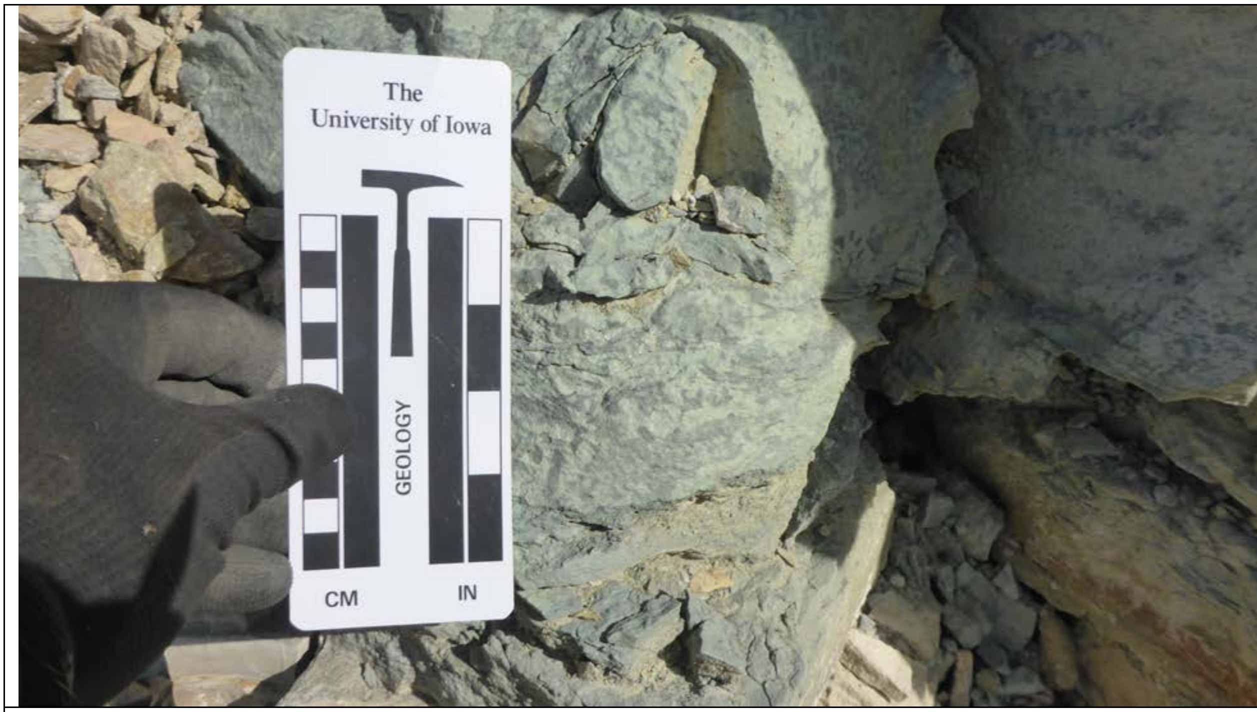


Photo 31: Mottled, bioturbated fabric in dolomite near the middle of the Coralville Formation at the Lesch Quarry (SW, NW, Section 13, R17W, T97N). (rock pick for scale)

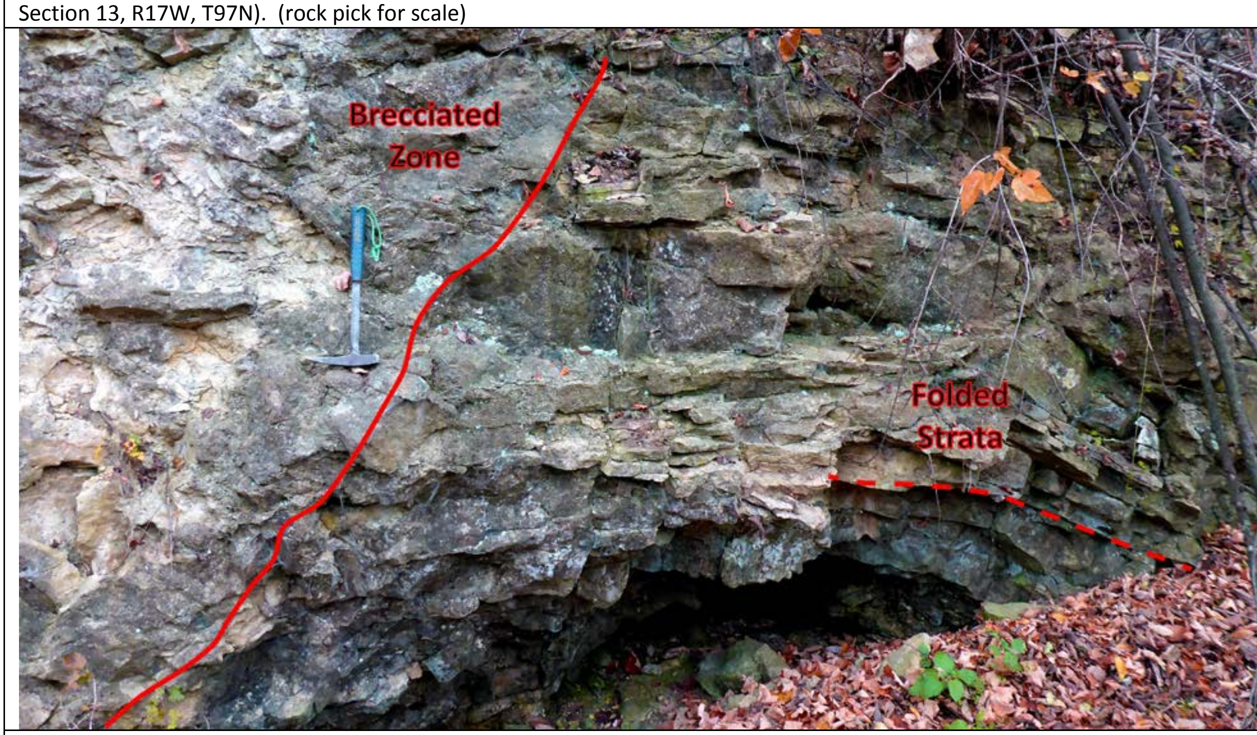


Photo 32*: Deformed and heavily brecciated strata of the Coralville Formation at exposure on the southeast bank of the Cedar River (NE, Section 28, R17W, T98N). (rock pick for scale)

Photo 33*: Brecciated unit of the Coralville Formation consisting of blocks of laminated carbonate in a matrix of carbonate residuum. Calcite veins and vug fills occur within some gaps of the blocks (NE, Section 28, R17W, T98N). (rock pick for scale)

Photo 34: IDOT bridge core (W-63616) of vuggy and fossil moldic dolomite of the lower Coralville Formation (Gizzard Creek Member). Core collected from east abutment where Highway 105 crosses the Cedar River in St. Ansgar. Cored interval shown is from 29 (lower left) to 39 (upper right) feet below ground surface (each row of core is approx. two feet in length).

* Indicates photo modified to enhance detail.

Photo 35: Dolomite of the Bassett Member of the Little Cedar Formation in the Boise Quarry in Chickasaw County (S, NE, Section 16, R14W, T95N). (car for scale)

Photo 36: Bassett Member dolomite with calcite-filled vugs and silicified brachiopod fossils from the Boise Quarry. (rock hammer for scale).

Photo 37: Gray shale of the Chickasaw Shale Member on top of Bassett Member dolomite in the Boise Quarry. (H. Paul Liu for scale).

Photo 38: The Chickasaw Shale Member hosts geodes in the Boise Quarry and at other known exposures such as Chickasaw County Park (1/2 mile south of the Boise Quarry), the type locality for the Chickasaw Shale and Bassett members. (rock hammer for scale).