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BEDROCK GEOLOGIC MAP OF SOUTH-CENTRAL IOWA

(produced with assistance from U.S.G.S. STATEMAP Cooperative Agreement 010-HQAG-0091)

by
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July 2002

INTRODUCTION

The new bedrock geologic map of south-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 17-county block of south-central Iowa, bordered to the south by the Missouri-Iowa line (see inset of map area). This region is primarily a rural agricultural area dotted by numerous towns and communities. The Des Moines metropolitan area (Polk Co.) forms the largest urbanized region in the map area. The mapping area incorporates classic bedrock exposures of Pennsylvanian rocks in the northern Midcontinent region, and it includes the type localities of a number of Pennsylvanian formations and members (see Ravn et al., 1984; Heckel and Pope, 1992; Pope and Emerman, 2000). Exposures of Mississippian strata are mostly found in the eastern portion of the map area (Monroe and Marion counties). The bedrock strata of south-central Iowa have yielded a number of natural resources of great economic importance to the region, both historic and recent. Coal mining played a major role in the economic development of the region, and huge quantities of coal were mined in the area from both underground and surface (strip) mines. However, at present no operating coal mines exist in the state. Additional bedrock resources include aggregate material (primarily limestone), building stone, clay for brick and tile manufacturing, sand and gravel, and other resources. Bedrock aquifers (especially Mississippian) are used for groundwater sources in portions of south-central Iowa, and their importance to the economy of the region is significant.

South-central Iowa is largely covered by a mantle of Quaternary deposits of various thickness, although extensive areas of shallow bedrock and bedrock exposure are also found in the map area, especially in Marion, Madison, Guthrie, Warren, and Monroe counties (see inset map of bedrock exposure). Elsewhere in the map area, bedrock exposure is more limited, generally to a few stream or river valleys in each county. Quaternary deposits in south-central Iowa are dominated by glacial till (diamicton) with lesser volumes of loess (across the Southern Iowa Drift Plain), sand and gravel, and paleosols. The Quaternary mantle, of various thickness across the region, reaches thicknesses of about 300 feet in deeply buried bedrock valleys, primarily in Ringgold, Decatur, Clarke, and Wayne counties.

The mantle of Quaternary materials defines two distinctive landform regions across the map area: most of the region is within the “Southern Iowa Drift Plain” whereas the northern counties are in the southern part of the “Des Moines Lobe” (Prior, 1991). The rolling and dissected landscape of the Southern Iowa Drift Plain, an eroded landscape of older Pleistocene (pre-Illinoian) glacial deposits, is mantled by a cover of Wisconsinan loess. A relatively mature stream and river drainage system is developed, which in places has exhumed and exposed the underlying bedrock. By contrast, 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 Raccoon and Des Moines) are more deeply incised and locally exhume the bedrock surface.

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 less than 600 feet in eastern Appanoose County to regions above 1200 feet elevation in areas of Guthrie and Adair counties. 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 south-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 of bedrock exposure including all previous as well as recent investigations); 2) extensive subsurface well records archived at the Iowa Geological Survey (IGS); 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 south-central Iowa. Published and unpublished sources archived at the IGSB provided the primary basis for identifying bedrock strata across much of the region. Stratigraphic information for virtually all bedrock exposure areas in south-central Iowa is available in archived files and field notes. These include descriptions of natural exposures, roadcuts, and quarries. The unpublished field notes of L.M. Cline and D.G. Stookey, who described hundreds of exposures in the map area during the 1920s and 1930s, were particularly valuable as sources of outcrop information for our map compilation. Additional outcrop information for the region is recorded in unpublished theses by Heuer (1948), Stark (1973), and Blair (1978). The highway construction materials report for southwest Iowa by Hershey et al. (1960) provided additional information. Much valuable bedrock geologic information for the region is also archived at the Iowa Department of Transportation (IDOT), Office of Geological Materials, and we are grateful for the helpful assistance of Brian Gossman, Adriana Reyes-Phelps, and Neal Tieck at the IDOT for making this information available.

Extensive field studies were undertaken as part of the current mapping program across the Pennsylvanian outcrop belt of south-central Iowa, especially by the senior author of the new bedrock map (J. Pope). Both limestones and shales (in the Pennsylvanian) were processed for conodonts, as most major marine cyclothems have a distinctive suite of conodont species that can be used to identify and correlate isolated outcrops. Bedrock outcrop information was variably compiled at a 1:100,000 scale on the various county topographic maps and on 1:24,000 7 ½ minute topographic quadrangle maps (U.S. Geological Survey) where possible. 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 several geologists, including those who preceded us as well as the current staff who actually prepared the new map. The high level of knowledge of Iowa stratigraphy represented by the authors of this new map could not be duplicated in any other group or institution, and it was most sensible that it was IGSB 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 IGSB. 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 accessible to the public at the IGS'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. of Iowa Dept. of Geoscience) working in cooperation with IGSB staff. Stratigraphic picks were coded into an expanding stratigraphic database to facilitate mapping and promote further accessibility of IGSB data in an electronic medium. Various driller's 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 south-central Iowa are reposited at the IGSB, and these provided the most reliable sources of subsurface stratigraphic data for the map area. These cores were derived from two major drilling programs in south-central Iowa, one sponsored by the U.S. Geological Survey in the 1960s and the other drilled by Iowa Geological Survey's Coal Project during the 1970s (see Ravn et al., 1984).

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 3.2), and all are available in an electronic format.

The mapping style reflected on the new bedrock geologic map of south-central Iowa provides a simple way to evaluate the density of data coverage and the confidence of the stratigraphic picks. Areas of bedrock exposure are well constrained geologically, and the map is correspondingly the most detailed in those areas. As seen across portions of Madison, Guthrie, Warren, Marion, and Monroe 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 southwestern area 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 Adair, Greene, Ringgold, Union, Wayne, and Clarke 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.

COMPARISON WITH PREVIOUS GEOLOGIC MAPS OF SOUTH-CENTRAL IOWA

The first bedrock geologic map for Iowa, albeit highly generalized, was published by Owen in 1852, 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 south-central Iowa were also published in the Annual Reports of the Iowa Geological Survey between 1896 and 1927 which incorporated all geologic information available at that time. Each of these compilations presented an informative but generalized view of the bedrock geology of south-central Iowa. However, stratigraphic refinements and new data accumulated since that time have made most of these early maps of limited value outside of their historical interest.

The 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 represents the most recent effort to present the bedrock geology of the entire state (1:500,000 scale). However, subsequent work has identified several significant mapping issues with the Hershey (1969) map in need of improvement for south-central Iowa: 1) Bedrock topography was not accurately reflected across large portions of the map area. 2) Subsequent studies using conodont biostratigraphy, especially in the Pennsylvanian Subsystem, have established the miscorrelation and mismapping of several geologic units. 3) Subsequent group-level reclassification of Missourian stratigraphy has necessitated a re-evaluation of mapping units. In particular, the thin Pleasanton interval is no longer given group status in Iowa (Ravn et al., 1984), and is not considered to be a practical bedrock mapping unit (shown as a thin pencil-line-width mapping unit on the Hershey map). Instead, the Pleasanton is mapped as the basal formation of the Bronson Group. 4) Long-standing stratigraphic miscorrelation of Pennsylvanian units along the Middle River in Adair and Madison counties promulgated major mapping errors. 5) The Thurman-Redfield Fault Zone, a re-activated Keweenawan (Proterozoic) fault that shows recurring movements through the Paleozoic, was not accommodated on the Hershey (1969) map, but significant displacements (in excess of 200 ft; 60 m) of Pennsylvanian strata are documented along the fault in the map area. The new bedrock geologic map of south-central Iowa presented herein represents an entirely new compilation that shows significant contrasts with the Hershey (1969) map, as summarized below.

1) Cretaceous strata (Dakota Fm) occupy much larger areas of Greene and Adair counties than shown on the Hershey (1969) map. 2) The detailed Cretaceous edge in Guthrie County reflects the presence of Pennsylvanian Cherokee Group bedrock extending much farther northwestward in the valley bottoms than displayed on the Hershey (1969) map. 3) Shawnee Group strata occupy a much smaller area of Adair County, and no Shawnee strata are shown to occupy the region along the Middle River (See 'Middle River Traverse' below). No Shawnee strata are shown in Madison County. 4) Douglas Group strata are shown to occupy larger areas of Ringgold and Adair counties. 5) Strata of the Kansas City Group are absent in Warren County. 6) The extent of lower Bronson Group strata (Pleasanton Fm) is greatly reduced in Wayne County, and no Bronson strata are recognized in Lucas County. 7) A greater extent of Marmaton Group strata is mapped in Monroe County. 8) Marmaton strata are identified within a northeast-trending syncline parallel to the Thurman-Redfield Fault Zone in southern Boone County. 9) Less Marmaton strata are recognized in Lucas and Warren counties. 10) A number of outliers of the Chariton Conglomerate, which is here provisionally included within the Marmaton Group, are identified in Lucas and Marion counties. 11) Mississippian strata are mapped within buried bedrock valleys in northern Polk County. 12) The map construction accommodates the Thurman-Redfield Fault Zone across Adair and Dallas counties (See Thurman-Redfield Fault Zone below).

'Middle River Traverse'

A stratigraphic survey of southwestern Iowa made by Tilton in 1919 was followed by the 'Middle River Traverse', conducted by Condra and Upp in 1933. Outcrops from the west-central part of Madison County and Adair County along the 'Middle River Traverse' were originally correlated as strata in the Kansas City to Deer Creek formations (Tilton, 1919/1920). Tilton also had the upper limestone member of the Pawnee occurring in sec. 21, T. 77 N., R. 31 W., Adair County. Condra and Upp (1933) recorrelated these outcrops and assigned them to the Oread, Kanwaka Shale, Lecompton, Tecumsah Shale, and Deer Creek formations of the Virgilian Stage. Both correlations were based on the macrofauna, including the fusulinid foraminifer *Triticites*, the brachiopod *Marginifera lasallensis* (misidentified by Tilton as the Desmoinesian species *Marginifera muricata*), other brachiopods, and the stratigraphic position of the beds. Condra and Upp (1933) were relatively confident of their new correlations although problems with certain fossils are mentioned, and to accommodate their new interpretations they had to have many key beds pinch out to the southwest of the traverse. These new miscorrelation were perpetuated by Hershey et al., 1960. Although Welp, Thomas, and Dixon (1957) properly recorrelated (Ervine Creek Limestone became Bethany Falls Limestone) the Howe Quarry in the NW sec.1, T. 76 N., R.30 W., Hershey (1960) did not accept it. However, subsequent conodont studies (von Bitter and Heckel, 1978; Heckel and Pope, 1992) have shown that this interval along the 'Middle River Traverse' should now be assigned to the Bronson, Kansas City, and Lansing groups of the Missourian Stage, and the lower part of the Douglas Group of the Virgilian Stage. The previous miscorrelations were the result of using difficult-to-identify fossils, and species that did not have very short stratigraphic ranges.

Thurman-Redfield Fault Zone

Even though Tilton (1919/1920) had miscorrelated the 'Middle River Traverse' he did recognize a fault in sec. 18, T. 76 N., R. 30 W., that he called the Thurman-Wilson fault. In his cross-sections he shows it as a high angle normal fault with the upthrown block to the northwest. Tilton's placement of the fault is surprisingly close to where we have placed a fault on the new geologic map.

Although Condra and Upp (1933) did not find any proof that Tilton's (1919/1920) Thurman-Wilson fault crossed the 'Middle River Traverse' in Sec. 18, T. 76 N., R.30W., or even existed, recorrelation of the Missourian and Virgilian Stages in Madison and Adair counties on the new map, now reflects the presence of a major fault. This fault, now named the Thurman-Redfield Fault Zone, extends from southwestern Adair County to the southwest corner of Dallas County northeastward to near the northeast corner of Dallas County in the south-central Iowa map area.

The Thurman-Redfield Fault Zone is associated with the Midcontinent Rift System that extends from northeast Kansas thru Iowa, Minnesota, Wisconsin, to Michigan (Anderson, 1992). The Iowa segment of the rift extends from northeastern Nebraska to southern Minnesota and is separated from segments to the north and south by transform faults. The Midcontinent Rift System is characterized by a central horst, called the Iowa Horst, in the Iowa segment of the rift system. The Iowa Horst is dominated by Keweenawan mafic volcanic and plutonic rocks (reaching thicknesses of up to 30,000 feet – 9,200 m) and is locally capped by Keweenawan clastic rocks in several discrete basins. The horst is separated from flanking clastic-filled basins by high-angle reverse faults with total modeled displacements in excess of 30,000 feet (9,200 m), with most movement occurring in the Precambrian. The Thurman-Redfield Fault Zone is the eastern bounding fault of the Iowa Horst; the Northern Boundary Fault Zone (not present in the mapping area) is the western bounding fault.

Southeast of the town of Howe in section 12, T. 76 N., R. 31 W., Adair County, the Thurman-Redfield Fault Zone displays about 200 ft. (60 m) of displacement, with the upthrown block on the northwest side. Six miles to the southeast of Howe near the Adair-Madison county line, on the downthrown block, beds dip apparently to the northwest toward the town of Arbor Hill at an average dip of 14 ft. (4 m) per mile. From

Arbor Hill to Howe the beds dip apparently southeast at an average dip of 15 ft. (4.6 m) per mile. Northwest of Howe on the upthrown block beds dip apparently to the northwest for about four to five miles at an average dip of 17 ft. (5 m) per mile. In NW sec. 17, T. 77 N., R. 31 W., beds dip apparently to the southeast at at least 52 ft. (16 m) per mile and dips could approach 90 ft. (27 m) per mile. The axes of both synclines run sub-parallel to the fault zone and can be traced northeastward into southeastern Guthrie and southwestern Dallas counties. The amplitude of the syncline on the downthrown block is smaller than that of the syncline on the upthrown block.

North of Redfield on the central horst is the Redfield Dome with about 250 ft. (76 m) of closure at the top of the Ordovician St. Peter Sandstone. Evidence of this structure can be seen in the exposures of the Redfield clay pit where the lower beds (lower Middle Pennsylvanain) dip to the southeast at up to 18 degrees. The upper beds, consisting of the upper Floris and lower Swede Hollow formations, overlie the lower southeast dipping beds with an angular unconformity and an apparent dip of about 2 degrees to the north.

Another syncline on the central horst can be seen northeast of the Redfield Dome. It extends into Boone County southwest and west of the town of Madrid. Here the lower Marmaton Group below the Myrick Station Limestone (lower Pawnee) is preserved in a long narrow doubly-plunging syncline trending southwest-northeast, sub-parallel to the Thurman-Redfield Fault Zone.

At the bedrock surface the Thurman-Redfield Fault Zone runs sub-parallel to where the seismic expression of the fault has been mapped in the Ordovician, but the bedrock surface expression is about a mile to the southeast. In southwestern Dallas County there is about 210 ft. (64 m) of displacement on the fault, but the fault apparently shows little surface expression in Cherokee bedrock exposures along the Des Moines River Valley, in northeastern Dallas County where there is apparently less than 20 ft. (6 m) of throw.

Another small fault is newly mapped, southwest and west of the town of Redfield in Dallas County. The fault is on the central horst with the downthrown block to the west. There is apparently about 50-60 ft. (15-18 m) of throw on this fault.

SUMMARY OF BEDROCK STRATIGRAPHY AND MAPPING UNITS

Cretaceous

Cretaceous strata are mapped in Greene, Guthrie, and Adair counties along the western border of the map area. These deposits are all included within the Nishnabotna Member of the Dakota Formation. The Nishnabotna Member (Munter et al., 1983; Witzke and Ludvigson, 1994) is the lower of two members of the Dakota Formation in Iowa, and principally consists of up to 46 m (150 ft) of fine- to coarse-grained sandstone and conglomerate in the map area. This unit has an overall sand sheet geometry that extends from western Iowa into eastern Nebraska (Brenner et al., 2000). The erosional edge of this lower portion of the Dakota Formation occurs in Greene, Guthrie, and Adair counties, where remnants of the unit are preserved along a regional north-south trending bedrock ridge along the western border of the map area.

The Cretaceous units in the map area consist of nonmarine fluvial and pedogenic facies associations characterized by a variety of bedrock lithologies. Lithologies are dominated by quartzose sandstones with secondary chert/quartz conglomerates. Because of their mineralogic maturity, sandstones in the Dakota Formation were readily discriminated from more feldspathic overlying Quaternary sands and underlying Pennsylvanian sandstones in a large number of borehole geophysical natural gamma logs from hydrocarbon exploration wells in Guthrie and Greene counties that are archived by the Iowa Geological Survey. These closely-spaced wells, in addition to long-term field studies (Witzke and Ludvigson, 1982, 1994, 1996, 1998; Phillips and White, 1998) and active field mapping for this project led to development of highly detailed information on the distribution of the Dakota Formation in Guthrie County.

Pale to medium gray mudstones, some red-mottled, are interbedded with the sandstones and are locally dominant. Many of these mudstones show signs of subtropical pedogenesis (ped structure, red mottling, sphaerosiderite grains or siderite pellets) in exposures in southern Guthrie County. Recent studies of basal Dakota strata in the Middle Raccoon River Valley in northern Guthrie County have led to discovery of exposures of laminated carbonaceous mudstones with sparse burrowing fabrics that show subtle marine influences on deposition, probably within a paleoestuary (Phillips and White, 1998).

Pennsylvanian

Pennsylvanian Paleogeography and the Midcontinent Basin

During the Pennsylvanian or Late Carboniferous Euramerica (North America and Europe) were joined to the rest of the continents in the south (Gondwana) by the Appalachian-Hercynian Orogenic belts. The Caledonian Mountains extended from the northern Appalachians thru the present day United Kingdom, Greenland, and Norway. Together Euramerica and Gondwana comprised the assembling supercontinent of Pangea, with most of its land area in the southern hemisphere. During this time most of the midcontinent lay within a few degrees south or north of the equator (Heckel, 1999).

The sediments deposited during the Pennsylvanian are now exposed in several structural basins, including the Appalachian, Michigan, Illinois, and Midcontinent. In addition there were a number of smaller tectonic basins in the western United States.

The Midcontinent or Western Interior Basin extends from southwest Iowa, northwest Missouri, and Nebraska in the north, to central Oklahoma to the south. It extends westward from west-central Arkansas to eastern Colorado at essentially the position of the present day Front Range of the Rocky Mountains. The northern part of the basin is known as the Northern Midcontinent Shelf and contains three main structural features: the Nemaha Uplift, the Bourbon Arch and, the Forest City Basin. The southern part of the basin contains the forearc Anadarko and Arkoma basins, north of the Arbuckle-Wichita-Amarillo uplift and the Ouachita uplift, respectively. During times of low sea-level stand the Midcontinent Basin was open to the Panthalassa Sea (Protopacific Ocean) only thru the Oklahoma basins and the Midland Basin of western Texas, and most of the area north and east of the Oklahoma basins was subaerially exposed. During times of high sea-level stand most of the present United States north of the Ouachita Mountains and west of the Appalachian Mountains was covered by a relatively shallow epiric sea (Heckel, 1999).

In Iowa the major area of deposition and present exposure of Pennsylvanian sediments is the Forest City Basin, which occupies about the southwestern third of the state. Here Pennsylvanian strata unconformably overlie Mississippian carbonates and generally dip to the south and west. South of the town of Winterset, in Madison County, the Bethany Falls Limestone of the Swope Formation dips to the southwest at about 10 ft. (3 m) per mile. Nearly 1700 feet (520 m) of Pennsylvanian sediment are known in the subsurface of southwestern Iowa. To the northeast, successively older Paleozoic strata are exposed; while to the north and northwest, the Pennsylvanian deposits are unconformably overlain by Cretaceous deposits of the Dakota Formation.

Cyclothems

It is now recognized that most lithic units in the Pennsylvanian of the Midcontinent were deposited in various environments that resulted from glacial-eustatic rise and fall of sea-level (Heckel, 1994). These cycles of transgression and regression were termed cyclothems by Wanless and Weller (1932) and are known as allostratigraphic (genetic) units ('stratigraphic sequences' of sequence stratigraphy) defined on the basis of bounding discontinuities. In south-central Iowa these discontinuities are often paleosols, developed during times of subaerial exposure.

On the Northern Midcontinent Shelf, cyclothems are classified informally into three orders of magnitude (Heckel, 1999). Major marine cycles are characterized by a widespread, conodont-rich gray to black shale, located between the transgressive and regressive limestones that extend across the entire shelf. Intermediate cycles are characterized by a conodont-rich gray shale or limestone, and are distributed with limited extent toward the northern part of the shelf. Minor cycles typically extend only a short distance northward from the Oklahoma basinal region or represent minor reversals of sea-level within more major cyclothems.

Most major cyclothems, and some intermediate ones, display a distinctive vertical sequence of lithic members. Each lithic member represents a particular phase of deposition during a single phase of glacial-eustatic sea-level change (transgression-regression). In south-central Iowa, most cyclothems overlie a basal mudstone paleosol, (*lowstand systems tract* of sequence stratigraphic terminology) which sometimes occurs below a coal. The coal represents the ponding of fresh water on a coastal plain of low relief ahead of the rise in sea-level. Above this is typically a thin transgressive limestone (*transgressive systems tract*) representing a deepening-upward sequence, which was deposited in a marine environment. Overlying this is the offshore 'core' shale (*highstand systems tract*) deposited as a condensed section under conditions of sediment starvation. Highstand water was deep enough to inhibit benthic carbonate-producing algal growth or to preserve carbonate mud. Overlying the highstand core shale is typically a thick regressive limestone (*regressive systems tract*) deposited as sea level lowered to the point that benthic algal production of carbonate mud resumed. These often shallow up into shoal water and tidal flat deposits. Above this is often shale with local sandstones deposited during final regression or lowstand. These shales are often capped by gray to red blocky mudstones identified as paleosols. Such deposits represent the lowstand systems tract where soil formation and erosion, including the formation of paleovalleys, occurred. The paleosol is the top of the underlying cyclothem or the base of the overlying cyclothem

Regional Stages

The Midcontinent Basin is the area in which the North American regional stage names were established. They are in ascending order: Morrowan, Atokan, Desmoinesian, Missourian, and Virgilian. The Morrowan is lower Pennsylvanian, the Atokan and Desmoinesian are middle Pennsylvanian, and the Missourian and Virgilian are upper Pennsylvanian.

The **Atokan Stage** was derived from the Atoka Formation named by Taff and Adams (1900) from a town in southeastern Oklahoma. In Iowa, the Atokan comprises up to 250 ft. (76 m) of shale, sandstone, and coal and includes strata in the lower Cherokee Group Kilbourn Formation and the lower part of the Kalo Formation. Ravn et al. (1984) and Ravn (1986) placed the Atokan-Desmoinesian boundary between the Blackoak and Cliffland coals of the Cherokee Group. (See discussion below, of the Atokan-Desmoinesian boundary in the Floris Formation of the Cherokee Group.) The Atokan has been considered to comprise the zones of the foraminifers *Profusulinella* and *Fusulinella* (Moore and Thompson, 1949). The Atokan thickens to 20,000 ft. (6100 m) in the Arkoma Basin of Oklahoma.

The **Desmoinesian Stage** was derived from the Des Moines formation, named by Keyes (1893) from outcrops along the Des Moines River in Iowa. In Iowa, it comprises a succession of cyclic shales, sandstones, coals, and rarer limestones. Limestones and phosphatic black shales are more common in the upper part. The Desmoinesian is generally less than 940 feet (285 m) thick in Iowa, but thickens to about 6600 feet (2000 m) in the Arkoma Basin of Oklahoma (Heckel, 1999).

The Desmoinesian is characterized by the presence of the fusulinid foraminifer *Beedeina* (*Fusulina*), chaetetid sponges, the conodont *Neognathodus*, brachiopods *Mesolobus* and *Desmoinesia*, certain ammonoid cephalopods, and plants represented by aborescent and subaborescent lycopods, ferns, seed-ferns, calamites, and cordaites.

The **Missourian Stage** was derived from the Missouri formation by Keyes (1893) for exposures along the Missouri River in Iowa and Missouri. It comprises about 270 ft. (82 m) of mainly shale, limestone, sandstone, mudstone, and rare coals, thickening southward into Kansas and Oklahoma. In south-central Iowa the Missourian Stage contains well-developed classic limestone-dominated cyclothems (transgressive-regressive marine cycles) with distinctive dark phosphatic shale members. It has been considered the lower zone of the fusulinid foraminifer *Triticites*, which first appears in the Dennis Formation. The Desmoinesian-Missourian boundary marks an extinction event across most of North America, characterized by the loss of the distinctive Desmoinesian taxa mentioned above. The boundary is also recognized by the appearance of the evolving conodont *Streptognathodus s.s.* lineages and the first appearance of the conodont *Idiognathodus eccentricus* (Heckel, 1999).

The **Virgilian Stage** was named after a town in east-central Kansas by Moore (1932) and forms the top of the Pennsylvanian Subsystem in the United States. It comprises about 240 ft. (73 m) of shale, limestone, mudstone, and minor sandstone and coal in south-central Iowa, with a total thickness of about 1400 ft. (425 m) in most of the northern Midcontinent. It is considered the upper part of the fusulinid foraminifer *Triticites* zone, and most other fossil groups are only slightly changed from those seen in the Missourian. The Missourian-Virgilian boundary is provisionally recognized by the first appearance of the conodont *Steptognathodus zethus* (Heckel, 1999).

The Desmoinesian, Missourian, and Virgilian succession on the northern Midcontinent Shelf in Iowa is subdivided lithostratigraphically into about 60 formations and about 150 members that are combined into ten groups. Only the lower seven groups occur in south-central Iowa, and they are subdivided into about 43 formations and about 100 members.

Major Lithostratigraphic Units

Cherokee Group

The Cherokee Group is the basal Pennsylvanian unit, lying with a major disconformable contact above various Mississippian formations in south-central Iowa. It encompasses strata of the lower part of the Desmoinesian Stage and includes Atokan strata. The Cherokee includes strata from the Mississippian surface to the top of the Mulky Coal Member of the Swede Hollow Formation.

In ascending order, the Cherokee Group in Iowa is divided into the Kilbourn, Kalo, Floris, and Swede Hollow formations representing distinct depositional regimes. Cherokee strata comprise a succession of shale-dominated, coal-bearing cyclothems with locally thick sandstones. A few contain thin limestones associated with minor and intermediate scale cyclothems, with the only known major cyclothem (Verdigris-Ardmore) being traceable from Oklahoma to Indiana. The Cherokee contains most of the coal resources of the Midcontinent area. In south-central Iowa, the Cherokee Group reaches about 500 ft. (152 m) in thickness; while in the Forest City Basin of the Iowa/Missouri/Nebraska border region, it thickens to about 800 ft. (240 m).

The Kilbourn Formation represents initial Pennsylvanian deposition on the land surface that was being developed on argillaceous and arenaceous Mississippian carbonates, where stream incision on these carbonates had produced a surface of considerable relief and irregularity. Kilbourn deposition was the result of subsidence in the Forest City Basin, in combination with several marine transgressions and regressions (Ravn et al., 1984). The deposition predominately took place in the incised paleovalleys during relative rises in sea-level, while pedogenesis and erosion continued on the interfluves (Pope and Goettemoeller, 2002). As many as seven depositional cycles are encountered in the subsurface of south-central Iowa, dominated by nonmarine sandstones, shales, siltstones, mudstones, and coals. Thin marine limestones and shales (including phosphatic black shales) were deposited in the distal ends of estuaries during maximum transgression. Most of the sediments are thin and discontinuous, but they eventually filled the paleovalleys and nearly leveled topographic relief. The prominent coals have been correlated to the Tarter, Manley, and Reynoldsburg coals of the Illinois Basin on the basis of palynology, but they have not been named in Iowa.

The Kalo Formation includes strata from the base of the Blackoak Coal to the base of the Laddsdale Coal in the overlying Floris Formation. Two major coals, the lower Blackoak and the upper Cliffland, are the only two named members of the Kalo Formation in Iowa. Because of the leveling of the Mississippian erosional surface by Kilbourn deposition, the first widespread episodes of coal deposition occurred in Iowa.

The Atokan-Desmoinesian boundary was placed by Ravn et al. (1984) and Ravn (1986) between the lower Blackoak and upper Cliffland coals. The top of the Atokan is recognized by the final regular appearance of the palynomorph *Dictyotriletes bireticulatus*, which occurs in the Blackoak Coal, but not in the Cliffland Coal of Iowa. This is in agreement with the boundary placement suggested in Illinois by Hopkins and Simon (1975). Further support for this boundary was suggested by Lambert (1988), who reported that the conodont genera *Idiognathoides* and *Declinognathodus* (both considered restricted to the Atokan of the Midcontinent) do not range above the Blackoak Coal. Based on palynology, the Blackoak Coal correlates to the Pope Creek Coal of Illinois, and the Cliffland Coal correlates to the Rock Island (No. 1) Coal of Illinois.

The Floris Formation includes strata from the base of the lower Laddsdale Coal to the base of the Whitebreast Coal at the top of the formation. The lower part of the Floris is characterized by the Laddsdale Coal Member, consisting of one to six coals that are usually lenticular and locally reach economic thicknesses. The associated strata are predominantly nonmarine shales and siltstones, which may coarsen-upward into sandstone. In some instances a fossiliferous marine shale or limestone may occur. Thus, these coals may represent from one to six depositional cycles over a period of time in which there was little change in the flora. As with the Blackoak and Cliffland coals they are palynologically distinct from other Cherokee coals, but the individual coals cannot be distinguished from each other (Ravn et al., 1984).

Above the Laddsdale are one or more palynologically distinct unnamed coals. Lenticular marine limestones are often associated with these coals. At this point the relationship of the coals and marine units to each other in this interval is poorly understood (Ravn, 1986).

Higher up is another palynologically distinct coal, the Carruthers. In contrast to the lower Floris coals it is relatively persistent over a wide area. A fossiliferous marine shale and/or limestone usually directly overlie the coal, and a thin, persistent, phosphatic black shale with a distinct conodont fauna lies two to ten feet above the coal. This shale carries a smooth platform species of *Gondolella*. The Carruthers correlates with the Greenbush and De Koven coals of Illinois. A persistent coal smut and lenticular marine sequence that lies several feet above the Carruthers Coal near the top of the Floris Formation, is thought to correlate with the Abingdon Coal of Illinois.

In general, the Floris represents a transition from nonmarine fluvial and deltaic processes to more marine processes (Pope, and Chantooni, 1996). Major incised valleys and their associated thick sandstone fills (Pope and Goettemoeller, 2002) probably occurred before deposition of the Carruthers Coal. These early Floris sequences of sandstone, 140 feet (42 m) or more thick, cut downward into the underlying Kalo and Kilbourn formations, and occasionally into the Mississippian. One exception to this is the 50 ft. (15 m) thick informally named ‘Hanging Rock Sandstone’ in southwestern Dallas County that occurs just below the paleosol below the overlying Whitebreast Coal.

The Swede Hollow Formation is the uppermost formation within the Cherokee Group and includes strata from the base of the Whitebreast Coal Member to the top of the Mulky Coal Member.

The lower members of the Swede Hollow Formation are part of the first major marine cycle in the Midcontinent Pennsylvanian. This cycle spans the interval from the top of the paleosol below the Whitebreast Coal, including the Oakley Shale, and Ardmore Limestone, to the top of the paleosol below the Wheeler Coal in Iowa. The Verdigris Limestone is a lithostratigraphic unit comprising the Oakley Shale overlain by the Ardmore Limestone. The Oakley Shale contains the highest known occurrence of the smooth platform conodont *Gondolella* sp. 1 of Swade (1985). The Verdigris extends across the entire Midcontinent and can easily be recognized on geophysical logs, in cores, outcrops, and well cuttings. Therefore it is an important unit for mapping purposes.

The Wheeler Coal represents a minor cycle and extends up to the top of the paleosol below the Bevier Coal. Marine units are rarely associated with this cycle in south-central Iowa.

The Bevier Coal represents another minor marine cycle and extends upward to the top of the paleosol below the Mulky Coal. A lenticular limestone or dark fossiliferous shale with an abundant conodont fauna occurs above the coal in the mapping area.

In southwestern Dallas County an unnamed, thick sandstone occurs in the upper Swede Hollow Formation. In places it cuts out the entire Verdigris cycle, but its exact relationship to the Wheeler and Bevier coals is unknown.

Marmaton Group

The Marmaton Group overlies the Cherokee Group with only a small disconformity, and encompasses the upper part of the Desmoinesian Stage. It comprises a succession of limestone-dominated cyclothems separated by locally thick shale and/or sandstone with some widespread coals. In Iowa it ranges from the base of the Excello Shale Member of the Mouse Creek Formation to the top of the Cooper Creek Limestone Member of the Lost Branch Formation. It is classified into 11 formations and 22 members traceable across most of the Midcontinent region. The Marmaton is about 140 ft. (42m) thick in Iowa, where it reflects the end of subsidence in the Forest City Basin.

The lower part of the Marmaton Group, formerly called the Fort Scott Formation, was subdivided into three newly named formations by Ravn et al., 1984. In ascending order these are the Mouse Creek, Morgan School Shale, and Stephens Forest formations. The lower strata constitute a major marine cycle including units from the top of the paleosol below the Mulky Coal, including the Blackjack Creek Limestone to the paleosol below the Summit Coal. The Excello Shale Member includes the lowest occurrence of *Diplognathodus iowensis*, the transversely ridged platform conodont *Gondolella* sp. 2 of Swade (1985), and the highest occurrence of *Diplognathodus coloradoensis*. The Stephens Forest Formation represents two marine depositional cycles. The lower cycle encompasses strata from the top of the paleosol below the Summit Coal, the newly named Clanton Creek Limestone (Heckel and Pope, 1992), Little Osage Shale, and the lower part of Blackwater Creek Shale up to the paleosol. The upper cycle is represented by the upper part of the Blackwater Creek Shale above the paleosol, the Higgensville Limestone, and the Labette Shale to the top of the paleosol below the Marshall (lower Mystic) Coal. The Marshall Coal may either represent a minor cycle or a split in the Mystic Coal.

The Pawnee Formation above the Labette Shale also represents two marine depositional cycles. The lower cycle includes the Mystic Coal, Anna Shale, Myrick Station Limestone, and lower Mine Creek Shale up to the paleosol, while the upper cycle includes an unnamed coal in the upper Mine Creek Shale, Coal City Limestone, and lower Bandera Shale up to the paleosol.

The Farlington Limestone (Heckel, 1999; Watney and Heckel, ms. in review) is a newly named bed in the Bandera Shale of Iowa. Formerly called the post-Mulberry cycle, it can now be correlated by conodonts (Pope, 2001, unpub. ms.) with the type Farlington in southeastern Kansas. This intermediate marine cycle extends from the top of the paleosol underlying the Mulberry Coal to the top of the paleosol near the top of the

Bandera Shale. The conodont fauna is strongly dominated by the first appearance of *Idiognathodus* sp. 5 of Swade (1985).

The Altamont Formation represents a major marine cycle that spans the interval from the paleosol at the top of the Bandera Shale, upward through the Amoret Limestone, Lake Neosho Shale, and Worland Limestone, up to the paleosol at the top of the Nowata Shale. The lowermost Amoret Limestone Member has been shown to be a minor cycle in its own right in southeastern Kansas (Heckel, 1999), and the limestone designated by Swade (1985) as the Amoret in Iowa may not be the same as the Amoret of Kansas.

The Lenapah Formation represents a minor marine cycle and includes the interval from the paleosol at the top of the Nowata Shale to the base of the Dawson Coal at the top of the Memorial Shale. At most places in south-central Iowa, the Lenapah Limestone is not present and the Memorial and Nowata shale boundary cannot be distinguished. The Memorial-Nowata shale interval varies from 30 ft. (9 m) in Appanoose County to over 80 ft. (24 m) in Madison County, and usually consists of red blocky mudstones (representing paleosols) and thick sandstones. This may be the interval in which major valley incision occurred in south-central Iowa and the formation of the valley-filling Chariton Conglomerate. The Chariton is a dominantly limestone- and siltstone-clast conglomerate fining upward into calcite cemented sandstone and sandy to silty shales. Some of the limestone clasts contain the fusulinid foraminifer *Beedeina megista* (Pope, unpub. ms) found in the Worland Limestone Member of the Altamont Formation (Thompson, 1934). At this point, the Chariton Conglomerate is known to be younger than the Altamont, and it may be as young as lower Missourian. It is provisionally placed in the upper Marmaton Group until further studies are made.

The uppermost formation of the Marmaton Group is the Lost Branch. The cyclothem includes the Dawson Coal, Sni Mills Limestone, Nuyaka Creek Shale, and Cooper Creek Limestone, upward to the top of the paleosol in the Hepler Shale. The Nuyaka Creek Shale contains an abundant conodont fauna, including *Idiognathodus* sp. 6 of Swade (1985), *Gondolella magna* (*G*. sp. 3 of Swade, 1985), and the platformless morphotype *G. denuda*. The Cooper Creek Limestone contains the last occurrence of *Neognathodus* in south-central Iowa.

Bronson Group

The Bronson Group overlies the Marmaton Group with disconformity and the newly proposed Desmoinesian-Missourian Stage boundary (Heckel, 1999) is placed near its base (base of the Exline Limestone). The Bronson Group includes strata from the base of the Pleasanton Group of Kansas (which has been reduced to formation level in Iowa), up to the top of the Dennis Formation of the Bronson Subgroup of the Kansas City Group of Kansas. In Iowa, the Bronson, Linn, and Zarah Subgroups of the Kansas City Group are not recognized. Instead, the Bronson Subgroup is elevated to group level and the Linn and Zarah Subgroups are discontinued, being replaced by the Kansas City Group. The Bronson Group is classified into 6 formations and 11 members, of which the Pleasanton Formation is a shale-dominated succession with local sandstone, while the upper part of the group includes 3 limestone-dominated cyclothems. This group is about 90 ft. (27 m) thick in south-central Iowa.

The marine cycle in the Pleasanton Formation includes the strata above the top of the paleosol beneath the Grain Valley Coal (where present) in the Hepler Shale, upward through the Exline Limestone and the Shale Hill members. The strata constitute an intermediate cycle dominated by the conodont *Idiognathodus sulciferus* and the first appearance of its descendant *I. eccentricus* (Heckel, Boardman, and Barrick, 1999), marking the Desmoinesian-Missourian Stage boundary. In Appanoose County, the Exline Limestone is separated from the underlying Cooper Creek Limestone by several feet of mudstone and gray shale, while in most of Madison, Guthrie, and Dallas counties the Exline Limestone sits directly on the Cooper Creek Limestone. Here, the two limestones can only be distinguished by their conodont faunas (Swade, 1985).

The Hertha Formation contains a major marine cycle that includes strata above the top of the paleosol below the Ovid Coal, the newly named East Peru Limestone (Pope and Emerman, 2000), Mound City Shale, and Sniabar Limestone, to the top of the paleosol in the Elm Branch Shale. In Madison County, the Sniabar Limestone varies from a single 8 ft. (2.4 m) thick algal calcilutites, to a three unit limestone consisting of thin lower calcilutites overlain by up to 15 ft. (4.6 m) of marine shale and thin capping calcarenites. This three layer aspect often caused confusion for early workers who could not distinguish the Exline Limestone from the Cooper Creek Limestone (see above), so they called the lower unit of the Sniabar Limestone the Exline Limestone. This long standing miscorrelation has been corrected by using conodont biostratigraphy (Swade, 1985; Pope and Emerman, 2000).

The Swope Formation contains a major marine cycle extending from the top of the paleosol in the Elm Branch Shale, upward through the Middle Creek Limestone, Hushpuckney Shale, and Bethany Falls Limestone, up to the top of the paleosol below the Davis City Coal in the Galesburg Shale. The Hushpuckney Shale carries an abundant conodont fauna including idiognathodids and the first appearance of the descendant genus *Streptognathodus* (*S. cancellosus*). *Gondolella denuda* occurs, as well as the first appearance of *Gondolella sublanceolata.* Fusulinids from the Bethany Falls Limestone are *Eowaeringella ultimata* (Thompson 1957), a species not found above the Swope in the Midcontinent. The Bethany Falls Limestone is about 22 ft. (6.7 m) thick where it occurs in the mapping area, and is a primary source of road metal and agricultural lime.

The Dennis Formation also contains a major marine cycle ranging from the top of the paleosol below the Davis City Coal, upward through the Canville Limestone, Stark Shale, and Winterset Limestone, to the top of the paleosol in the Fontana Shale. The Stark Shale contains an abundant conodont fauna of idiognathodids, including possible ‘pre’ *Idiognathodus magnificus* forms. Also occurring are *Streptognathodus cancellosus,* and its descendant *S. confragus* which first appeared in the stratigraphically lower minor marine Mound Valley cycle that only extends northward from Oklahoma to Bourbon County, Kansas. The Winterset Limestone records the lowest occurrence of the triticitid fusulinid foraminifers in the Midcontinent (Thompson 1957), which along with the distinctly different fusulinids in the underlying Bethany Falls Limestone, have resolved correlation problems between the Nebraska-Iowa outcrop and the Kansas City area (Heckel and Meacham, 1980). The Winterset Limestone is a heavily quarried unit in Adair, Madison, Clarke, Union, and Decatur counties.

Kansas City Group

The Kansas City Group overlies the Bronson Group with slight disconformity in Iowa and comprises strata from the top of the Dennis Formation to the base of the Plattsburg

Formation of the Lansing Group. In Iowa, it comprises 7 formations and 12 members traceable across the Midcontinent region. The lower part is a shale dominated succession while the upper part is a subequally limestone/shale dominated succession. It is about 114 ft. (35 m) thick in south-central Iowa.

The Cherryvale Formation contains an intermediate marine cycle extending upward from the top of the paleosol in the Fontana Shale, through the Block Limestone, and Wea Shale, with a minor transgression recorded in the Westerville Limestone, and final transgression at the top of the paleosol in the Nellie Bly Shale. The Cherryvale cyclothem carries a conodont fauna dominated by the first abundant appearance of more deeply troughed morphotypes of *Streptognathodus*, including *S. gracilis, S. elegantulus*, *S. excelsus*, and *S. corrugatus.*

Above the Cherryvale, the major marine cycle in the Dewey Formation includes strata from the top of the paleosol in the Nellie Bly Shale, an unnamed coal (Iowa), the newly named Pammel Park Limestone in Iowa (Heckel and Pope, 1992), the Quivira Shale and the Cement City Limestone, upward to the top of the paleosol in the Chanute Shale. The conodont fauna includes *Streptognathodus gracilis, S. elegantulus, S. excelsus*, and *S. corrugatus* and is dominated by the first abundant appearance of the prominently lobed *Idiognathodus magnificus.* The Dewey Formation in south-central Iowa was previously misidentified as the Iola Formation.

The Iola Formation contains a major marine cycle that extends from the top of the paleosol in the Chanute Shale, and includes the Paola Limestone, Muncie Creek Shale, and Raytown Limestone, up to the top of the paleosol in the Liberty Memorial Shale. The Muncie Creek Shale carries an abundant conodont fauna that includes *Streptognathodus gracilis*, *S. elegantulus*, *S. excelsus*, and *S. corrugatus,* and the descendant of *Idiognathodus magnificus,* a less prominently lobed form informally called "postmagnificus". The Iola Formation in south-central Iowa was previously misidentified as the Wyandotte, Island Creek Shale, and Farley Limestone. The Farley is now recognized to pinch out within the overlying Lane Shale near the Iowa-Missouri border (Heckel and Pope, 1992). The Raytown Limestone is a major unit for limestone production in south-central Iowa.

The Wyandotte Formation contains an intermediate marine cycle and includes strata from the top of the paleosol in the Liberty Memorial Shale, including the Quindaro Shale, and Argentine Limestone, to the top of the paleosol in the Lane Shale. The Quindaro Shale carries an abundant conodont fauna including *Streptognathodus gracilis, S. elegantulus, S. excelsus,* and *S. corrugatus,* plus a troughed morphotype with a curved platform.

The name, Lane Shale, is now confined to the shale interval above the Argentine Limestone up to the base of the Plattsburg Formation where the Farley Limestone is not present. To the south, where the Farley Limestone (now regarded as a member of the Lane Shale) is present, the lower Lane Shale is now the Island Creek Shale Member, and the upper Lane Shale above the Farley Limestone is called the Bonner Springs Shale Member (Heckel and Pope, 1992).

Lansing Group

The Lansing Group overlies the Kansas City Group with some disconformity in Iowa and comprises strata from the base of the Plattsburg Formation to the top of the Stanton

Formation. It comprises 5 formations with 9 members and includes 3 limestone-dominated cyclothems separated by paleosol mudstones. It is about 50 ft. (15m) thick in south-central Iowa.

The Plattsburg Formation contains an intermediate marine cycle including strata above the top of the paleosol in the Lane Shale, upward through the Merriam Limestone, Hickory Creek Shale, and Spring Hill Limestone, to the top of the paleosol in the Vilas Shale. The Hickory Creek Shale has a conodont fauna similar to that of the Quindaro Shale, but *S. elegantulus* and the morphotype with the curved platform is more common.

The Stanton Formation contains a major marine cycle extending from the top of the paleosol in the Vilas Shale, including the Captain Creek Limestone, Eudora Shale, and Stoner Limestone, to the top of the paleosol in the Rock Lake Shale. The Eudora Shale carries an abundant conodont fauna, including the first appearance of *Idiognathodus simulator* and in its upper part the first appearance of a morphotype resembling *Streptognathodus firmus*. The lower part contains the last appearance of the *Streptognathodus gracilis, S. elegantulus, S. excelsus,* and *S. corrugatus* group. The Stanton Formation in western Madison County was previously misidentified with the much higher Oread Formation (Snyderville Shale, Leavenworth Limestone, Heebner Shale, and Plattsmouth Limestone) of the Shawnee Group (Heckel and Pope, 1992).

The intermediate marine cycle in the South Bend Limestone Formation spans the interval from the top of the paleosol below an unnamed coal in the Rock Lake Shale, and includes the Little Kaw Limestone, Gretna Shale, and Kitaki Limestone, to the top of the paleosol in the Weston Shale. The Gretna Shale is dominated by *Streptognathodus firmus* and the first appearance of its descendant *S. pawhuskaensis*.

Douglas Group

The Douglas Group overlies the Lansing Group with only a slight disconformity in Iowa. It comprises 5 members in 3 formations, a thin limestone-dominated middle one between lower and upper shale-dominated ones. It is about 60 ft. (18m) thick in south-central Iowa.

The Stranger Formation contains an intermediate marine cycle including strata from the top of the paleosol in the lower Weston Shale Member, the Iatan Limestone, upward to the top of the paleosol at the top of the upper Stranger Formation.

The major marine cycle in the Cass Formation spans the interval from the top of the paleosol at the top of the upper Stranger Formation, including the Haskell limestone, Little Pawnee Shale, and Shoemaker Limestone, to the top of the paleosol in the Lawrence Formation. The Missourian-Virgilian boundary is provisionally placed within the Haskell Limestone Member of the Cass Formation in Woodson County, Kansas with the first appearance of the conodont *Streptognathodus zethus* (Heckel, 1999).

The Lawrence Shale is about 72 ft. (22 m) thick in a core in western Union County and thickens to nearly 100 ft. (31 m) in the Bedford core, located just to the southwest of the map area in Taylor County.

Shawnee Group

The Shawnee Group overlies the Douglas Group disconformably and forms most of the lower one third of the Virgilian Stage up to the Wabaunsee Group. In Iowa it comprises 7 formations, four of which are limestone-dominated. It is about 180 ft. (55 m) in total thickness in Iowa.

The Oread Formation contains an intermediate marine cycle at its base, a major marine cycle in the middle and another intermediate marine cycle at the top. The lower cycle spans the interval from the top of the paleosol in the Lawrence Shale, and Toronto Limestone, to the top of the paleosol in the Snyderville Shale. The strata above the top of the paleosol in the Snyderville Shale, including the Leavenworth Limestone, Heebner Shale, Plattsmouth Limestone, and the lower Heumader Shale constitute the middle cycle. The upper cycle includes the upper Heumader Shale, Kereford Limestone, and the Kanwaka Shale up to the top of the paleosol. The conodont fauna of the middle major marine cycle is dominated by *Idiognathodus simulator* and *I. pawhuskaensis*. It also contains *I. tersus*, platformless *Gondolella postdenuda,* and the last appearance of *Idioprioniodus* in the Midcontinent (Heckel, 1989). Together these three cycles are known as the Oread Megacyclothem (Boardman, 1999).

Like the underlying Oread Formation, the Lecompton Formation contains an intermediate marine cycle at its base, a major marine cycle in the middle, and another intermediate marine cycle at the top. The lower cycle consists of strata from the top of the paleosol in the Kanwaka Shale Formation, the Spring Branch Limestone, up to the top of the paleosol in the Doniphan Shale. The middle cycle includes strata from the top of the paleosol in the Doniphan Shale, the Big Spring Limestone, Queen Hill Shale, and Beil Limestone, upward to the top of the paleosol in the King Hill Shale. The upper cycle consists of the upper King Hill Shale above the paleosol, the Avoca Limestone, and the Tecumseh Shale below the top of the paleosol. The conodont fauna of the middle major marine cycle is dominated by *Idiognathodus pawhuskaensis*. It is also characterized by *I. tersus*, the last appearance of *Gondolella postdenuda,* the absence of *Idioprioniodus*, and the first appearance of *Streptognathodus virgilicus* (Ritter, 1994; Heckel, 1989). Collectively these three cycles are known as the Lecompton Megacyclothem (Boardman, 1999).

The Deer Creek Formation contains a minor marine cycle at its base, a major marine cycle in the middle and an intermediate marine cycle at the top. The lower cycle comprises the upper Tecumseh Shale above the top of the paleosol, Ozawkie Limestone, and the lower Oskaloosa Shale below the top of the paleosol. The middle cycle includes the upper Oskaloosa Shale above the top of the paleosol, Rock Bluff Limestone, Larsh Shale, Haynies Limestone, Burroak Shale, Ervine Creek Limestone, and the lower Calhoun Shale Formation below the top of the paleosol. The conodont fauna of the middle major marine cycle is dominated by *Idiognathodus pawhuskaensis* and contains *Streptognathodus virgilicus* (Ritter, 1994). These cycles, including the stratigraphically higher Hartford cycle, are included in the Deer Creek Megacyclothem (Boardman, 1999).

The Hartford Limestone, part of an intermediate cycle at the base of the Topeka Formation may also occur in the southwestern corner of Adair County, as it is seen in the Mt. Etna Quarry in Adams County about 2 miles to the south of this part of the map area.

Mississippian

"St. Louis" and 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 type 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 south-central Iowa is characterized by interbedded dolomite (commonly sandy), sandstone, limestone, green-gray shale, and gypsum/anhydrite. Sandstone units reach thicknesses to 40 ft (12 m), but are usually thinner. The inteval is locally brecciated, especially in the lower part, forming a complex admixture of lithologies. Lower strata of the "St. Louis" Formation in areas of south-central Iowa locally contain evaporite intervals of gypsum and anhydrite, which reach thicknesses of up to 60 ft (18 m) in Monroe County and 40 ft (12 m) in Marion County. The "St. Louis" interval reaches maximum thicknesses to about 125 ft (38 m) in the map area (where thick gypsum-anhydrite units are present).

The Pella Formation comprises the highest Mississippian interval in southern Iowa, characterized by fossiliferous calcareous shale and limestone. Where the formation is thickest, it locally contains scattered sandstone interbeds in the upper part. The Pella Formation was named for exposures within the south-central Iowa map area near Pella in Marion County. The formation probably correlates with the upper Ste. Genevieve Formation of Missouri (Witzke et al., 1990). The Pella Formation reaches maximum thicknesses to about 55 ft (17 m) in the map area, but it is thin to absent across much of the map area due to significant sub-Cherokee erosional beveling and truncation.

Mississippian strata of the "St. Louis"-Pella interval form the bedrock surface in parts of northwest Dallas, southern Boone, Marion, Monroe, and eastern Appanoose counties, mostly mapped within buried bedrock channels. However, significant Mississippian exposures are known in northeast Monroe and eastern Marion counties, primarily within the valleys of the Des Moines River and its immediate tributaries. "St. Louis" and Pella strata are locally well displayed in cut-banks, roadcuts, and active and inactive quarries in that area.

Augusta Group

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. Augusta Group strata in the map area are dominated by variably argillaceous dolomite lithologies, but shale and limestone are locally significant. These strata are variably cherty, and some beds are abundantly cherty. Chalcedony and quartz crystals (probably derived from quartz geodes) are commonly seen in well cuttings. Quartz geodes are common throughout much of the Augusta Group interval as seen in bedrock cores from Polk, Marion, and Warren counties in the map area, and partial quartz and chalcedony replacements of anhydrite nodules from Marion County apparently represent incipient partially-formed geodes. Glauconite and phosphatic enrichments 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 190 feet (58 m) in the map area, but thicknesses are generally less because of significant sub-“St. Louis” erosional beveling. The sub-Cherokee Group erosional surface is deeply incised into the Augusta Group in many places across south-central Iowa, and this incision displays up to 100 ft (30 m) of local erosional relief on the Mississippian surface.

The Augusta Group is the oldest bedrock unit mapped in south-central Iowa, and its mapped occurrences are limited to buried bedrock valleys in parts of northeast Marion and northern Polk counties. These occurrences comprise bedrock strata, primarily cherty dolomites of the Keokuk Formation. Although strata of the Warsaw Formation likely occur in places within the map area, “St. Louis” strata directly overlie the Keokuk Formation across most of the region. The Keokuk overlies the Burlington Formation, which is characterized in the subsurface of south-central Iowa by cherty dolomite and crinoidal limestone strata.

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