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BEDROCK GEOLOGIC MAP OF NORTH-CENTRAL IOWA

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INTRODUCTION

The new bedrock geologic map of north-central Iowa presented herein is an entirely new compilation which incorporates all available sources of bedrock information for the region. The mapping area encompasses a 12-county block of north-central Iowa, bordered to the north by the Minnesota-Iowa line. This region is primarily a rural agricultural area dotted by numerous small towns and communities. No major metropolitan area is contained within the mapping area -- the largest cities include Mason City, Clear Lake, Webster City, and Charles City. The mapping area incorporates classic bedrock exposures of Devonian rocks of the northern Iowa facies belt, including the type localities of a number of Devonian formations (Lithograph City, Shell Rock, Lime Creek, Sheffield, Aplington formations). Exposures of Mississippian strata in the southern portion of the map area also comprise an important reference area for the Iowa Mississippian stratigraphic succession. The bedrock strata of north-central 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, lithographic engraving stone, clay for brick and tile manufacturing, sand, coal, and other resources. Bedrock aquifers are extensively used for groundwater resources across north-central Iowa, and their importance to the economy of the region cannot be overstated.

North-central Iowa is largely covered by a mantle of Quaternary deposits, although extensive areas of shallow bedrock and bedrock exposure are found along portions of the Cedar and Shell Rock drainages and to a lesser extent along the Iowa River (see inset map of bedrock exposure). These Quaternary sediments are dominated by glacial till (diamicton) with lesser volumes of loess (eastern map areas), sand and gravel, and paleosols. The Quaternary mantle is of varying thickness across the region, reaching thicknesses in excess of 300 feet in buried bedrock valleys across portions of Grundy, Hardin, and Hamilton counties. Outside of the buried bedrock valleys the Quaternary mantle is more typically 75 to 150 feet in thickness across most of the map area. The mantle of Quaternary materials defines two distinctive landform regions across the map area: the eastern half comprises part of the broad "Iowan Surface" whereas the western half forms the eastern part of the "Des Moines Lobe" (Prior, 1991). The relatively subdued landscape of the Iowan Surface, an eroded surface of older Pleistocene (pre-Illinoian) glacial deposits, is dissected by a relatively mature stream and river drainage system which in places has exhumed and exposed the underlying bedrock. The Iowan Surface landform region is largely blanketed by late Pleistocene (Wisconsinan) wind-blown silt deposits known as loess. By contrast, the Des Moines Lobe region primarily displays a landscape of more recent glacial deposits (Wisconsinan) which have buried the older pre-Illinoian glacial materials and bedrock surface. The loess mantle is absent across the Des Moines Lobe, and distinctive glacial landforms, including moraines, are still evident in places. The modern stream drainage network is relatively youthful and poorly integrated across much of the Des Moines Lobe, although some of the larger rivers (the Iowa and Boone) are more deeply incised and locally exhume the bedrock surface in a few places.

Because much of the bedrock surface in the map area is buried by Quaternary sediments, our understanding of the distribution of bedrock geologic units derives primarily from a study of the numerous well records in the region. The topography of the buried bedrock surface has been interpreted from available well penetrations, and a newly constructed bedrock topographic map formed an essential basis for the development of the new geologic map. The bedrock surface across the map area ranges from its lowest elevation (above sea level) of 700 feet in southeastern Grundy County to broad regions above

1200 feet elevation in Worth and Mitchell counties (and smaller portions of Hancock and Cerro Gordo cos.). More detailed geologic mapping is possible in regions of bedrock exposure, where natural exposures (especially stream banks), roadcuts, and quarries afford opportunities for more precise stratigraphic and geographic coverage.

DATA SOURCES AND APPROACHES TO MAPPING

The new geologic map of north-central 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 shown in the detailed county-scale soils maps from 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 north-central 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 north-central 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 several key areas within the Mississippian outcrop belt, especially in Hardin and Franklin counties. Bedrock outcrop information was primarily 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 reflects the comprehensive stratigraphic expertise and extensive field experience acquired during the professional careers of 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. Most of these well logs are publicly accessible at GSB's website (see Geosam records). All existing well logs were examined and systematically re-evaluated for bedrock elevation and stratigraphy as part of the new mapping program. This involved the support of student aides (Univ. Iowa Dept. of Geoscience) working in cooperation with GSB staff. Stratigraphic picks were coded into an expanding stratigraphic database 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 and geology. In addition, a number of bedrock cores from north-central Iowa are reposited at the GSB, and these provided the most reliable sources of subsurface stratigraphic data for the map area. A deep core penetration of Mississippian strata in Hamilton County (Briggs Woods County Park) was, in fact, completed during the latter stages of map preparation (5/2001), affording detailed stratigraphic information for the region. An earlier core-drilling program in Floyd-Mitchell counties (Witzke and Bunker, 1985) provided a necessary framework for the Devonian stratigraphy of northern Iowa.

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 a few 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 3.2) and all are available in an electronic format.

The mapping style reflected on the new bedrock geologic map of north-central Iowa provides a simple way to evaluate the density of data coverage and the confidence of the stratigraphic picks. Areas of bedrock exposure in the drainage networks of the Cedar and Shell Rock/Winnebago rivers are well constrained geologically, and the map is correspondingly the most detailed in those areas. As seen across portions of Mitchell, Floyd, Cerro Gordo, and Franklin counties, the mapped stratigraphic boundaries closely follow existing surface topography, which reflects the detailed stratigraphic control possible in these areas. By contrast, less detailed line work characterizes other regions of the map area, especially in the western half where bedrock exposure is 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 Winnebago, Hancock, Wright, Hamilton, and Grundy 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. Hardin and Butler counties).

COMPARISON WITH PREVIOUS GEOLOGIC MAPS OF NORTH-CENTRAL IOWA

The first bedrock geologic map for 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 north-central Iowa were also published in the Annual Reports of the Iowa Geological Survey between 1896 and 1909 which incorporated all geologic information available at that time. Each of these compilations presented an informative but generalized view of the bedrock geology of north-central 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 north-central Iowa: 1) bedrock topography is not accurately reflected across portions of the map area; and 2) subsequent stratigraphic studies, especially in the Devonian and Mississippian, have established the miscorrelation and mismapping of several geologic units.

More recent stratigraphic syntheses have resulted in a number of significant changes on the new geologic map of north-central Iowa with respect to the Hershey (1969) map. 1) The Cedar Valley

Limestone (Devonian) is shown on the Hershey (1969) map to directly overlie Ordovician strata across the northern map area, with no Wapsipinicon strata between. This map construction is now known to be in error in eastern Floyd and Mitchell counties, and resulted from the miscorrelation of basal Wapsipinicon strata in the northern part of the map area (Spillville Fm.) with Cedar Valley strata to the south. The new map reflects the occurrence of Wapsipinicon strata (Devonian) at the bedrock surface within the northeastern most bedrock valley. 2) The Shell Rock Formation (Devonian) was mapped as a separate unit from the Cedar Valley Limestone on the Hershey (1969) map, but the Shell Rock Formation is now assigned as the uppermost formation of the Cedar Valley Group in northern Iowa. The mapped configuration of the Shell Rock Formation on the Hershey (1969) map reflects westward onlap of upper Shell Rock strata past the lower Shell Rock edge, but lower Shell Rock units are now recognized across Cerro Gordo and Hancock counties (and into central Iowa) requiring modification of the Hershey (1969) map. However, because of considerable difficulties in clearly defining the base of the dolomite-dominated Shell Rock Formation across the northwestern map area, the formation is not included as a separate map unit on the new map compilation. Further stratigraphic study is needed to adequately and independently map all four constituent formations of the Cedar Valley Group across the region.

3) The Lime Creek Formation (Devonian) overlaps the Cedar Valley edge in the northwestern part of the map area. In addition, the constituent formations of the Cedar Valley Group are interpreted to progressively onlap the underlying Ordovician surface to the northwest, and the group thereby thins beneath the Lime Creek Formation in that direction. Therefore, some strata formerly identified as Cedar Valley Limestone on the Hershey (1969) map in portions of Hancock and Winnebago counties are now assigned to the Lime Creek Formation producing a notably different map configuration. 4) New well penetrations and the distribution of recently mapped shale-derived soils units indicate that an elongate body of Lime Creek Formation occurs east of the Shell Rock River in Floyd County not identified on the Hershey (1969) map. 5) The Hershey (1969) map shows northwestward truncation of Famennian strata (Devonian) beneath the Mississippian in Hancock County (originally mapped under the label Yellow Spring Group). This truncation is not recognized on the new map compilation, and Famennian units are now identified across Hancock County (which extend a considerable distance westward into the subsurface of adjoining northwestern Iowa).

6) The Hershey (1969) map shows a general absence of Osagean (Mississippian) strata of the Burlington, Keokuk, and Warsaw formations in the north-central map area, except for a small region along the southernmost fringe of the north-central Iowa map area. These strata are now collectively grouped together within the Augusta Group, which are identified on the new map compilation across a larger region that encompasses parts of Grundy, Hardin, Hamilton, and Wright counties. In addition, more recent biostratigraphic studies have confirmed that a significant portion of the Gilmore City Formation, which was included in the Kinderhookinan Series on the Hershey (1969) map, also should be included in the Osagean Series. The Gilmore City Formation comprises a separate mapping unit on the new geologic map. 7) The mapped distribution of Meramecian strata (Mississippian), primarily the "St. Louis" Formation, is significantly modified from the Hershey (1969) map across Hamilton, Hardin, and Wright counties. These strata overlie a major erosional unconformity developed across units of the Augusta and Gilmore City resulting in the complex sub-"St. Louis" geometry portrayed on the new geologic map.

8) The mapped distribution of Pennsylvanian strata (undifferentiated Cherokee Group) is geographically expanded on the new geologic map in comparison with the Hershey (1969) map. Significantly larger areas of Hamilton and Hardin counties are shown with Pennsylvanian cover, and Pennsylvanian outliers are more numerous in parts of Grundy, Franklin, and Wright counties compared to the Hershey (1969) map. 9) A geographic expansion of Cretaceous strata is evident on the new geologic map. However, the mapped distribution is still considered to have partially underestimated the actual distribution of Cretaceous outliers across the region, as many small outliers have certainly been missed by the random and partial coverage of well penetrations across the map area. The most accurate representation of Cretaceous rock is seen for Floyd County, where the identification of modern soil units

developed on Cretaceous sandstone and shale by the NRCS soils mappers has enabled a more detailed coverage of the actual distribution of Cretaceous strata for that county.

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 were chosen as 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.

The general Paleozoic stratigraphy of the 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 north-central 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 occurrences of Cretaceous strata are mapped in Winnebago, Hancock, Wright, Cerro Gordo, Franklin, Mitchell, Floyd, and Butler counties, locally reaching thicknesses up to 150 feet. These strata have been assigned to the Windrow Formation in the eastern map area (Thwaites and Twenhofel, 1921; Andrews, 1958), but Cretaceous occurrences across the western map area have generally been included within the Dakota Formation on most well logs and published GSB county reports. The lithostratigraphic distinction between the Dakota and Windrow is an artificial one, as both formations represent correlative strata composed of identical lithologies and deposited by the same fluvial systems that drained the region during the mid Cretaceous. It may be desirable to synonymize these stratigraphic terms. The Dakota Formation has historic precedence as a stratigraphic term, and the Windrow was introduced at a later date as a label for scattered Cretaceous outliers in northeast Iowa, southeast Minnesota, and western Wisconsin that are physically separated from the main body of the Dakota Formation. Some of the Cretaceous strata of western Winnebago and Hancock counties are physically connected with the main body of the Dakota Formation, which stretches from adjoining Kossuth County westward to the Missouri River Valley and beyond. All other Cretaceous strata in the north-central Iowa map area represent isolated erosional remnants of what was once a more regionally extensive body of the Dakota Formation.

The Cretaceous strata of the map area comprise a nonmarine fluvial and pedogenic facies succession characterized by a variety of lithologies. Lithologies are commonly dominated by quartzose sandstones with secondary chert/quartz conglomerates, in part cemented by iron oxides. Pale to medium gray mudstones interbed with the sandstones and are locally dominant. Many mudstones show signs of subtropical pedogenesis (red mottling, sphaerosiderite grains). A chert residuum with red-mottled mudstone is locally developed above some Paleozoic carbonate units. The Cretaceous succession overlies a major unconformity surface. The north-central Iowa map area displays Cretaceous strata overlying a number of different Paleozoic units, including Ordovician (Winnebago Co.), Devonian (Winnebago, Hancock, Cerro Gordo, Mitchell, Floyd, Butler cos.), Mississippian (southern Hancock, Wright, Franklin cos.), and Pennsylvanian (Wright Co.) strata. The sub-Cretaceous surface is highly irregular with up to

100 feet of local relief.. Based on studies in adjoining northwest Iowa, the Cretaceous strata of the north-central Iowa map area (Dakota, Windrow fms) are probably of mid-Cretaceous age (late Albian – Cenomanian). Cretaceous fossils have been found at exposures in Floyd County, including petrified gymnosperm wood and petrified *Tempskya* fern wood. The latter occurrence verifies a mid-Cretaceous age (Albian-Cenomanian) for the basal interval in Floyd County.

A remarkably insightful soil survey of Floyd County completed under the leadership of Kermit Voy (Voy, 1995) identified various soils units that are developed on shallow Cretaceous sandstone and mudstone bedrock, especially in the western half of the county. New soils units were introduced for these occurrences in Floyd County representing the Norville, Aureola, and Rocksan series. The mapping of these bedrock-derived soils provides a much more accurate representation of the distribution of Cretaceous bedrock for Floyd County than any other county contained in the map area. The distribution of Cretaceous strata elsewhere across the map area was estimated from a scattering of well penetrations, which collectively cover only a small percentage of the bedrock surface. Due to the irregular and disparate coverage of bedrock wells across the region, the actual distribution of Cretaceous strata is very likely significantly greater than that encountered only by well penetrations. This consideration is amplified for Floyd County, where only two wells are known to penetrate Cretaceous strata, but the county soil survey (Voy, 1995) constrains in excess of 50 Cretaceous outliers (several apparently exceeding 1 to 2 square miles in size) in the same area. The moral here is that other counties in the map area with a low number of Cretaceous well penetrations likewise may have actual Cretaceous bedrock distributions similar to that identified in Floyd County. It therefore seems reasonable to suggest that the mapped distribution of Cretaceous rocks for the map area represents a low estimate, especially for Mitchell, Worth, Cerro Gordo, and Franklin counties.

Pennsylvanian

Pennsylvanian strata are restricted to the southern and southwestern portions of the map area (parts of Wright, Hamilton, Hardin, Franklin, and Grundy counties). Most Pennsylvanian occurrences in this area represent erosional outliers, but the margins of Hardin and Hamilton counties are contiguous with the main body of Pennsylvanian strata which extends from central Iowa into Nebraska and Missouri. The Pennsylvanian succession in the map area reaches maximum thicknesses to 170 feet in Hardin County, but most occurrences are less than 50 feet thick. These strata are assigned to the Cherokee Group based on their geographic continuity with well-known Cherokee Group strata in adjoining areas of central Iowa. The Cherokee Group is of Middle Pennsylvanian (Atokan-Desmoinesian) age. Pennsylvanian strata are dominated by gray shale and/or sandstone at most localities in the map area. Additional minor lithologies include black shale, coal, siltstone, pale gray to red shale, limestone, pyrite, and pebbly sandstone. Pennsylvanian sandstone is well exposed along the Iowa River in Hardin County downstream from Steamboat Rock, but outside of Hardin County Pennsylvanian strata are covered by Quaternary sediments. Well penetrations of Pennsylvanian strata reveal lithologies that may resemble those seen in the Cretaceous, but Pennsylvanian units can usually be distinguished by the abundance of gray shale and the feldspathic content of the sandstones (Cretaceous sandstones are quartzarenites with little or no feldspar).

Cherokee Group strata overlie a major unconformity developed on an eroded surface of Mississippian carbonate rocks in the map area. Pennsylvanian units are noted to variably overlie strata of the Maynes Creek Fm., Gilmore City Fm., Augusta Group, and "St. Louis" Fm., and considerable sub-Pennsylvanian erosional relief is locally evident (50 feet or more). Some of the Pennsylvanian sandstones and shales apparently infill ancient bedrock channel systems that are eroded into the Mississippian carbonates.

Mississippian

The succession of Mississippian strata in north-central Iowa is subdivided into four mapping units, in descending order: 1) "St. Louis" and Pella formations (M_{sp}); 2) Augusta Group (M_a); 3) Gilmore City

Formation (M_g); and 4) Maynes Creek and Prospect Hill formations (M_{mp}). Mississippian strata are exposed in portions of Franklin, Butler, Hardin, and Hamilton counties.

"St. Louis"-Pella Formations. The highest Mississippian strata in the map area belong to a poorly-defined interval that has historically been included within the so-called "St. Louis" and Pella formations of Meramecian age. Although the term "St. Louis" has been widely used in Iowa to label strata above the Augusta Group, these strata show significant lithologic dissimilarities (especially the abundance of sandstone and sandy carbonate) with strata of the type St. Louis Formation in Missouri. In addition, it is now known that the upper part of the so-called "St. Louis" interval in southeast Iowa does not biostratigraphically correlate with the St. Louis Formation, but is probably equivalent to part of the younger Ste. Genevieve Limestone (Witzke et al., 1990). Pending further investigations, the "St. Louis" formation will serve as an informal and provisional label for the purposes of this mapping project, although new stratigraphic terminology is recommended to replace use of the name "St. Louis" in Iowa.

The "St. Louis" of north-central Iowa is characterized by interbedded dolomite (part sandy), sandstone, limestone, and green-gray shale. The interval is brecciated in part, forming a complex admixture of lithologies. The Pella Formation was named for the highest Mississippian interval in southern Iowa, characterized by calcareous shale and limestone; the formation probably correlates with the upper Ste. Genevieve of Missouri (Witzke et al., 1990). Although the exact correlation of the Meramecian succession in north-central Iowa is not known with certainty, it is likely that equivalents of the Pella Formation locally occur above the "St. Louis." Like the "St. Louis," these strata also include shale, carbonate, and sandstone. The Meramecian interval ("St. Louis"-Pella) reaches maximum thickness to 60 feet in the map area (Hamilton Co.). The "St. Louis" overlies a major regional erosional unconformity, and the interval is known to variably overlie units of the Augusta Group and Gilmore City Formation in the map area. A major sub-Pennsylvanian erosional unconformity bevels and locally truncates the Meramecian interval in north-central Iowa.

Augusta Group. A considerable degree of confusion concerning the identity of strata overlying the Gilmore City Formation and below the "St. Louis" interval is evident from previous studies. Many geologists had labeled certain brecciated to "sublithographic" units above fossiliferous Gilmore City limestone strata in northern Iowa as the "St. Louis limestone" (e.g., VanTuyl, 1925), but these units, in fact, represent limestone facies that belong within the Gilmore City Formation (see Woodson, 1989). This miscorrelation led VanTuyl (1925) and others to exclude strata of the Burlington, Keokuk, and Warsaw formations from northern Iowa, although these formations are well known in southeast Iowa. Subsequently, various well logs for north-central Iowa identified other informal units above the Gilmore City, bearing labels of undifferentiated "Burlington-Keokuk" or "Keokuk-Warsaw." Because of the general uncertainty of the actual correlation of these strata, they are grouped here under the broader label "Augusta Group" pending further study.

The Augusta Group is a lithostratigraphic concept that groups strata of the Burlington, Keokuk, and Warsaw formations (see Witzke et al., 1990), all of Osagean age in Iowa. Across most of the map area, the Gilmore City Formation is probably capped by Augusta units that are lithostratigraphically equivalent to the Keokuk Formation of southeast Iowa, but no biostratigraphic data actually confirms this correlation (samples are now being prepared for conodont processing). However, where the Gilmore City Formation thins in southeast Hardin County (and southward), it is probably capped by units that belong to the Burlington Formation. Exposures along the Iowa River in southeast Hardin County and northernmost Marshall County that were examined during this mapping project contain faunas and lithologies that seem most consistent with inclusion in the Burlington Formation (additional study of these are currently underway). Strata included in the Burlington Formation of this area are dominated by cherty dolomite with minor limestone, and much of the interval is glauconitic to varying degrees. Burlington strata in southeast Hardin County reach thicknesses in excess of 50 feet and are overlain by upper Augusta units informally assigned to "Keokuk-Warsaw" interval.

Augusta Group strata elsewhere in the map area (above thick sections of the Gilmore City Fm) are dominated by variably argillaceous dolomite lithologies, but shale and limestone are locally significant. These strata are variably cherty, and chalcedony and quartz crystals (possibly derived from quartz geodes) and commonly seen in well cuttings. Glauconite and phosphatic enrichment ("bone beds") are seen in some beds. Shale units (locally in excess of 10 ft thick) are most common in the upper part of the interval. The Augusta Group reaches maximum thickness to 85 feet in the map area. A major intra-Mississippian erosional unconformity of regional extent was developed above the Augusta Group, and Mississippian strata of the "St. Louis" overlie a beveled and locally truncated Augusta Group in north-central Iowa.

Gilmore City Formation. The Gilmore City comprises a distinctive limestone-dominated formation in north-central Iowa. It is primarily a fragmental limestone interval containing units of denser "sublithographic" and locally brecciated limestone near the middle and at the top of the formation. Fine skeletal and peloidal to coated-grain (part oolitic) packstones dominate, and coarser oncolitic and intraclastic limestones and coarse skeletal packstones are prominent in some intervals. Much stratigraphic confusion arose from the fact that the thick limestone facies of the Gilmore City are laterally replaced by dolomite facies, especially in the lower part of the formation. These laterally equivalent dolomite facies comprise the type succession of the Iowa Falls Dolomite, and the formation is dominated by dolomite facies across large areas of Hardin County. These are fine to medium crystalline dolomites that are seemingly devoid of identifiable fossils and primary sedimentary features. The Gilmore City Limestone succession is subdivided into two members, a lower member (informally called the "Marble Valley Member" by Woodson, 1993) and the upper Humboldt Member. The members are separated above a "sublithographic" unit (peritidal facies) in the middle part of the formation, although this subdivision is difficult to identify in many well logs.

The Gilmore City Formation reaches thicknesses to 170 feet in Hamilton and Wright counties, but it thins to 50 feet or less in southeast Hardin County. Southeastward stratigraphic relations of the Gilmore City Formation are difficult to constrain, but it has been proposed by Witzke and Bunker (1996) that the Gilmore City Formation is equivalent to part or all of the Burlington Formation in southeast Iowa. Recent biostratigraphic studies confirm that most or all of the Gilmore City Formation is of Osagean age (Brenckle and Groves, 1983; Woodson, 1993), not Kinderhookian as previously believed. Only the basal strata of the lower member (which contains the conodont Siphonodella) might be included within the Kinderhookian. Lower Gilmore City strata appear to thin and merge with the basal Burlington Dolbee Creek Member across central Iowa, and this transitional interval is in turn overlain by units of the middle and upper Burlington. The southeastward thinning of the Gilmore City Formation along the southern margin of the map area likely reflects this transitional relationship whereby upper Gilmore City strata are replaced by units of the Burlington Formation in that area. The Gilmore City Formation is overlain by units of the Augusta Group, most likely representing equivalents of the Keokuk Formation across most of the map area but probably including units of the Burlington Formation in southeast Hardin and southwest Grundy counties.

Prospect Hill-Maynes Creek Formations. A thick interval of carbonate rock overlies the Prospect Hill in north-central Iowa, and a confusing array of stratigraphic names has historically been applied to this interval including the Hampton, Chapin, Maynes Creek, Eagle City, and Iowa Falls (VanTuyl, 1925; Laudon, 1931). The Hampton Formation originally incorporated, in ascending order, alternations of limestone and dolomite units termed the Chapin (limestone), Maynes Creek (dolomite), Eagle City (limestone), and Iowa Falls (dolomite) members in stratigraphic position below the Gilmore City Limestone (Laudon, 1931). However, the recognition of complex interfingering limestone-dolomite lithofacies relationships within the succession (Hughes, 1977) posed difficulties with this stratigraphic classification. In addition, the Iowa Falls Member was shown to be a dolomitized lateral facies of limestones of the Gilmore City Formation (Thomas, 1960; Woodson, 1989), thereby obviating the stratigraphic distinction between the upper Hampton and Gilmore City formations. As such, the Hampton

Formation has been dropped as a stratigraphic label, and the stratigraphic interval between the Prospect Hill Siltstone and the Gilmore City Formation is now largely included within an expanded Maynes Creek Formation (Woodson, 1989). Harris (1947) noted that the term Hampton was preoccupied and had earlier suggested abandonment of the name, as followed here.

The Maynes Creek was originally used as a stratigraphic term in north-central Iowa for an interval of cherty dolomite about 50 feet thick above the basal Mississippian units (Prospect Hill, Chapin) and below the limestones of the Eagle City (VanTuyl, 1925; Laudon, 1931; Thomas, 1960). However, Burggraf (1981) found that the type section of the Maynes Creek (in Franklin Co.), in fact, occupies a much higher stratigraphic position (probably equivalent to the Eagle City). This discovery further underscores the desirability of expanding the original concept of the Maynes Creek to incorporate the Mississippian succession up to the base of the Iowa Falls-Gilmore City interval (as defined by Woodson, 1989). As presently used, the Maynes Creek Formation of north-central Iowa is a dolomite-dominated interval reaching thicknesses to 155 feet. It comprises the most productive part of the Mississippian aquifer in the region.

The Maynes Creek Formation is subdivided into two units of subequal thickness: 1) a lower very cherty dolomite, and 2) an upper dolomite with variable chert content. The lower interval locally overlies a thin non-cherty carbonate interval (0 to 15 feet thick), variably dolomite or limestone (skeletal to oolitic), that has been termed the Chapin beds or formation, named after a locality in Franklin County (VanTuyl, 1925). Because of its thin and discontinuous character, it is recommended that the Chapin be relegated to member status within the larger Maynes Creek Formation. The upper part of the lower interval of the Maynes Creek is locally developed as a limestone facies (skeletal to oolitic) or fossiliferous to oolitic dolomite, and this unit apparently encompasses the type locality of the Eagle City beds (Hardin Co.). The upper interval of the Maynes Creek is dominated by dolomite, but unlike the consistently cherty lower interval, the upper interval shows highly variable chert content across the region. The highest part of the upper interval is characterized by a relatively thin limestone unit (8 to 25 ft thick), dense and “sublithographic” and locally stromatolitic. This limestone unit is used to mark the top of the Maynes Creek Formation across the region (Woodson, 1989). It forms the lowest exposed beds at Iowa Falls (Hardin Co.), which previously were assigned to the Eagle City beds by VanTuyl (1925) and Laudon (1931) (this is probably not equivalent to the type Eagle City interval). The Prospect Hill-Maynes Creek succession is entirely of Kinderhookian age. The Maynes Creek Formation is disconformably overlain by the Gilmore City Formation in the region. The Maynes Creek overlies the basal Mississippian Prospect Hill Siltstone, and the contact is slightly irregular suggesting disconformable relations (e.g., Briggs Woods core in Hamilton Co.).

The base of the Prospect Hill Formation marks the base of the Mississippian System in the map area, where it unconformably overlies Upper Devonian Famennian strata. The Prospect Hill is dominantly a siltstone, dolomitic in part, and in places containing minor shale. It is a relatively thin interval, generally only 5 to 10 feet in thickness (locally to 30 ft in Franklin Co.; as thin as 3 ft in Hamilton Co.). This Mississippian siltstone interval was informally assigned to the “English River Siltstone” in northern Iowa by Anderson (1966), but that stratigraphic name is now restricted to the uppermost part of the Devonian succession in southeast Iowa. Local stratigraphic confusion may arise in parts of Franklin, eastern Hardin, and western Grundy counties where two siltstone units are locally present (Woodson, 1989, p. 4), separated by dolomite strata. However, the stratigraphic position of these units remain uncertain, and it is possible that the lower siltstone could belong in the Devonian.

Devonian

The Devonian stratigraphic successsion in north-central Iowa is subdivided into four mapping units, in descending order: 1) a grouping of Famennian shale and carbonate units (D_f); 2) Lime Creek Formation (D_l); 3) Cedar Valley Group (D_c); and 4) Wapsipinicon Group (D_w). The map area includes the type sections of many Devonian stratigraphic units and the region comprises a classic reference area for Devonian cratonic sedimentation. Devonian strata are well exposed in parts of Mitchell, Floyd, Worth, Cerro Gordo, Butler, and Franklin counties.

Famennian Interval. An interval of shale and dolomite of Famennian age (Upper Devonian) occupies a position above the Lime Creek Formation and below the basal Mississippian unconformity in north-central Iowa. This interval includes strata commonly labeled as Sheffield Shale, Aplington Dolomite, and "Maple Mill" Shale, each usually accorded formational status. The type sections of the Sheffield and Aplington are found within the map area in Franklin and Butler counties, but the term "Maple Mill" derives from southeast Iowa. These names have commonly been used to define a stratigraphic succession in northern Iowa (e.g., Anderson, 1966), in ascending order: Sheffield (shale), Aplington (dolomite), and Maple Mill (shale). Unfortunately, this succession is not seen in some well sections in northern Iowa, and different lithologic sequences are locally observed within this interval (e.g., shale-dolomite; shale-dolomite-shale-dolomite-shale; dolomite-shale; or all shale). If a carbonate unit (Aplington Fm) does not occupy the middle position in the Famennian succession, the bounding shale units cannot be consistently constrained (that is, the Sheffield and "Maple Mill" as lithostratigraphic units cannot be defined without respect to their positions above or below the Aplington). Because of these stratigraphic variations, it seems more likely that the three Famennian "formations" of northern Iowa may not represent discrete and regionally correlatable formational units, and they are considered to collectively comprise part of a larger shale-dominated grouping that contains one or more tongues of carbonate. The carbonate facies within this interval disappear southeast of the map area, and the Famennian interval across southern Iowa entirely lacks Aplington-style carbonate facies. Anderson (1966, p. 401) suspected that "the entire sequence of 'Maple Mill,' Aplington, and Sheffield [in north-central Iowa] may actually correspond to the complete Maple Mill Shale of southeastern Iowa" (which lacks carbonate facies). Metzger (1988) applied an informal label, "Sheffield-Maple Mill undifferentiated," to this interval in northern Iowa.

The grouping of Famennian strata in northern Iowa correlates with a portion of the "Sheffield- Maple Mill" succession (also termed "Yellow Spring Group") of southeast Iowa (see conodont biostratigraphy of Pavlicek, 1986; Metzger, 1988). The type Sheffield Shale contains conodonts indicating a lower Famennian age (Anderson, 1966), but basal Famennian strata elsewhere in central Iowa and eastern Nebraska are younger (approximately mid Famennian; see Pavlicek, 1986; Metzger, 1988). In general, where the Famennian interval is thin (<50 to 70 ft), stratigraphic units correlative with the type Sheffield likely are absent. This suggests that the Sheffield Shale may be absent in the western part of the map area (where the Famennian interval is as thin as 40 ft). The shale interval above the Aplington Dolomite in northern Iowa has been informally termed the "Maple Mill" Shale (e.g., Anderson, 1966). The Maple Mill as a stratigraphic term has been applied to different lithostratigraphic intervals by different workers, and its application in northern Iowa to the uppermost shale interval (0 to 45 ft thick) seems tenuous.

While full resolution of the stratigraphic nomenclature for the Famennian interval in northern Iowa is not yet clear, one possible stratigraphic solution would be to classify the interval as a formation, although the name to apply to this formation is not immediately clear. The term "Maple Mill" could conceivably incorporate the entire Famennian interval. This Famennian formation could be subdivided in turn into three members corresponding to a lower shale ("Sheffield member"), intertongues of dolomite in the lower to middle part of the formation ("Aplington member"), and an upper shale (an unnamed interval equivalent to part of the "Maple Mill-English River" interval in southeast Iowa).

The Famennian interval in the map area varies from a maximum thickness of 150 feet in southeast Hardin County to as thin as 40 feet in parts of Wright County. The lower shale member (Sheffield) is dominated by green-gray shale, silty and dolomitic in part; it thickens southeastward in the map area (reaching thicknesses to 80 ft). The middle dolomite member (Aplington) is dominated by argillaceous dolomite (minor dolomitic limestone) containing scattered chert nodules, chalcedony, and silicified fossils. The Aplington carbonates include some fossiliferous wackestones to packstones (with crinoid debris and brachiopods). Aplington carbonate facies intergrade with shaley dolomites and shales, and these carbonate strata apparently intertongue with units of the lower and upper shale members. Dolomite units reach maximum thicknesses to 50 feet (usually 25 ft or less). The upper shale member is dominated by green-gray dolomitic shale, and the interval is silty to varying degrees (including minor siltstone). A thin but distinctive unit of oolitic ironstone (1-2 mm limonite pellets) is identified in the upper shale, and this unit is widely traceable across much of Iowa. An erosional unconformity caps the Famennian interval, and the upper shale member may be locally truncated. The Famennian interval unconformably overlies the Lime Creek Formation.

Lime Creek Formation. The Lime Creek Formation is a distinctive interval of Upper Devonian (upper Frasnian) shale and carbonate strata in north-central Iowa. The formation is exposed in portions of Butler, Floyd, Cerro Gordo, Hancock, and Franklin counties. The Lime Creek Formation derives its name from typical exposures along the Winnebago River (formerly known as Lime Creek) in eastern Cerro Gordo County. The formation is subdivided into three members, in ascending order: Juniper Hill Shale (type locality in western Floyd Co.), Cerro Gordo Member (named for exposures in Cerro Gordo Co.), and Owen Member (type sections along Owen Creek, Cerro Gordo Co.). In general, the Lime Creek Formation displays a general upward decrease in shale content and a concomitant increase in carbonate content: the lower Juniper Hill Member is dominantly a green-gray calcareous shale, the Cerro Gordo Member is an argillaceous fossiliferous limestone with interbedded shale, and the upper Owen Member is dominantly a carbonate interval (limestone, dolomite).

Across the map area, the entire Lime Creek Formation displays a westward increase in overall carbonate content, and the basal shale interval significantly thins in that direction (indicating a regional facies transition between the Juniper Hill and Cerro Gordo members). In addition, carbonate lithologies show a general westward increase in dolomite content (Koch, 1963), whereas limestone is characteristic to the east. The formation is primarily a dolomite-dominated interval in the western map area and across northwestern Iowa. The Lime Creek Formation in the map area is world-renowned for its remarkable fossil fauna, especially the abundance of brachiopods in the Cerro Gordo Member. The Owen Member includes skeletal, peloidal, and oolitic limestones; stromatoporoids are locally abundant in the lower part, and coral-rich facies occur in the upper Owen.

The Lime Creek Formation disconformably overlies the upper Cedar Valley Group over most of the map area, and it is disconformably overlain by Famennian strata. The formation marks a general transgressive-regressive depositional cycle (Witzke and Bunker, 1996) that onlaps westward past the Cedar Valley edge in the northwestern part of the map area. Beginning in western Winnebago County and continuing across much of northwestern Iowa, the Lime Creek Formation unconformably overlies the Ordovician Maquoketa Formation. The Lime Creek Formation varies in thickness only slightly across north-central Iowa (about 130 to 160 feet).

Cedar Valley Group. The interval historically known as the Cedar Valley Limestone was elevated to group status by Witzke et al. (1988), who subdivided it into four constituent formations, in ascending order: 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. Each formation of the Cedar Valley Group is marked by marine transgression in the lower part (primarily fossiliferous dolomite) capped by an upward-shallowing succession of restricted-marine and peritidal mudflat facies (sublithographic limestones and unfossiliferous dolomite/limestone). Each formation is bounded by subaerial exposure surfaces. Two of these formations, the Lithograph City and Shell Rock, are named after localities in the north-central Iowa map area. The name Cedar Valley Limestone derives from exposures along the Cedar River in northern Iowa, including Floyd and Mitchell counties. Cedar Valley strata are exposed in the map area in parts of Worth, Cerro Gordo, Butler, Mitchell, and Floyd counties. The Cedar Valley Group reaches thickness to 350 feet in this area.

The Little Cedar Formation, the lowest formation of the Cedar Valley Group, has limited exposure in the map area in eastern Floyd and Mitchell counties. It is commonly about 100-110 feet thick. The formation is dominated by a thick lower dolomite interval (Bassett Member), a discontinuous shale (Chickasaw Shale in eastern map area), and an upper "sublithographic limestone" to laminated dolomite interval (Hinkle Member). The Little Cedar Formation overlies the Wapsipinicon Group in the eastern part of the map area, but it oversteps the Wapsipinicon edge westward in the map area (west of central Cerro Gordo County) to unconformably overlie the Ordovician Maquoketa Formation. The Little Cedar Formation is of Middle Devonian (upper Givetian) age.

The Coralville Formation is well exposed in the map area in portions of Floyd, Mitchell, and Butler counties. It commonly ranges between about 50-75 feet in thickness. The formation includes a lower fossiliferous dolomite unit (the Gizzard Creek Member, named after a locality in Floyd Co.) and an upper interval of “sublithographic” limestone, laminated dolomite, breccia, and minor shale (Iowa City Member). The Coralville Formation is of Middle Devonian (upper Givetian) age.

The Lithograph City Formation was introduced as a distinct formation in northern Iowa by Bunker et al. (1986), named after the limestone quarries at the now-defunct town of Lithograph City, Floyd County (Bunker, 1995). These strata were previously labeled as “Coralville member,” but they do not correlate with any portion of the type Coralville succession in eastern Iowa (Witzke et al., 1988). The formation is well exposed in parts of Floyd, Mitchell, Butler, Worth, and Cerro Gordo counties, where it ranges between about 80-110 feet in thickness. It includes a lower fossiliferous dolomite unit (Osage Springs Member, type section in Mitchell Co.) and an upper interval of interbedded lithographic and “sublithographic” limestone, laminated to intraclastic limestone and dolomite, fossiliferous limestone and dolomite (with locally common stromatoporoids), and thin shale (Idlewild Member, type section in Floyd Co.). The Lithograph City Formation straddles the Middle-Upper Devonian boundary, and includes strata of upper Givetian and lower Frasnian age.

The Shell Rock Formation forms the upper portion of the Cedar Valley Group in the map area, where it ranges between about 55-80 feet in thickness. This interval was excluded from the Cedar Valley Limestone in its original definition (Belanski, 1927), but, because of clear lithostratigraphic similarities with underlying carbonate units, Witzke et al. (1988) included the Shell Rock within the Cedar Valley Group. Calvin (1897) had originally included Shell Rock strata within the Cedar Valley succession. Belanski (1927) and Koch (1970) documented the formation in its outcrop belt of northern Iowa (Floyd, Cerro Gordo, and Worth counties), and they subdivided it into three members, in ascending order, Mason City, Rock Grove, and Nora (named after localities in the map area). Although Koch (1970) interpreted a broad overstepping of upper Shell Rock strata (Nora Member) across Cerro Gordo and Worth counties, Belanski (1927) and Witzke et al. (1988) recognized the continuity of Shell Rock units across northern and central Iowa. In general, the Shell Rock Formation in Floyd County is characterized by skeletal and biostromal (stromatoporoid-rich) limestone units (Mason City, Nora members) that are separated by a sparsely fossiliferous argillaceous dolomite and dolomitic limestone interval (Rock Grove Member). Westward in the outcrop belt of Cerro Gordo County, the formation becomes more dolomitic and incorporates additional biostromal units and peritidal facies (including “sublithographic” limestone) not seen to the east; the Rock Grove Member largely loses its lithologic identity westward in north-central Iowa (Witzke et al., 1988; Witzke, 1998). The Shell Rock Formation is of Upper Devonian age (lower Frasnian).

Although the full thickness of the Cedar Valley Group is over 300 feet across most of the map area, it thins beneath the overlying Lime Creek Formation across western Hancock and Winnebago counties (0-200 feet thick). The stratigraphic relations of Cedar Valley strata in Hancock and Winnebago counties are not well understood, but progressive northwestward overstepping of the four constituent formations has been proposed (Witzke et al., 1988).

Wapsipinicon Group. The Wapsipinicon Group is not exposed anywhere in the map area, but these strata form the bedrock surface within a bedrock channel that transects a small area of eastern Floyd and eastern Mitchell counties. The Wapsipinicon edge is overstepped by strata of the Cedar Valley Group westward from central Cerro Gordo County, and, hence, the Wapsipinicon Group is absent across a large portion of the map area. The Wapsipinicon Group is comprised of two formations in the map area: a lower Spillville Formation (dominated by fossiliferous dolomite) and an upper Pinicon Ridge Formation (Witzke et al., 1988). The Pinicon Ridge includes a lower Kenwood Member (argillaceous to shaley dolomite, minor chert/chalcedony and sandstone) an upper combined interval of the Spring Grove-

Davenport members (laminated dolomite, sublithographic limestone, and breccia). The Wapsipinicon Group reaches maximum thicknesses to about 130 feet in the eastern map area. It unconformably overlies the Ordovician Maquoketa Formation across much of the map area (including Floyd and Mitchell counties), but it unconformably overlies Silurian strata in parts of Grundy and Butler counties (where Wapsipinicon and Silurian strata are buried beneath younger Devonian units). The Wapsipinicon Group is of Middle Devonian age (upper Eifelian-lower Givetian).

Ordovician

Ordovician strata are not actually exposed in north-central Iowa, but they form the bedrock surface (beneath the Quaternary cover) in part of Winnebago County. Two stratigraphic intervals are mapped in this area: the Maquoketa Formation and the Galena Group.

Maquoketa Formation. The Maquoketa Formation is an Upper Ordovician (Richmondian) interval dominated by carbonate strata in the map area. It is dominated by cherty dolomite with lesser amounts of fossiliferous limestone and minor shale. The Maquoketa Formation is erosionally beveled beneath Devonian units across most of the map area, and only the lower part of the formation (Elgin Member) is present in Winnebago County (maximum thickness to 95 feet). The Maquoketa Formation conformably overlies the Galena Group in north-central Iowa.

Galena Group. The Galena Group is an Upper Ordovician (Chatfieldian-Maysvillian) carbonate-dominated interval in northern Iowa that is subdivided into four constituent formations, in ascending order: 1) Decorah (shale, limestone); 2) Dunleith (variably cherty limestone/dolomite); 3) Wise Lake (relatively pure limestone/dolomite); 4) Dubuque (limestone/dolomite, minor shale interbeds). Only upper Galena units are represented at the bedrock surface in Winnebago County, but the full thickness of the Galena Group is approximately 285 feet in the county.

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