Iowa DNR Geological Survey Bureau 109 Trowbridge Hall Iowa City IA 52252-1319
Phone: 319-335-1575 **http://www.igsb.uiowa.edu**

BEDROCK GEOLOGIC MAP OF NORTHEAST IOWA

by Brian Witzke
Iowa Department of Natural Resources
Geological Survey Bureau

INTRODUCTION

The new bedrock geologic map of northeast Iowa presented herein is an entirely new compilation which incorporates all available sources of bedrock information for the region. The mapping area encompasses an 17-county region of northeast Iowa, bordered to the east by the valley of the Mississippi River and extending southward to Scott County and westward to Black Hawk County. This region includes a number of Iowa's major metropolitan areas such as Davenport (Quad Cities area), Cedar Rapids, Dubuque, and Waterloo. The mapping area incorporates a significant portion of the classic Upper Mississippi Valley Paleozoic outcrop, with numerous bedrock exposures especially along the deeply-dissected valleys of the streams and rivers which drain southeastward to the Mississippi. The bedrock strata of northeast Iowa have yielded a number of natural resources of great economic importance to the region, both historic and recent. These include aggregate resources, building stone, materials for cement manufacture, iron ore, lead-zinc mineralization, sand, minor coal, and other resources. Bedrock aquifers are extensively used for groundwater resources across northeast Iowa, and their importance to the economy of the region cannot be overstated.

Northeast Iowa is covered by a mantle of Quaternary deposits to varying degrees, although much of the eastern region has traditionally been included within the so-called "Driftless Area." The southern and western portions of the region include a substantial cover of eroding Pleistocene glacial deposits, which form a distinctive but subdued landscape termed the "Iowan Surface" (Prior, 1991). Much of the bedrock surface is buried in this area, and our understanding of the bedrock geology derives from a study of numerous well records supplemented with scattered bedrock exposure found in places primarily along stream courses and in quarries. By contrast, the landscape across much of the eastern and northern portions of the map area is to a large extent controlled by the bedrock geology as expressed by the modern drainage network, and only a thin mantle of Quaternary materials occurs in this region, primarily colluvium, alluvium, and loess. Although glacial deposits are largely absent across this area, the region is not truly "driftless," as scattered erosional outliers of glacial till are noted in a few places. Nevertheless, the landforms and landscapes in this region are strongly and clearly influenced by the Paleozoic bedrock geology, and the term "Paleozoic Plateau" has been applied to this landform region (Prior, 1991). The Paleozoic Plateau region displays numerous exposures of Cambrian and Ordovician strata. The region is bounded to the south by a topographic escarpment of Silurian strata.

The southeastern part of the map area is characterized by a rolling dissected landscape largely mantled by pre-Illinoian glacial deposits and loess, the "Southern Iowa Drift Plain" region of Prior (1991). Bedrock exposures are typically scattered, but are locally extensive along some valley courses in the region. Quaternary alluvial deposits of varying thickness line the valley bottoms throughout the northeast Iowa map area, reaching their greatest thicknesses in the Mississippi River Valley (300 ft; 90 m). Older erosional episodes of bedrock incision across the regions of the present-day Iowan Surface and Southern Iowa Drift Plain have formed a complex bedrock topographic surface now largely covered by Quaternary deposits. Buried bedrock valleys are filled by thick deposits of alluvium and glacial till in these regions, reaching maximum thicknesses to about 400 ft (120 m). The location of these buried bedrock valleys has been interpreted from available well penetrations, and their form and depth has strongly reflected the construction of the new bedrock geologic map.

DATA SOURCES AND APPROACHES TO MAPPING

The new geologic map of northeast 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: 1) field studies and mapping programs (present study as well as all previous investigations) of bedrock exposure; 2) extensive subsurface well records archived at the Geological Survey Bureau (GSB); and 3) distribution of bedrock exposure and shallow bedrock provided by the detailed county-scale soils maps provided by the Natural Resources Conservation Service (NRCS). These data sources are more fully discussed below.

The newly compiled geologic map incorporates extensive data sources derived from a long history of bedrock geologic investigations in northeast Iowa. Published and unpublished sources archived at the GSB provided the primary basis for identifying bedrock strata across much of the region. Stratigraphic information for virtually all bedrock exposure areas in northeast Iowa is available in archived files and field notes. These include descriptions of natural exposures, roadcuts, and quarries. Additional field studies were undertaken as part of the current mapping program in a number of key areas, especially within the Cambrian and Ordovician outcrop. Mapping in these areas was largely completed on 7 ½ minute (1:24,000) topographic quadrangle maps (U.S. Geological Survey). Elsewhere, bedrock outcrop information was compiled at a 1:100,000 scale on the various county topographic maps (U.S. Geological Survey). Mapping units were selected to subdivide meaningful and recognizable packages of strata that could be realistically mapped, as discussed in the subsequent section. The accuracy and detail of the new geologic map has been contingent on the comprehensive stratigraphic expertise and extensive field experience acquired during the professional careers of the geologists at the GSB, including those who preceded us as well as the current staff who actually prepared the new map. The high level of experience on Iowa geology currently at the GSB could not be duplicated in any other group or institution, and it was most sensible that it was GSB staff who provided the impetus and direction for the new geologic mapping synthesis.

In regions of Quaternary cover, information on the bedrock topography and stratigraphy was derived largely from extensive subsurface well data archived at the GSB. Well logs provide lithologic information derived from descriptions of well cuttings samples (generally with 5 foot sample intervals), tied to surface elevation, to produce files of color-coded strip logs with lithologic descriptions and interpretations of the stratigraphy. All existing well logs were examined and systematically re-evaluated for bedrock surface and stratigraphy as part of the new mapping program. This involved the support of two Research Assistants (graduate students in the Univ. Iowa Dept. of Geology) working in cooperation with GSB staff. Stratigraphic picks were coded into an expanding stratigraphic data base to facilitate mapping and promote further accessibility of GSB data in an electronic medium. Various drillers logs and other well penetrations that lack detailed logs were used to supplement and refine our interpretations of bedrock topography. A number of bedrock cores from northeast Iowa are reposited at the GSB, and these provided the most reliable sources of subsurface stratigraphic data for the map area.

The detailed county soil surveys prepared by the U.S. Department of Agriculture, Natural Resources Conservation Service, have mapped soil series and bedrock exposure at a 1:15,840 scale. These maps have been extremely useful for recognizing areas of shallow bedrock as reflected by the mapped distribution of rock exposure and bedrock-derived soils units. Occurrences of bedrock-derived soils mark areas where bedrock is generally within several feet (~1 m) of the surface. County soil surveys used in conjunction with subsurface well data have provided the basis for interpreting the bedrock surface across much of the map area. Bedrock topographic maps have been constructed for each county using these data, now digitized and available via our Geographic Information System (GIS). The configuration of the bedrock surface is of primary importance in mapping the distribution of various stratigraphic units in areas buried beneath the cover of Quaternary materials.

Our approach to mapping has been multi-faceted utilizing: 1) the distribution of all exposed bedrock; 2) all subsurface well control; 3) stratigraphic re-evaluation of all areas of bedrock exposure and available well points; 4) interpretations of bedrock topography. Well and outcrop data were used to construct local

to regional structure contour maps for various stratigraphic datums. These structure maps were intercepted with the bedrock topography to enable geologic maps to be constructed in areas of Quaternary cover and limited data coverage. Geologic contacts of mapping units were drawn using GIS software (ESRI's ArcView 3.0) and all are available in an electronic format.

The mapping style reflected on the new bedrock geologic map of northeast Iowa provides a simple way to evaluate the density of data coverage and the confidence of the stratigraphic picks. Areas of extensive bedrock exposure in the northeastern sector of the map area are well constrained geologically, and the map is correspondingly the most detailed in that area. As seen across much of Allamakee, Clayton, Winneshiek, eastern Fayette, and eastern Dubuque counties, the mapped stratigraphic boundaries closely follow existing surface topography, which reflects the detailed stratigraphic control possible in this area of abundant bedrock exposure. By contrast, less detailed line work characterizes other regions of the map area to the south and west, where bedrock exposure is more sparse and well control is locally limited. In areas of more limited data coverage, the stratigraphic contacts are correspondingly portrayed with less detail, and the line work is drawn in a more generalized style. For example, this more generalized style is evident across large portions of Chickasaw, Bremer, Black Hawk, and Buchanan counties, characterized by broadly sweeping or arcuate line work lacking intricate detail. Regions of intermediate data coverage and bedrock exposure are portrayed by an intermediate style of line work which shows varying levels of detail (e.g. Jackson, Linn, Cedar counties).

PREVIOUS GEOLOGIC MAPPING IN NORTHEAST IOWA

The first bedrock geologic map for eastern Iowa, albeit highly generalized, was published by Owen in 1857, who presented the first geological survey of the Upper Mississippi Valley region that included Iowa. A series of bedrock geologic maps of Iowa were subsequently published by the Iowa Geological Survey between 1894 and 1937, each one an improvement over the previous version. In addition, county-scale geologic maps for northeast were also published in the Annual Reports of the Iowa Geological Survey between 1895 and 1906 which incorporated all geologic information available at that time. Each of these compilations presented an informative but generalized view of the bedrock geology of northeast Iowa. However, stratigraphic refinements and new data accumulated in the interim period have made most of these early maps of limited value outside of their historical interest.

The 1969 Geologic Map of Iowa (Hershey, 1969) marked a major improvement over previous versions, as it incorporated a more extensive array of subsurface well points and a generally thorough survey of bedrock exposure. This map is the most recent effort to present the bedrock geology of the entire state (1:500,000 scale). However, subsequent work has identified two significant mapping issues with the Hershey (1969) map in need of improvement for northeast Iowa: 1) bedrock topography is not accurately reflected across portions of the map area; and 2) subsequent stratigraphic studies, especially in the Silurian and Devonian, have established the miscorrelation and mismapping of several geologic units. This latter issue is reflected by several significant changes on the new geologic map of northeast Iowa with respect to the Hershey (1969) map. 1) Elongate channel-like bodies assigned to the cherty "Alexandrian Series" (Lower Silurian) are prominently shown on the Hershey (1969) map across areas of Fayette, Buchanan, Delaware, Dubuque, Jones, and Clinton counties. However, two stratigraphically separated cherty intervals are now known to be represented in the construction shown on the Hershey map, which includes a lower cherty unit (Blanding Fm.) and an upper cherty interval (Scotch Grove Fm., Buck Creek Quarry Mbr.). In addition, no bedrock channels or channel geometries support the Hershey map construction. 2) Outliers of the "LaPorte City Chert," assigned to the "Lower Devonian Series," are shown at a few places on the Hershey (1969) map. These strata are now known to be a cherty limestone facies of the Silurian, not Devonian. The new map of northeast Iowa shows an expanded distribution of this Silurian limestone facies, including excellent exposures in Delaware County. 3) The Cedar Valley Limestone (Devonian) is shown on the Hershey (1969) map to directly overlie Ordovician strata across the northern map area, with no Wapsipincon strata between. This map construction is now known to be

in error, and resulted from the miscorrelation of basal Wapsipinicon strata in the northern part of the map (Spillville Fm.) with Cedar Valley strata to the south. The new map correctly reflects the presence of thick Wapsipinicon strata in the northern area, and correspondingly diminishes the area of Cedar Valley outcrop.

Additional bedrock geologic mapping projects have taken place in northeast Iowa subsequent to the Hershey (1969) map, and some of these were incorporated into the new geologic map. A version of the bedrock geology of northeast Iowa (1:500,000 scale) was presented in Hallberg and Hoyer (1982); this is a hybrid of the Hershey (1969) map that incorporated some new interpretations of the bedrock geology. The new geologic map presented herein, however, represents an entirely new compilation that differs from the 1982 version. Detailed field mapping on 7 ½ minute topographic quadrangles in portions of Clayton and southermost Allamakee County (15 x 15 miles) was summarized on a page-size figure contained in Hallberg et al. (1983, p. 19). This mapping was incorporated on the new map.

The Plum River Fault Zone, which stretches across portions of Jackson, Jones, Clinton, and Linn counties, was the focus of several detailed mapping projects in several small outcrop areas during the late 1970s and 1980s. Most of these maps were summarized as figures in Bunker et al. (1985), Ludvigson and Bunker (1989), and Ludvigson (1988). Graduate thesis projects also involved field mapping along the fault zone, including Chao (1980) and Baik (1980). The field data from these geologists are incorporated on the new geologic map of northeast Iowa.

Additional field projects mapped the bedrock geology on quadrangles for areas of Clayton and Fayette counties, and these are summarized on figures contained in Seigley (1994) and Pearson (1982). Their data are incorporated on the new geologic map, although the northern portion of Pearson's map area has been significantly modified to accommodate well data. Published geologic maps for the Dubuque South and Dubuque North 7 ½ minute topographic quadrangles are available in Brown and Whitlow (1960) and Whitlow and Brown (1963), and their maps have not been significantly improved upon since they were first published. The Cretaceous outlier near Waukon, Allamakee County, was mapped by Howell (1916), and his version remains the best available for this occurrence of economic iron ore.

The bedrock hydrogeology of portions of Linn County was investigated by Wahl and Bunker (1986), and their geologic synthesis included new subsurface information and a significantly revised bedrock geologic map. Linn County was also the focus of a recent Statemap project, and a detailed bedrock geologic map was presented as part of that project (Ludvigson et al., 1995; 1997) which differed in many respects from that of Hershey (1969) and Wahl and Bunker (1986). The latest digital version of the Linn County geologic map was largely incorporated on the new bedrock geologic map of northeast Iowa, although a few minor changes were made for the Silurian-Devonian contact along the Delaware and Jones county lines. More significantly, the Silurian bedrock geology of Linn County has been further subdivided into four map units on the new map of northeast Iowa (the previous version left the Silurian undivided). With the exception of the few small-scale mapping projects mentioned previously, the remaining 16 counties in the map area represent new compilations.

BEDROCK STRATIGRAPHY AND MAPPING UNITS

Stratigraphic units mapped on the new bedrock geologic map of northeast Iowa are outlined on the map Legend. The boundaries separating the various map units were selected to reflect 1) prominent lithologic changes and 2) major regional unconformities and/or disconformities. The map units are considered the most practical and recognizable packages of strata for mapping purposes at a 1:100,000 scale. The general lithologic features and maximum thicknesses are noted for each map unit in the Legend. Maximum thicknesses represent the thickest known well penetration within the outcrop belt of each unit. However, significant variations in thickness occur for each unit across the map area, and even greater thicknesses for many mapping units are known from other regions in Iowa. Only the Silurian units preserve their greatest known thicknesses within the northeast Iowa map area.

The general Paleozoic stratigraphy of the eastern Iowa region is summarized by Bunker et al. (1985) and Witzke and Bunker (1996). Paleozoic deposits in eastern Iowa are primarily of shallow-marine and restricted-marine origin and accumulated within broad cratonic basins and shallow shelves. The structural configuration and loci of these cratonic basins shifted and changed through the Paleozoic, as reflected by significant changes in thickness and depofacies patterns over time (Bunker et al., 1985). Portions of the stratigraphic section found in the northeast Iowa map area were deposited in nonmarine settings (primarily fluvial), especially for the Pennsylvanian and Cretaceous units. A brief summary of each map unit is presented below, which expands on the information provided in the map Legend.

Cretaceous

Scattered outliers of Cretaceous strata are mapped in Allamakee and Howard counties, and all are assigned to the Windrow Formation (Thwaites and Twenhofel, 1921; Andrews, 1958). These outliers are of limited extent, and represent erosional outliers of nonmarine strata, primarily sandstones and conglomerates commonly cemented by iron oxides. They are known to overlie Ordovician and Devonian units in the area. The most significant of these Cretaceous outliers occurs near Waukon, Iowa, capping Iron Hill, where the massive iron oxides were once mined as iron ore (Howell, 1916). This outlier is the type locality of the Iron Hill Member (Andrews, 1958). The age of the Windrow Formation is not known with certainty, but obvious compositional and stratigraphic similarity with the Dakota Formation of western Iowa suggests a mid Cretaceous age. Additional Windrow outliers likely occur within the map area, but limited exposure enables only five to be recognized at present.

Pennsylvanian

Pennsylvanian strata are recognized at a number of localities in the southern half of the map area, and most of these are found as small erosional outliers overlying Devonian, Silurian, and Upper Ordovician units. A partial listing of many of these outliers is provided by Bunker et al. (1985), and a summary is provided by Ludvigson, 1985). Pennsylvanian strata reach their maximum development in southwestern Scott County. The Pennsylvanian deposits are primarily of nonmarine fluvial origin, but a minor component of estuarine or marginal-marine facies are present. Pennsylvanian strata overlie a complex erosional surface developed primarily on Devonian and Silurian carbonate rocks, and valley fills and karstic infillings are identified. Pennsylvanian shale and sandstone karst and fracture fills are common in many exposures of Silurian and Devonian strata in the map area, but these small-scale occurrences are not typically mappable. Many mapped outliers are composed primarily of sandstone, with subordinate mudrock. However, the Pennsylvanian strata of Scott County are dominated by gray mudrock (commonly associated with coal) with subordinate fluvial sandstone. Sandstones are more resistant to erosion than the mudrocks and were likely left preferentially as outliers north of Scott County during the long episode of post-Pennsylvanian erosion.

The Pennsylvanian strata in the map area represent two different stratigraphic units: 1) the Caseyville Formation of Lower Pennsylvanian age (Morrowan), and 2) the Cherokee Group (including “Spoon” Formation) of Middle Pennsylvanian age (Atokan-Desmoinesian). Each of these units contains a distinctive and recognizable suite of sandstone, with quartzarenites characterizing the older interval and feldspathic sandstones dominating above (Ludvigson, 1985). However, sandstone petrography has not been undertaken for all Pennsylvanian outliers and well penetrations in the area, and, without the requisite lithologic criteria, it is presently impossible to adequately distinguish between Lower and Middle Pennsylvanian units across the map area, each highly variable in thickness. To further complicate the stratigraphic differentiation of Pennsylvanian strata, Middle Pennsylvanian units are locally incised into and through Lower Pennsylvanian strata, and both Lower and Middle Pennsylvanian units can thereby directly overlie the sub-Pennsylvanian surface. Therefore, the stratigraphic position of these units cannot serve to adequately distinguish between them. Until extensive stratigraphic, petrographic, and palynostratigraphic studies are undertaken across the map area, it is impossible to accurately subdivide the Pennsylvanian interval into more than one map unit.

Devonian

Three map units of Devonian age are recognized in northeast Iowa, but the stratigraphically highest of these, the Lime Creek Formation, is only mapped in western Black Hawk County. These shale and shaly carbonate strata are best displayed to the west in the exposure belt of north-central Iowa. Lime Creek marine deposition was initiated following a period of karstic erosion, and the formation overlies a prominent regional unconformity above strata of the Cedar Valley Group. Green-gray shale fills derived from the Lime Creek Formation are common in karstic openings and fractures across much of the Silurian and sub-Lime Creek Devonian outcrop belt, and these fills document the regional extent of sub-Lime Creek karstic erosion (Bunker et al., 1985; Witzke and Bunker, 1996). None of these Lime Creek fills are of mappable extent, but large cavern-filling occurrences in Buchanan County were once thought to be a separate sub-Cedar Valley stratigraphic unit (the so-called "Independence Shale"). Lime Creek strata are replaced by a thinner facies tract of darker-colored shales to the southeast across Iowa, where the equivalent interval is known as the Sweetland Creek Shale. Although no exposures of the Sweetland Creek Shale are confidently recognized in the map area, the type area is only a few miles west of the Scott County line, and it is likely that a few sub-Pennsylvanian Sweetland Creek outliers occur in western Scott County.

As noted previously, significant revision of Devonian stratigraphy in eastern Iowa has resulted in a notably different mapped distribution of Devonian units on the new geologic map over that shown by Hershey (1969). Two sub-Lime Creek Devonian mapping units are portrayed on the new map, the Cedar Valley and Wapsipinicon groups, each with an extensive outcrop in the western and southern map areas. The interval formerly termed the Cedar Valley Limestone was elevated to group status by Witzke et al. (1988), who subdivided it into four constituent formations, in ascending order, the Little Cedar, Coralville, Lithograph City, and Shell Rock. These formations each represent a transgressive-regressive cycle of marine deposition, and each is bounded by regional disconformity/unconformity surfaces. Three of these formations are well represented in the map area, but the highest formation, the Shell Rock, is not known to occur in the area (its outcrop is restricted to north-central Iowa).

Significant facies changes are observed within each formation of the Cedar Valley Group across the map area. Two generalized facies tracts are represented. 1) The southern area, best developed in Linn and Scott counties, is dominated by fossiliferous limestone, part argillaceous. These strata were deposited in middle-shelf subtidal marine settings, and each formation is bounded by submarine hardground surfaces (Witzke and Bunker, 1996). 2) The northern region, developed in Black Hawk county and areas to the north, is marked by mixed dolomite and limestone facies with subordinate shale. These facies were deposited in shallow inner-shelf settings. Each formation is marked by marine transgression in the lower part (fossiliferous dolomite and biostromal limestones) capped by an upward-shallowing sequence of restricted-marine and peritidal mudflat facies (sublithographic limestones and unfossiliferous dolomite/limestone). Each formation is bounded by subaerial exposure surfaces in the northern area.

The Wapsipinicon Group includes a diversity of carbonate lithologies with subordinate shale. These strata overlie and onlap a prominent sub-Wapsipinicon erosional surface developed on various Silurian units to the south and Upper Ordovician strata to the north. The Wapsipinicon interval was elevated to group status by Witzke et al. (1988) to include, in general ascending order, the Bertram, Otis, Spillville, and Pinicon Rige formations. Dense dolomites of the Bertram Formation are geographically restricted to the region north of the Plum River Fault Zone, and, except for an outlier in Jones County, is restricted to Linn County in the northeast Iowa map area (Bunker et al., 1985). The Otis Formation overlaps the Bertram edge and is more geographically widespread across the southern map area (Scott, Cedar, Linn, Buchanan counties), where it is characterized by restricted-marine limestone and dolomite facies. Basal Wapsipinicon strata in the northern map area (Winneshiek, Howard, Chickasaw counties) are assigned to the Spillville Formation, which is correlative with, but geographically separated from, the Otis Formation to the south. Spillville strata, characterized by fossiliferous dolomite facies, were mistakenly correlated with lower Cedar Valley units in earlier reported. Klapper and Barrick (1983) were the first to clearly recognize that these strata were significantly older than any Cedar Valley unit and therefore erected a new formation, the Spillville, for this northern facies. The Spillville Formation is restricted to the area north of

the Silurian edge, and its depositional margins were apparently marked at an erosional paleoescarpment of Silurian rocks in that area.

The Pinicon Ridge Formation (Witzke et al., 1988) is the most widespread unit of the Wapsipinicon Group, and the formation is recognized across the entire Wapsipinicon outcrop. Pinicon Ridge strata overlap the Spillville and Otis edges to overlie the Silurian paleotopographic high across Fayette, Bremer, Black Hawk, southern Chickasaw, and northern Buchanan counties (Bunker et al., 1985). Across most of the map area the Pinicon Ridge is dominated by restricted-marine facies of dolomite and limestone, with extensive evaporite-solution-collapse breccias in the upper part. The basal strata, however, are marked by argillaceous dolomite and shale, sandy to varying degrees (Kenwood Mbr.). Where the Pinicon Ridge onlaps the above noted paleotopographic high, the formation dramatically thins, as reflected by the very thin outcrop belt shown particularly for Fayette and Bremer counties. In fact, the exposure belt of these strata in Fayette-Bremer counties is so narrow in places, that its outcrop width has been slightly exaggerated on the map in an attempt to indicate its presence in that area at the scale presented. The constituent members of the formation are observed to onlap the Silurian surface in that area. The formation is locally absent in Bremer County, where Cedar Valley strata directly onlap an irregular eroded Silurian surface.

Silurian

Compared to the other Systems, the Silurian outcrop covers the largest portion of the northeast Iowa map area. Silurian strata are dominated by remarkably pure dolomite facies across most of the region, although minor limestone facies are recognized and mapped. A general stratigraphic summary of Silurian stratigraphy in eastern Iowa is provided by Witzke (1992). The Silurian strata are subdivided into four mapping units: 1) Hopkinton Formation and sub-Hopkinton Silurian strata; 2) Scotch Grove Formation; 3) Gower Formation; and 4) Silurian limestone facies (Waucoma and LaPorte City formations). The mapping units portrayed on the new map are significantly different from the two-part Silurian subdivision shown on the Hershey (1969) map. In addition, as noted previously, the basal Silurian mapping unit ("Alexandrian") on the Hershey (1969) map was incorrectly mapped for several counties owing to a stratigraphic miscorrelation.

The Gower Formation is the youngest formation of the eastern Iowa Silurian outcrop belt, and the formation is primarily developed along the southern and western areas of Silurian outcrop. It is dominated by a highly distinctive laminated dolomite facies (Anamosa Member) across most of its extent which has produced an abundance of high-quality building stone for the region. These laminated facies were deposited in subtidal restricted hypersaline environments (Witzke, 1992). Distinctive brachiopod-rich carbonate mound facies (Brady Member) are locally developed that interfinger with the laminated dolomites. The Gower Formation of eastern Scott County is dominated by vuggy to fossiliferous locally mounded dolomite facies (LeClaire Member), where laminated facies are more poorly developed. The LeClaire facies were deposited near the mouth of the restricted embayment in a more open-marine setting (Witzke, 1992).

Strata of the Scotch Grove Formation were variously miscorrelated or misassigned to the Hopkinton or "LeClaire" dolomite by most previous workers. It was recognized as a distinct formation and formally named by Bunker et al. (1985). It is a distinct mapping interval characterized by a variety of complex carbonate facies. The eastern outcrop (Jackson, Clinton counties) is dominated by porous crinoidal dolomite facies, but westward these crinoidal facies interfinger with and are replaced by denser very cherty dolomites. The basal part of the formation includes complex carbonate mound ("reef") facies. The upper part of the formation also displays complex facies including large carbonate mounds reaching dimension to 1.5 miles (2.4 km) in diameter and 200 feet (60 m) thick (Witzke, 1992). Because of the laterally discontinuous nature of this upper mound facies, the formation varies accordingly in thickness and is thinnest where inter-mound facies are developed. The upper Scotch Grove mounds are exposed at a number of localities primarily in Linn, Jones, and Cedar counties, where they commonly form resistant masses of dolomite ("klints") along stream courses. Scotch Grove deposition occurred in open-marine subtidal environments. It is abruptly, possibly disconformably, overlain by contrasting laminated and

mounded dolomite facies of the Gower Formation in the southern map area, although Wapsipinicon strata overlie the Scotch Grove farther to the north.

Strata of the lower Silurian dolomite map unit (Hopkinton and sub-Hopkinton Silurian) consist of four formations, in ascending order: Mosalem, Tete des Morts, Blanding, and Hopkinton. The Mosalem Formation crops out in portions of Dubuque, Jackson, Clinton, and Clayton counties, where it unconformably overlies an erosional surface developed on underlying Upper Ordovician strata of the Maquoketa Formation. This surface displays up to 100 feet (30 m) of erosional relief, and the Mosalem (argillaceous dolomite, part cherty) correspondingly varies in thickness from 0 to 100 feet. The Mosalem is locally onlapped by purer dolomite strata of the Tete des Morts Formation. The Mosalem-Tete des Morts interval is, in turn, overlain and overlapped to the west by the Blanding Formation. The Blanding is a distinctive very cherty dolomite interval, including both bedded and nodular cherts. The Hopkinton Formation, the thickest formation of this map unit, is widely exposed in eastern Iowa, and everywhere is known to overlie the Blanding. The Hopkinton consists of four members of differing dolomite lithologies, variably cherty. All of the constituent formations of this map unit were deposited in subtidal marine environments, and several large-scale transgressive-regressive cycles of deposition are recognized (Witzke, 1992; Witzke and Bunker, 1996).

Two stratigraphic intervals of limestone facies are recognized in the eastern Iowa Silurian outcrop belt, and these are laterally equivalent to dolomite facies. These limestones are shown as a single map unit, although two outcrop regions of these limestones subdivide two separate Silurian limestone formations, each of which occupies a different stratigraphic position. Silurian limestone strata are exposed in portions of Winneshiek and northern Fayette counties, extending into parts of Chickasaw and Bremer counties. These limestones are included in the Waucoma Formation, an interval that correlates with dolomite strata of the Tete des Morts, Blanding, and Hopkinton formations to the south. The Waucoma Formation unconformably overlies the Ordovician Maquoketa Formation and is variably overlain by Silurian dolomite strata (Hopkinton Fm.) or Wapsipinicon units (Devonian). A second Silurian limestone interval is exposed in western Delaware County, extending into parts of northern Linn, southern Black Hawk, and Buchanan counties. These limestone strata are included within the LaPorte City Formation, which differs from the Waucoma Formation by its more cherty character and higher stratigraphic position. LaPorte City strata primarily correlate with Scotch Grove dolomites elsewhere in eastern Iowa, although basal LaPorte City strata locally include upper Hopkinton equivalents in part of Delaware County. LaPorte City strata, where capped by the Wapsipinicon Group, locally display a conglomeratic chert residuum interval of varying thickness at the top of the formation, likely formed during the prolong period of regional erosion that separates Silurian and Devonian sedimentation.

Ordovician

Ordovician strata are well exposed in northeast Iowa, and a number of the constituent stratigraphic units derive their names from northeast Iowa and adjacent parts of the Upper Mississippi Valley. Three Ordovician map units are portrayed on the new northeast Iowa map, in ascending order: 1) Prairie du Chien Group and St. Peter Sandstone; 2) Platteville Formation and Galena Group; and 3) Maquoketa Formation.

The Maquoketa Formation is an Upper Ordovician (Richmondian) interval characterized by shale and carbonate strata. It shows considerable north-to-south facies variations within the outcrop belt of northeast Iowa. The formation in the southern map area (Dubuque, Jackson, Clinton counties) is dominated by green-gray shale with subordinate interbeds of dolomite in the lower and uppermost parts. The lower interval in this area includes a basal phosphorite and brown organic shale facies, locally with phosphatic dolomites (Witzke et al., 1997). Significant sub-Silurian erosional relief on the Maquoketa shales is seen in this area, but, where the Maquoketa is thickest, a red mudstone with oolitic ironstone (Neda Member) is locally present at the top (ibid.). Northward in the outcrop belt the formation incorporates progressively more carbonate facies, where the Maquoketa can be readily subdivided into four constituent members, ascending: 1) Elgin (limestone/dolomite, variably cherty, shale interbeds, basal phosphorite); 2) Clermont (shale and argillaceous limestone/dolomite); 3) Fort Atkinson

(fossiliferous limestone); 4) Brainard (green-gray shale, dolomite interbeds in upper part). The alternation of resistant carbonates and easily-eroded shale seen in the vertical progression of members produces a distinctive landscape within the Maquoketa exposure belt. The Maquoketa is capped by Silurian strata over much of eastern Iowa, but the Maquoketa is beveled northward in Winneshiek County beneath the Devonian (Devonian overlies Fort Atkinson to Elgin Members). The Maquoketa overlies a prominent submarine hardground surface at the top of the Galena Group, capped by a distinctive condensed phosphorite unit. The formation was deposited entirely within subtidal open-marine environments, alternating between times of widespread benthic oxygen stress (deepest facies) and more oxygenated benthic conditions with an abundant skeletal benthos (shallowest facies) (Witzke and Bunker, 1996; Witzke and Kolata, 1988).

The Galena Group is a resistant carbonate interval that is well displayed in the Ordovician outcrop of northeast Iowa. This interval is subdivided into four constituent formations in the map area, ascending: 1) Decorah (shale, limestone); 2) Dunleith (variably cherty limestone/dolomite); 3) Wise Lake (relatively pure limestone/dolomite); 4) Dubuque (limestone/dolomite, shale interbeds). The Decorah is a shale-dominated interval in the northern area, but the shales are replaced southward by limestone-dominated facies (with a basal shale member). The remainder of the Galena Group (Dunleith, Wise Lake, Dubuque formations) is a thick carbonate-dominated interval that shows a complete transition between exclusively dolomite facies to the south (Dubuque County) and exclusively limestone facies to north (Winneshiek County). Intervening regions are a mix of limestone and dolomite (Witzke, 1983). Galena Group strata were deposited in an open-marine subtidal shelf setting, and the constituent formations and members display remarkable stratigraphic continuity. Numerous submarine hardground surfaces punctuate the Galena sequence marking episodes of starved sedimentation.

Middle Ordovician strata of the Platteville Formation are included within the same mapping unit as the Galena Group. The Platteville is a limestone and dolomite interval that includes one or more discrete transgressive-regressive cycles of marine deposition. A thin shale interval, the Glenwood Shale, is included in the basal part of mapping unit. The Glenwood locally includes thin sandstones in the upper part, and it everywhere overlies the St. Peter Sandstone.

The stratigraphically lowest Ordovician mapping unit recognized for northeast Iowa includes the Prairie du Chien Group and upper Jordan Formation of Lower Ordovician age and the overlying St. Peter Sandstone of Middle Ordovician age. Although a significant erosional unconformity separates the Prairie du Chien from the St. Peter, these strata are included within the same mapping unit for two reasons. 1) Lower St. Peter strata are typically not well exposed, and, although significant erosional relief marks the basal contact (up to 200 feet; 60 m), the contact remains an elusive one to accurately map in the field. The Prairie du Chien and St. Peter share complementary thickness relationships, and a more consistent mapping interval can be defined if the two units are lumped together. 2) The St. Peter forms the upper part of the regionally important Cambro-Ordovician aquifer, which also includes Prairie du Chien strata. The St. Peter Sandstone is a remarkably pure very-fine to medium-grained quartzarenite of Middle Ordovician age. The St. Peter is a widely recognized and lithologically distinctive rock unit throughout much of the central and northern United States.

The Prairie du Chien Group includes two formations, in ascending order, the Oneota and Shakopee (Witzke and McKay, 1987; McKay, 1993). These strata are dominated by sparsely fossiliferous dolomite, variably cherty. Distinctive oolitic cherts are found in both formations. The Oneota is a relatively pure carbonate interval that typically lacks sandy and shaly beds. By contrast, the Shakopee includes a basal sandstone and sandy dolomite interval (New Richmond Member) overlain by variably sandy, cherty, and stromatolitic dolomite with scattered green-gray shale interbeds (Willow River Member). The upper Jordan (Coon Valley Member) is included with this mapping interval 1) because of its lithologic similarity with Prairie du Chien strata (includes sandy to intraclastic dolomite and thin sandstones) and 2) because of the lithologic contrast between upper Jordan dolomitic strata and underlying sandstones of the lower and middle Jordan Formation. In addition, the Coon Valley Member is likely of Lower Ordovician age, whereas much if not all of the underlying Jordan interval is of Upper Cambrian age. Coon Valley

strata were included within the Prairie du Chien Group in some previous stratigraphic reports for the Upper Mississippi Valley area.

Cambrian

Exposures of Cambrian strata in Iowa are restricted to the northeastern-most portion of the map area in Allamakee and northern Clayton counties. Two Cambrian intervals are mapped: 1) an upper interval includes, in ascending order, the Lone Rock, St. Lawrence, and Jordan formations (but not the upper Jordan); and 2) a lower interval includes, in ascending order, the Mt. Simon, Eau Claire, and Wonewoc formations. An overview of the Cambrian exposures of northeast Iowa can be found in McKay (1993), Witzke and McKay (1987), and Schuldt (1943). Exposures of the upper mapping interval are found beneath the resistant ledges of the overlying Prairie du Chien Group along the Mississippi River and its tributaries in Allamakee and northern Clayton counties. The Jordan Sandstone is characterized by friable very fine to coarse grained sandstones, commonly crossbedded. The underlying St. Lawrence Formation is dominated by dolomitic siltstones and silty dolomite containing scattered Dikelocephalus trilobites and other fossils. The Lone Rock Formation is a distinctive greensand interval containing galuconitic siltstones and very fine to fine-grained sandstone, argillaceous in part. Surface exposures of the St. Lawrence and Lone Rock formations are restricted to Allamakee County.

The lowest exposed Cambrian strata in northeast Iowa are assigned to the Wonewoc Formation, Ironton Member. These strata can be seen at the surface only in northeastern Allamakee County, characterized by fine to medium-grained sandstone, some beds containing abundant inarticulate brachiopods. Sub-Ironton Cambrian units form the bedrock surface beneath the Quaternary alluvium in the lower portions of the Upper Iowa River Valley in Allamakee County and the adjacent Mississippi River Valley. These units include strata of the lower Wonewoc (Galesville Member) and Eau Claire Formation. The thick Mt. Simon Sandstone occurs beneath the Eau Claire and above the Precambrian basement, although it is uncertain if the Mississippi Valley incises into this interval.

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