GSI SPRING 2011 FIELD TRIP
THE GEOLOGICAL WONDERS OF BREMER COUNTY

edited by
Thomas Marshall, Jason Vogelgesang, and Jamie Frauenholtz

Geological Society of Iowa

April 30, 2011 Guidebook 88

Cover Photograph

Bob McKay standing next to steeply-tilted flanking beds of carbonate mound on western high wall of upper-most bench at Tripoli-Platte Quarry. Strata consists of fine to coarse dolomites of Silurian lower Hopkinton Formation.

Geological Society of Iowa

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CORALS, CARBONATE BUILD-UPS, AND FOSSILS FROM THE SILURIAN OF BREMER COUNTY

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INTRODUCTION

Iowa has a great Paleozoic fossil record and offers lots of opportunities for paleontological and stratigraphic study. The bedrock in Bremer County is composed of Ordovician, Silurian, and Devonian age rocks. The Ordovician age rocks in Bremer County are not exposed on the surface. Although we will be able to see Devonian age rocks on the field trip, our ability to examine and collect fossils from them will be limited. Therefore, the primary focus of this article is to discuss the major groups of fossils exposed in the Silurian rocks (see Figure 1) that we will see on this field trip and the basic paleoenvironmental and paleoecological interpretations that can be made based on them. In addition, I will discuss the corals in greater detail with a discussion about what is a reef compared to the broader concept of a carbonate build-up.

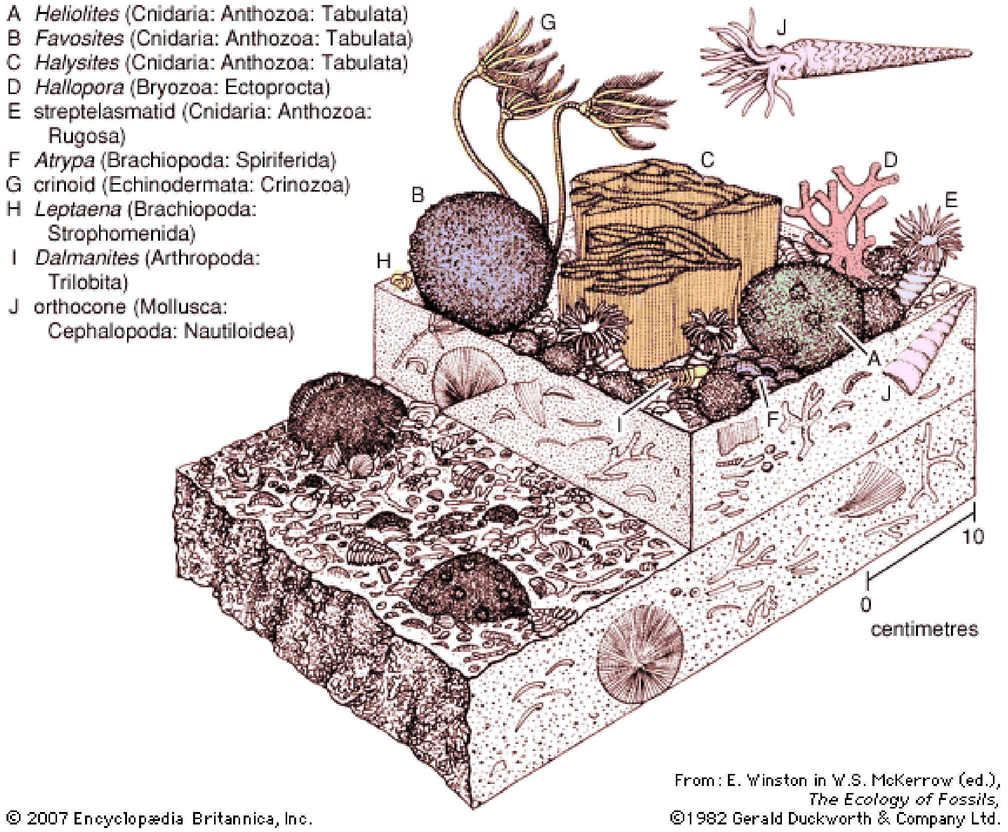

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Figure 1. Example of an Early Silurian community with representatives of major fossil groups that we can see in the Silurian of Iowa. Adopted from the Encyclopædia Britannica Online.

The major groups of fossils will seem very similar from the Ordovician to Devonian formations, but only in a broad sense. Jack Sepkoski (1981) recognized three major evolutionary faunas based on a statistical analysis of the similarities in stratigraphic ranges of marine families throughout the Phanerozoic. The fossils that we will see are typical of his Paleozoic Fauna. In the rocks from Ordovician, Silurian, and Devonian time periods of Iowa, you will be able to find brachiopods, crinoids, tabulate and rugose corals, stromatoporoids, cephalopods, and other important, but less abundant groups that represent Sepkoski's Paleozoic Fauna. The beauty of Sepkoski's work is that it fits what we generally can notice in Paleozoic age marine rocks without resorting to a complex statistical analysis and can be a useful tool for teaching about the fossil record. However, the species and genera that represent the Paleozoic Fauna can greatly vary from the Ordovician to the Devonian except instances where researchers have recognized the same taxa across long stratigraphic ranges (ex: the tabulate coral genus *Favosites*). In addition, the diversity and abundance of these groups will be impacted by complex environmental and ecological factors.

NOTABLE GROUPS OF FOSSILS FROM THE SILURIAN OF BREMER COUNTY

The Corals

The corals (phylum Cnidaria, class Anthozoa) are related to more recognizable soft bodied jellyfish and sea anemones. Like these groups, corals have two tissues layers, tentacles, and a central mouth structure. Corals spend most of their life cycle attached to the seafloor with less time floating in the water column like the jellyfish do. In between their tissues, corals secrete a calcareous skeleton and as a result have a good fossil record. The soft tissues are very seldom preserved, but the skeletal material is useful for determining which species you may have preserved in the fossil record since it is directly related to the soft tissues.

The two major groups of Paleozoic corals are the subclasses Tabulata and Rugosa. All tabulate corals are colonial with many individual polyps living in close association. The polyps each live in a tube-like structure called a corallite. The corallites for tabulate corals are general smaller with horizontal skeletal partitions called tabula. The polyps sit on top of the tabula and as the colonial grows, new tabula are developed further up in the corallites.

The rugose corals have both colonial and solitary forms. In general, the corallites for the rugose corals are larger than the ones found in the tabulate corals and have vertical skeletal partitions called septa, which are known to be directly related to the tentacles in modern corals. These septa are sometimes present in tabulate corals, but in general are much reduced in size. The solitary rugose corals can have larger individuals than those in a colony. They can have various corallite shapes and commonly described as the horn corals, cup corals, and button corals. The corals that live in modern environments, called the Scleractinia, also have solitary and colonial forms with septa, but the general insertion pattern of the septa as the polyp grows is different from the rugose corals. The current view is that the scleractinian corals are not directly related to the rugose corals, but derive from an anthozoan group that did not secrete a skeleton, such as sea anemones (order Actinaria or Corallimorpharia), and as such does not have a good enough fossil record to resolve this issue. However, you may notice lots of basic similarities in the overall structure and look to between the Paleozoic rugose corals and the modern scleractinian corals and will understand why the relationship is still not completely resolved. If you are interested in the details about this debate, visit the Tree of Life web project, http://tolweb.org/, for a good discussion and further references (Fautin et al., 2000).

Tabulate corals tend to be more prominent in Silurian age rocks than the rugose corals. Common tabulate corals in the Iowa Silurian rock record are the honeycomb coral *Favosites,* the chain coral *Halysites*, and the organ pipe coral *Syringopora*. We will likely see *Favosites* in the rocks of the Tripoli Quarry. For the rugose corals, we are most likely to see some horn corals that may be difficult to identify to the genus level in the outcrop. Norton (1906) recognized in Bremer County the tabulate corals

Halysites catenulatus, *Favosites favosus*, *F. hisingeri*, and *Heliolites subtubulatus*. In addition, he recognized the rugose corals of *Zaphrentis* sp. and *Streptelasma* sp., which are both horn corals. I have not had a chance to verify and update Norton's identifications, so please use this information wisely.

The Stromatoporoids

The stromatoporoids (phylum Porifera) are an extinct group with a dense calcareous skeleton that are considered to be related to sponges based on a peculiar group of living encrusting sponges. Unlike the majority of sponges, stromatoporoids do not have spicules. Their skeletons are composed of a series of layers or laminae with vertical pillars between them. Stromatoporoids may not be that easily identified to the species level in the outcrop, but certainly their general shapes can be described with terms like branching, digitate, massive, hemispherical, tabular or laminar. Laminar shaped stromatoporoids are found in the Tripoli Quarry and do make up a benthic association with the corals. In addition, due to the nature of their skeletons, the stromatoporoids tend to be part of the framework for reefs or carbonate build-ups and you should see the discussion on this below.

The Brachiopods

The brachiopods (phylum Brachiopoda) can be considered the most diverse and abundant macrofossil group in middle Paleozoic age rocks in Iowa. Brachiopods live in our modern oceans, but have a diminished role in the ecosystem. Brachiopods have two shells (valves), a soft tissue pedicle for attachment to the ocean floor, and a soft tissue arm-like structure called a lophophore used to capture food floating in the water column. Brachiopods may seem very close to bivalve mollusks due to both groups having two valves. However, the valves of brachiopods are each bilaterally symmetric. For the bivalves, the valves are not symmetric, but have a line of symmetry that is in between the two valves instead of through the valves.

Brachiopods have traditionally been divided into two major groups the Articulata and the Inarticulata. The main difference between these groups is the presence and absence of structures, called teeth and sockets, that hold the two valves together. The inarticulates do not have teeth and sockets at the edge of their valves to hold them together. Instead, they use muscles to accomplish this feat. Also, the pedicle goes between the two valves in the inarticulate brachiopods where articulate brachiopods, in general, have an opening in the valve for the pedicle. *Lingula* is one important inarticulate brachiopod genus and is considered to be a "living fossil" since this same genus can be easily recognized in modern environments as well as in approximately 500 million year old rocks. *Lingula* has a simpler and relatively distinct morphology with oblong valves that do not have much in terms of ridges, spines, or other structural features on the values. *Lingula* has been found in Iowa, but there is not a record of it in the outcrops that we will see today.

There are several different groups of articulate brachiopods in the Silurian of Iowa. The articulate brachiopod *Pentamerus* will be one of the most noticeable fossils in the Tripoli Quarry (see Figure 2). *Pentamerus* is a very large brachiopod with an oblong shape to its relatively smooth valves. *Pentamerus* along with *Stricklandia* and *Costistricklandia* are important components of well recognized Silurian benthic faunal associations in Iowa described by Johnson (1975, 1979) based on the work by Ziegler (1965) from the Welsh Borderland. Johnson (1980) estimated water depths for the pentamerid brachiopod community to be 30 to 60 meters. In addition, he estimated the water depth for the coral-stromatoporoid community to be 10 to 30 meters. These two communities give the overall possible water depth represented at the Tripoli Quarry to be between 10 to 60 meters.

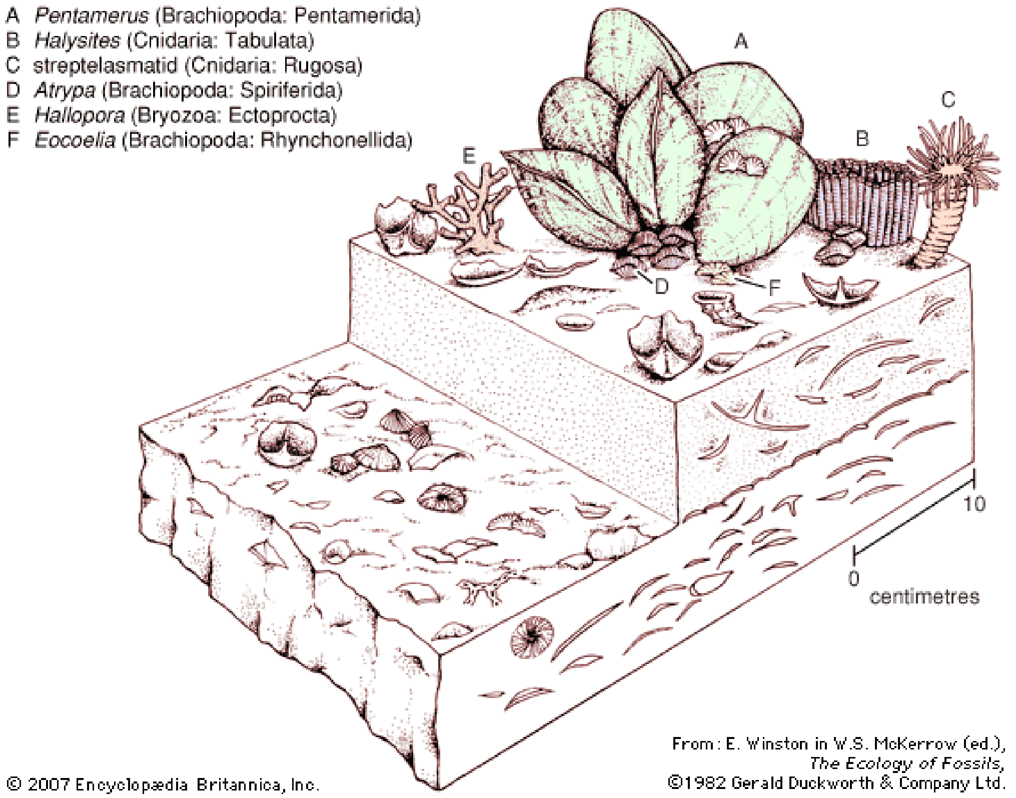

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Figure 2. The *Pentamerus* community from the Silurian, which can be found in Iowa. Adopted from the Encyclopædia Britannica Online.

The Crinoids

The crinoids (phylum Echinodermata, class Crinoidea) have been given the nickname sea lilies due to their overall resemblance to a flower, but they are not a plant. Crinoids have a central plated head called a calyx with arm-like structures extending from them. The calyx is attached to a long stalk or stem and is attached to the seafloor with a root-like structure. Crinoids are related to more well-known echinoderms of sea stars and sea urchins. As such, they have a skeleton composed of many calcite plates that protect its central structure and appendages (arms and stems). In addition, echinoderms are characterized by having a complex water vascular system. Crinoids can be disarticulated easily after death, and, typically, you will find isolated parts of the stem, arms, or the plates of the calyx. Crinoid debris has been noted in the Tripoli Quarry, and you should be able to find them in the rocks easily.

Other Fossils

There are several other groups of fossils that are found in Silurian age rocks in Iowa, but they may not be as easily identifiable in the rocks of the Tripoli Quarry. These groups include the bryozoans, ostracodes, trilobites, and cephalopods. If you see one of these or other fossil groups while looking at the rocks in the quarry, please ask if you are not sure what you have.

A BRIEF HISTORY OF THE STUDIES OF SILURIAN CORALS OF IOWA

The very first fossils in Iowa were described around the time that Iowa became a state. Geologists such as James Hall, Charles White, Robert Whitefield, David Dale Owen, and Samuel Calvin worked on the general geology and paleontology of Iowa during the 1800s. Early workers would have described the fossils in Iowa in large compendiums (ex: Whitefield and Hall, 1873; Rominger, 1876) from a few specimens that were sent to them or collected by them personally. However, it was very common to describe fossils from Iowa and relate them to better known outcrops in upstate New York. Throughout the Paleozoic, marine rocks in Iowa can be associated with similar rocks in other regions, but early taxonomists might not have been careful enough about potential differences between populations that are separated by large distances. Norton (1906) described the geology of Bremer County and did reflect on the limited geologic work in the county with the exception of a few fossils collections described by Hall in 1873.

For the Silurian corals found in Iowa, there has been very little recent systematic work on them. Most of the work still reflects some of the large scale coral systematic completed prior to 1900. Most of the recent work on Silurian age corals from Iowa has focused on their paleoecology and the geometry of their growth (Philcox 1970a, 1970b, 1971; Johnson 1975, 1979, 1980; Sorauf 1974). Some of these workers have reflected on the difficulty to describe species of corals based on the relatively poor preservation of the fossils. More recent work on Latest Ordovician to Earliest Silurian corals from East-Central United States has described some tabulate and rugose corals from Iowa (Elias, 1982; McAuley and Elias, 1990; Young and Elias, 1995). However, these corals reflect the far western edge of their study area and it appears that sometimes the researchers attribute the taxa to Iowa based on outcrops from Illinois with correlated formations across the border in Iowa. As a comparison, a lot more recent work has been accomplished on the Devonian rugose corals than the Silurian corals of Iowa (Belanski, 1927; Stainbrook 1940, 1946; Pitrat 1962; Sorauf 1998). It's clear that some new and detailed systematic work could be accomplished for the Silurian tabulate and rugose corals of Iowa.

Tabulate and rugose corals can be difficult to study due to a limited number of characters that can be observed while the specimens are in the outcrop. Some of the most obvious morphological characters can be conservative in the sense that they may not reflect evolution in the corals, but ecological and environmental influences. In order to do a more thorough and detailed systematic of Paleozoic corals, you need to examine some of their microstructures in thin-section and look at specimens across environmental gradients. For example, Young and Elias (1995) describe the difference in *Favosites* and a close relative *Paleofavosites* based on the presence of corner pores between corallites. This is character that would be difficult to almost impossible to observe in the outcrop or in a hand specimen, so someone that is mostly interested in paleoecology may not note the difference between these two genera in their field work.

REEFS, BIOHERMS, MUD MOUNDS, OR CARBONATE BUILD-UPS?

Corals have been known to build reefs in the modern and geologic records. However, corals are not the only organisms that have contributed to these skeletal build-ups. Many different organisms from mollusks, brachiopods, algae, and sponges have contributed to reef development over time (one good reference amongst many would be Wood, 1999). Recently, there has been a lot of discussion about what defines a reef by conservationists, since they are concerned about the decline of deep water or cold water reefs created by a single coral species due to trawling the ocean floor for fish (see Roberts et al., 2006 for example). However, deep water coral reefs are extremely different than their shallow-water counterparts which are more resistant to wave erosion. Shallow water reefs have species of corals that have evolved much thicker branches, more massive colonies, and are more resistant to the impacts of the fair-weather and normal wave action. To a geologist that is concerned about recognizing reefs in the fossil record, this recent attempt to redefine a reef does create havoc with the work that has already been done to define reefs as wave-resistant features with an organic framework.

Based on the argument by Anderson (1996), the carbonate mound that we will see in the Tripoli Quarry is not a true reef, but similar type features in the Midwest have been argued to be reefs. Anderson (1996) makes the argument that the structure in the Tripoli Quarry is not a reef because the more steeply-inclined beds on the south wall of the quarry probably represent post-depositional compaction and slumping. For geologists, it's important to be aware that every noticeable structure that appears to be related to the deposition of skeletal debris from fossils needs to be considered carefully. The generic term of carbonate build-up is preferred since it reflects the descriptive observation that we can make of the geologic feature without automatically contributing an origin to the structure, such as applying the term reef. Heckel (1974) thoroughly discussed this topic, and Witzke (1992) used this terminology for known carbonate build-ups in the Silurian of Iowa. At the time, Witzke, in his summary, had not applied the term "carbonate build-up" to the Tripoli Quarry. However, Anderson (1996) described the features in the Tripoli Quarry, including a nice summary of Witzke's earlier work, which you may want to check out. On today's field trip, we can have a discussion on the definition of a reef and how the terms bioherms, mud mounds, and carbonate build-ups are appropriately used. The main points to ponder, which I summarize a little differently than Anderson (1996) and Witzke (1992), during our discussions about distinguishing between reef versus carbonate mound:

1) The presence (or absence) of corals does not mean you have a reef.
2) You need to have evidence that the preserved structure formed at fair-weather wave base.
3) There needs to be a central "reef core" or organic framework.
4) Evidence of the overall volume and relative position of organic skeletal material compared to the carbonate mud can indicate if you have a reef or not.

Overall, I hope you collect some good specimens and take time to contemplate what defines a reef or a carbonate mound. Hopefully, you can come to your own conclusions on the subject matter.

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QUATERNARY GEOLOGY OF BREMER COUNTY, IOWA

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INTRODUCTION

Today's field trip stops are located in Bremer County, which lies in the heart of the Iowan 'Erosion' Surface (IES) landform region (Fig. 1). The two areas we will visit today have vastly different geomorphology and Quaternary stratigraphy. The Waverly area is dominated by shallow bedrock and the Tripoli-Platte Quarry area is a more traditional IES landscape with a thick till package. The western third of the county, including the City of Waverly, is dominated by shallow bedrock, abundant colluvial material, and limited coverage of glacial materials. East of Waverly, the topography is more level, outcrops are limited, glacial materials thicken extensively and the area takes on characteristics more typical of the IES. These two contrasting settings have a major impact on the water quality of the Silurian-Devonian aquifer. In the Waverly area, which is characterized by shallow bedrock, thin glacial till cover and thick colluvial packages, high nitrates have been an issue for the community water supply. While in the eastern part of the county (Tripoli area), with a thick Quaternary till package, there have been no reports of high nitrate values in water supplies.

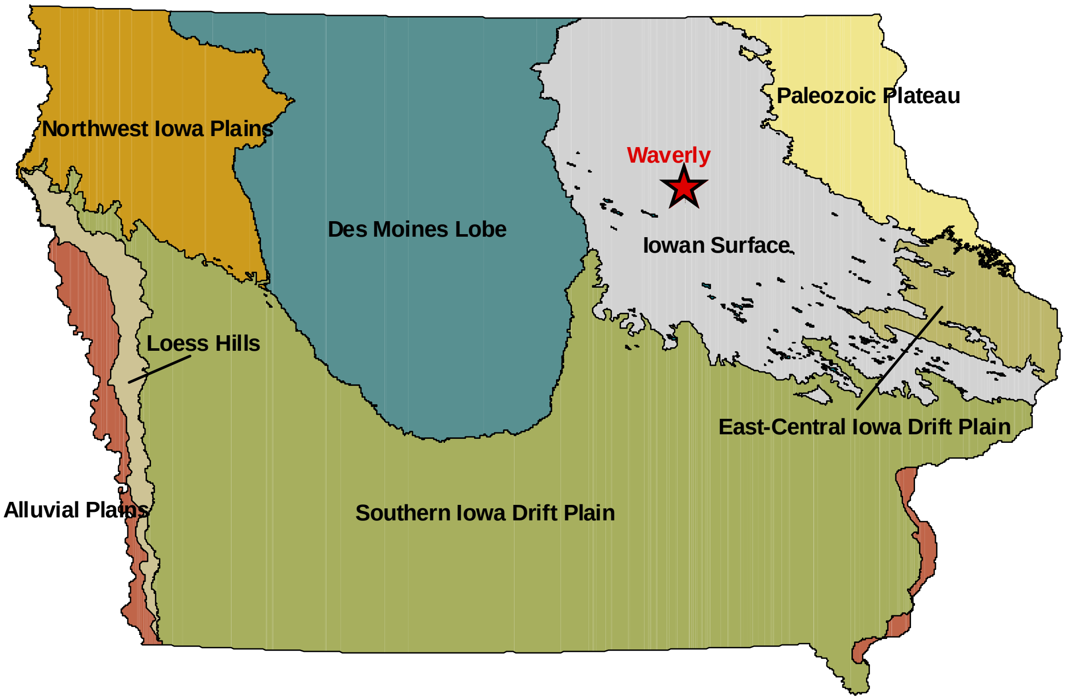


Figure 1. Landform Regions of Iowa (Prior, 1991) showing the regional setting of Waverly, Iowa.

REGIONAL SETTING

Iowan 'Erosion' Surface

The Iowan Surface Landform Region (Fig. 1) comprises much of northeastern Iowa. This region has a complex geologic history consisting of multiple glaciations that occurred between 2.2 million and 500,000 years ago during the Pre-Illinoian Episode, followed by 500,000 years of extensive subaerial erosion which was followed by a period of intense cold from 21,000 to 16,500 years ago, during the Wisconsin Episode. A periglacial environment prevailed during this period with intensive freeze-thaw action, upland erosion, solifluction, strong winds and a host of other periglacial processes (Walters, 1996). The result was that the Pre-Illinoian till surface was significantly eroded leading to the development of the distinctive landform recognized as the Iowan 'Erosion' Surface (Prior, 1991). The IES erosional features were formed by stream action, slope wash and wind deflation that occurred during the coldest part of the Wisconsin Episode. In this area the older Pre-Illinoian glacial deposits may be capped by associated Wisconsin age colluvium (slopewash) and Wisconsin age loess (wind blown silt).

The IES is characterized by gently rolling terrain, thin discontinuous loess overlying reworked, weathered glacial till, bedrock at or near the land surface, and local karst conditions in areas of shallow bedrock. Characteristic surficial features on the IES include a stone line, glacial erratics, ice wedge polygons (sand filled wedges), and paha (Fig. 2). Extensive erosion of the upland stripped material from the surface resulting in the development of a regional colluvial lag deposit, or 'stone line'. Glacial erratics, boulders that have been transported by glaciers from their original depositional position, are commonly seen in this part of the state and are also a remnant deposit. Ice-wedge polygons formed in frozen sediments (permafrost) during this period of intense cold, and subsequently filled with material.

Another common feature of this region is isolated and uneroded topographic highs of loess mantled Pre-Illinoian till, known as paha. These elongated hills are oriented northwest to southeast and are most abundant near the boundary between the IES to the north and the Southern Iowa Drift Plain to the south. The stratigraphic units present within a paha are the same as what is typical on the Southern Iowa Drift Plain (oldest to youngest): Pre-Illinoian till, Sangamaon Geosol, Pisgah Formation materials, Farmdale Geosol and Peoria Formation silt and sand. Surrounding landscapes have had the upper materials eroded and only have Pre-Illinoian materials overlain by weathered or colluviated materials. Good exposures showing the internal stratigraphy of paha are rare, but intensive studies have been completed using drill core. Several paha are located along the east side of the Cedar River near Waverly.

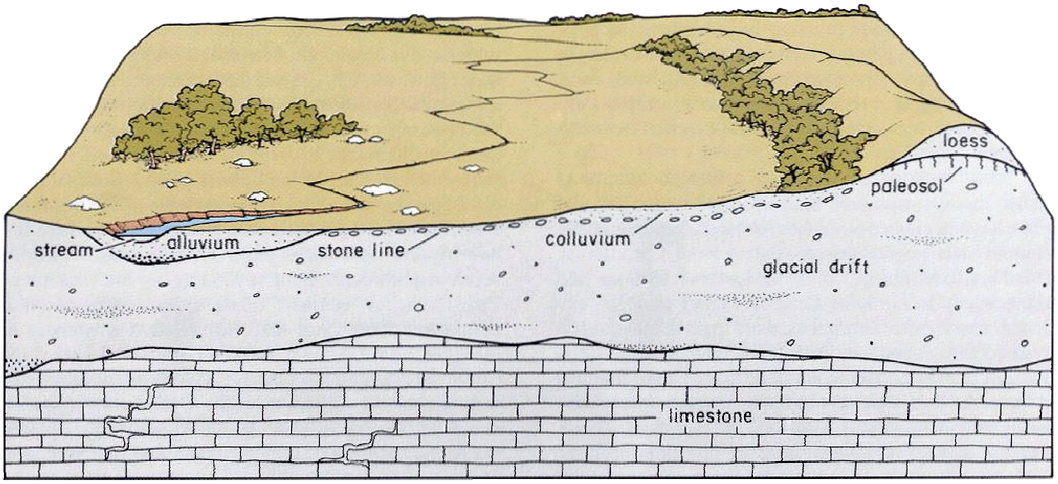


Figure 2. Block diagram showing typical landscape geomorphology and characteristic features of the Iowan Surface (Prior, 1991).

Stratigraphy

The surficial deposits of Bremer County are composed of five formations: DeForest, Peoria, Noah Creek, Wolf Creek, and Alburnett formations as well as unnamed erosion surface sediments. Fine-grained alluvial and colluvial sediments of the DeForest Formation are subdivided into the Camp Creek, Roberts Creek, Gunder and Corrington members. The Noah Creek Formation includes coarse sand and gravel associated with outwash from the Des Moines Lobe during the Wisconsin Episode. The Noah Creek Formation 2 includes coarse to finer grained fluvial deposits associated with stream and river valleys carrying IES material eroded from nearby uplands. Unnamed erosion surface sediments consist of reworked till and slopewash deposits associated with peri-glacial activity during the Wisconsin ice advance. Peoria and Pisgah formation eolian materials may also be intermittently present mantling most other mapping units, and are more abundant near stream valleys. Thick areas of loess (paha) are present northeast of Waverly and near Denver. Pre-Illinoian glacial deposits in northeast Iowa consist of two formations: the younger Wolf Creek Formation and the Alburnett Formation. The Wolf Creek is divided into the Winthrop, Aurora and Hickory Hills members (oldest to youngest). The Alburnett Formation consists of several “undifferentiated” members. Five bedrock mapping units (Devonian Lithograph City, Coralville, Little Cedar and Wapsipinicon formations; and the Silurian Hopkinton and Blanding formations) are exposed as outcrop in Bremer County (McKay et al., 2010).

QUATERNARY GEOLOGY NEAR WAVERLY, BREMER COUNTY, IOWA

Description of Materials

The primary surficial deposits in the Waverly area include Pre-Illinoian till and weathered IES materials. Wind-blown deposits (eolian sand and loess), as well as alluvial deposits are also present. Pre-Illinoian age tills in northeast Iowa are composed of the Wolf Creek and Alburnett formations and are typically uniform, massive, loam to light clay loam textured, basal tills with associated fluvial deposits and intervening paleosols (ancient land surfaces). However, on the IES a combination of weathering, freeze-thaw and slopewash processes has created a package of much less consolidated materials at the surface. IES materials are commonly loamy and sandy sediments, massive to weakly stratified, poorly consolidated, and may contain significant interbedded gravelly or pebbly loam units. There may be up to 20 feet of these materials, and they are commonly thicker on slopes and near stream valleys as part of solifluction lobes related to Wisconsin Episode erosion. Some areas are also overlain by a thin increment (less than 5 feet) of loess (Peoria Formation silt). In localized areas thicker sequences of loess (up to 30’) may be present in pahas. Due to the nature of these deposits, IES materials do not provide the same groundwater protection as an unaltered Pre-Illinoian till would. Oxidized tills and colluviated materials have a much higher hydraulic conductivity than unweathered Pre-Illinoian till deposits. Exposed bedrock strata in the Waverly area are seen in quarries and natural outcrops and include several Silurian and Devonian bedrock units.

Figure 3 (Tassier-Surine et al., 2010) is a portion of a recent Iowa Geological and Water Survey (IGWS) map of Bremer County showing the surficial mapping units near Waverly, Iowa. There are abundant rock outcrops near the Cedar River and a thin veneer of sand and gravel over bedrock near the valley walls. The slope units are colluviated IES materials overlying rock. Consolidated glacial till is only present in upland landscape positions in this area.

South Riverside Park at fieldtrip Stop 1 is mapped as bedrock and Noah Creek Formation sand and gravel shallow to bedrock (Qnw3 on Fig. 3). This unit consists of 1 to 3 m (3-10 ft) of yellowish brown to gray, poorly to well-sorted, massive to well stratified, coarse to fine feldspathic quartz sand, pebbly sand and gravel with fractured carbonate bedrock less than 5 m (16 ft) below the land surface. The unit encompasses deposits that accumulated in river and stream valleys during the late Wisconsin as well as exhumed Pre-Illinois Episode deposits of the Wolf Creek and Alburnett formations. Deposits may be slightly thicker along the Cedar River. The adjacent upland map unit is unnamed erosion surface loamy and sandy sediment shallow to rock (Qwa5 on Fig. 3). This unit is generally 1 to 6 m (3-19 ft) of yellowish brown to gray, massive to weakly stratified, well to poorly sorted loamy, sandy and silty erosion surface sediment and may include some areas mantled with less than 3 m (10 ft) of Peoria Formation sand facies (eolian sand).

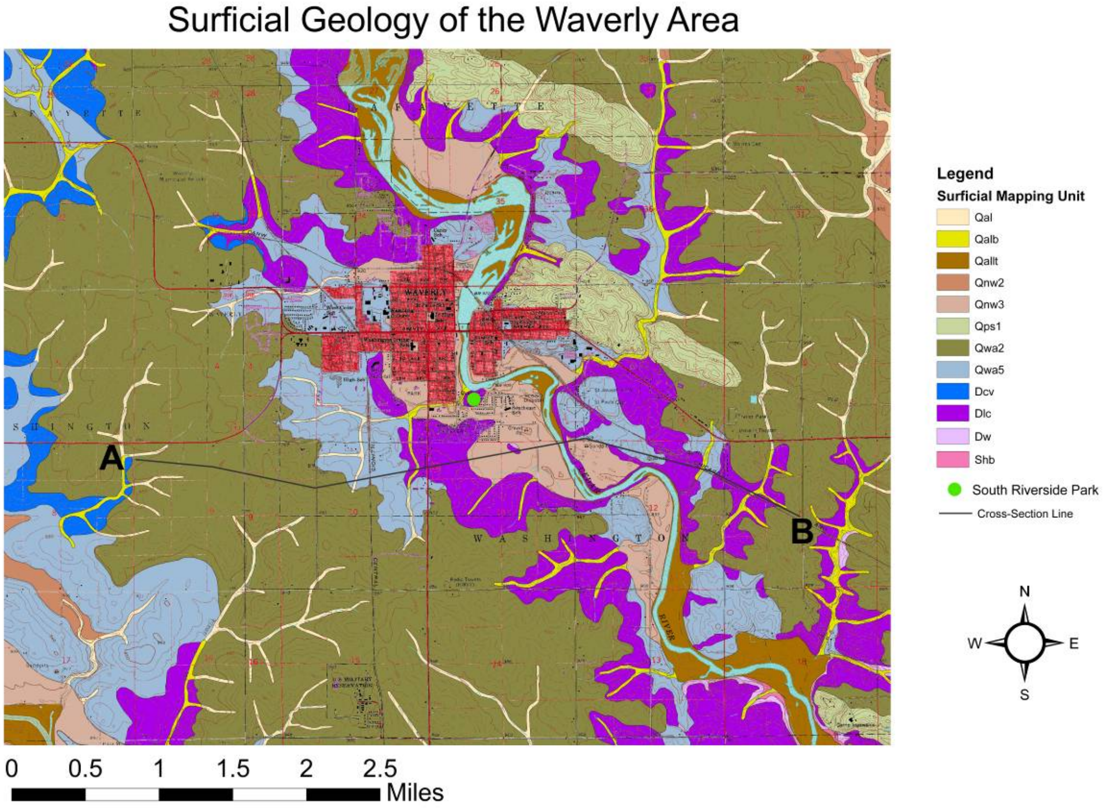
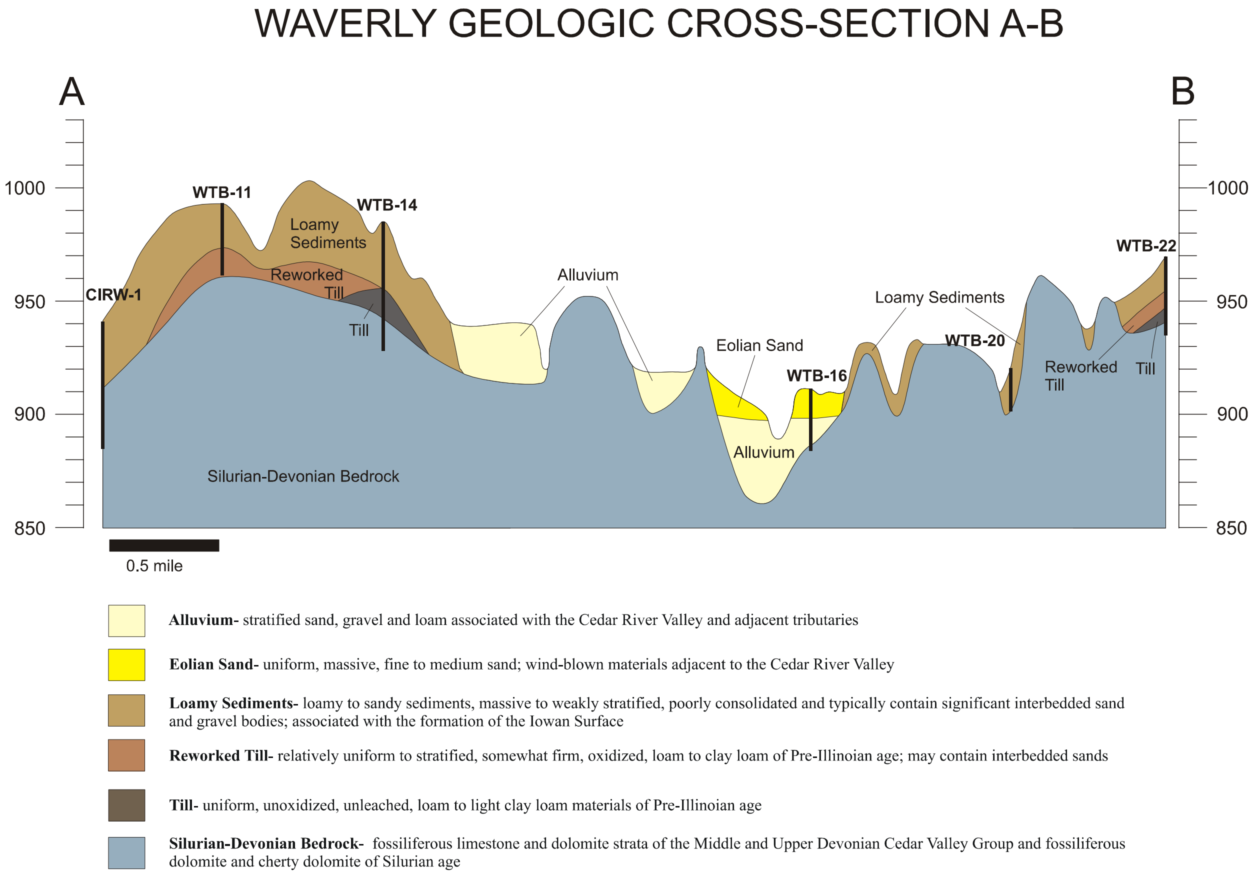


Figure 3. Surficial Geology of the Waverly area modified from The Surficial Geology of Bremer County, Iowa (Tassier-Surine et al., 2010). Qal- Holocene alluvium; Qalb- Holocene alluvium shallow to bedrock; Qallt- Holocene channel belt, modern floodplain alluvium; Qnw2 and Qnw3- Noah Creek Formation sand and gravel outwash deposits; Qwa2- unnamed IES sediments; Qwa5- unnamed IES sediments shallow to bedrock; Dcv- Devonian Coralville Formation; Dlc- Devonian Little Cedar Formation; Dw- Devonian Wapsipinicon Group; and Shb- Silurian Hopkinton and Blanding formations.

A cross-section (Fig. 4) is shown for the area just south of fieldtrip Stop 1 (see Fig. 3 for cross-section location). This cross-section shows the relationship between the upland and the river and shows the transition from less permeable glacial till at the high to poorly consolidated erosion surface materials on the slopes to bedrock or thin sands over bedrock near the valleys. Cross-Section A-B traverses the Cedar River Valley from west to east. Especially important to note is the relationship between shallow rock and the overlying alluvial materials in the river valley, as these locations will provide very little in the way of groundwater protection. Upland areas have a much thicker package of less permeable materials with the presence of a confining unit only at upland positions and an increasing thickness of loamy sediments downslope. This is typical in valleys on the IES. A characteristic paha is present to the northeast of the cross-section as noted in Figure 3 with a relatively thick sequence of loess materials.



▨ **Alluvium-** stratified sand, gravel and loam associated with the Cedar River Valley and adjacent tributaries

▨ **Eolian Sand-** uniform, massive, fine to medium sand; wind-blown materials adjacent to the Cedar River Valley

▨ **Loamy Sediments-** loamy to sandy sediments, massive to weakly stratified, poorly consolidated and typically contain significant interbedded sand and gravel bodies; associated with the formation of the Iowan Surface

▨ **Reworked Till-** relatively uniform to stratified, somewhat firm, oxidized, loam to clay loam of Pre-Illinoian age; may contain interbedded sands

▨ **Till-** uniform, unoxidized, unleached, loam to light clay loam materials of Pre-Illinoian age

▨ **Silurian-Devonian Bedrock-** fossiliferous limestone and dolomite strata of the Middle and Upper Devonian Cedar Valley Group and fossiliferous dolomite and cherty dolomite of Silurian age

Figure 4. Cross-section for the area just south of fieldtrip Stop 1.

Groundwater Vulnerability

The Iowa Department of Natural Resources-Iowa Geological and Water Survey completed a Source Water Report for the City of Waverly (IDNR, 2008). A Source Water Report details a public water supply's active wells, aquifer, aquifer susceptibility, and potential contaminant sources. The report evaluated the nature and thickness of glacial till within the City of Waverly's source water area using a combination of conductivity profiles, continuous coring, soils information and groundwater sampling. The information was combined to summarize the location and extent of confining layers above the Silurian-Devonian aquifer in relation to the location of the public wells. The confining layer map was combined with the land-use map to target priority conservation areas that have the greatest potential for groundwater quality improvements. The City of Waverly can use these priority areas to focus their efforts for funding and best management practices.

The primary source of water for Waverly is the Silurian-Devonian aquifer. Although the Silurian-Devonian near Waverly is a very productive aquifer, certain issues arise when water moves through the subsurface so quickly. In Iowa, the most prominent water quality issue in shallow bedrock or karst areas is nitrate contamination from nonpoint sources. Based on extensive sampling of private wells in Iowa, nitrate concentrations in groundwater are inversely related to confining layer thickness (Hallberg, 1990). A confining layer is a geologic unit that slows the movement of water and potential contaminants to an aquifer. Confining beds often consist of unoxidized glacial till, clay, and shale layers. Glacial till covers much of Iowa and acts as an excellent confining layer for most of Iowa's bedrock aquifers. Where unoxidized glacial till is present over an extensive area, nitrate concentrations are usually low. By contrast, high nitrate concentrations are found in areas with thin or absent confining layers.

Cross Section A-B (Fig. 4) indicates the most vulnerable areas within the source water capture zone near the Cedar River Valley where bedrock is at or near the surface. The thin soil above the bedrock is primarily eolian sand, sandy alluvium, and very thin loamy sediments. Recharge into the underlying bedrock would occur very quickly in these areas, and the lack of any confining bed would allow for the leakage of point and non-point sources of contamination into the Silurian-Devonian aquifer.

The transition zone between the alluvium and the uplands is dominated by outwash, which is primarily sand and gravel. These soils allow rapid recharge of precipitation and would also be classified as highly vulnerable to potential point sources and non-point sources of contamination.

The best confining bed occurs on the uplands to the west and east of the Cedar River Valley where IES materials overlie reworked glacial till or unoxidized glacial till. The reworked glacial till consists of fine sand, silt and clay, and are classified as loamy sediments. These loamy sediments would act as a semi-confining bed. Semi-confining beds may slow the movement of recharge and precipitation, but would still allow for movement of groundwater to the underlying bedrock. Unoxidized till provides the best confining unit of Quaternary materials.

QUATERNARY GEOLOGY OF THE TRIPOLI-PLATTE QUARRY

Stratigraphy

Several Pre-Illinoian age tills are exposed at the Tripoli-Platte Quarry and directly overlie bedrock. At least two tills are visible in the east quarry wall with a weathering profile in between (Fig. 5). Another is visible on the north wall, but due to slumping the relationship could not be confirmed as to whether they are the same weathering horizon or two separate horizons. The upper portion of the till is oxidized and leached with common sandy zones, typical of IES materials. Ice-wedge polygons related to freeze-thaw activity and a stone line have previously been noted in this quarry.

Figure 5. East wall of the Tripoli-Platte Quarry. Photo by Tom Marshall.

The exposure in the Tripoli-Platte Quarry is consistent with mapping that was completed by IGWS as part of the STATEMAP program (Mckay et al., 2010, Tassier-Surine et al., 2010). The area was mapped as unnamed IES materials which are described as loamy sediments shallow to glacial till (unit Qwa2 on the surficial map). These materials are generally 2 to 8 m (6-26 ft) of yellowish brown to gray, massive to weakly stratified, well to poorly sorted loamy, sandy and silty erosion surface sediment. Some areas may be mantled with less than 2 m (7 ft) of Peoria Formation materials (loess and eolian sand) and they overlie massive, fractured, firm glacial till of the Wolf Creek and Alburnett formations. IES materials overlie

Pre-Illinoian till of the Wolf Creek or Alburnett formations which are generally 3 to 91 m (10-300 ft) of very dense, massive, fractured, loamy glacial till.

A cross-section of Bremer County from a recent Statemap project (Tassier-Surine et al., 2010) is shown in Figure 6 and shows the contrast throughout the county of Quaternary materials. The cross-section runs nearly west to east. Note the variability in glacial till (units Qwa3 and Qwa2) thickness between the western and eastern portions of Bremer County. Based on the glacial till thickness, the eastern part of the county has a much thicker confining unit and therefore better groundwater protection than the area near Waverly.

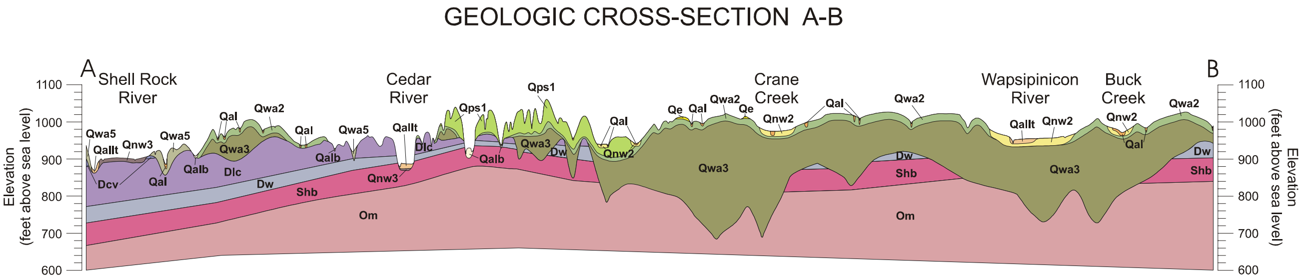


Figure 6. West to east cross-section across Bremer County. Qwa2 and Qwa3 mapping units are glacial till. Bedrock is much closer to the land surface in the western part of Bremer County than the east.

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WATER AND WAVERLY

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GROUNDWATER

Like many communities in the Cedar River Valley, the primary source of drinking water for Waverly is the porous limestone and dolomite of the Silurian-Devonian aquifer. The Silurian-Devonian aquifer represents a complex grouping of several separate carbonate formations that generally act as one hydrologic unit because of their hydraulic connection. The base of the Silurian-Devonian aquifer is typically the Ordovician-age Maquoketa Shale. The upper confining beds are usually Mississippian-age siltstones. The aquifer is the first bedrock unit for over 21% of the state (Horick, 1984).

At Waverly, the Silurian-Devonian aquifer is at or near the land surface and has undergone extensive erosion and weathering from flowing water and past glaciation events. This erosion and weathering has fractured the underlying shallow limestone, forming large open channels that water can move through very quickly. This geologic feature is called 'karst' terrain. Karst can be seen on the land surface as sinkholes, cave openings, and low-lying wet areas. Figure 1 is a three-dimensional representation of both the lateral and vertical pathways typically found in karst regions. Water is generally plentiful in karsted areas, with groundwater flow usually towards the stream/river except during periods of flood. Through groundwater, the river is highly influenced by the land use around it.

Although the karsted Silurian-Devonian at Waverly is a very productive aquifer, certain issues arise when water moves through the subsurface so quickly. Karst wells are normally typified by high (>1,000 gallons per minute) pumping levels, with very little drawdown. Also, water quality in karst wells tends to mimic surface water, with seasonally high nitrates, greater chance of bacteria, and some organic content (algae and bacteria). In Iowa, high nitrate concentrations in both surface and groundwater are normally due to nonpoint sources from row crop agriculture, fertilizer, and manure application.

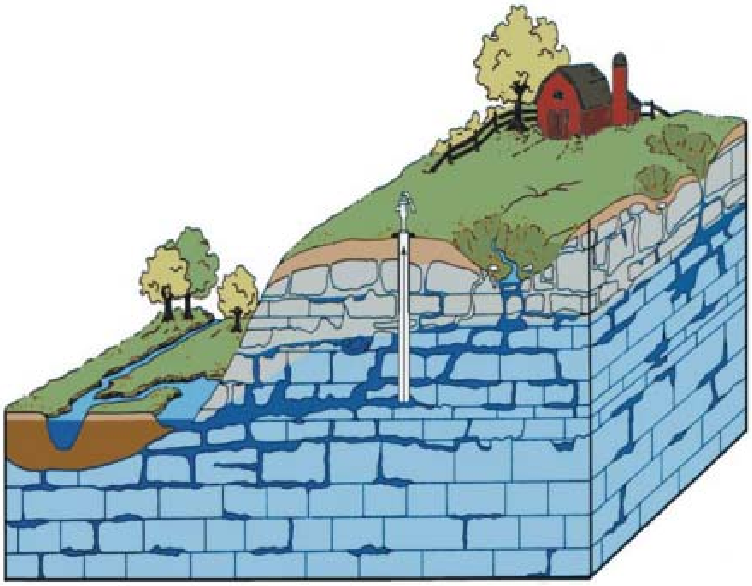

Figure 1. Diagram of a karst system with sinkholes, fractures, caves and springs. This representation illustrates the direct connection of the aquifer with surface water and the high potential for aquifer contamination in the karst system (Hallberg, 1982).

SURFACE WATER

History

According to Alexander Fulton’s 1882 publication: “Red Man of Iowa”, the Cedar’s original name “Red Cedar River” was derived from the Sac and Fox name “Mosk wah wak wah” the translation being “Mosk wah,” red; “wak wah,” cedar. Many of the first written encounters of the Cedar River go to great lengths to talk about the pristine beauty of the water and foliage along its shores. One of the better historical reports on the original beauty of the Cedar River is from the John C. Hartman’s 1915 publication “History of Black Hawk County, Iowa, and its people, Volume 1”

> *“Favored indeed were they who were permitted to view the Red Cedar River in its primitive loveliness. Long before the advent of the white men its wooded valley was the accustomed haunt and the hunting grounds of the red men, and village sites of these aborigines, as well as those of the mound builders can still be traced. Flowing over a bottom of white sand, gravel, and limestone, the water of the Cedar prior to the cultivation of the land along its banks was as clear as crystal the greater part of the year. It abounded with fishes of every known variety of the inland streams of the Middle West which formed a substantial source of food supply for the Indians. Here and there a stretch of the river was bordered with naked prairie, but for the most part from its source in Freeborn and Mower counties, Minnesota to its junction with the Iowa thirty miles from the Mississippi, the banks of the river were bordered with woodland which in some sections consisted of heavy bodies of timber. The predominating varieties were soft woods such as the different kinds of willows, basswood, soft maple, red cedar, cottonwood, and elm, but the oaks hickory and butternut ash hard maple and walnut were very plentiful. Shrubbery including wild gooseberry currant and hazel bushes grapevines and haws supplied food for bird and beast as well as man....*
> *...The avarice of the white man and the spirit of commercialism have robbed the Cedar of much of its natural beauty. Its channel has become an avenue for sewage disposal and its banks have been stripped of trees and excavated in many places for building materials. The park improvements have at this date restored much of the virgin beauty in certain sections of the river's course. The wanton and ruthless manner in which Nature's most beautiful handiwork has been marred in the despoliation of the natural scenery in the immediate vicinity of Waterloo is a sad commentary on the public intelligence. The so called savages loved and venerated the old river and in their keeping it was pure and beautiful to look upon. Should not the citizens of an educated and cultured commonwealth share this veneration and cherish Nature's loveliness?”* -Hartman, p376.

As you can tell from the writing, the historic Cedar River first encountered by the adventuresome pioneer was a sight to behold. Very quickly, however, around 1850 the very first pioneers set up mills to process trees, and constructed dams to harness the river's power. In fact many of the cities today first began as mills. Early settlers William Patterson Harmon of Waverly, William Sturgis of Cedar Falls, and Osgood Shepherd of Cedar Rapids are just a few of the founding pioneers that saw the great potential in the trees along the river. The change from densely forested to cleared landscape was so immediate that even in 1915 the 'clear as crystal' waters described by the early settlers were nothing but a distant memory.

Flow and Flood

Figure 2 shows the U.S. Geological Survey gaging station, landscape around Waverly, and estimated extent of the historic 2008 floods. The flooding zone is extrapolated from stream gage height measured at the Waverly station. As can be seen, flooding occurred all the way to Wartburg College, ending at the tennis courts north of the football field. The gage height measured 19.33 ft, almost three feet higher than the previous record of 16.8 ft. measured in 1999.

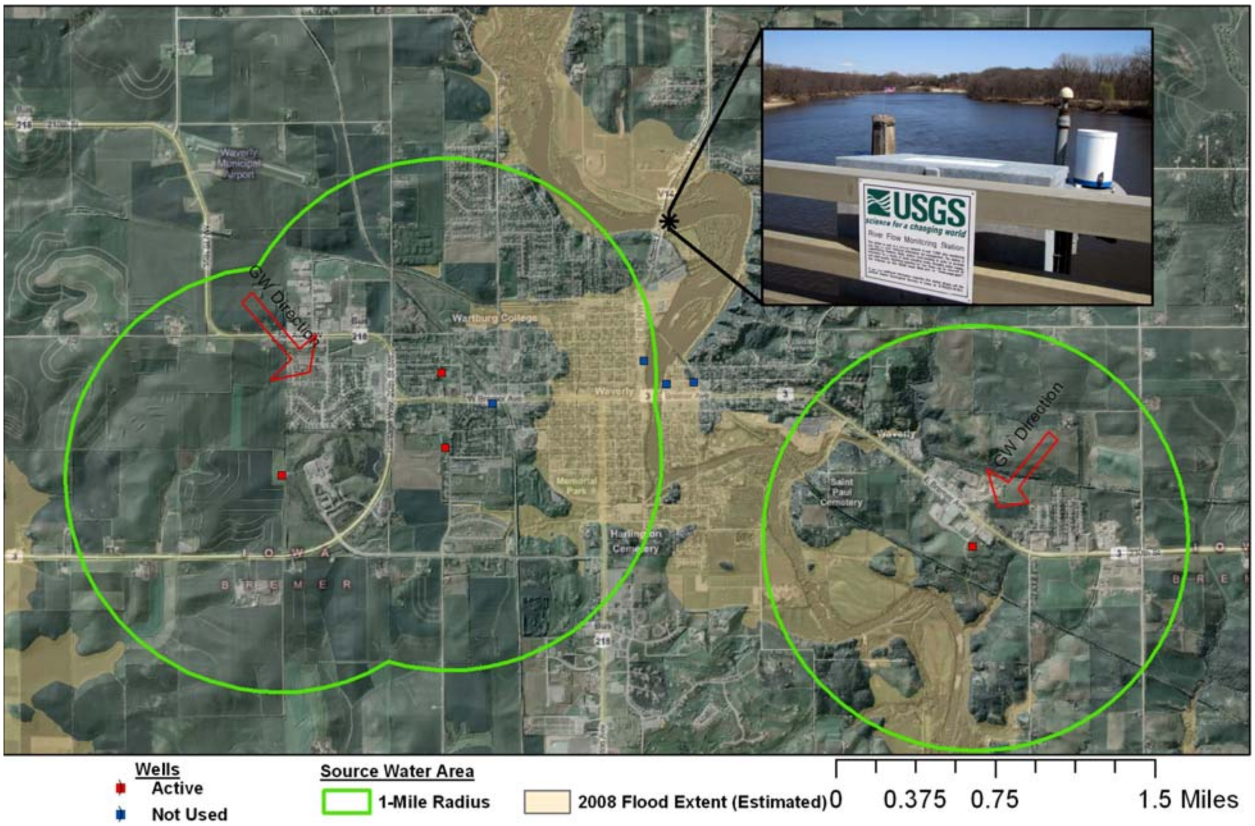

Figure 2. Map of the areal extent of the Silurian-Devonian drinking water, USGS stream gage, and estimated extent of flooding of the Cedar River in June, 2008.

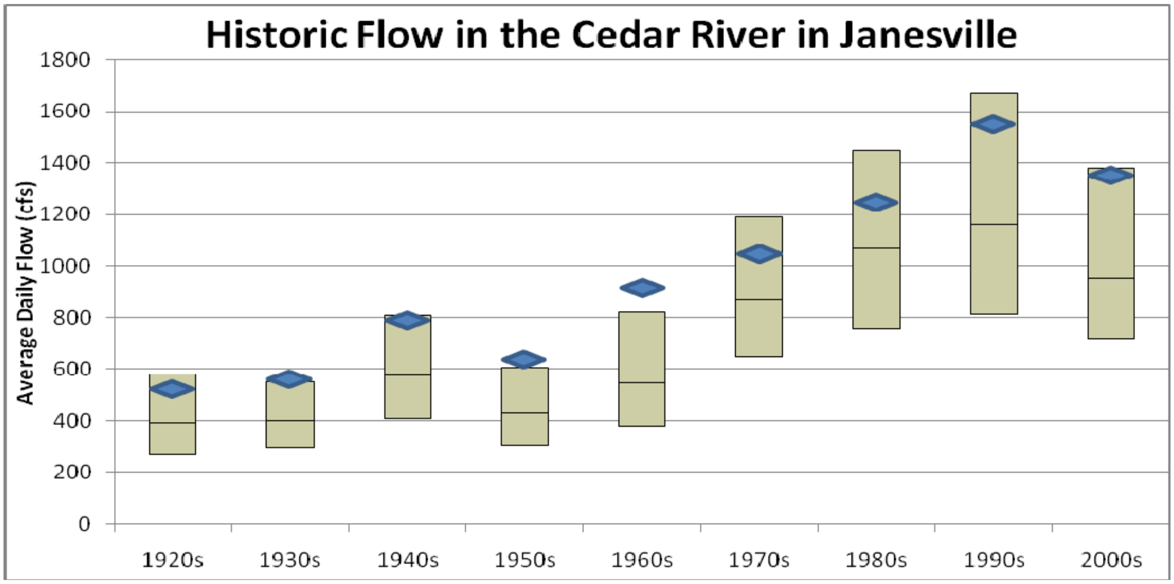

Figure 3. Historic flow in the Cedar River, measured at the Janesville U.S. Geological Survey Janesville gaging station. Flow is shown in cubic feet per second, grouped by decade, in boxplot (population median + quartiles) and decadal average (blue diamond).

Without question, flow has increased dramatically in the Cedar River during the past century. River flow has been historically measured in the Cedar River at Janesville, just south of Waverly by the USGS going back to the early 1900's. Continuous flow has been taken since the 1920's. Figure 3 above details the dramatic increase in flow of the Cedar during the last century. Flow has more than doubled during the past 90 years, increasing from an average of 630 cubic feet per second (cfs) from 1920s-1950s, to an average of 1300 cfs from 1970s-2000s. This increase is statistically significant ($p<0.0001$) without even transforming the data (a rarity with highly skewed flow data).

Although the increase in flow is relatively easy to determine, finding the cause of the increase is much more difficult, and has been debated for much of the past 20 years. The major suspects are: 1) increasing precipitation, or precipitation intensity, 2) increasing tile drainage in the watershed 3) land-use changes (primarily agricultural).

Figure 4 shows precipitation totals and rainfall intensity measurements taken at Waterloo station since 1931. Both precipitation and rainfall intensity have a small, non-significant increasing trend. The non-significant trend does not correlate with the doubling of the flow during the past century. Total precipitation values show the least amount of rainfall during 1988-89 drought years. High rainfall and precipitation intensity were measured in 1965, and 1993. These don't directly correlate with the high flow values measured during 1999 and 2008, indicating the complex nature of flooding.

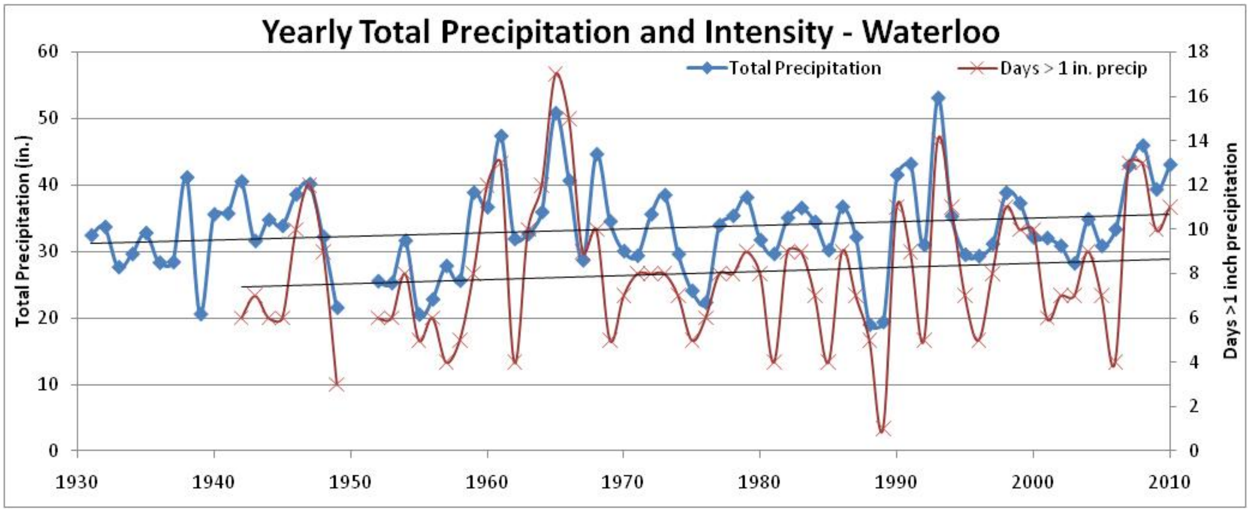

Figure 4. Yearly total precipitation since 1931, and rainfall intensity (days >1 inch) since 1942 taken from the Waterloo municipal airport.

Increased flow is often attributed to the increased use of tile lines. While this may be true for some areas of Iowa, the Cedar River is blessed with bedrock at or near the land surface under much of the watershed. This subsurface drainage acts as natural tile lines, whether or not additional tile lines were added.

The final, and most often cited, reason for increased flow is the increase of acreage in row-crop production. Since the mid-1900s, the area of the Iowa in corn production has seen a modest increase, from approximately 10.4 million acres in 1944 to 14 million acres in 2007. However, during the same period, land use for soybean production has increased from 1.9 to 10.2 million acres while land use for oats has declined from 4.7 to 0.1 million acres. The increase of over 8 million acres of soybeans has likely had a major impact on flow in the Cedar River. Other regional studies have shown regional correlations between agricultural land use and flow (Knox, 2001; Mao and Cherkauer, 2009).

Water Quality

For the past decade water quality samples have been taken at monthly intervals near the USGS gaging station at Janesville. These samples are taken as part of the Iowa DNR Watershed Monitoring Program ambient water monitoring network. Figure 5 shows the levels of nitrate-nitrite-N (NOx) concentrations during the past decade. NOx values have shown high variation (from 1-16 ppm) a (barely) non-significant upward trend since the beginning of the program. The current concentration of nitrates tend to be close to the Environmental Protection Agency's maximum contamination level of 10 ppm nitrate-N.

Although no historical nitrate values exist specifically at Waverly, downstream nitrates were taken at Cedar Rapids from 1944-1951. These averaged 2 ppm, much lower than the 6 ppm measured today. The increased nitrate concentration in the Cedar River is noted in almost all Iowa streams and rivers. This has led to notable drinking water problems, and helps contribute to the "Dead Zone" in the Gulf of Mexico.

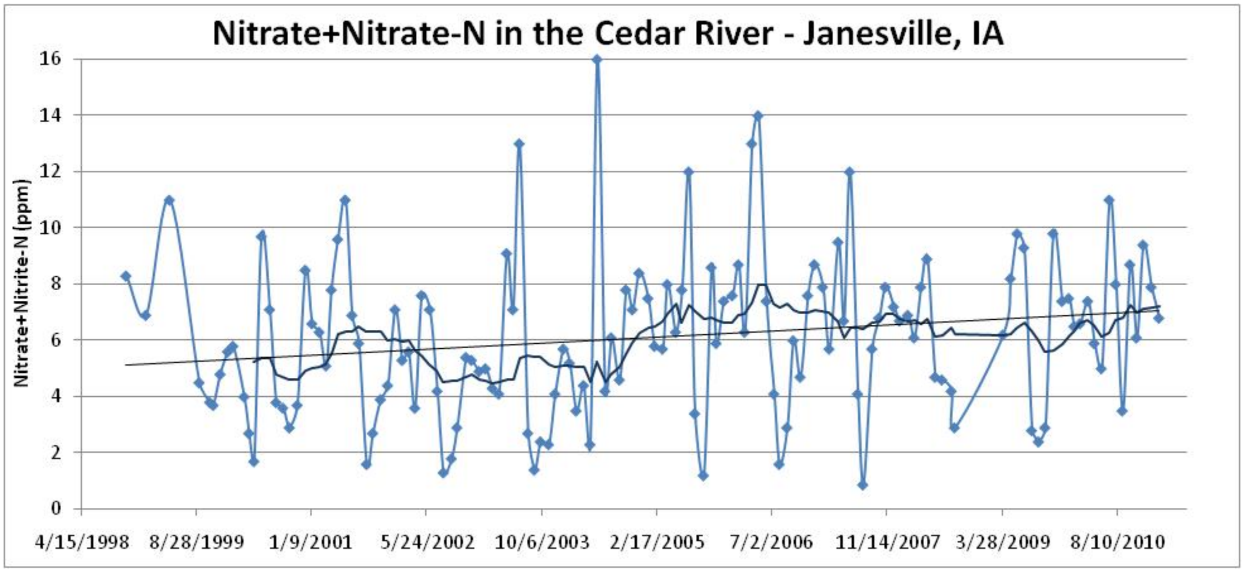

Figure 5. Historic nitrate-nitrite-N concentrations in parts per million (ppm) measured at Janesville, IA.

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STOP 1 - SOUTH RIVERSIDE PARK, WAVERLY

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The first stop on the trip is at the City of Waverly's, South Riverside Park (Figure 1). The park is situated on the west and south banks of the Cedar River along a large meander that incises a bedrock high of the Little Cedar Formation, the lowest formation of the Middle Devonian Cedar Valley Group (Witzke et al., 1988). The southeast area of the park encompasses the remnants of a former quarry that Norton (1906) characterized as one of the more important Waverly quarries at the time of his report (Figure 2). The quarry was owned by G. R. Dean, but was referenced by Norton as the Nichol's Quarry. Norton reported that 11 feet of limestone was quarried and that the stone had been used for the construction of a stone house adjacent to the quarry and also had been fashioned into sills and caps for the high school building.

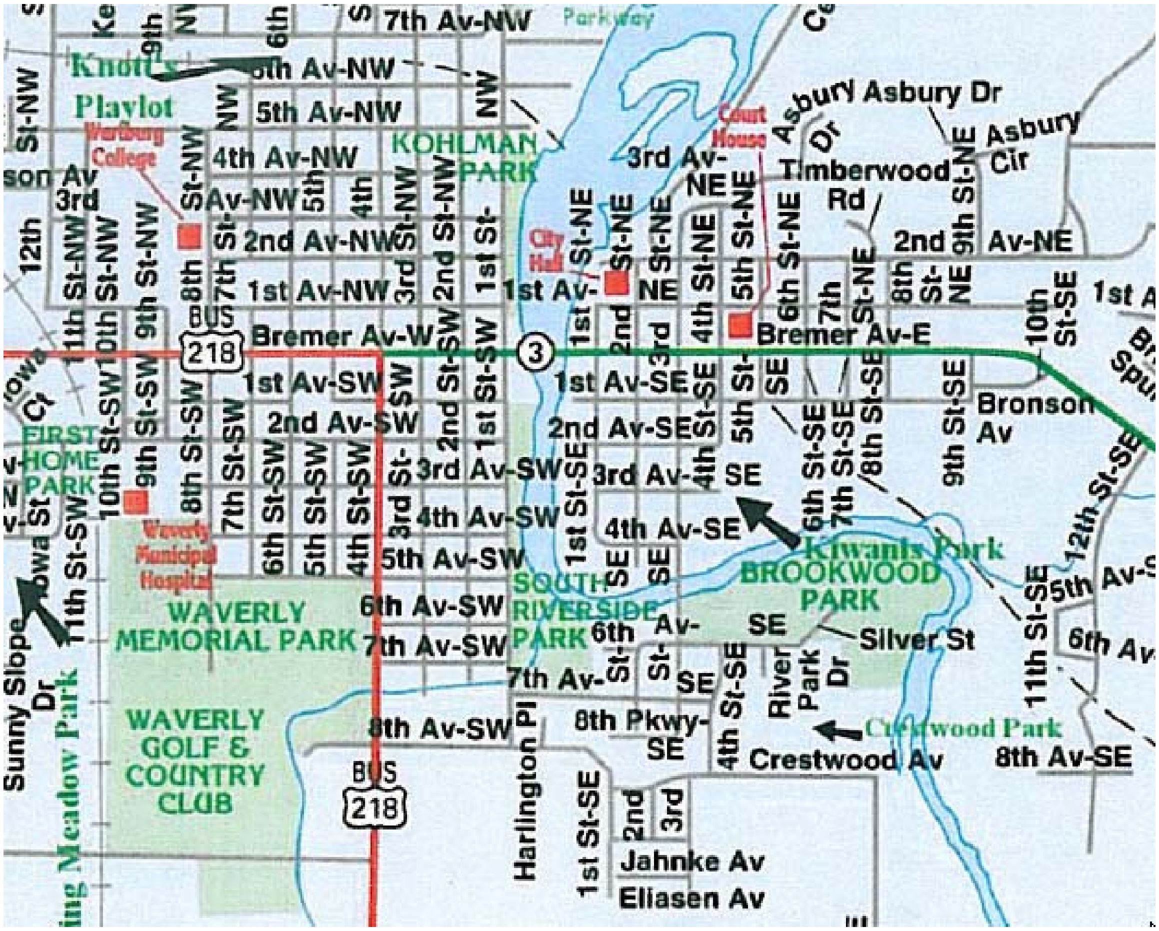

Figure 1. South Riverside Park (319 1st St. SW) is south of the Fire Station and is along the Cedar River for 5 blocks. It has a new recreational trail, shelter, porta-potty, new playground equipment and some undeveloped area to the south. Fishing is popular along the river in this park.

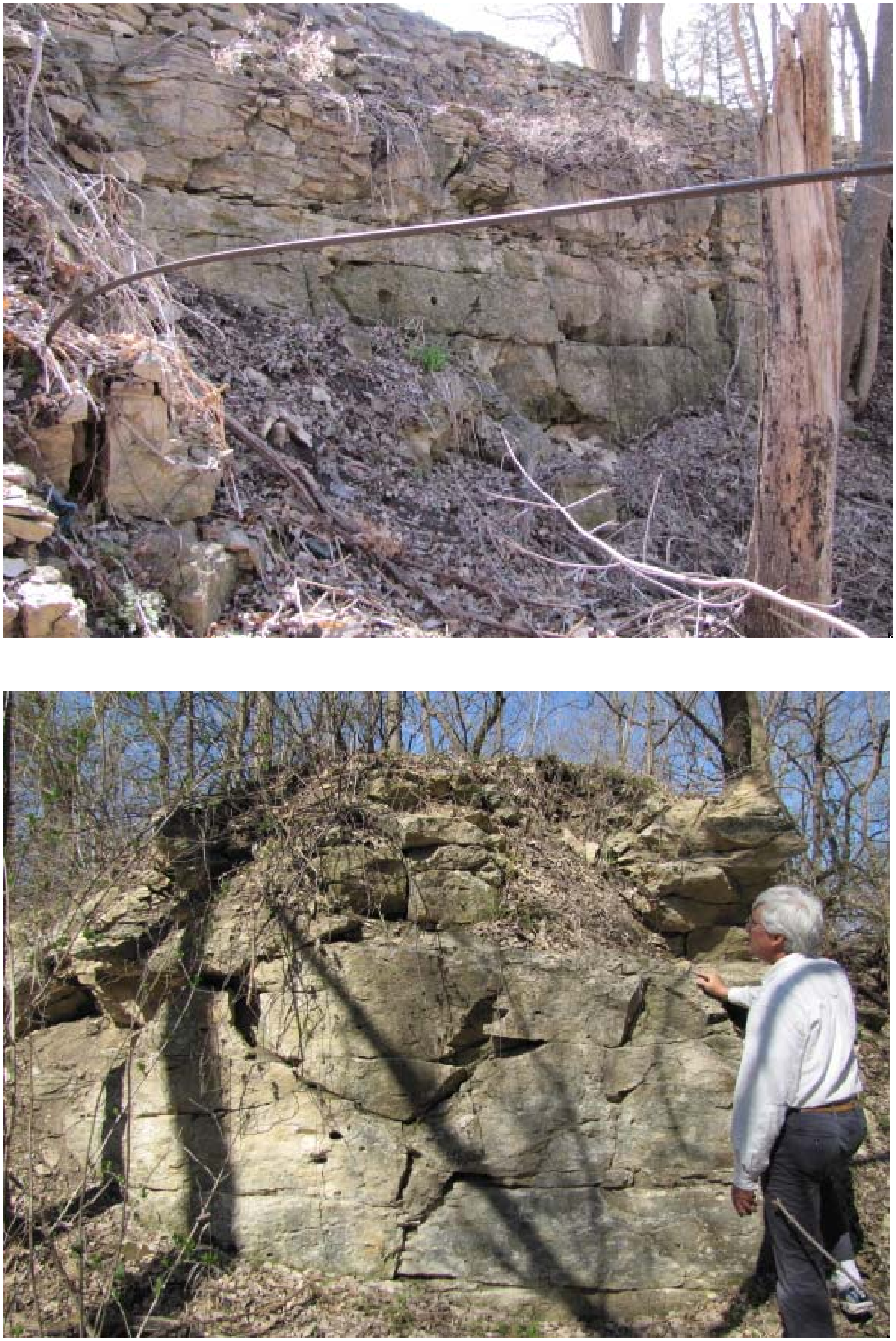

Figure 2. Exposures of lower Little Cedar Formation skeletal wackestone in the old Nichol's Quarry, South Riverside Park, Waverly. Note the old drill rod protruding from the rock in the upper photo.

The Little Cedar Formation at this locality is a skeletal wackestone rich in whole valve brachiopods with lesser echinoderm debris; ichnofossil burrows and trails are also noted (Figure 3). The best exposures are in the old quarry, but a weathered outcrop close to the river bank contains common brachiopod fossils. White chert nodules a few centimeters in diameter are present in the upper strata of the old quarry. Brachiopods include *Orthospirifer iowensis* and *Schizophoria* sp. (Figure 4).

Figure 3. Whole valve brachiopod fossils in the valley wall outcrop at South Riverside Park.

Figure 4. *Orthospirifer iowensis* and *Schizophoria* sp.

Through the town of Waverly, the Cedar River is clearly incised into the lower portion of the Little Cedar Formation, and it is suspected, from well log data in downtown, that uppermost Wapsipinicon Group strata may comprise the bedrock surface along the axis of the bedrock valley. This bedrock outcrop pattern is reflected on both the new statewide and county bedrock geologic maps (Witzke, Anderson, and Pope, 2010; McKay, Liu and Giglierano, 2010).

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STOP 2 – TRIPOLI-PLATTE QUARRY

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The second stop on the trip is at the Paul Niemann Construction Company's Tripoli-Platte Quarry, 2131 160th Street, Tripoli, Iowa 50676 (Figure 1). The quarry is approximately 7 miles east on State Highway 3 and 7 miles north on US-63 from Wartburg College and 6 miles west of Tripoli, Iowa. The rocks exposed at this stop consist of fine to medium crystalline dolomites mainly of the lower part of the Silurian Hopkinton Formation, possibly Marcus Member (Anderson, 1996). Figure 2 illustrates the stratigraphic position of the Hopkinton Formation within the Silurian System of eastern Iowa. Most of the beds seen in the quarry are structurally deformed to some degree. 30° dips are not uncommon for strata seen on the western high walls of the quarry, and 10 to 20° dips are common on the northern high walls (Anderson, 1996). Along the southern high walls, strongly-tilted, nearly-vertical, and overturned beds can be seen (Anderson, 1996). Anderson (1996) believed that beds with 10 to 40° dips reflect original depositional slopes while the more steeply-dipping and overturned beds represent post-depositional compaction and slumping. Slickensides found on bedding planes at various points in the quarry probably resulted from slumping and rotation of beds or blocks. Some workers believe that the structures and features present at the Tripoli-Platte Quarry are part of a reef system. However, the arguments as to this not being a reef have been laid out in Anderson (1996) and John Dawson's article earlier in this guidebook. As per their suggestion, we will refer to this feature as a carbonate mound in this article.

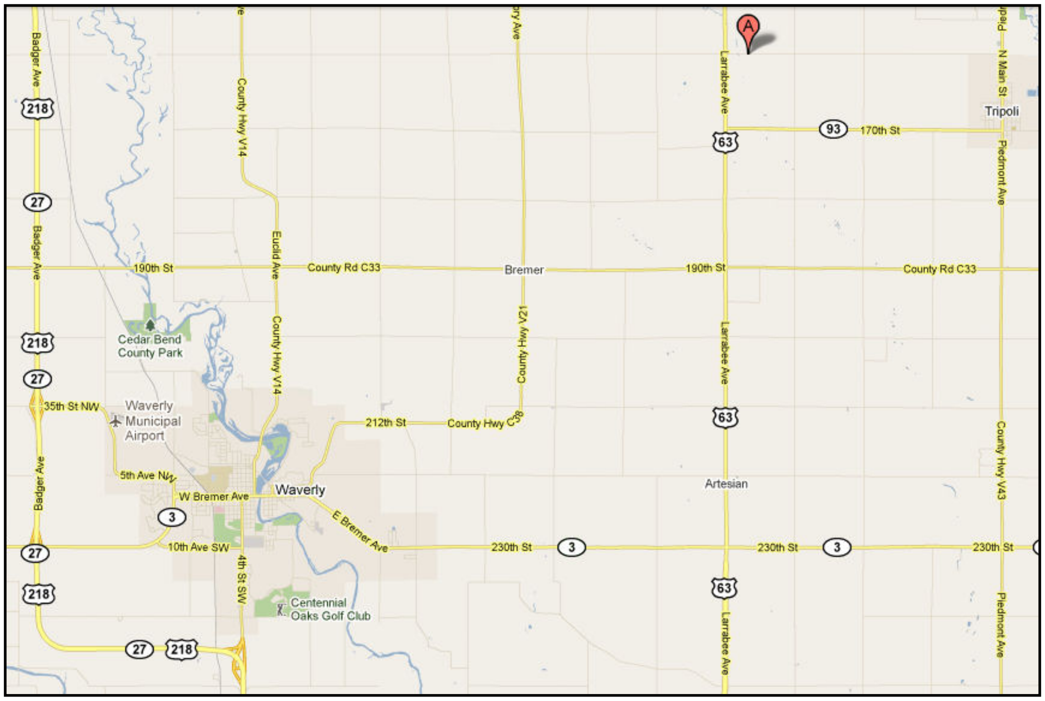

Figure 1. Location of the Tripoli-Platte Quarry in relation to Waverly and Tripoli, Iowa. Quarry marked by the letter 'A' on the map. State Highway 3 and US-63 are the main routes we will use to travel from South Riverside Park (Stop 1) to the quarry. Image taken from Google maps (2011).

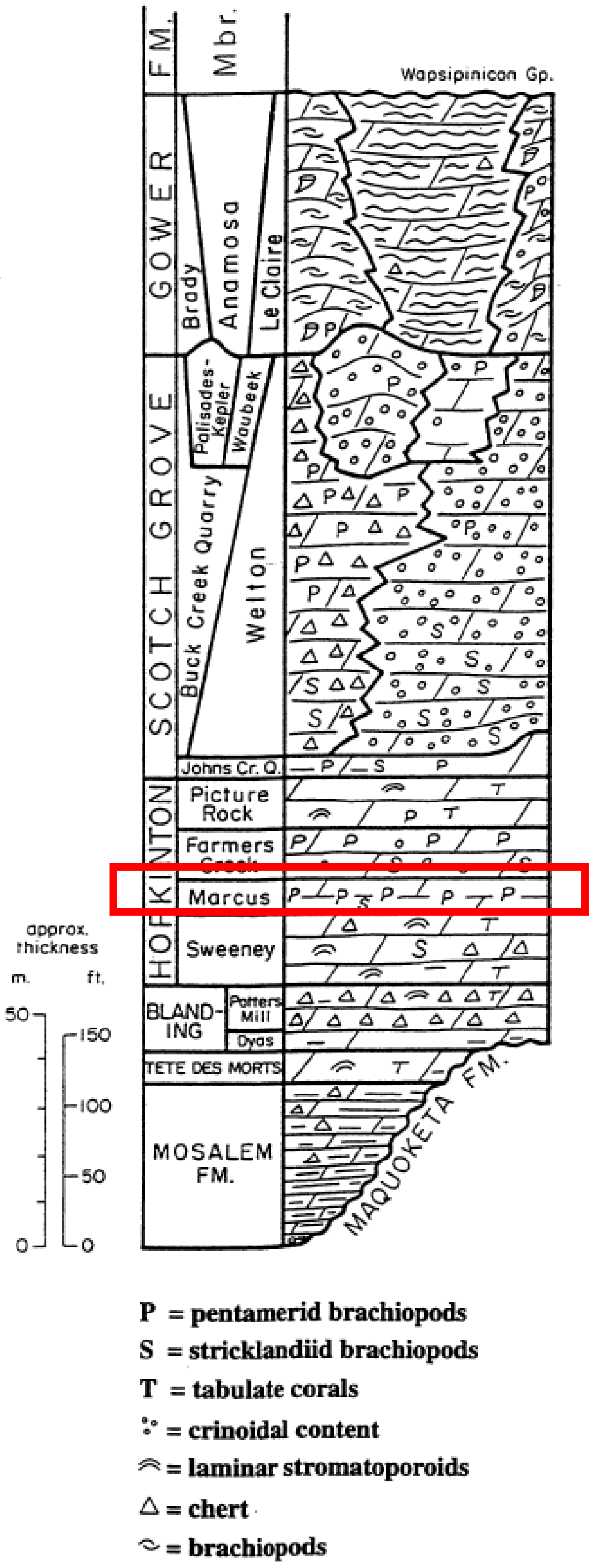

Figure 2. Generalized stratigraphic column for the Silurian System of eastern Iowa. Red box outlines the Marcus Member of the Hopkinton Formation, probable unit seen in Tripoli-Platte Quarry. While well-documented in the higher Scotch Grove and Gower formations, Tripoli Quarry is the only known place in Iowa to see a carbonate mound in the Hopkinton Formation exposed on the surface (Anderson, 1996). Note distribution of the brachiopod *Pentamerus* (marked by a 'P') in the Silurian. *Pentamerus* is common in the Hopkinton and a biomarker for that unit. Stratigraphic column from Witzke (1992).

There are four main benches here; we will start at the uppermost bench and work our way down to lowest part of the quarry. Along the uppermost bench, you will see structures related to one or more carbonate mounds (Figures 3 and 4). On the northern wall, the *Pentamerus*-rich core of the carbonate mound is visible (Figures 5a and 5b). Away from the core, tilted and folded flank beds are prominently displayed along the western part of the northern wall and on the western wall (Figures 6 and 7). The western wall of the uppermost bench has flank beds that seem to be tilting *away* from the mound core strongly indicating the presence of several carbonate mounds coalescing together in this area. Other features seen along the western wall include slickensides (Figure 8) and chert (Figure 9) along bedding planes. The uppermost bench is also the best place to observe and collect fossils including horn corals, crinoids, the chain coral *Halysites*, the honeycomb coral *Favosites*, and stromatoporoids (Figures 10, 11, 12, 13 and 14). Furthermore, the articulate brachiopod *Pentamerus* is very common here, particularly in the mound core (Figure 15). Nearby spoil piles provide an excellent opportunity to collect beautiful specimens of *Pentamerus*, *Halysites*, *Favosites*, crinoids, and corals; however, care must be taken in collecting slabs of *Pentamerus*-rich rock as they can be quite heavy.

Figure 3. The northern high wall of the uppermost bench, the *Pentamerus*-rich core of the carbonate mound can be seen on the right side of the picture. To the left, the folded and tilted flanking beds of the mound are visible. This is a good location to observe and collect the common fossils of this quarry including corals (*Halysites*, *Favosites*, and horn corals), crinoids, stromatoporoids, and the articulate brachiopod *Pentamerus*. Note the strongly-folded beds curving downward in the middle of the picture. Geologist Robert M. McKay (small blue figure in middle of picture) for scale.

Figure 4. The western high wall of the uppermost bench. Strongly-tilted flanking beds are prominently visible in high wall. Note that flanking beds are tilted *away* from mound core illustrated in Figure 2. These are probably flanking beds of another carbonate mound that has coalesced with the mound seen in Figure 2. Other features seen in the western wall include slickensides along bedding planes and chert. The gray band in the middle of the picture is Quaternary till above bedrock. The highest light-colored material is back-fill used by the quarry operators.

Figure 5a. *Pentamerus*-rich carbonate mound core on northern high wall of uppermost bench. Geologist Bob McKay for scale.

Figure 5b. Close-up of *Pentamerus*-rich carbonate mound core on northern high wall of uppermost bench. Geologic hammer approximately 12 inches long.

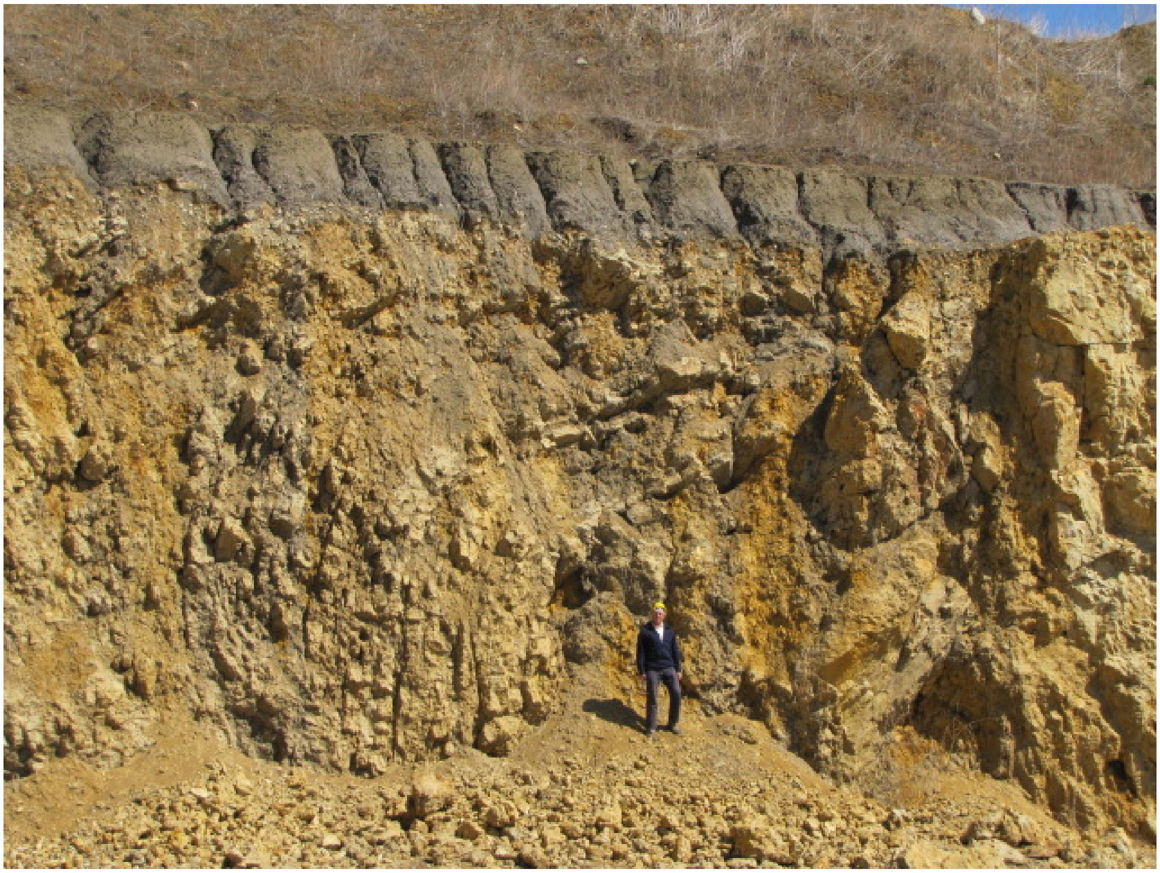

Figure 6. Close-up of folded and tilted flanking beds illustrated in Figure 2. Note strongly-folded beds just to the right of geologist Robert McKay. The *Pentamerus*-rich mound core is to the left of McKay beyond the frame of the photograph. The uppermost dark gray band is Quaternary till.

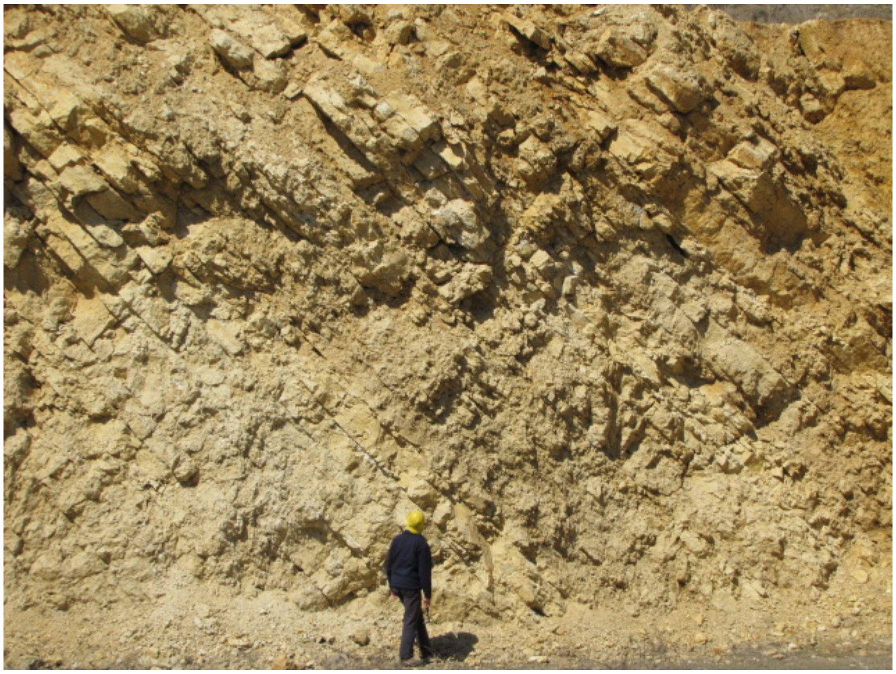

Figure 7. Close-up of tilted beds with dips of 40 to 45° along western high wall of uppermost bench illustrated in Figure 3. Geologist Robert McKay for scale.

Figure 8. Slickensides on bedding planes likely resulting from post-depositional slumping and rotation of beds and blocks on western high wall of uppermost bench. Geological hammer approximately twelve inches in length.

Figure 9. Chert (light-colored spots on rock) along bedding planes of strongly-tilted flanking beds of western high wall. Some chert nodules can be found as inclusions within the rock as well. Note angle of dip of beds, around 40 to 45°. These dipping beds probably reflect original depositional slopes of carbonate mound(s) (Anderson, 1966). However, nearby slickensides (Figure 7) indicate some post-depositional compaction, slumping, and rotation. Geological hammer used for scale.

Figure 10. Unidentified horn coral, quarter for scale. Fossil molds scattered around coral probably resulted from dissolution of crinoids and brachiopods.

Figure 11. Close-up of crinoid stem molds found at Tripoli Quarry.

Figure 12. The chain coral *Halysites*, Tripoli Quarry.

Figure 13. Honeycomb coral *Favosites*, taken from one of the spoil piles on the uppermost bench, Tripoli Quarry.

Figure 14. Close-up of cross-section of a stromatoporoid sponge, Tripoli Quarry.

Figure 15. Dolomitic slab riddled with the articulate brachiopod *Pentamerus* found at one of the spoil piles at the uppermost bench, Tripoli Quarry. *Pentamerus* is the most common brachiopod found at Tripoli and a good biostratigraphic marker for the Hopkinton Formation.

The second bench (Figure 16) affords a good opportunity to see lower-angle dipping beds (Figure 17) and to see how they might possibly merge laterally to the west into a massive-bedded mound core, especially along the south wall. Medium brown clay stringers can also be seen high along the south wall (Figure 18). However, because of large unstable blocks on the upper parts of the high wall, these features must be observed from a safe distance (Figure 19).

Figure 16. Side view of eastern high wall of second bench. Geological survey vehicle for scale.

Figure 17. Low-angle dipping beds along southern high wall of second bench. Angle of dip around 5 to 10° and probably reflects original depositional slopes of carbonate mound.

Figure 18. Close-up of brown clay stringer on southern high wall of second bench.

Figure 19. Large unstable block seen at western edge of the southern high wall of the second bench. Since this high wall is very unstable, it must be observed from a safe distance. Note low-angle dip of beds.

The beds observed at the third bench exhibit significant deformation (Figure 20). Along the northern wall, there are strongly-folded and tilted chert-bearing strata (Figures 21 and 22) in addition to nearly vertical beds (Figure 23). A high degree of bed deformation can be seen on the western wall; because of overturned and vertical beds, this deformation is probably post-depositional (Figure 24). However, access to this wall is limited so we will be unable to observe these features closely. Still, the question remains as to when most of the slumping and compaction took place; is it syndepositional or post-depositional? In addition to structure, tripolitic chert can be found here; other minerals include calcite scalenohedra and massive quartz. There is a water-filled trench separating the northern high wall from the area where we will park so care must be taken.

Figure 20. Some of the significant post-depositional deformation of beds observed along the northern high wall of the third bench. Note the strong folding of beds in the middle of the photograph. Vertical beds can be seen on the right side of the photograph. Geologist Robert M. McKay for scale.

Figure 21. Close-up of folded strata seen on the northern wall of the third bench. The fold axis is above point of arrow. Geologist Robert M. McKay for scale.

Figure 22. Close-up of tilted chert-bearing beds visible on the northern high wall of the third bench. Geologist Bob McKay for scale, his arm is oriented along dip of tilted strata. Some folded strata are visible in upper part of photograph.

Figure 23. Close-up of nearly vertical chert-bearing strata along northern wall of third bench. In upper part of photograph, strata fold to the east, behind geologist Robert McKay. Fold axis is at point of arrow, directly above the head of McKay. This is likely post-depositional.

Figure 24. Significant post-depositional deformation of strata on western high wall of third bench. Extremely overturned and vertical beds can be seen in middle of picture. Some folded beds can be seen on the left side of the photograph.

After the third bench, we will make our down into the lowest part of the quarry. Along the southern high wall, massive-bedded facies can be seen (Figure 25). There does appear to be vertical beds at various points along the high wall. However, closer inspection will reveal that this is recent silt and clay deposited by water cascading down the rock face. Towards the extreme eastern of the high wall, faint horizontal beds can be seen; these beds seem to die out towards the middle part of the high wall. Furthermore, some of these beds exhibit some minor folding, particularly just east and west of the massive-bedded facies (Figure 26 and 27). The massive-bedded facies is probably the core of a carbonate mound and the beds off to the east are flanking beds. As with the third bench, a water-filled trench and muddy areas lie between where we will park and the high wall. The high wall can be accessed at certain areas but extreme care must be taken.

Figure 25. Close-up of massive-bedded facies seen on southern high wall of lowest quarry bench. Likely the core of a carbonate mound. Note vertical discoloration in middle of picture from recent silt and clay washed down rock face.

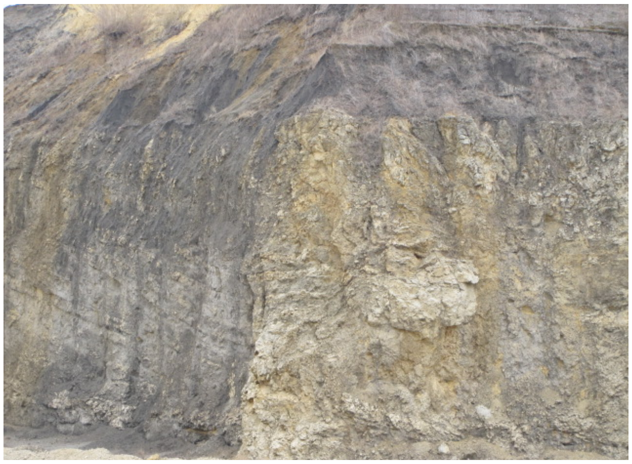

Figure 26. Slightly folded upward beds just to the east of the massive-bedded facies in Figure 25. Folding can be seen just to the right of the photograph's middle.

Figure 27. Strongly-folded beds to the west of the massive-bedded facies in Figure 25. Folds can be seen as two hummocks along the bottom of the high wall. Likely post-depositional.

Figure 28 is a photomosaic tracing of the southern high wall of the lowermost bench and the western high wall of the third bench made by Brian Witzke, an IGWS geologist, in November, 1995 to illustrate to complex structural geometry of the strata in this quarry.

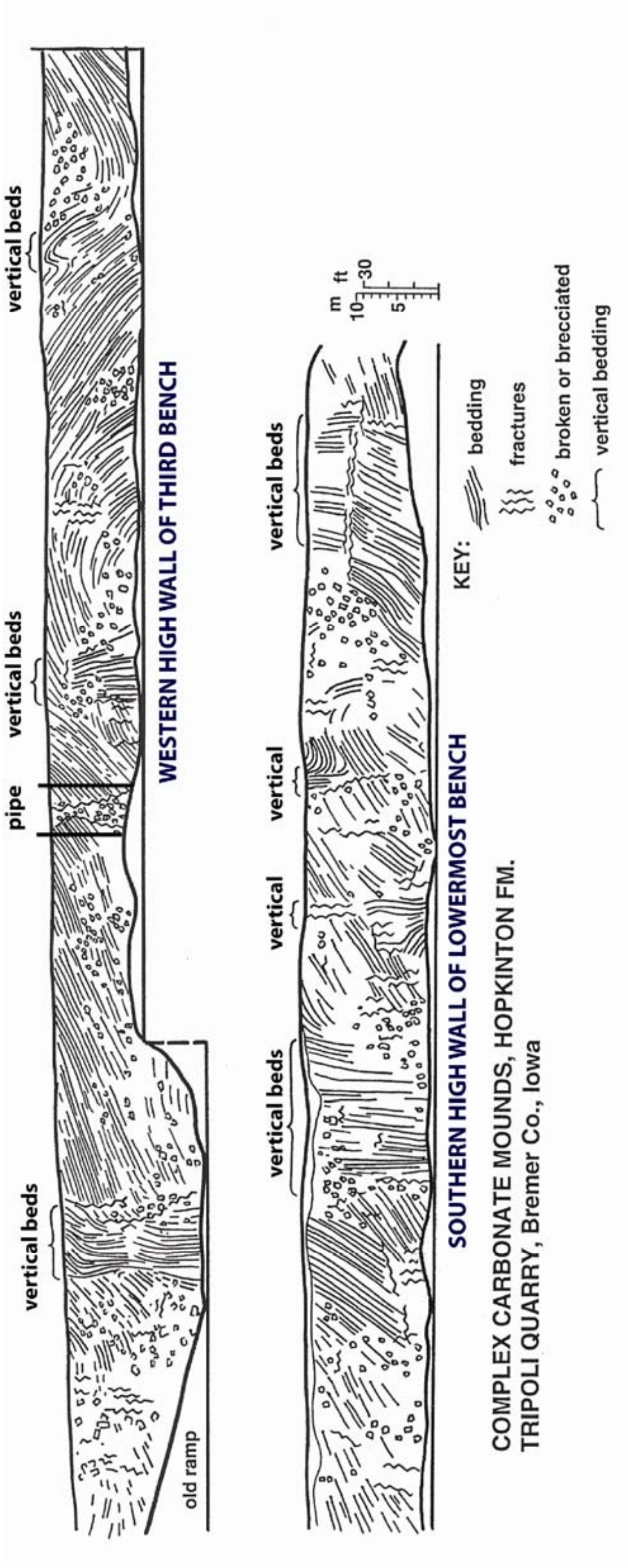

Figure 28: Structural complexity of two high walls at Tripoli Quarry. Photomosaic tracing prepared by Brian Witzke, November 1995. From Anderson (1996).

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Witzke, BJ, 1992, Silurian Stratigraphy and Carbonate Mound Facies of Eastern Iowa: Field Trip Guidebook to Silurian Exposures in Jones and Linn Counties, Guidebook Series 11, Geological Survey Bureau, Iowa Department of Natural Resources, Iowa City.

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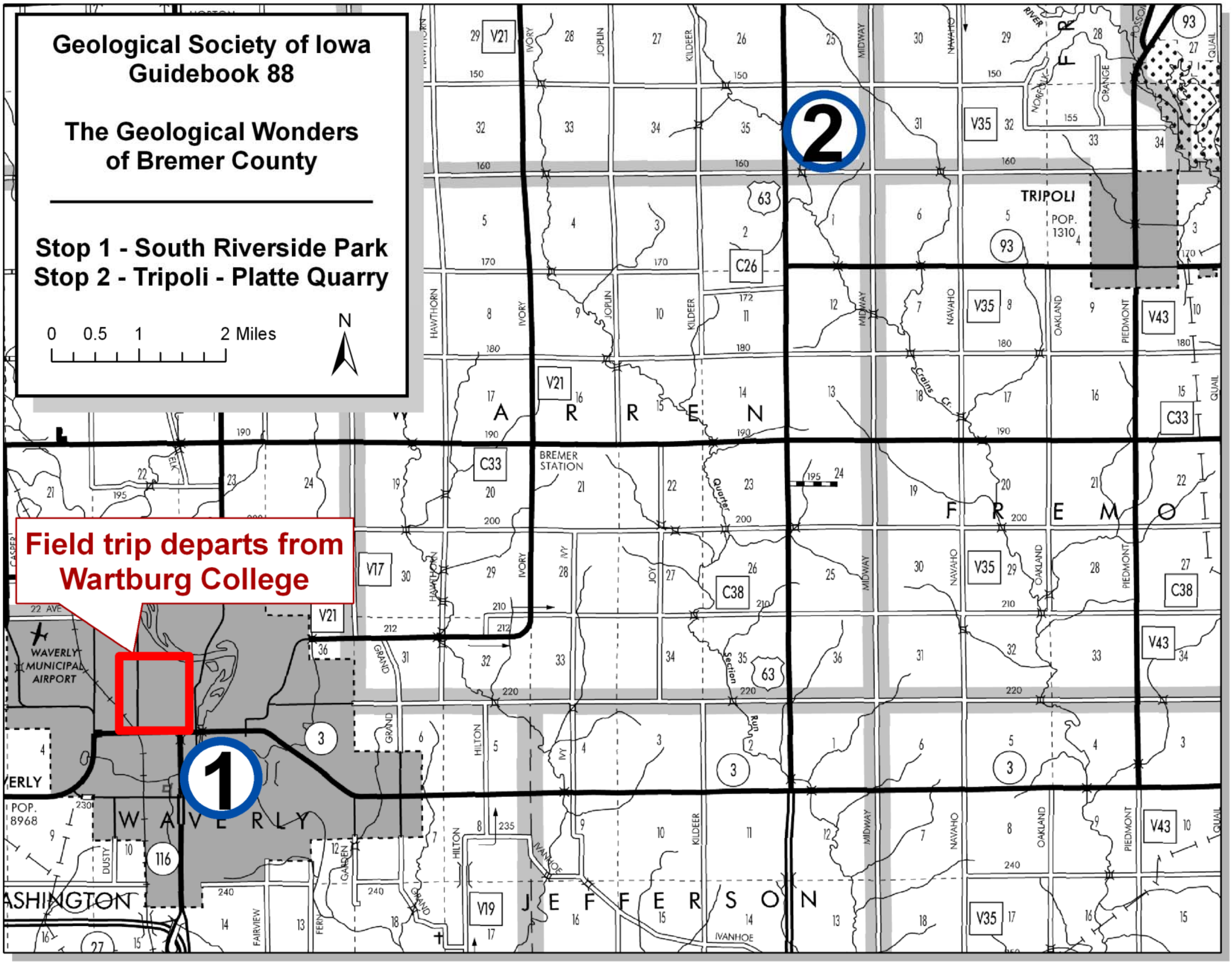

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The Geological Wonders of Bremer County

Stop 1 - South Riverside Park

Stop 2 - Tripoli - Platte Quarry

Field trip departs from Wartburg College