GEOLOGY OF THE SAYLORVILLE SPILLWAY; AFTER THE FLOOD OF 2008

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Geological Society of Iowa

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Cover Photograph

Rocks of the Pennsylvanian Cherokee Group exposed in the Saylorville Dam emergency spillway after the flood of 2008. In this view guidebook author and Northwestern Missouri State University professor John Pope holds a stadia rod as a photographic scale. In the background a large slab of concrete, installed to stabilize the spillway after the floods of 1993, has been undercut by 2008 flooding and hangs into the spillway cut. Cover photo by Diana Pope.

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INTRODUCTION TO THE SAYLORVILLE DAM AND EMERGENCY SPILLWAY

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Figure 1. Aerial photograph (looking northeast) of the Saylorville Dam. The dam's emergency spillway lies just below the lower edge of the photograph.

INTRODUCTION

The U.S. Army Corps of Engineers describe the Des Moines River as the largest river in central Iowa. The river also has a history of too much or too little water, depending on the season. With major flooding occurring on the river in 1851, 1903, 1935, 1938 and 1944, the Committee on Commerce of the United States Senate authorized a study of the Des Moines River in the interest of providing additional flood protection for the city of Des Moines. On December 22, 1944 the Des Moines Local Flood Protection Project was authorized by Congress. In 1947 another major flood impacted Des Moines forcing a total of 500 people from their homes, drowning two. Again in 1954, heavy flooding struck the area and drove 1,800 people from their homes. In 1958, after investigating nine sites, six on the Des Moines River, two on the Raccoon, and one on the South Raccoon, Congress authorized construction of Saylorville Lake by the US Army Corps of Engineers at a site about 11 miles upstream from the city of Des Moines.

The principal purpose of the Saylorville project was to help provide flood protection for the city of Des Moines. Additionally, the project also provided additional storage to supplement the flood control capacity of Lake Red Rock downstream to reduce flood crests on the Des Moines and Mississippi Rivers.

CONSTRUCTION OF THE SAYLORVILLE DAM

Excavation work for the emergency spillway and construction of the first section of the earth embankment for the west part of the dam began in July of 1965 and was completed in the fall of 1967. Construction of the concrete outlet for the dam began in May of 1967 and was completed in December of 1971. Building of the final section of the earth embankment began February of 1973 and was completed in October of 1975 (Fig. 1). In July of 1975 Des Moines River flow was diverted through the outlet channel, and the final section of the dam was built across the old river channel between July and October of 1975. The impounded lake reached its conservation pool elevation of 833 feet msl (above mean sea level) and became fully operational in September of 1977. The permanent conservation pool level of Saylorville Lake was raised to 836 feet in 1985, creating a lake of about 5,950 acres that extends some 17 miles upstream from the dam. The total cost of constructing the Saylorville Dam and related facilities was about $130.1 million.

Saylorville Dam is an earth-filled embankment-type structure with over 7½ million cubic yards of compacted material. It is 6,750 feet long, 105 feet high and 44 feet wide at the top. The outlet channel is fed through a single circular concrete conduit 22 feet in diameter, located at the bottom of the west bluff. The control structure is located at the upstream end of the conduit and houses three gates, which have the capability of releasing a maximum outflow of 21,000 cfs (cubic feet per second). A stilling basin was constructed to dissipate the energy of the discharge from the outlet conduit.

The Saylorville Dam control structure was not equipped for use as a hydroelectric system, because fluctuation results in an unpredictable amount of electricity produced, thereby making such a system undependable and not cost efficient. While maximum dam outflows can reach 21,000 cfs, these extreme outflows are rare. Normal outflows range between 200 and 6,000 cfs.

The full flood control pool at 890 feet is 54 miles long and covers 16,700 acres. This maximum flood elevation is 54 ft. above the normal lake level of 836 feet. The emergency spillway, located on the west side of the Administration Complex, sits at an elevation of 884 feet and acts as a backup system to the main outlet conduit. It is a passive system utilized only when lake levels exceed 884 feet. When lake levels reach the maximum 890 feet, an estimated 21,000 cfs of water flows over the emergency spillway.

The Saylorville Dam and lake have several uses in addition to flood control. Wildlife habitat is carefully monitored on and around Saylorville Lake, and the quality of the habitat is improved through careful maintenance of the adjacent lands. The water quality downstream from the dam is also improved by the deposition of silt and clay from the waters of the Des Moines River into the lake before it continues downstream. In contrast to its flood control function, the lake is also able to provide a steady water supply to the city of Des Moines in times of drought.

The structure and planning of the Saylorville Lake and Dam project was first fully tested as a flood control project in the spring of 1984. Lake levels reached a maximum height of 889.29 feet, with water flowing over the emergency spillway for 16 days.

The Saylorville Dam Project was originally designed to handle a hypothetical flood including a lake level at 907 feet and flows of 162,000 cfs. At the time of its design this was the Probable Maximum Flood. The dam’s emergency spillway was designed to carry water safely past the dam when the lake level exceeded 884 feet. This situation occurred on several occasions since the dam’s construction, sending flood waters surging through the structure’s emergency spillway. The emergency spillway was constructed for just such conditions.

The spillway was modified after the floods of 1993 to add another six foot flood gate, called a Pneumatic Crest Gate System, on top of the spillway's crest at 884 feet. As a flood crest approaches, batters inflated with air lift tgates (Fig. 2), allowing the pool level to raise to 890 feet.

Since 1977, the Army Corps of Engineers estimates that the operation of Saylorville Reservoir has resulted in an estimated $174 million in savings from flood damages to the city of Des Moines and areas below the reservoir.

Figure 2. A sequence of photographs showing the raising of the pneumatic gates at the Saylorville Dam emergency spillway.

HISTORIC FLOODS AT SAYLORVILLE

1984 Flood. In the Spring of 1984 flooding on the Des Moines River provided the first full test of the Saylorville Lake and Dam Project. It performed as designed allowing excess water to pass without damaging the main body of the Saylorville Dam. That year, on June 22, the lake level reached a maximum of 889.29 feet, 53 feet above the normal pool level. The flood waters flowed over the spillway for a total of 15 days from June 18 and July 4, 1984. The maximum inflow to Saylorville Lake in 1984 occurred on June 2 when 38,000 cfs of water entered the lake. The maximum outflow during the 1984 flood occurred on June 22 when 29,000 cfs passed the dam. Although the Saylorville emergency spillway performed as it was designed, the resulting erosion below the spillway's concrete curtain cut deeply into the Pennsylvanian bedrock, producing a canyon called the Saylorville Gorge.

1991 Flood. In 1991, the flooding Des Moines River flowed over the emergency spillway for 11 days between June 6 and June 17. At that time the lake reached a maximum level of 888.94 feet. The maximum inflow into Saylorville Lake during the flooding in 1991 was about 38,000 cfs, with a maximum outflow of 26,000 cfs passing the dam on June 10-11, 1991. The prolonged period of flow through the Saylorville emergency spillway further deepened and widened the Saylorville Gorge.

1993 Floods. The Saylorville dam was subjected to two floods in 1993. In the first episode of flooding, the lake level increased from 836 feet on March 25 to 882 feet on April 12, an increase of 46 feet in just 18 days! The water flowed over the emergency spillway for nine days between April 22 and May 1. During this first 1993 flood Saylorville Lake received a maximum inflow of 45,000 cfs, with a maximum of 21,000 cfs passing the dam. The lake reached a maximum pool elevation of 886 feet on April 27.

Later in 1993 a second flood crest passed the Saylorville Dam. The lake level reached the 884 feet emergency spillway level and began flowing over on June 17, 1993. Saylorville Lake received a maximum inflow of 61,000 cfs, and reached a maximum lake level of 892.3 feet, 56 feet above the 834 feet conservation pool, on July 11. Flood water flowed through the emergency spillway for 42 days, with continuous total outflow (through the flood gates and emergency spillway) of over 21,000 cfs for 46 days, including a maximum outflow of 45,000 cfs.

2008 Flood. Once again, in 2008 heavy rains and snow melt combined to push the Des Moines River to flood conditions. By mid June the maximum inflow of water into Saylorville Lake during 2008 was 60,600 cubic feet per second (cfs). The 891.03 foot crest at the Lake in 2008 was slightly less than the 1993 record crest of 892.3 feet, and the 2008 peak outflow from

Saylorville Lake was 47,000 cfs, greater than the 44,500 cfs peak in 1993. More details on the 2008 Des Moines River flooding can be found beginning on page 5 of this guidebook.

THE SAYLORVILLE EMERGENCY SPILLWAY

Where it meets Saylorville Lake, the Saylorville Dam's emergency spillway is a 430 feet wide concrete structure, which transitions into an earthen channel below the dam. Water begins flowing over the spillway when the lake level reaches 884 feet msl. The average slope on this stretch of the Des Moines River is 2.5 feet per mile. However, since the emergency spillway provides a shorter route its slope is steeper. The drop from the top of the emergency spillway wall to the area where it meets the Des Moines River is 80 feet in less than a mile. The force and speed of the water flowing over the spillway during the flood of 1984 cut a "gorge" through the surficial materials into the underlying Pennsylvanian strata, revealing about 60 foot-thick sequence of Cherokee Group sandstones, shales, limestones, and coals. With each successive flooding, new materials, units, and geologic artifacts were exposed.

THE GEOLOGICAL SOCIETY OF IOWA AT SAYLORVILLE

This field trip will be our third visit to the Saylorville Gorge. Our first field trip to the gorge was in 1984, shortly after the waters from the 1983 flood first excavated the gorge. Bettis and others (1985) led the field trip into the gorge. The guidebook from this trip GSI guidebook 43 is available as a downloadable pdf from http://www.iowageology.org/pdf/GB43.pdf, at the Geological Society of Iowa's web site. The second GSI field trip into the gorge was in 1993, in conjunction with the 57th Annual Tri-State Geological Field Conference, led by Dr. Bill Simpkins (Iowa State University). The visit to the Saylorville Gorge was the first stop of the field trip, led by Iowa Geological Survey Geologists. This field trip guidebook, GSI Guidebook 58, is also as a downloadable pdf from the GSI web site at http://www.iowageology.org/pdf/GB58.pdf.

ENJOY AND BE SAFE

The US Army Corps of Engineers have been very gracious to allow us to visit the Saylorville Gorge. This area is potentially dangerous, and the Corps has required us to follow their rules including protective clothing and behavior. Please obey all of the rules detailed by the trip leaders and your field trip will be enjoyable and informative.

REFERENCES

Bettis, E.A., III, Kemmis, T.J., Witzke, B.J., 1985, After the great flood: exposures in the emergency spillway, Saylorville Dam. Geological Society of Iowa Guidebook -43 , 81 p. available as downloadable pdf file at http://www.iowageology.org/gsiGuidebooks.htm.

Simpkins, W.W. 1993, Water, water, everywhere. Geological Society of Iowa Guidebook 58 and 57th annual Tri-State Geological Field Conference, 139 p. available as downloadable pdf file at http://www.iowageology.org/gsiGuidebooks.htm.

US Army Corps of Engineers (1), History, http://www2.mvr.usace.army.mil/Saylorville/History.cfm

THE IOWA FLOODS OF 2008

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Figure 1. Aerial photograph (looking north) of downtown Cedar Rapids being flooded by the Cedar River in June 2008. The cost of repair and replacement of damages in the 1,300 city blocks (9.2 square miles) flooded is estimated to exceed $1 billion, with another $850 million needed to construct protection from future floods.

INTRODUCTION

The Iowa flood of 2008 was a hydrological event involving most of the rivers in central and eastern Iowa beginning around June 8 and ending in early July, 2008. Major rivers that experienced flooding included (from north to south, east to west), the Upper Iowa River, the Turkey River, the Maquoketa River; the Wapsipinicon River, the Cedar River (and its significant tributaries the Shell Rock and Winnebago rivers), the Iowa River, the Skunk River, and the Des Moines River. The Upper Mississippi River which receives the outflow from all these rivers remained at flood stage for many weeks (Wikipedia, 2009).

The cities of Cedar Rapids and Iowa City experienced the greatest monetary flood damage. Recovery, particularly for Cedar Rapids (Fig. 1), is considered to be a protracted and costly affair. At Iowa City the crest of the Iowa River, and the associated damage, was less than predicted, however at of Cedar Rapids the Cedar River's flood crest and related damage was much higher than anticipated. In Iowa City (Fig. 2), vulnerable University of Iowa buildings on the Iowa River floodplain, especially the arts campus, literature facilities, and physical plant, bore the brunt of the damage, estimated to ultimately reach $743 million.

Figure 2. Aerial photograph (looking north) of 2008 flooding of the University of Iowa's arts campus by the Iowa River. The building with the orange roof (lower left) is the new Art West building. Cost of damage, repair, and replacement of flooded facilities on the University campus is estimated to exceed $743 million.

The Des Moines River also experienced flooding in 2008, with damage inflicted on U.S. Army Corps of Engineers' Saylorville Lake and Dam facilities as well as the down-stream city of Des Moines. At Saylorville, the lake level reached maximum flood stage and water rushed through the emergency spillway for 12 days. Initial estimates suggest that the 2008 flooding caused $25 million damage at the Saylorville facility.

The levee in the Birdland area of north Des Moines has been known as a weak spot in the city's flood-control system for years (Environmental News Service, 2008). Constructed in the 1950s, the levee was originally poorly built and was further weakened over the years by tree roots, according to officials of the U.S. Army Corps of Engineers. A 2003 Corps report called for nearly $10 million in improvements across Des Moines, but money to complete all of the work was not available. As flood waters rose in 2008, Des Moines city crews and National Guard units had worked to build a temporary berm to reinforce the Birdland levee, but by midmorning on Saturday, June 14, 2008, the flood waters had cut through mounds of dirt and sandbags to inundate the homes and other buildings in the area (Fig. 3), including North High School.

An erroneous story that circulated in many media outlets (e.g. Wikipedia, 2009) stated that the 2008 flooding in the Des Moines area was moderated by the flooding of abandoned coal mines beneath Des Moines, which supposedly trapped "an estimated 300,000 acre feet of Raccoon and Des Moines river flood water in the labyrinthine shafts and corridors a few feet beneath the land surface." What this story failed to consider was that all of these shafts and corridors were already naturally flooded with groundwater, leaving no space for flood waters.

The 2008 floods were classed as “100-year” floods or greater in most areas. The term "100-year flood" is misleading because it leads people to believe that it happens only once every 100 years. The truth is that an uncommonly big flood can happen any year. The term "100-year flood" is really a statistical designation, and there is a 1-in-100 chance that a flood this size will happen during any year. Perhaps a better term would be the "1-in-100 chance flood" (U.S. Geological Survey, 1996). The “500 year flood” indicates that there is a 1-in-500 chance that a flood this size will happen during any year or a 1-in-500 chance that that area will flood in a given year. The actual number of years between floods of any given size varies a lot. Big floods happen irregularly because the climate naturally varies over many years. We sometimes get big floods in successive or nearly successive years with several very wet years in a row.

Figure 3. Aerial photograph (looking south down Second Avenue) showing flooding in the Des Moines Birdland area near the Des Moines River after a levee breach . A mandatory evacuation was ordered for 270 homes, however many residents of the area already had left after a voluntary evacuation request was issued on the previous day.

ORIGINS OF THE 2008 FLOODING

The year 2007 was the fourth wettest year in Iowa’s recorded history, with the winter of 2007-2008 particularly severe in the northeastern portion of Iowa. A heavy snow cover persisted in many areas of the state until early spring rains. The first six months of 2008 were the wettest recorded in Iowa, with a statewide average precipitation of 24.30 inches (7.96 inches above normal for the first half of a year). Beginning in the last week in April, the state experienced heavy rain, particularly in the form of thunderstorms, which saturated the soils. The period from May 29 through June 12 was exceptionally wet, with a statewide precipitation average of 8.99 inches for the 15 day period. Extremes of rainfall for the period were recorded at Massena (Clark County) which received 15.05 inches and Dorchester (Allamakee County) with 15.13 inches. The normal precipitation for that 15-day period is 2.45 inches. In Late-May 2008 a record sequence of tornados struck Iowa producing 12 fatalities and bringing even more huge downpourings of rain when thunderstorm systems stalled. Things were not much better in June when non-flood related severe weather was reported in 97 of Iowa's 99 counties, with severe storms, including heavy rains (Fig. 4) reported somewhere in Iowa on 21 of the 30 days in June.

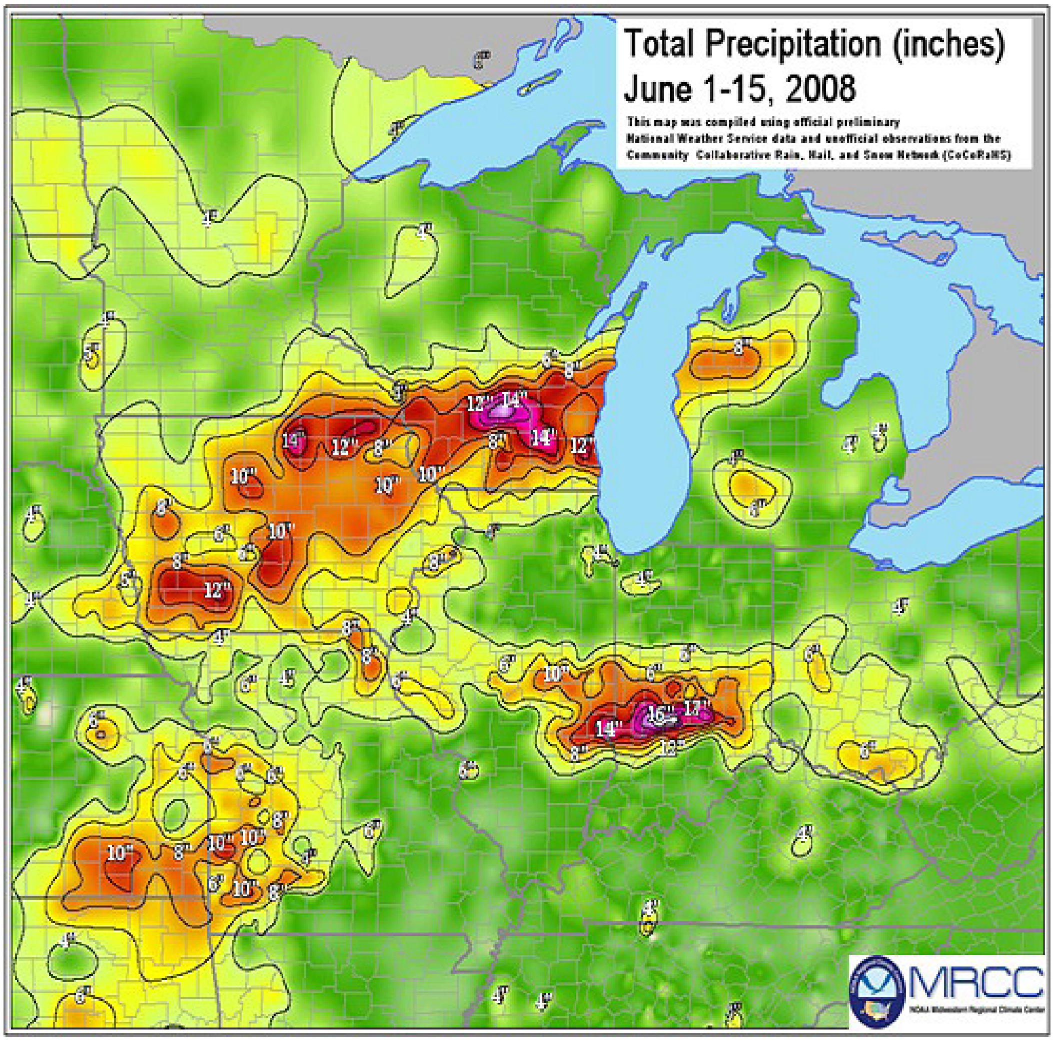

Figure 4. Map showing total precipitation for June 1-15, 2008, in the states of the upper Midwest.

During late May and early June, the jet stream pattern in the U.S. featured a trough in the west and ridge in the east. This pattern resulted in enhanced southwesterly flow at upper levels in the Midwest and enhanced southerly flow at low levels. These conditions acted like a conveyor belt moving moisture up from the Gulf of Mexico into the upper Midwest.

EFFECTS OF THE FLOODING

While the Great Flood of 1993 had a greater affect on the Midwest of the US, for Iowa the June, 2008 floods were considerably more damaging. Lessons learned in 1993, however, helped prevent or otherwise ameliorate what could have been even more extensive damage. The city of Des Moines presents one example the lessons learned. After the 1993 floods the city raised its levee around its domestic water and sewage treatment plants, saving them from being devastated again in the 2008 flooding. Other areas were not so quick to take a lesson from the 1993 event, and they suffered greatly in 2008. Key among these were the Cedar Rapids and Iowa City areas, where the flooding exceeded that of 1993, forcing hundreds of people to evacuate their homes, devastating businesses, and causing hundreds of millions of dollars in damage.

Flooding in Cedar Rapids

Cedar Rapids had experienced severe flooding on numerous occasions, the most severe being in 1851, 1965, and 1993, so the city thought that they were prepared when the Cedar River neared flood stage in 2008. The city had constructed its sandbag dikes and made all the preparations for a predicted June 6 crest of 19 feet, matching the crest of the 1993 flood and 5 feet above the 14 foot flood stage. When the Cedar River reached 19 feet on June 6, it continued to rise for another week, reaching a new record of 31 feet on June 13, 2008, 12 feet higher than predicted and 11 feet higher than 1851's previous record. The higher than predicted crest was due in large part to a 5 inch rainfall upstream from Cedar Rapids around June 12 that added to the crest (Fig. 5).

Cedar Rapids was totally unprepared for this record crest. Over 1,300 city blocks (9.2 square miles) were flooded, with 5,340 homes damaged, and 10,000 people evacuated from their homes. Additionally, 1,049 commercial properties were damaged, with between 6,000 and 7,000 jobs lost. Five bridges and the downtown district were inundated (Fig. 1), a railroad bridge was destroyed, and the city's sewage treatment plant was destroyed, forcing the city to pump up to 25 million gallons of raw sewage a day into the Cedar River for months. The oldest mosque in the United States, the Mother Mosque, was flooded, and many museums and cultural landmarks, including the National Czech and Slovak Museum and Library and the Cedar Rapids City Library were badly damaged. Flood damage in Cedar Rapids will exceed $1 billion, with over $569 million damage to Cedar Rapids city property alone.

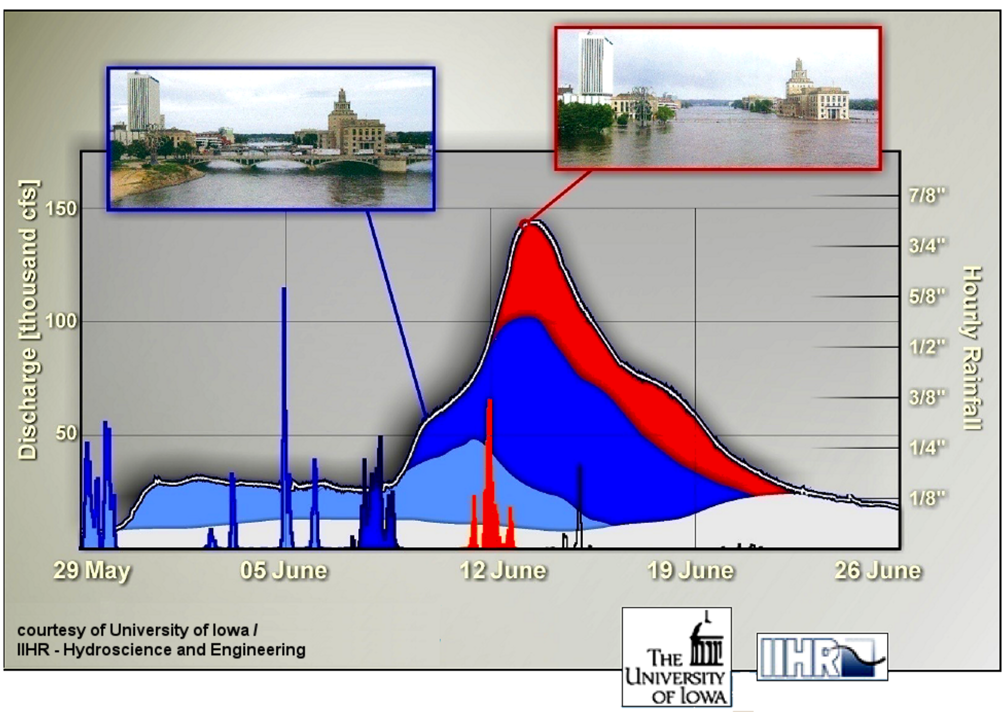

Figure 5. Graph showing discharge. The curved line shows Cedar River discharge at Cedar Rapids from late May through late June, with shaded areas under the curve relating portions of the discharge to periods of rainfall, shown by vertical bars.

Flooding in Iowa City

The City of Iowa City and the University of Iowa, like Cedar Rapids were not prepared for the magnitude of the flooding in 2008. Iowa City took few lessons from the flooding that inundated the town in 1993. The 1993 flood waters had barely subsided when contractors began work on an extensive condominium complex on the Iowa River floodplain in the Idlewild area on the north side of Iowa City. To be consistent with city code, the condominiums were built on earthen pads that raised the structures 1 foot above the FEMA 100 year flood line; as can be seen in Figure 6 this provided little protection. This was one of numerous projects that included floodplain filling in Iowa City after the 1993 flood. This floodplain filling reduced the space available for flood waters, raising the flood levels.

Figure 6. Aerial photo of the flooded Idlewild condominium complex and Parkview Church (right) in northern Iowa City.

On June 15, 2008, the Iowa River in Iowa City reached a record flood level of 31.5 feet, 3.5 feet above the previous (1993) record and 6.5 feet above flood stage. Although the flooding affected only a small area of Iowa City, 500 to 600 homes were ordered to be evacuated and hundreds of others were under a voluntary evacuation (MSNBC, 2008).

On the University of Iowa campus the rising flood waters brought out thousands of volunteers to construct sandbag levies along the Iowa River where it crossed the campus in Iowa City. The dikes were built and rebuilt as much as three times, as flood crest estimates continued to rise, but they were ultimately compromised by the flood waters, inflicting severe damage to many university buildings.

Although the floods of 1993 had inflicted $6 million damage on University of Iowa facilities, the university also continued an active program of building construction on the Iowa River floodplain after the 1993 flood. The new $21.5 million Art Building West, with an award winning design by Steven Holl that was dedicated in 2006 suffered $8.9 million damage in the flood of 2008 (Fig. 2), and the Adler Journalism Building, dedicated in 2005, suffered $3.5 million damage. They were two of the 20 buildings (about 2.8 million square feet of campus facilities) that were flooded, including Hancher Auditorium (the performing arts center) and Voxman Music Building complex ($26 million damage), Frank O. Gerry designed Advanced Technology Labs ($42 million damage), the Mayflower dormitory (the largest on the campus with $8 million damage), and the University's Power Plant ($20.1 million damage). The total estimated University of Iowa 2008 flood recovery cost is now $743 million (The Cedar Rapids Gazette, 2008).

Flooding at the Saylorville Dam

The flood of 2008 had a great impact at the Saylorville Dam. The high water level of Saylorville Lake forced the closure of State and local parks and numerous roads. Water ultimately went over the emergency spillway for the 4th time in the in Saylorville Lake history. Many compared the 2008 flood to the floods of 1993. In reality, the 2008 flood at Saylorville Lake was not as severe as 1993.

1993 Flooding. 1993 brought 2 floods to Saylorville Lake. The first flood began in late March with an increase in lake level of 46 feet in just 18 days. Water flowed over the Emergency

Spillway for nine days from April 22-May 1. Maximum lake level was 886 feet msl on April 27. The second flood came in June and July. Water started flowing over the Emergency Spillway on June 17 and continued for 42 days. The record lake level of 892.03 msl was reached on July 11.

Figure 6. Coarse limestone aggregate used in the post-1993 spillway reinforcement can seen in the overturned concrete slab on the left. For scale DOT geologist Adriana Reyes-Phelps stands on the right.

The huge volume and energy of the floodwaters surging through the emergency spillway twice in 1993 cut deeply into the bedrock, adding depth and width to the canyon first cut by flooding in 1984. Of special concern was the undermining and erosional retreat of the sandstone ledge on which the spillway was constructed. This concern led to the reinforcement of large areas of the spillway with special concrete containing large limestone blocks in the aggregate (Fig.6). These reinforcement efforts helped to reduce further damage to the emergency spillway during the flooding in 2008, but much of the concrete was ultimately ripped up and will probably need extensive repairs.

After the floods of 1993, pneumatic crest gates were added to the top of the Emergency Spillway. These gates allow for an extra 6 feet of storage before water flows over the spillway (see page 3 of this guidebook for more information and photographs). They were used for the first time in 2008. The gates performed as designed, but had to be lowered as the lake level continued to rise, threatening to over-top them.

2008 Flooding. In the spring of 2008 the Des Moines River quickly reached flood levels, with large volumes of snow melt and heavy spring rains quickly filling Saylorville Lake. As lake levels neared the 840 foot elevation of the top of the emergency spillway, the Corps of Engineers raised the pneumatic gates adding 6 feet to the lake's capacity. However, flood waters continued to rush into the lake and the lake level continued to rise until on June 12 the 890.99 foot maximum lake level was reached and the pneumatic gates were lowered to prevent damage. This sent water surging over the emergency spillway, and it continued to flow for 12 days (Fig. 7). The maximum inflow of water into Saylorville Lake during 2008 was 60,600 cubic feet per second (cfs), far exceeding the 47,100 cfs maximum in 1993. The 891.03 foot crest at the Lake in 2008 was slightly less than the 1993 record crest of 892.00 feet. The 2008 peak outflow from Saylorville Lake was 47,000 cfs, greater than the 44,500 cfs peak in 1993. The 2008 flood utilized 105% of the controlled storage capacity of the Saylorville Dam and Lake. The flood was considered to be greater than the predicted 500 year flood.

After the flood waters receded, the extent of the damage to the facilities in the Saylorville Lake and Dam area became evident. Initial assessments suggest $25 million damage to Saylorville facilities. Several downstream parks and popular access points along the Des Moines River were closed until damage could be repaired, and some remain closed. Cottonwood and Bob Shelter Picnic Areas are scheduled to open on schedule in April and May. Repairs are planned for 9 campsites along the east side of the river in Bob Shelter Campground. Two significant areas will remain closed for the 2009 recreation season. NW 78th Avenue which connects the dam and Bob Shelter Park with Beaver Drive is not expected to be repaired in time for the recreation season. Access to the Saylorville Gorge, a popular spot for fossil hunting, will be prohibited due to safety concerns.

Figure 7. 2008 flood waters began flowing over the Saylorville Dam emergency spillway (left) on June 28 and continued to surge through the spillway (right). Photos compliments of Michael Coltrain, U.S. Army Corps of Engineers.

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REFERENCES

Cedar Rapids Gazette, 2008, University of Iowa's new flood damage estimate: $743 million. http://data.desmoinesregister.com/flash/UnivIowaflooding.swf.

Des Moines Register, 2008, Flood Damage at University of Iowa Campus. http://data.desmoinesregister.com/flash/UnivIowaflooding.swf.

Environmental News Service, 2008, 500 Year Flood Submerges Iowa. http://www.ens-newswire.com/ens/jun2008/2008-06-16-01.asp

MSNBC, 2008, Hundreds Forced to Flee Homes in Iowa City. http://www.msnbc.msn.com/id/25020185

U.S. Geological Survey, 1996, The "100-Year Flood." Fact Sheet 229-96, http://pubs.usgs.gov/fs/FS-229-96/.

Wikipedia, 2009, Iowa Flood of 2008. http://en.wikipedia.org/wiki/Iowa_flood_of_2008

QUATERNARY HISTORY OF THE SAYLORVILLE LAKE AREA

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PREFACE

Today's trip will focus on bedrock deposits associated with the Saylorville Emergency Spillway which occurs along the western margin of the present Des Moines River Valley in Polk County. At this time all Quaternary exposures are deemed unstable and are off limits for close viewing. During the Summer and Fall of 1984, IGS staff visited the emergency spillway to view recently exposed sections. At that time five Quaternary stratigraphic units were described and identified, and a number of cross sections were prepared of these exposures from photo mosaics. These exposures were unique in affording a rare view of the Wisconsinan and older fine-grained alluvial deposits occupying a buried bedrock valley which is cut successively through the Pennsylvanian-age Swede Hollow and Floris Formations. The emergency spillway sequence includes deposits of glacial, glaciofluvial, eolian, alluvial and colluvial origin. The discussion today will focus on the general Quaternary history of the Central Des Moines River Valley (DMV).

EARLIER PLEISTOCENE STUDIES OF THE CENTRAL DES MOINES RIVER VALLEY AREA

The first geological investigations of the area were completed in the 1840's under the direction of David Dale Owen and published in 1852 complete with a map of the valley and a lithograph with geologic sections. In the 1880's Upham (1880) and Chamberlin (1883) mapped the upper Des Moines River Valley. Both recognized two moraines on the Des Moines Lobe (DML). The outer moraine was named the Altamont Moraine and presumed to be a contiguous ridge running through Altamont, South Dakota. Chamberlin mapped the inner moraine as the Gary Moraine, presuming it was the contiguous ridge running through Gary, South Dakota. This terminology was adopted by the Iowa Geological Survey and used in county reports in Boone, (Beyer, 1895) and Polk (Bain, 1897). Nearly a century ago a dispute erupted between geologists H.F. Bain and James H. Lees as to the age of the valley. Bain maintained that the valley above Beaver Creek (near Saylorville Dam in Polk County) was late Wisconsin in age and related to the DML. Meanwhile Lees (1916) concluded at a later date that the valley above Des Moines, Iowa was pre-Wisconsin and probably "Kansan" in age. Earlier, Bain (1897) had concluded that Beaver Creek, which headed on an earlier advance of the DML, had reoccupied an older Pre-Wisconsin valley in the Des Moines area. More recent studies (Bettis and Hoyer, 1986) agreed with Bain that the valley above Beaver Creek is very young and related to the drainage of the DML and this conclusion was confirmed in drilling investigations (Quade, personal communications) that described approximately 70 feet of DML associated outwash overlying

Pennsylvanian bedrock in Beaver Creek deposits. To his credit, Lees (1916) recognized three benches in the DMV: 1) one ranging 10 to 30 feet (3 to 9 m) above the river and forming the immediate boundary with the floodplain (Holocene High Terrace), 2) another level ranging 50 to 60 feet (15 to 18 m) above the river and 3) an uppermost level ranging from 70 to 100 feet (21 to 30 m) above the bottoms. He recognized that the gravels on the upper levels were Wisconsinan-age and that downcutting was intermittent.

In 1922 Leverett extensively revised the nomenclature and mapping of moraine systems on the Des Moines Lobe (Leverett, 1922). He recognized that the outer margin of the Des Moines Lobe did not pass through Altamont, South Dakota, but instead Bemis, South Dakota. He proposed the Bemis Moraine as the terminal moraine of the DML. In addition, he identified that the former Gary Moraine was actually the ridge passing through Altamont, South Dakota. Later Smith (1924) would identify two moraines north of the Altamont, the Humboldt and Algona.

Ruhe (1952) conducted an extensive remapping of the DML, significantly changing the extent and location of moraine systems. He included extensive "minor moraine" areas (first identified by Gwynne, 1942) within the end moraines. With the development of radiocarbon dating, it was found that Des Moines Lobe sediments were deposited 14,000 to 13,000 RCYBP (radiocarbon years before present) and reclassified as Cary-age (Ruhe and Scholtes, 1959).

In August 1965, the VIIth congress of the International Association for Quaternary Research (INQUA) hosted a field trip to various localities in the Upper Mississippi Valley (Schultz and Smith, 1965). The trip passed through the DMV west of Boone and mention was made of three distinct terrace levels, Cary and post glacial-age. In addition, the road cut for then new U.S. highway 30 on the western valley was visited. The cut exhibited the typical stratigraphy found in upland positions in the southern portion of the Des Moines Lobe: 22 feet (6.8 m) of Des Moines Lobe till overlying 15.3 feet (4.7 m) of loess overlying "Kansan" till. Wood from the loess was radiocarbon dated at 16,000+/-1000 RCYBP (I-1270).

INTRODUCTION

The generalized Quaternary stratigraphy of the Saylorville Lake area and Central DMV is well understood and has been the subject of several recent investigations (Bettis and Hoyer, 1986, Bettis et al., 1985). Pennsylvanian rocks of the Cherokee Group (Swede Hollow and Floris Formations) are the oldest rocks exposed. A hiatus of approximately 280 million years separates the Pennsylvanian rocks from the overlying Quaternary deposits. The oldest Quaternary deposits in the area bury the Pennsylvanian rocks and consist of interbedded Pre-Illinoian tills and sand and gravel that may be separated by paleosols. Investigations north of the Saylorville, at the Brushy Creek dam site in Webster County revealed Pre-Illinoian age tills (both Wolf Creek and the older Alburnett Formation) are present (Hallberg, 1980). These deposits are at least 500,000 years old (Hallberg, 1980 and Hallberg and Boellstorff, 1978). It is common for a paleosol to separate Pre-Illinoian deposits from the overlying Wisconsin-age sediments. Paleosols in this stratigraphic position include the Yarmouth-Sangamon, Sangamon, and Late-Sangamon paleosols. The paleosols may be developed in till, alluvium, or colluvium. In some areas the pre-Wisconsinan paleosols may be eroded off prior to deposition of Wisconsinan-age sediments. Where present, Wisconsinan-age loess buries the eroded and pedogenically altered Pre-Illinoian deposits. The A-C profile is developed in the lower portion of the loess and this soil is informally known as the basal loess paleosol or the Farmdale Geosol of the Pisgah Formation (Bettis, 1990). In this part of the state the Farmdale Geosol appears to have developed between 21,000 to 23,000 years ago (Bettis and Hoyer, 1986). Numerous radiocarbon dates indicate that loess began accumulating on the landscape around 21,000 years ago and was buried by the advancing DML ice around 14,000 years ago (Ruhe, 1969).

OVERVIEW OF THE DES MOINES LOBE ADVANCE IN IOWA

The distinctive landform region called the Des Moines Lobe formed from a lobate extension of the last great continental glacier. During the Wisconsinan Episode, the southern edge of the Laurentide Ice Sheet split into several lobes that each flowed down regional topographic lows. The Des Moines Lobe extended from central Canada through the Dakotas and Minnesota into Iowa, terminating at what is now the City of Des Moines (Figure 1).

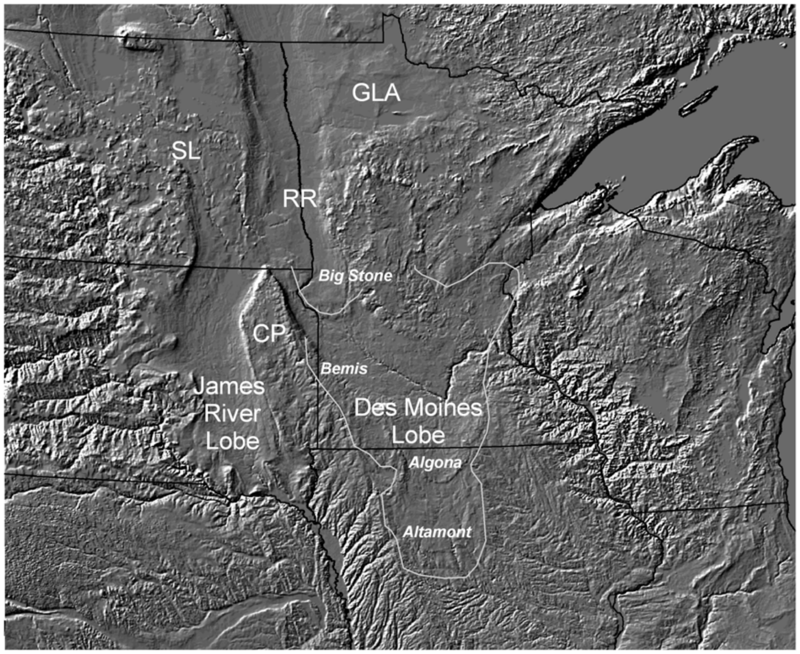

Figure 1. Location of the Des Moines Lobe in the Upper Midwest and the Coteau des Prairies (CP), Glacial Lake Souris (SL), Red River Valley (RR) and Glacial Lake Agassiz (GL).

The Des Moines Lobe was active in Iowa between about 15,000 and 12,000 RCYBP, about 5,000 to 8,000 years later than glacial lobes to the east made their southernmost maximum advance (Johnson, 1986; Fullerton, 1986). The Lobe advance occurred well into a period of regional warming and was thus climatically out of equilibrium (Kemmis et al., 1994). Ice thickness reconstructions indicate that the lobe was probably thin and gently sloping (Mathews, 1974; Clark, 1992; Brevik, 2000; Hooyer and Iverson, 2002). Clark (1992) reconstructed the Lobe's thickness near Ames, Iowa, at ~80 m. More recently, ice reconstructions by Hooyer and Iverson (2000) were based on a model assuming the Bemis Moraine was ice-covered, which yielded ice thickness estimates of ~250 m. Despite these variations, all agree that the Des Moines Lobe ice sheet was extremely thin and gently sloping. This ice advance was rapid and episodic, and was most likely fueled by basal lubrication; in other words, a warm-based, non-deforming bed glacier. These assumptions are backed up by evidence of numerous plants (Baker et al., 1986) and trees (Bettis et al., 1996) found near the base of the DML package. The complex landform sediment assemblages found on the DML in Iowa seem more indicative and explained by regional stagnation by a surging-type glacier, not rapid recession.

The age of the Des Moines Lobe is well established by radiocarbon dates (Bettis et al., 1996). The Lobe entered Iowa shortly before 15,000 radiocarbon years before present (RCYBP) and reached the terminal position at Des Moines about 13,800 RCYBP. After reaching its terminus the glacier stagnated. The lobe readvanced to the position of the Altamont ice margin just north of Ames and Boone about 13,500 years ago, then stagnated. Between 13,500 and 12,600 RCYBP, there were three minor readvances marked by the Clare, Renwick, and West Bend moraines. The morainic topography associated with these advances is discontinuous, and only the terminal margins are recognized. The final advance into Iowa, the Algona ice margin, occurred about 12,300 RCYBP (Figure 2). This advance also was followed rapidly by stagnation and wastage of the glacier. It was during the Algona advance that the upper Des Moines River, the major axial drainage of the Lobe, originated (Bettis and Hoyer, 1986).

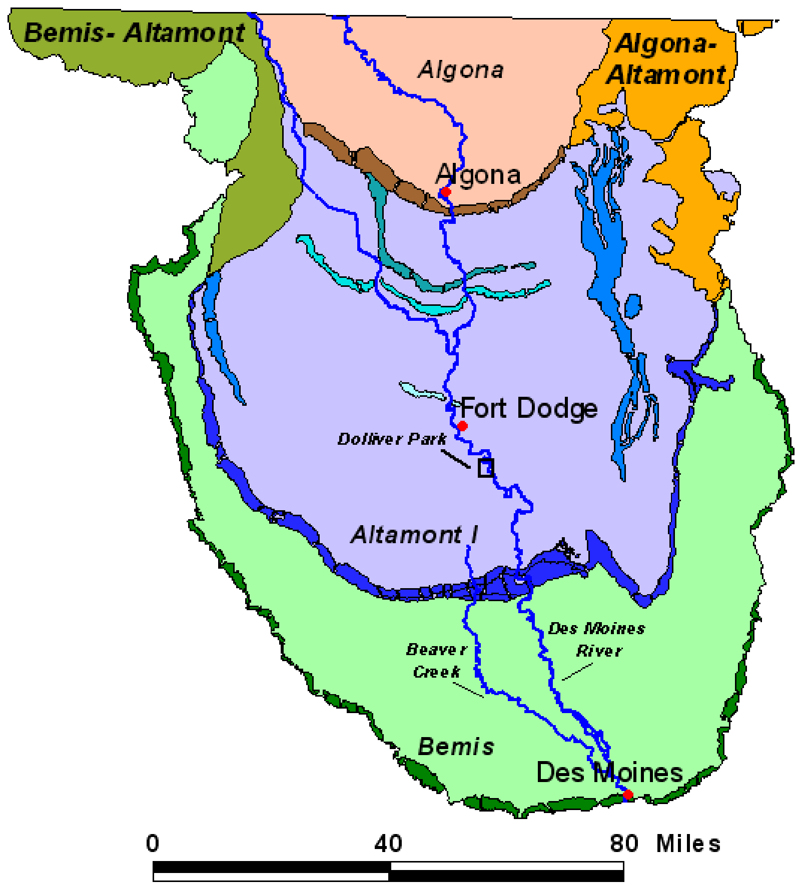

Figure 2. Extent of Des Moines Lobe in Iowa with end moraines. The Des Moines River and Beaver Creek valleys are shown for reference to Des Moines Lobe moraines. The Saylorville Lake Area is located north of Des Moines and the confluence of Beaver Creek and Des Moines Valley.

BRIEF QUATERNARY HISTORY OF THE SAYLORVILLE LAKE AREA

As mentioned earlier, historical discussions concerning the Des Moines River valley centered on the age and origin of the valley. More recent studies (Bettis and Hoyer, 1986) summarized and expanded on investigations of the DMV. Their comments noted that the nearby Beaver Creek valley ended abruptly at the Altamont Moraine in Greene County and surmised that Beaver Creek was functioning as an outwash channel when the DML stood at that position. The interbedded nature of sand, gravel and till may suggest that the channel was subglacial when the DML stood at the terminal Bemis front. After ice retreated north of the Altamont position, Beaver Creek no longer carried outwash and the active stream became confined to a narrow meanderbelt within the broad Beaver Creek Valley (nearby Camp Dodge area). In the DMV, initial valley formation is related to downcutting by meltwaters issuing from the DML when the ice margin sat at the position of the Algona Moraine, the youngest advance of the DML in Iowa. A sequence of discontinuous, unpaired late Wisconsin terraces were formed between 12,600 years to perhaps 11,000 radiocarbon years before present (RCYBP). Kemmis et al., 1988, in their investigations of the DMV noted that entrenchment in the Boone area had resulted in 220 ft of valley deepening over a relatively short period of time. The terraces associated with the DMV are "benched", therefore the outwash does not extend to the present floodplain. The late Wisconsin (LW) terraces are multi-leveled and indicate that there were multiple periods of incision and aggradation, with successive terraces benched progressively lower into glacial deposits or bedrock. The more extensive LW terrace deposits tend to occur high on the landscape and at the inside of valley meanders. These are the oldest LW terraces and may have been formed as meanders were cutoff by episodic flood events. The youngest LW terraces at lower elevations tend to have a narrower, longitudinal geometry. All of these terraces are capped with a sequence of coarse sand and gravel that represents greatly increased meltwater and sediment supply that are most likely related to subglacial lake outbursts (jökullups). On the DML, these gravel deposits are highly valued since they can be readily mined and in many places are able to be extracted without encountering the water table.

In 1984, an exposure along an eroded nose slope on the west side of Saylorville Lake was described after the high water levels of that year. This section is referred to as the 77 Acorn Valley Section. A complete discussion of this section is included in Bettis et al., 1985, and Figure 3 shows a cross section of that location. The stratigraphic sequence at this location is typical of the upland stratigraphy associated with the southern portion of the DML. At this location there is approximately 24 feet (7.3 m) of DML subglacial till (Dows Formation-Alden Member) overlying 9 feet (2.7 m) of loess (Peoria Formation-silt facies). At the base of the loess is a thin increment of pedisediment or slopewash materials that are identified as the basal loess sediments (BLS) that most likely were deposited during the Wisconsinan from approximately 21,000 to 16,500 years ago. In turn, the BLS overlies a Late Sangamon Paleosol developed in thin hillslope sediments overlying a weathered Pre-Illinoian till deposit.

OVERVIEW OF SLUMPED SPILLWAY SEDIMENTS

As you look Southeast (down) the emergency spillway you may see a thin, resistant ledge of Pennsylvanian limestone. The limestone is overlain by pre-Wisconsinan alluvium exposed at the base of slumped exposures. These sediments accumulated in a small tributary valley of the paleo-Des Moines River (presently Beaver Creek) prior to the development of the Sangamon Soil. Farther down the spillway the Pennsylvanian limestone is absent and late Wisconsinan deposits make up the entire exposed section. Most of the section consists of fossilferous (plant macrofossils, beetles, gastropods) alluvium that accumulated in a large wetland as the paleo Des Moines Valley aggraded during the advance of the Des Moines Lobe. The alluvium is overlain by Des Moines Lobe glacial diamicton with basal ages averaging 13,500 B.P. The fossil record in this alluvial package provides us with a detailed picture of the period between 16,200 and 13,500 B.P. when the Des Moines Lobe advanced into north-central Iowa. The general scenario is one of rapid, then continued warming as the glacier advanced to the terminal position. The record here is consistent with other, shorter paleoenvironmental records from Iowa, all indicating that an advance of the DML occurred during a warming interval.

Most of the Spillway exposures revealed five Quaternary stratigraphic units, from youngest to oldest: 1) Holocene-age alluvium and colluvium; 2) late Wisconsinan-age glaciogenic deposits (Des Moines Lobe deposits); 3) late Wisconsinan-age alluvium; 4) late Wisconsin-age loess; and 5) pre-Wisconsinan age alluvium. The geometry of the deposits was not a typical 'pancake layer' stratigraphy. Instead, the Holocene deposits, late Wisconsinan glaciogenic deposits and pre-

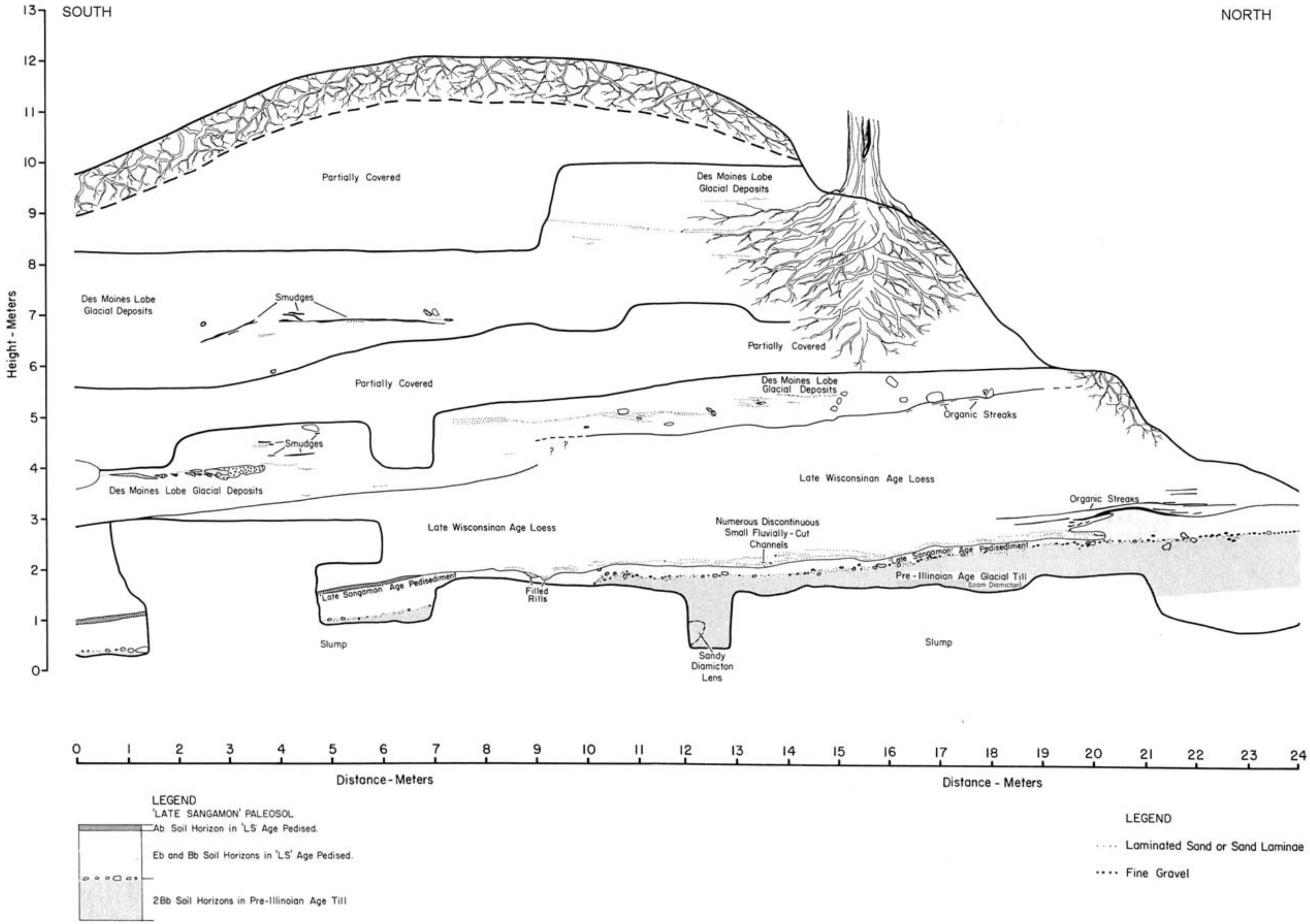

Figure 3. Detailed cross section of the Acorn Valley section (Bettis et al., 1985).

Wisconsinan age alluvium comprised multiple fills with cross cutting relationships. In addition, the Quaternary sequence is dominated by alluvial fills including Wisconsinan and Pre-Wisconsinan alluvial fills which are rarely preserved in stratigraphic section across the state. To view more detailed discussions on the past reconnaissance sampling and illustrations from the 1984 exposures please see *GSI Guidebooks 43 and 58*.

REFERENCES

Bain, H.F., 1897, Relations of the Wisconsin and Kansan drift sheets in central Iowa and related phenomena: Iowa Geological Survey Annual Report, v. 9, p. 49-107.

Baker, R.G., Rhodes, R.S. II, Schwert, D.P., Ashworth, A.C., Frest, T.J., Hallberg, G.R., and Janssens, J.A., 1986, A full-glacial biota from southwestern Iowa, USA: Journal of Quaternary Science, v.1, p. 91-107.

Bettis, E.A. III, Kemmis, T.J., Quade, D.J. and Littke, J.P., 1985, The Quaternary Deposits of the Emergency Spillway. In After the Great Flood: Exposures in the Emergency Spillway, Saylorville Dam. E.A. Bettis III, T.J. Kemmis, and B.J. Witzke, editors, pp. 2-1 -2-42. Geological Society of Iowa Guidebook 43, Iowa City.

Bettis, E.A., III, and Hoyer, B.E., 1986, Late Wisconsinan and Holocene landscape evolution and alluvial stratigraphy in the Saylorvile Lake area, central Des Moines River Valley, Iowa: Iowa Geological Survey Open File Report 86-1, 71 p.

Bettis, E.A., III, trip leader, 1990, Holocene Alluvial Stratigraphy and Selected Aspects of the Quaternary History of Western Iowa. Midwest Friends of the Pleistocene 37th Field Conference, Geological Survey Bureau Guidebook Series No. 9, 197p.

Bettis, E.A. III, Quade, D.J. and Kemmis, T.J., 1996, in Hogs, Bogs, and Logs: Quaternary Deposits and Environmental Geology of the Des Moines Lobe. Edited by: E.A. Bettis, III, D.J Quade, and T.J Kemmis. Iowa Department of Natural Resources-Geological Survey Bureau, Guidebook Series No. 18, 170 p.

Beyer, S.W., 1895, Geology of Boone County. Iowa Geological Survey, Annual Report V:177-239, Iowa City.

Brevik, E., 2000. Limits of ice thickness in Iowa during the Late Wisconsian: Journal of the Iowa Academy of Science, v.107, p. 46-50.

Chamberlin, T.C., 1883, Preliminary paper on the terminal moraine of the second glacial epoch: U.S. Geological Survey Third Annual Report, p. 291-402.Clark, P.U., 1992, Surface form of the southern Laurentide Ice Sheet and its implications to ice-sheet dynamics. Geological Society of America Bulletin, v. 104, p. 595-605.

Fullerton, D.S., 1986, Stratigraphy and correlation of glacial deposits from Indiana to New York and New Jersey, in Richmond, G.M. and Fullerton, D.S., eds., Quaternary Glaciations in the United States of America, in Sibrava, V., Bowen, D.Q., and Richmond, G.M., eds., Quaternary Glaciations in the Northern Hemisphere: Quaternary Science Reviews, v. 5, p 23-37.

Gwynne, C.S., 1942, Swell and swale pattern of the Mankato Lobe of the Wisconsinan drift plain in Iowa. Journal of Geology 50:200-208.

Hallberg, G.R., 1980, Pleistocene stratigraphy in east-central Iowa, Iowa Geological Survey Technical Information Series 10, 168p.

Hallberg, G.R. and Boellstorff, J.D., 1978, Stratigraphic "confusion" in the region of Type Areas of Kanasan and Nebraskan deposits. Geological Society of America Abstracts with Programs 10(6):255.Hooyer, T.S. and Iverson, N.R., 2000, Clast-fabric development in a shearing granular material: Implications for subglacial till and fault gouge. Geol. Soc. Am Bull., 112(5), 683-692

Johnson, W.H., 1986, Stratigraphy and correlation of the glacial deposits of the Lake Michigan Lobe prior to 14 ka BP, in Richmond, G.M. and Fullerton, D.S., eds., Quaternary Glaciations in the United States of America, in Sibrava, V., Bowen, D.Q., and Richmond, G.M., eds., Quaternary Glaciations of the Northern Hemisphere: Quaternary Science Reviews, v. 5, p.17-22.

Kemmis, T.J, Bettis, E.A. III, and Quade, D.J., 1994, The Des Moines Lobe in Iowa: a surging Wisconsinan glacier: American Quaternary Association, Program and Abstracts, 13th Biennial Meeting, Minneapolis, p. 112.

Kemmis, T.J., Quade, D.J., and Bettis, E.A. III, 1988, Part II, Hallet Gravel Pits, *in* Bettis, E.A. III, et al., Natural history of Ledges State Park and the Des Moines River Valley in Boone County: Geological Society of Iowa Guidebook 48, p. 37-71.

Lees, J.H., 1916, Physical features and geologic history of Des Moines Valley. Iowa Geological Survey Annual Report XXV:423-615.

Leverett, F., 1922, What constitutes the Altamont Moraine? Geological Society of America Bulletin 33:102-103.

Mathews, W.H., 1974, Surface profile of the Laurentide ice sheet in its marginal areas: Journal of Glaciology, v. 13, p. 37-43.

Ruhe, R.V., 1952, Topographic discontinuities of the Des Moines Lobe. American Journal of Science 250:46-56.

Ruhe, R.V.., 1952, Classification of the Wisconsinan Glacial Stage. Journal of Geology 60:398-401.

Ruhe, R.V., 1969, Quaternary Landscapes in Iowa: Iowa State University Press, Ames, IA, 255 p.

Schultz, C.B. and Smith, H.T.U., 1965, Upper Mississippi Valley, Guidebook for Field Conference C., VIIth Congress of the International Association for Quaternary Research.

Upham, W., 1880, Report of progress in exploration of the glacial drift and its terminal moraines. Minnesota Geological and Natural History Survey, 8th Annual Report: 371-446.

A SHORT HISTORY ON THE PHILOSOPHY OF PENNSYLVANIAN MIDCONTINENT CYCLOTHEMS

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INTRODUCTION

The coals, limestones, sandstones, clays, and shales of the Pennsylvanian Subsystem have been deposited in repeated cycles of land being covered by seas then exposed. These cyclic deposits of clay (fire clay), coal, shale, limestone, black shale, and sandstone are known to geologists as cyclothems. The term "cyclothem" was first established by Wanless and Weller (1932) who combined the Greek words *cyclos* and *thema*. *Cyclos*, obviously, means 'cyclic' in English while *thema* means 'deposit'; cyclothem literally means 'cyclic deposits' (Wanless and Weller, 1932).

EARLY 20TH CENTURY

One of the first geologists to notice the cyclical nature of Pennsylvanian rocks was Udden in 1912; in the vicinity of Peoria, Illinois, he observed four cycles of coal, shale, limestone, and fire clay (Heckel, 1984). Udden (1912) described each lithology as a separate stage in a cycle, "(1) accumulation of vegetation; (2) deposition of calcareous material; (3) sand importation; and (4) aggradation to sea-level and soil making." He interpreted this sequence as a succession which began with a coal swamp (accumulation of vegetation). Over time, a shallow sea depositing calcareous material (limestone) flooded the swamp. Afterwards, sandstone was deposited when sand and other clastics were brought in and deposited in the sea; upon exposure, weathering of the sediments produced soil (fire clay). Eventually, another coal swamp developed, and the cycle began anew (Heckel, 1984). The main driver for Udden's cyclothem model was simply changes in sedimentation patterns and weathering of preexisting sediments. As for black fissile shales, Udden believed they were deposited in shallow seas soon after inundation of the coal swamp but before deposition of the limestone (Heckel, 1984). Udden placed the base of each cycle at the base of the coal, in line with current thinking.

DIASTROPHISM

Later on, other ideas were developed in attempts to better explain Pennsylvanian cycles. These ideas usually centered on one of two things: nature of the black shales and identifying where one cycle ends and another begins. Most of the early ideas on the depositional environment of black shales were simply different flavors of Udden's (1912) shallow marine or nearshore model. Weller (1930) agreed with most of Udden's interpretations except for the sandstones (Heckel, 1984). Weller believed that fluvial channels deposited the sandstones, and therefore, the unconformity at the base of the sandstone would be the justifiable base of the cycle (Heckel, 1984). To better explain the black shales, Weller (1930) introduced the concept of 'algal flotants', "lowly organized plants, such as marine algae, may have been present in sufficient abundance to prevent the development of waves, and when they died they left no other trace than the carbonaceous content of the shales." Weller was also responsible for one of the most controversial concepts involving Pennsylvanian cyclothems, diastrophism (Heckel, 1984). Also called "yo-yo" tectonics, this model explained cyclothems through the repeated uplift and subsidence of the land surface over time. According to Weller (1930), the diastrophic cycle begins with uplift. Afterwards, clastics, possibly fluvial in origin, accumulated on the exposed surface. Following this, during a period of stability, non-deposition and thus erosion took place. Subsidence then occurred where poor drainage allowed coal swamps to develop. Seas flooded the land, and the resulting shallow sea deposited the limestone. Finally, more uplift started the cycle all over again. Unfortunately, Weller (1930) failed to propose an adequate mechanism that could explain the hundreds of uplifts and subsidence needed to deposit the many cyclothems throughout the Pennsylvanian.

MOVING ON…

Looking at the western part of the Midcontinent in Kansas and Nebraska, Moore (1929, 1931) noted that these cycles often contained three to four limestones with most of them yielding marine fossils. Looking at the sandy shales above and below these limestones, Moore noted that some contained marine fossils while others yielded plants and coal. In an attempt to explain these discrepancies, Moore proposed that the shales with the marine fossils were deposited in clear water (when interbedded with the limestones) while the shales with the plant fossils and coal were deposited in more turbid water. Tackling the black shales, Moore (1929) subscribed to a hypothesis similar to Weller's (1930) algal flotant hypothesis for some of the black shales. However, unlike in Illinois, the juxtaposition of some black shales to obviously marine limestones and shales in Kansas and Nebraska precluded peat bogs, coal swamps, or algal flotants as origins for all of the black shales in the Midcontinent. Moore (1929) believed in a marine origin for some of the black fissile shales although he believed that the organics and sulfides indicated that it was a very shallow, stagnant, toxic sea. The shallowness of this sea prevented wave action, tidal agitation, and oxygen circulation resulting in possibly an anoxic sea as well. However, the presence of marine fossils in many black fissile shales show that at least some of them were deposited in an environment somewhat healthier than what Moore proposed.

At the Illinois Geological Survey, Weller (1931) developed the 'ideal' or 'typical' Illinois cyclothem (Fig. 1). His model was similar to Udden's except that he identified a limestone between the sandstone and underclay which he interpreted as deposited in fresh-water ponds. He also noted that the black fissile shale was directly above the coal. Like Udden, Weller (1931) interpreted the black fissile shale as very shallow marine and part of the transgressive limb of the cycle. The limestone was noted as the most offshore unit in the cycle, thus becoming the highstand, point of maximum water depth (Weller, 1931).

Wanless and Weller (1932) attempted to mass correlate the cyclothems of Illinois, Iowa, western Missouri, eastern Kansas, and northeastern Oklahoma. They included the Verdigris (Ardmore) Limestone and Croweburg (Whitebreast) Coal to the Liverpool cyclothem of Illinois. The lower Chelsea Sandstone was included in either the Greenbush or Liverpool cyclothems of Illinois. Both the Ardmore Limestone and Whitebreast Coal occupy the uppermost complete cyclothem at the Saylorville Dam Emergency Spillway. The Chelsea Sandstone lies above and occasionally incised into the Tiawah Limestone and Tebo Coal of Oklahoma. At the Saylorville Dam Emergency Spillway, the Chelsea Sandstone would occupy the stratigraphic position between the Saylorville Coal and Elliot Ford Limestone.

WANLESS AND SHEPARD (1936)

In one of the better known papers in Pennsylvanian cyclothem history, Wanless and Shepard (1936) provided a much more realistic driver for cyclothems of the Midcontinent and elsewhere, the one that is accepted today. They proposed that the growth and shrinkage of glaciers in the Southern Hemisphere created worldwide (eustatic) sea level changes. This glacier-driven rise and fall of sea level occurred hundreds of time throughout the Pennsylvanian and Permian. As glaciers shrank (melted) the input of water caused a rise in sea level, covering large portions of low-lying land. Because the slope of the land in what is now the Midcontinent was fairly gradual,

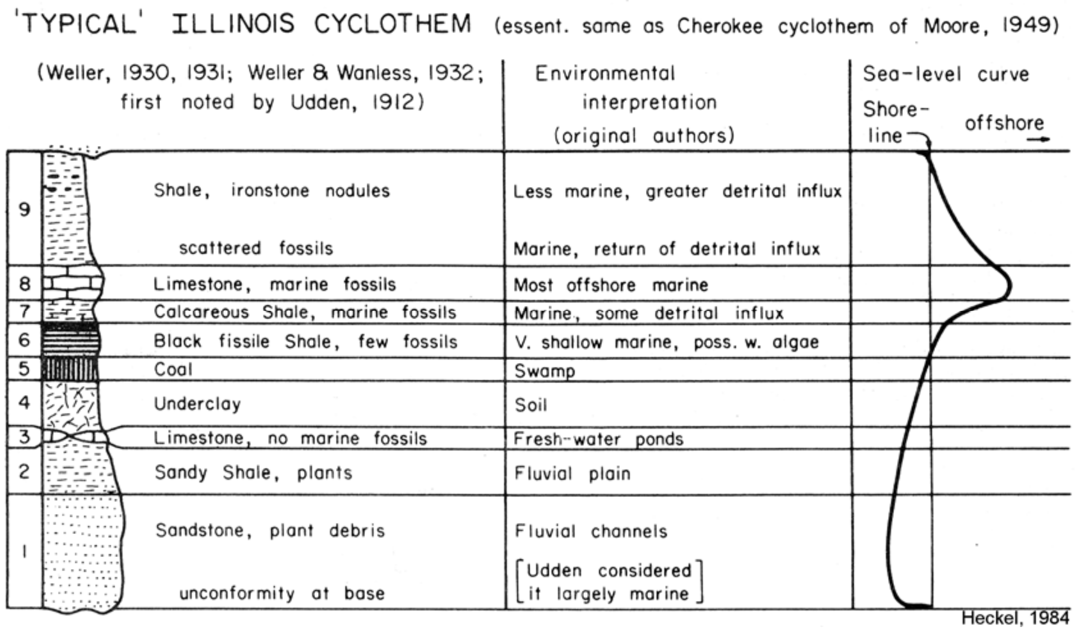


Figure 1. Typical or ideal Illinois cyclothem from Weller (1931), note placement of highstand at limestone instead of black fissile shale. In Illinois cyclothems, the black fissile shale often overlies the coal. Also note freshwater limestone (unit 3). from Heckel (1984)

a moderate rise in sea level would inundate large portions of land allowing the shoreline to invade far inland, a process known as transgression. This resulted in a widespread deposition of marine shales and limestones. The buildup of glaciers locked up water resulting in the fall of sea level. Sea level fall would expose the previously inundated land allowing for the development of ancient soils (paleosols). Fluvial sandstones would also be deposited as rivers made their way across the landscape. The retreat of the sea from the land is known as regression. As sea level began to rise again, a coastal swamp would develop during very early transgression resulting in the deposition of coal.

Wanless and Shepard (1936) also recognized three basic types of North American cyclothems: piedmont, deltaic, and neritic. The type of cyclothem one encountered was largely controlled by geographic distribution. The piedmont type was deposited in the Appalachian Mountains and southern Illinois near the source area. These cyclothems were largely terrestrial with a few poorly developed marine intervals. The piedmont-type cyclothem usually exhibits the thickest and most well-developed coals and paleosols of Pennsylvanian cyclothems. In Illinois and the eastern part of the Midcontinent (including eastern Iowa), the cyclothems were farther from the source area but still received a high influx of siliciclastic material. Here, the delta-type cyclothem prevails. While coals and paleosols are not as thick or as well-developed as in the piedmont-type cyclothem, the presence of clastics prevented significant amounts of limestone from forming. The neritic cyclothem developed more offshore so marine deposits are dominant. Limestones are thick and well-developed while coals and paleosols are not. Furthermore, the marine black fissile shale is the most thickest and widespread in neritic-type cyclothems. Neritic-type cyclothems dominate the western part of the Midcontinent (Kansas, Oklahoma, Nebraska, and western Iowa). Of course, there are exceptions to the rule, and all three types of cyclothems can be encountered outside of their primary geographical area.

MEGACYCLOTHEMS

Moore (1936) created the megacyclothem model to reconcile his earlier observations of cyclothems in the western part of the Midcontinent with the relatively simpler Weller (1931) Illinois model of Pennsylvanian cyclothems. He listed the components of an "ideal" Midcontinent cyclothem (Fig. 2) with their corresponding 'Dewey decimal' numbers (referring to lithologic homologues with other Pennsylvanian cyclothems) as:

"*.9. Shale (and coal).*
.8. Shale, typically with molluscan fauna.
.7. Limestone, algal, molluscan, or with mixed molluscan and molluscoid fauna
.6. Shale, molluscoids dominant.
.5. Limestone, contains fusulinids, associated commonly with molluscoids.
.4. Shale, molluscoids dominant.
.3. Limestone, molluscan, or mixed with molluscan and molluscoid fauna.
.2. Shale, typically with molluscan fauna.
.1. c. Coal.
.1. b. Underclay.
.1. a. Shale, may contain land plant fossils.
.0. Sandstone." (Moore, 1936)

The highstand of this cycle was placed at unit 0.5, the limestone with fusulinids (Fig. 2). Some of the Upper Pennsylvanian Kansas cyclothems were quite complex with smaller repeated packages of shale and limestone. Additionally, each of these shale-limestone couplets must be a genetically related part of a much larger package. In an attempt to better explain these more complex cyclothems, Moore (1936) viewed the complexities of the cyclothems of the Upper Pennsylvanian Shawnee Group within the context of his "ideal" cyclothemic succession (Fig. 3). Moore envisioned these more complex cyclothems as a succession of related smaller cycles, in effect, a megacyclothem:

> *"The repeated succession of cyclothems of differing character indicates a rhythm of larger order than that shown in individual cycles and suggests the desirability of a term to designate a combination of related cyclothems. The word "megacyclothem" will be used in this sense to define a cycle of cyclothems." (p. 29)*

Moore (1936) continued to elaborate on his 'cycle within a cycle' concept:

> *"Careful analysis of this succession of units leads to the conclusion that we are dealing here not with a single unbroken rhythm in types of sedimentation, marked by the uniform direction of changes in what might be termed respectively transgressive and regressive hemicycles, but there is indication rather of oscillations that are superimposed on a large cyclic movement." (pp. 31-32)*

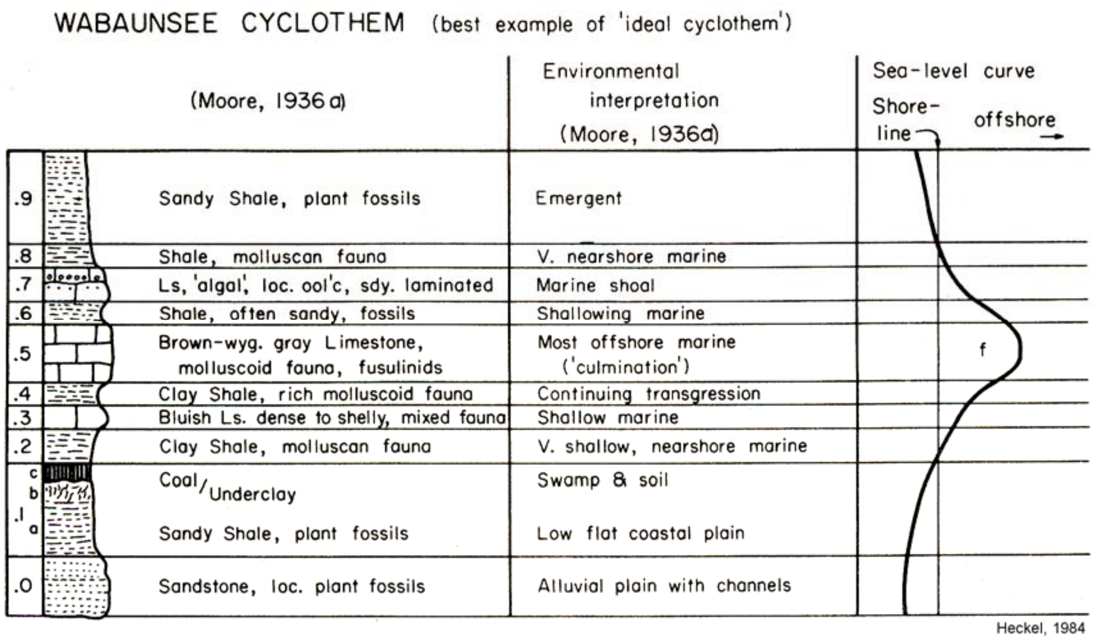


FIGURE 2. Graphic illustration of Moore's (1936) "ideal" cyclothem, the highstand of this cycle is at unit 0.5, the fusulinid-bearing limestone. Moore (1936) used the term 'molluscoid' to refer to brachiopods and bryozoans; rocks that yielded molluscs, brachiopods, and bryozoans are referred to as 'mixed'. Please note the 'Dewey decimal' designations for each unit, particularly unit 0.1. from Heckel (1984).

Moore took the transgressive-regressive cyclic models of Udden (1912) and Weller (1931) based upon Illinois cyclothems and made them fit the more complex cyclothems of the western Midcontinent. In many ways, Moore's megacyclothem model made sense. It is reasonable to expect, for instance, smaller 6th or 5th order cycles to be superimposed on larger 4th order cycles. Furthermore, because of the gradual slope of the land surface, relatively small changes in sea level can have dramatic effects on facies distribution. As a result, smaller changes in sea level can be captured in the rock record. Another argument Moore made was that the transgressive and regressive limbs of a cyclothem can be very complex indeed. Nature is complex, and so are cyclothems. Whereas Udden and earlier workers had more or less a smooth transition from land to sea and back again, Moore believed that this transition was not always as smooth. Like the daily spikes and drops of the Dow Index superimposed on a larger downturn or upturn of the Market, a cyclothem in its regressive phase can have temporary rises in sea level. The same holds true for its transgressive phase. In this way, Moore's megacyclothem concept proves useful because it can put these smaller changes into their proper context.

However, the one major drawback to the megacyclothem concept is that each limestone-shale couplet may not represent a separate cycle. While these packages may represent minor oscillations in sea level, they do have the terrestrial components to make them complete cyclothems. They also lack the deep-water black fissile shale component. In reality, instead of being a cycle of cyclothems, the megacyclothem may just be one cyclothem with several sea level fluctuations in its transgressive or regressive limbs.

Moore also reversed his 1929 stance on the depositional environment of black fissile shales by assigning the black fissile shale within a typical megacyclothem with the Dewey decimal '0.1', which is described as, "shale, may contain land plant fossils" (Moore, 1936). Moore (1936) also stated that the shale and coal with the unit designation of 0.1 (Fig. 3) were

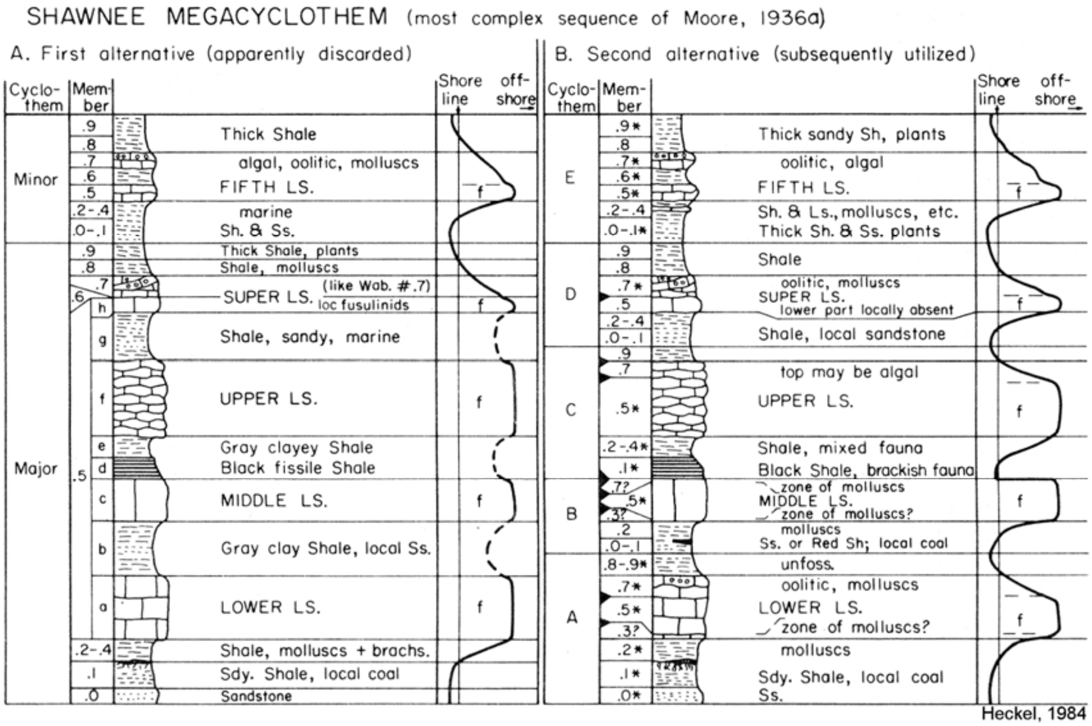


Figure 3. Moore's first alternative explanation **(A)** for the more complex Shawnee Group cyclothems involved a larger (major) cycle with a smaller overlying (minor) cycle. The highstand of the major cycle (unit .5) is very complex with three limestones and a black fissile shale. Although it was interpreted to be not as deep as the three limestones, the black fissile shale was still, by default, marine. The highstand of the minor cycle was termed the 'fifth' limestone. This alternative was not ultimately utilized. Moore's second alternative **(B)** is the megacyclothem concept. The capital letters in alternative B refer to the separate smaller cyclothems of the megacyclothem. The 'Dewey decimal' members refer to the homologous components to the "ideal" cyclothem. In this scenario, the black shale (unit 0.1 of cyclothem C) is relegated to either shallow marine or nearshore environments. from Heckel (1984)

continental, deposited on a low, flat coastal plain. This led Heckel (1984) to conclude, "This essentially equated the black shale to the coal environment…" Another curiosity, which Moore never fully explained, is why sea level fall only deposited black shale once (betweens cyclothems B and C) in the megacyclothem model (Fig. 3) and not multiple times, especially since sea level fall wasn't any greater between cyclothems B and C than elsewhere in the megacyclothem (Heckel, 1984).

Elias (1937), observing Permian cyclothems, noted that fusulinids occupied the highstands of these cycles and thus were likely deepest-water benthic faunas in a cycle. Although the Permian cyclothems that Elias (1937) studied lacked black shales and were probably not good analogues to most Pennsylvanian cyclothems, Elias' conclusions did lend support to Moore (1936) placing the highstand of his cycles at the fusulinid-bearing limestones. Interestingly, Heckel (1984) made note that if fusulinids were benthic they probably wouldn't be found in the deep-water black shales if the bottom water was anoxic.

SECOND HALF OF THE 20TH CENTURY

Determining the depositional environment of the black fissile shale dominated the debate on Pennsylvanian cyclothems in the second half of the 20th Century. In essence, two camps had developed: those who insisted that the black fissile shale was either terrestrial or very shallow marine, and a group of upstarts that insisted that at least some of these shales were deep-marine. Those in the former camp simply had difficulty accepting that significant water depths could be achieved by a transgressing sea flooding what was once dry land. Moore continued to believe that the black fissile shale was not marine in origin but rather the product of a marine swamp choked with seaweed (Heckel, 1984). Weller (1956, 1957) believed that the black fissile shale were marine although in very shallow kelp-choked seas. The algae prevented water circulation leading to anoxia on the sea bottom. Interestingly, he also attempted to reinstate diastrophism as a driver for cyclothems in the Pennsylvanian Cherokee Group. However, by the early 1960s attitudes toward the black fissile shale began to change.

Zangerl and Richardson in 1963 recognized the black fissile shale as transgressive. But, they interpreted it as being deposited by rapid marine invasion of a shoreline bayou. Floating vegetation was once again resurrected to explain the lack of water circulation and the resulting anoxia (Heckel, 1984). In the early 1960s, J.K. Evans and P.E. Schenk independently concluded that the black shale was the most offshore facies in the cyclothem, deposited at maximum depth during transgression (Heckel, 1984). Other workers began to concur with this interpretation; Payton (1966) used the position of black shales between transgressive and regressive limestones in two Missourian cycles to argue this point (Heckel, 1984). James (1970) believed that the Excello Shale in the uppermost Cherokee Group was offshore (Heckel, 1984).

Despite the gradual change in paradigm, some workers were still not ready to accept that some black fissile shales were deposited in the deepest part of the marine transgression. Ferm (1970) proposed the hypothesis of delta switching to explain Pennsylvanian cyclothems. As a delta lobe builds out onto a shallow carbonate sea, the ever-increasing clastic input creates a coarsening-upward sequence over the limestone: from mud to silt to sand. Eventually, the lobe would be abandoned allowing for reinvasion of the carbonate sea to redeposit limestone over the clastic sequence. The appearance of another lobe repeated the cycle all over again. According to Ferm's model, it would be possible to get the necessary facies changes for the range of lithologies within a cyclothem (coal, limestone, sandstone, etc…) without major sea level changes (Heckel, 1984). Merrill (1975) incorporated Ferm's delta switching model with Zangrel and Richardson's 1963 floating vegetation model to explain both cyclothems and black fissile shales. According to Merrill, black fissile shale was deposited in shallow stagnant lagoons between delta lobes and behind sedimentary barriers such as barrier islands (Heckel, 1975). The floating vegetation prevented water circulation leading to stagnation and probably anoxia.

Regardless, new ideas about the black fissile shale continued to evolve. By the early to mid 1970s, paleontological evidence was used to conclusively prove that many Pennsylvanian black fissile types of shale were indeed deep-water marine. Seddon and Sweet (1971) used a common marine vertebrate, conodonts, to help figure out the depositional environments of marine shale and limestone. They believed that conodonts were pelagic and that various genera were stratified in different depth zones of the water column. Heckel and Baesemann (1975), working with Missourian cyclothems of eastern Kansas, concurred that Seddon and Sweet's depth model was probably the most parsimonious explanation for conodont distribution patterns observed in those cyclothems. They also noted the model also explained the variations in conodont distributions in cyclothems from the eastern to central parts of North America (Heckel and Baesemann, 1975). *Adetognathus* dominated low-diversity faunal assemblages indicating adaptation to fluctuating or unstable marine conditions (Fig. 4) (Heckel and Baesemann, 1975). Coupled with its association with limestones and nearshore shales, Heckel and Baesemann (1975) concluded that *Adetognathus* was a shallow-water conodont. *Gondolella* and *Idioprioniodus* seemed to be associated with the black fissile shale facies (1975). Heckel and Baesemann (1975) pointed out the abundance of conodonts and their diversity, phosphate laminae and nodules, the facies transition of black shales with mainly pelagic faunas into nonblack shales with benthonic marine faunas, and the widespread regional distribution of black shales as evidence for the deep-water, marine origin of black fissile shales. Therefore, *Gondolella* and *Idioprioniodus* were likely the deepest-water conodonts in the succession (Fig. 4) (1975). Furthermore, a general order of succession of first appearance of genera with increasing water depth within a megacyclothem was worked out (from shallowest to deepest): *Adetognathus-Ozarkodina minuta-Aethotaxis-Idiognathodus-Idioprioniodus-Gondolella* (Heckel and Baesemann, 1975). Because *Idiognathodus* is associated with both *Adetognathus* and *Idioprioniodus-Gondollela*, *Idiognathodus* probably had a widespread distribution and was the most abundant (Heckel and Baesemann, 1975). From all of this information, Heckel and Baesemann (1975) determined that the limestone below the black fissile shale is transgressive, the black fissile shale is the highstand, and the overlying limestone is regressive.

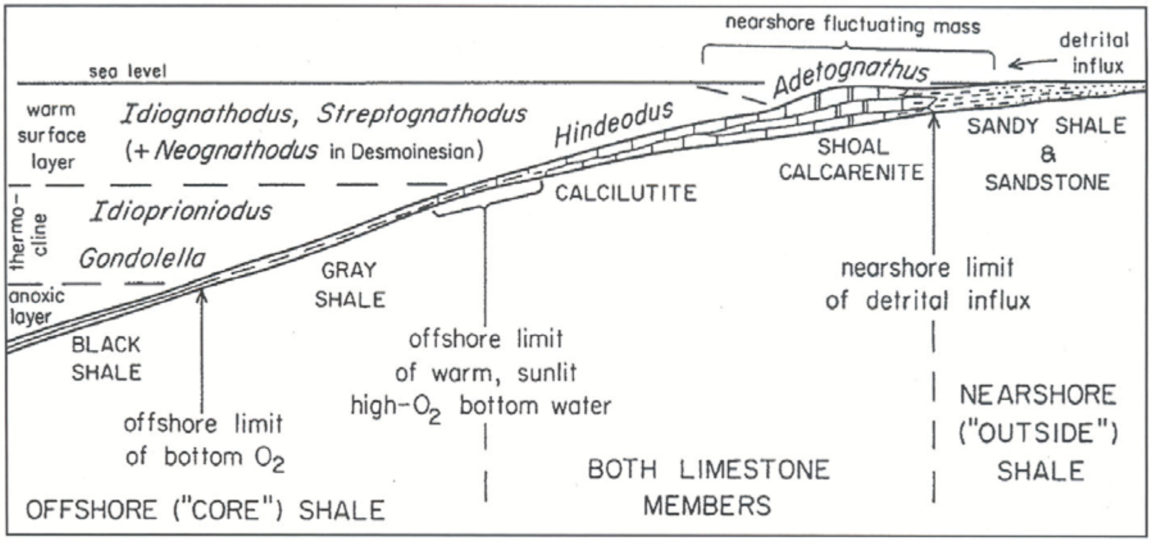


Figure 4. Inferred living distribution of seven major conodont genera in the Midcontinent Pennsylvanian Sea relative to major water masses developed at maximum transgression. Modified from Heckel and Baesemann (1975) and Swade (1985), taken from Pope and Chantooni (1996)

HECKEL (1977)

Heckel's 1977 paper is probably one of the most famous papers in the world of the Pennsylvanian. In it, he proposed a model for cyclothems that integrated oceanic and atmospheric circulation systems, conodont biostratigraphy, and lithofacies. His cyclothem model included four components: the outside shale, middle (transgressive) limestone, core shale, and upper (regressive) limestone (Heckel, 1977).

The outside shale consists of sandy or silty shales, sandstones, paleosols, coals, and other nearshore deposits. The outside shale is mainly terrestrial to marginal marine. As sea level rose, the environment would change from coastal to marginal marine to a shallow carbonate sea. Here, the middle (transgressive) limestone would be deposited. At the maximum depth of sea level or highstand, the core shale would be deposited. According to Heckel (1977) there are actually two facies within the core shale: the black fissile shale with phosphatic nodules and the gray shale with phosphate nodules. The black fissile phosphatic shale actually represents the deepest part of the core shale. Accumulation of organic material from above is what makes the black shale black. However, to keep the organics from decomposing, bottom water conditions must be anoxic; anoxia exists when water circulation is prevented from bringing oxygen down from above and/or water is deep enough to create anoxia. Once water depth decreases a little, the bottom becomes oxygenated allowing for the organic material to decompose, and the gray phosphatic shale would be deposited. As water depth continued to decrease, another shallow carbonate sea would appear, and the upper (regressive) limestone would be deposited. As sea level continued to fall, another outside shale would be deposited on the upper limestone completing the cycle (Heckel, 1977).

Heckel (1977) proposed that the black fissile shale was deposited in water depths up to 200 meters covering the Midcontinent. The water was deep enough for a thermocline (temperature differentiation between surface and bottom waters) to be established. The surface waters would not only be warmer but would have more oxygen due to air/water interchanges. Yet, the thermocline prevents water circulation from the surface to the bottom resulting in colder and oxygen-poor bottom waters (Fig. 5). The position of the Midcontinent during the Pennsylvanian was likely in the trade wind belt. The prevailing winds were probably out of the northeast and pushed the warmer surface waters southwestward away from the coastline, setting up large quasi-estuarine circulation cells. As a result, the cooler, oxygen-poor bottom water rose up from deeper parts of the basin in West Texas to replace the surface water. However, although oxygen-poor, the water was nutrient-rich because of all of the organic material that had rained down from above. The increased nutrients encouraged algal blooms in addition to increased populations of other marine organisms. Unfortunately, the increased biological activity depleted what little oxygen was in the water resulting in mass death. As the corpses of dead fish, conodonts, algae, and other organisms settled to the bottom, their organic material became the black mud that would ultimately become black fissile shales. The calcium phosphate in their skeletal material settled out as phosphatic nodules (Heckel, 1977).

A similar situation exists today off of the coast of Peru. Prevailing winds push water off of the western coast of Peru causing the upwelling of nutrient-rich cold water. Fishermen are very happy about this because the increased nutrients in the water lead to great fishing. However, every now and then, the prevailing winds shut down and the upwelling of colder, nutrient-rich waters ceases. The fishing drops off dramatically. Because fishermen noticed this phenomenon usually around Christmas time, they named it *El Niño*, after the Christ child. The opposite of *El Niño* is *La Niña*, when the prevailing winds are stronger than normal causing an upwelling of even colder water. Both *El Niño* and *La Niña* affect weather worldwide. Some areas (such as the Midwest and Iowa) have drier or wetter weather and/or colder or warmer temperatures than normal when these phenomena are at play.

Finally, the limestone-shale couplets were no longer considered as cyclothems (Heckel, 1977), and this, in effect, dismantled Moore's (1936) definition of megacyclothems (Fig. 6). Heckel (1977) applied the term to the far more complex sequences of cycles in Kansas and Illinois. In addition, he also recognized two types of black fissile shales: the offshore black shales as described above, and the nearshore or terrestrial black shale deposited in lagoons or swamps (Heckel, 1977). Nearshore or terrestrial black shales can be identified because they grade into tidal flat siltstones, shales, or sandstones or other shallow-water deposits, contain lenses or

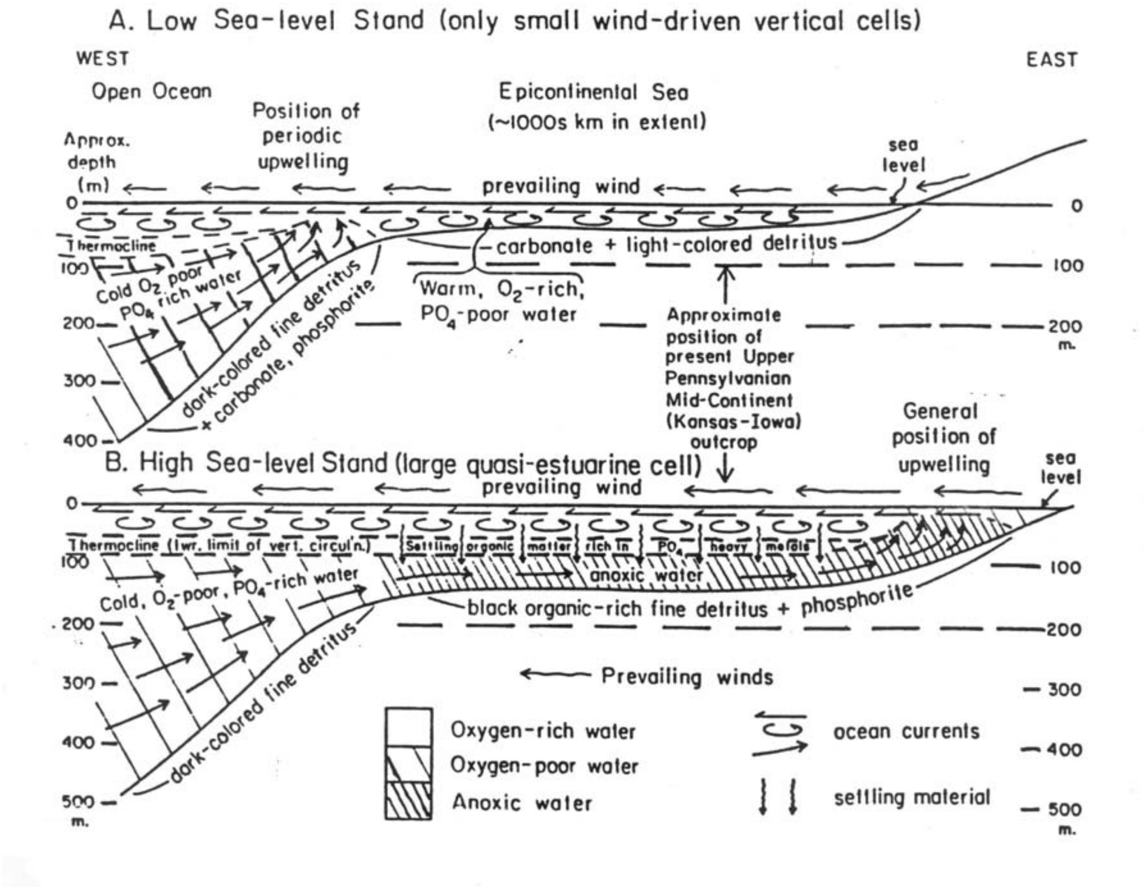


Figure 5. Two views of the vertical circulation patterns off of the western coast of a tropical epicontinental sea. **A.** At lowstand, numerous small wind-driven vertical circulation patterns combined with algal photosynthesis provide for well-oxygenated bottom waters. **B.** At highstand, water level is deep enough for the development of a thermocline. As prevailing winds push water away from the coast setting up quasi-estuarine circulation, upwelling of colder, nutrient-rich water occurs. This leads to algal and plankton blooms encouraging increased organic activity. Oxygen depletion results leading to mass death. The settling of organic matter and skeletal debris contributes to the deposition of black fissile phosphatic shales. A modern day analogue to quasi-estuarine circulation can be observed off of the coast of Peru.
from Heckel (1977)

laminae of quartz sand or silt, yield benthic fossils, have sparse to no conodonts, lack *Gondolella* and *Idioprioniodus*, and lack phosphatic nodules or laminae (Heckel, 1977). Interestingly, Heckel (1977) extended his model of deep-water black shales to Illinois, despite such shales often directly overlying coals. Possibly, a single black shale unit could represent a shallow-water or nearshore environment in its lower part and an offshore deep-water environment in its upper part as sea level increased (Heckel, 1977).

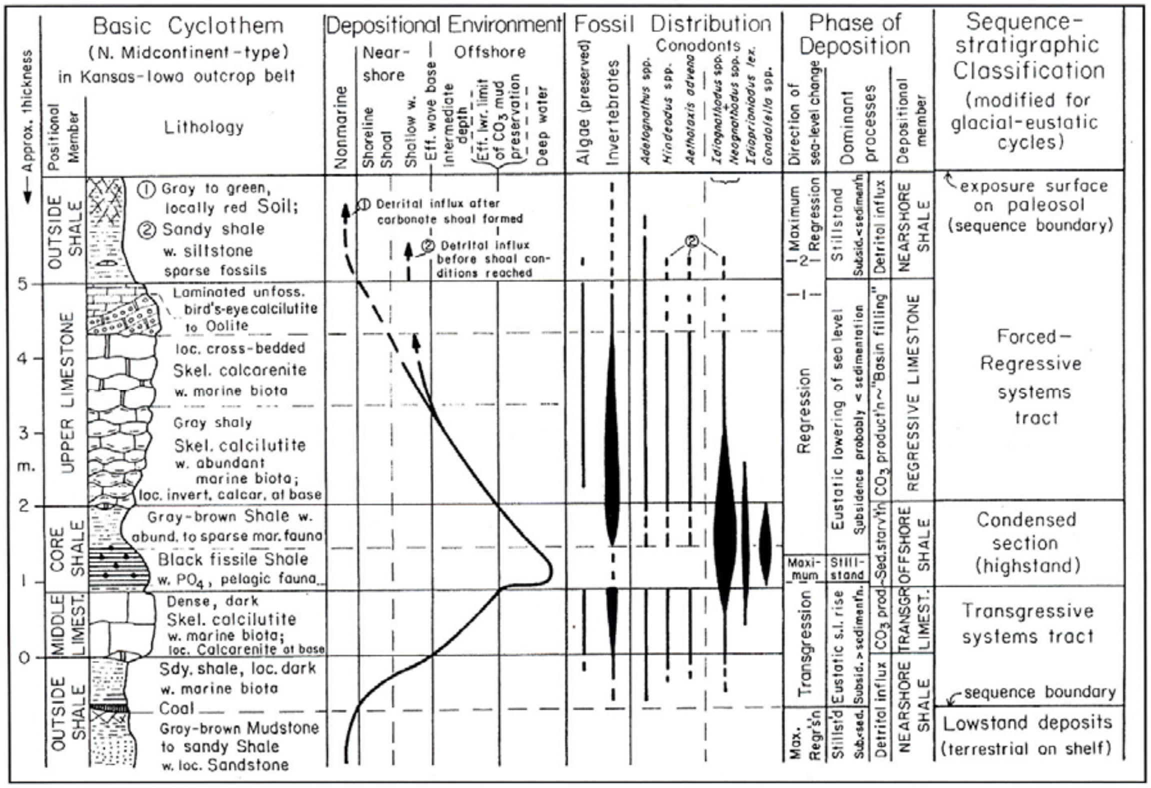


Figure 6. Basic Kansas cyclothem simplified from Heckel (1977) Compare with Moore's (1936) megacyclothem (Figs. 2 and 3). The black fissile phosphatic facies of the core shale is the highstand of the cycle.

MOVING ON, PART II…

Klapper and Barrick (1978) cautioned against using distributional patterns of conodonts in the rock record to determine a pelagic versus benthic mode of life. They point out that some benthic organisms have pelagic larval stages while other benthic organisms, such as some isopods, are still able to maintain a widespread distribution (Klapper and Barrick, 1978). However, they do concede that conodonts found in black shales devoid of other benthic fauna were probably pelagic (1978).

Ravn and others (1984) instituted some revisions and refinements of the Pennsylvanian Subsystem in Iowa. They renamed the Desmoinesian Series the Desmoinesian Supergroup since it applies to lithostratigraphic not chronostratigraphic units (Ravn and others, 1984). They also instituted four new formations within the Cherokee Group in Iowa, in ascending order: Kilbourn, Kalo, Floris, and Swede Hollow (1984). Coal bed nomenclature was also formalized with news coals names in the Cherokee Group including the Blackoak Coal in the Kalo Formation and the Carruthers Coal in the Floris Formation (Ravn and others, 1984). The overlying lower Marmaton Group Fort Scott Formation was broken up into three smaller formations since the Fort Scott consisted of two cyclothems, in ascending order: Mouse Creek, Morgan School Shale, and Stephens Forest (Ravn and others, 1984). Other revisions were made in the Missourian of Iowa as well. The revision of Cherokee Group nomenclature, while necessary, has unfortunately added to the complications in the current attempts at correlation of Midcontinent Cherokee cyclothems.

Swade (1985) working with two cores, CP #22 in Appanoose County and CP #37 in Clarke, in south-central Iowa noted that four genera of condonts were consistently found in black fissile phosphatic shale: *Idiognathodus*, *Neognathodus*, *Idioprioniodus*, and *Gondolella*. Based upon

Klapper and Barrick (1978), he concluded that these four genera were pelagic and inhabited different zones in the stratified water column (Swade, 1985). Swade (1985) concluded that *Idiognathodus* and *Neognathodus* inhabited warm, well-oxygenated surface waters, *Idioprioniodus* inhabited cooler, less-oxygenated offshore water near the top of the thermocline, and *Gondolella* inhabited the deepest, coldest, and least-oxygenated water (probably lower in the thermocline) of the four genera (Fig. 4). Because of its restrictive paleoecological range, *Gondolella* was probably not present during every episode of upwelling becoming a rare constituent to the conodont faunas of the Cherokee Group and the Pennsylvanian, even in the black fissile phosphatic shales. Hanley (2008) noted certain zones of unusual abundances in *Gondolella* in black fissile phosphatic shales of the middle part of the Cherokee, indicating episodes of upwelling of very cold, low-oxygenated water. Swade (1985) did note that some offshore black to green clayey phosphatic shales yielded great abundances in conodont elements (up to thousands of elements per kilogram). Nearshore outside shales and regressive limestones usually exhibited abundances of tens of elements per kilogram; *Adetognathus*, *Idiognathodus*, *Neognathodus*, and to a lesser extent *Aethotaxis* dominated regressive deposits (Swade, 1985). *Adetognathus* dominated the base of transgressive deposits while Idioprioniodus dominated the tops (Swade, 1985). *Idiognathodus* increased upward in transgressive deposits while *Neognathodus*, *Anchignathodus*, and *Diplognathodus* were found throughout (1985). Swade (1985) also believed that conodont faunas in the cyclothems studied in these cores were distinctive enough to make correlating cyclothems throughout the Midcontinent possible.

INTO THE 21ST CENTURY…

It would seem that after all of the previous work on Pennsylvanian cyclothems throughout the 20th Century there is not much left to do in this arena today. While it is true that, except for a few holdouts, most workers have accepted Heckel's model of deep-water black shale deposition, that most have accepted the boundaries of cyclothems at the base of the coals or, in the case of incisement, the base of sandstones, and that most have accepted the growth and shrinkage of glaciers in the Southern Hemisphere as drivers for cyclicity, there is still much that needs to be done with regional correlation and the sequence stratigraphy of cyclothems.

Pope (2002, 2006) has identified radiolarians in the black fissile phosphatic Excello Shale in the basal Marmaton Group. Radiolarians are single-celled organisms with very intricate shells (tests) made of silica. More importantly, radiolarians are marine creatures, some deep marine; assuming that radiolarians of the Pennsylvanian lived in similar environments, this is further, and nearly conclusive, evidence that some black fissile shales are marine. Recently, Fisher andPope (2009) have identified pyritized radiolarians (Figs. 7 and 8) from the Oakley Shale at the Saylorville Dam Emergency Spillway (personal communication).

In the Cherokee Group, Marshall (2002) identified 28 cycles of transgression and regression based on outcrop work in eastern Oklahoma and southeastern Kansas. While others such as Moore (1936), Abernathy (1936), Searight and others (1953), Howe (1956), Swade (1985), Heckel (1986) and Hemish (1986) had noted and even worked on the cyclical nature of deposition in the Cherokee Group, Marshall's work was more comprehensive since it was in the Arkoma Basin of Oklahoma where the Cherokee succession is more complete. Furthermore, he utilized conodont biostratigraphy. Some conodonts of the Cherokee Group, particularly *Idiognathodus*, evolved rapidly enough that many of the morphotypes are different from one major cycle to the next. This allows Midcontinent-wide correlation of cyclothems from Oklahoma to Iowa. Hanley (2008) correlated the cyclothems of the middle part of the Cherokee Group across the Midcontinent. One of the sections included in her correlation is the Saylorville Dam Emergency Spillway. From this, it is possible to put the stratigraphic succession at the Saylorville Spillway into regional context. Marshall's PhD work, in progress, involves correlating cyclothems of the lower part of the Cherokee Group across the Midcontinent. In the

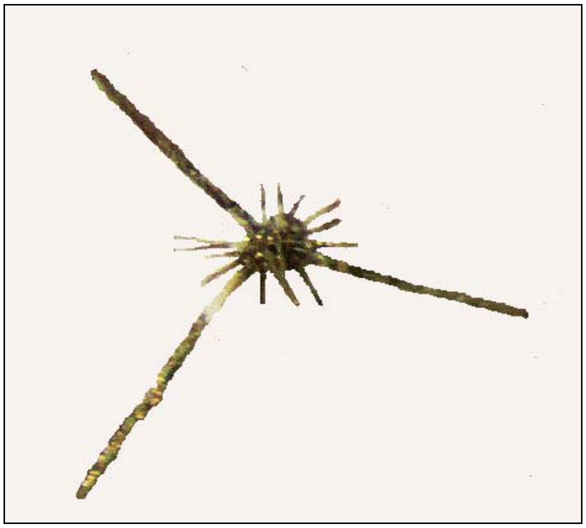
Midcontinent, the lithostratigraphic nomenclature of the Cherokee Group changes from state to state (for example, Croweburg Coal of Oklahoma versus Whitebreast Coal of Iowa; Verdrigris Limestone of Oklahoma versus Ardmore Limestone of Iowa); because of this, there is much confusion in trying to trace out coal beds or sandstone reservoirs. Hopefully, the recent work of Marshall and Hanley will provide an overarching regional nomenclature to resolve this issue.

CONCLUSIONS

When reviewing the history of the concept of Pennsylvanian cyclothems in North America, it is striking how many early ideas are still accepted today. Udden's (1912) ideas about the processes of cyclicity and placing the base of each cycle at the base of the coal have more or less stood the test of time. Even Weller (1930) placing the base of the cyclothem at the base of what he believed to be fluvial sandstones is still current. Some of the larger Pennsylvanian sandstones have cut down (incised) into underlying units; today, these incisement surfaces are still recognized as boundaries between cycles. In fact, at Saylorville, there is a fluvial channel sandstone in the upper part of the section. The base of this sandstone serves as a sequence boundary between it and the underlying Verdrigris cyclothem. And, of course, Wanless and Shepard's (1936) ideas concerning the waxing and waning of glaciers in the Southern Hemisphere driving glacio-eustatic sea level changes leading to cyclic deposits in North America and elsewhere are still accepted today.

The most interesting part of the history of Pennsylvanian cyclothems is the debate on the depositional environment of black fissile shales. Looking back from our modern perspective, it seems strange that some workers simply couldn't accept the idea of some black fissile shales being deep-marine. However, this resistance is very understandable when you consider a couple of things. The Heckel model for deep-water black shales calls for water depths up to 200 m (650 feet); to be fair, it is rather fantastic to expect that during maximum transgression places like Oklahoma, Kansas, or Iowa were covered by over *650 feet* of seawater. Furthermore, Weller (1931) noted that black fissile shales were directly above the coal in Illinois cyclothems. If we accept that most of the coals were deposited in coastal swamps marking the beginning of marine transgression, not only was depths of 650 feet achieved in these transgressing seas, but there were achieved over a relatively short period of time. For many, this stretches credulity to its breaking point. Still, the evidence kept coming in for deep-marine black fissile shales. Also, in southern Oklahoma, central Texas, and Arkansas there were mountains as nearly as tall as the Himalayas, the Appalachians were taller, and the Ancestral Rockies were in what is now Colorado and New Mexico. Considering the geography, a basin surrounded by rugged highlands, it would not be that hard to get great water depths. The position of such shales between two clearly marine units (the transgressive and regressive limestones), the abundance and variety of conodont faunas, the widespread distribution of these shales, and the presence of radiolarians all provided very convincing evidence that these shales were indeed deposited in "impossibly" deep water. As Hamlet said, "*There are more things in heaven and earth, Horatio, than are dreamt of in your philosophy*" (*Hamlet*, Act 1, scene 5, 159-167).

FIGURE 7. Pyritized radiolarian from Oakley Shale at Saylorville Dam Emergency Spillway (courtesy Dr. John Pope)



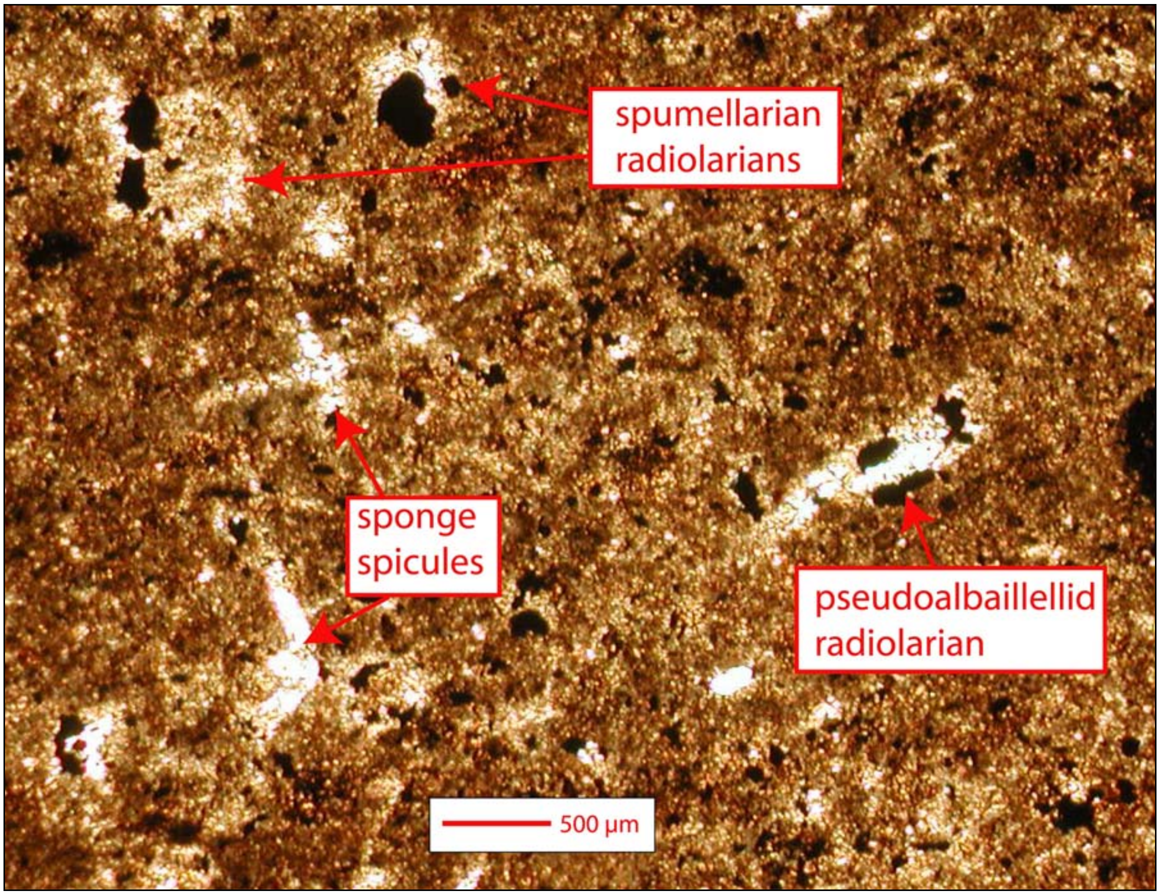


FIGURE 8. Thin-section of Oakley Shale from Saylorville Dam Emergency Spillway with two different varieties of radiolarians displayed (courtesy Dr. John Pope)

Yet, the world of cyclothems is unique because it is possible for everyone to be right, at least to some degree. For instance, at the Saylorville Dam Emergency Spillway, the Oakley Shale is a deep-marine black shale that yielded *Gondolella* and contains phosphatic lenses, nodules, and laminae (Pope and Chantooni, 1996) and pyritized radiolarians (Pope, personal communication). In contrast, above the lower Ardmore bed at the Saylorville Dam Emergency Spillway, there is a black fissile shale with sparse fossils and pyrite-filled vertical tubes that has been interpreted as being nearshore, both shales can be easily seen at the spillway. It is this variation and complexity inherent in Pennsylvanian cyclothems that will continue to cause people to scratch their heads and keep a lively debate active for years to come. Remember always, nature is complex, but Pennsylvanian cyclothems are even more complex!

REFERENCES

Abernathy, G.E., 1936, The Cherokee of southeastern Kansas: Unpublished PhD dissertation, University of Kansas, Lawrence, KS, United States, 108 p.

Boardman, D.R. II, and Marshall, T.R., 2002, Preliminary conodont biostratigraphy of the Cherokee Group (lower Desmoinesian) of Oklahoma and southern Kansas: Oklahoma Geological Survey Circular, report 108: p. 238

Boardman, D.R. II, Marshall, T.R., and Lambert, L.L., 2002, Sea-level fluctuation curve for the Cherokee Group (Lower and Middle Desmoinesian/Upper Moscovian) in the Arkoma-Cherokee Basin area of eastern Oklahoma: Newsletter on Carboniferous Stratigraphy, v. 20, p. 26-28

Elias, M.K., 1937, Depth of deposition of the Big Blue (late Paleozoic) sediments in Kansas: Geological Society of America Bulletin, v. 48, no. 3, p. 403-432

Ferm, J.C., 1970, Allegheny deltaic deposits: Society of Economic Paleontologists and Mineralogists Special Publication 15, p. 246-255

Fisher, and Pope, J.P., 2009, Paleontology, Petrology and Petrography of early diagenetic calcareous concretions in the Oakley Shale Member of the Verdigris Formation at Saylorville Dam Emergency Spillway, Polk County, Iowa: South-Central Geological Society of America Abstracts with Programs, v. 41, no. 2, p. 10

Hanley, K.D., 2008, Sequence stratigraphy and correlation of Middle Cherokee Group cyclothems (Middle Pennsylvanian, Early Desmoinesian) from Oklahoma to Iowa: Unpublished PhD dissertation, University of Iowa, Iowa City, IA, United States, 163 p.

Heckel, P.H., 1977, Origin of phosphatic black shales in Pennsylvanian cyclothems of Midcontinent North America: American Association of Petroleum Geologists Bull., v. 61, no. 3, p. 1045-1068

Heckel, P.H., 1984, Changing concepts of Midcontinent Pennsylvanian cyclothems, North America, *in* Belt, E.S., and Macqueen, R.W., eds., *Neuvième Congrès International de Stratigraphie de Gèologie du Carbonifère*, Part 3: Sedimentology and Geochemistry: Southern Illinois University Press, Carbondale and Edwardsville, p. 535-553

Heckel, P.H., 1986, Sea-level curve for Pennsylvanian eustatic marine transgressive-regressive depositional cycles along Midcontinent outcrop belt, North America: Geology (Boulder), v. 14, no. 4, p. 330-334

Heckel, P.H., and Baesemann, J.F., 1975, Environmental interpretation of conodont distribution in Upper Pennsylvanian (Missourian) megacyclothems in eastern Kansas: American Association of Petroleum Geologists Bull., v. 59, no. 3, p. 486-509

Hemish, L.A., 1986a, Coal geology of Craig County and eastern Nowata County: Oklahoma Geological Survey, Bull. 140, 131 p.

Hemish, L.A., 1986b, Stratigraphy of the lower part of the Boggy Formation (Desmoinesian) in northwestern Muskogee and southwestern Wagoner Counties, Oklahoma: Oklahoma Geology Notes, v. 46, no. 5, p. 168-187

Howe, W.B., 1956, Stratigraphy of the pre-Marmaton Desmoinesian (Cherokee) rocks in southeastern Kansas: Kansas Geological Survey Bull., no. 123, 132 p.

James, G.W., 1970, Stratigraphic geochemistry of a Pennsylvanian black shale (Excello) in the Mid-continent and Illinois Basin: Unpublished PhD dissertation, Rice University, Houston, TX, United States

Klapper, G., and Barrick, J.E., 1978, Conodont ecology: pelagic versus benthic: Lethaia, v. 11, no. 1, p. 15-23

Marshall, T.R., 2002, Outcrop-based cyclic stratigraphy of the Cherokee Group (Desmoinesian, Pennsylvanian): Unpublished Master's thesis, Oklahoma State University, Stillwater, OK, United States, 438 p.

Marshall, T.R., and Boardman, D.R., 2002, Outcrop-based cyclic stratigraphy of the Cherokee Group: Oklahoma Geological Survey Circular, report 108, p. 244

Merrill, G.K., 1975, Pennsylvanian conodont biostratigraphy and paleoecology of northwestern Illinois: Geological Society of America, microform publication 3

Moore, R.C., 1929, Environment of Pennsylvanian life in North America: American Association of Petroleum Geologists Bull., no. 60, p. 247-257

Moore, R.C., 1931, Pennsylvanian cycles in the northern Midcontinent region: Illinois Geological Society Bull., no. 60, p. 247-257

Moore, R.C., 1936a, Stratigraphic classification of the Pennsylvanian rocks of Kansas: Kansas Geological Survey Bull., no. 22, 256 p.

Moore, R.C., 1950, Late Paleozoic cyclic sedimentation in central United States: 18th International Geological Congress Report (Great Britain 1948) part 4, p. 5-16

Payton, C.E., 1966, Petrology of carbonate members of the Swope and Dennis Formations (Pennsylvanian), Missouri and Iowa: Journal of Sedimentary Petrology, v. 36, no. 2, p. 576-601

Pope, J.P., 2002, Occurrence of abundant well-preserved Pennsylvanian radiolarians in the Excello Shale (basal Marmaton Group, upper Desmoinesian) of south-central Iowa: North-Central and Southeastern Joint Annual Meeting, GSA (Lexington, KY), Abstracts with Programs, v. 34

Pope, J.P., 2006, Three groups of unusual microfossils in the Pennsylvanian and Permian successions in Midcontinent North America: Unpublished PhD dissertation, University of Iowa, Iowa City, Iowa, 192 p.

Pope, J.P., and Chantooni, A.M., 1996, Pennsylvanian geology of the Saylorville Dam emergency spillway after the floods of '93: Prepared for the Army Corps of Engineers, Saylorville Dam, unpublished manuscript, Iowa Geological and Water Survey, 114 p.

Ravn R.L., Swade, J.W., Howes, M.R., Gregory, J.L., Anderson, R.R., and Van Dorpe, P.E., 1984, Stratigraphy of the Cherokee Group and revision of Pennsylvanian stratigraphic nomenclature in Iowa: Iowa Geological Survey Technical Information Series 12, 76 p.

Searight, W.V., Howe, W.B., Moore, R.C., Jewett, J.M., Condra, G.E., Oakes, M.C., and Branson, C.C., 1953, Classification of Desmoinesian (Pennsylvanian) of northern Mid-Continent: AAPG Bulletin, v. 37, p. 2747-2749

Seddon, G., and Sweet, W.C., 1971, An ecological model for conodonts: Journal of Paleontology, v. 45, no. 5, p. 869-880

Swade, J.W., 1985, Conodont distribution, paleoecology, and preliminary biostratigraphy of the upper Cherokee and Marmaton Groups (Upper Desmoinesian, Middle Pennsylvanian) from two cores in south-central Iowa: Iowa Geological Survey Technical Information Series 14, 71 p.

Wanless, H.R., and Shepard, F.P., 1936, Sea level and climate changes related to late Paleozoic cycles: Geological Society of America Bulletin, v. 47, no. 8, p. 1177-1206

Wanless, H.R., and Weller, J.M., 1932, Correlation and extent of Pennsylvanian cyclothems: Geological Society of America Bulletin, v. 43, no. 4, p. 1003-1016

Weller, J.M., 1930, Cyclical sedimentation of the Pennsylvanian Period and its significance: Journal of Geology, v. 38, no. 2, p. 97-135

Weller, J.M., 1931, The conception of cyclical sedimentation during the Pennsylvanian Period: Illinois Geological Survey Bull., no. 60, p. 163-177

Weller, J.M., 1956, Argument for diastrophic control of late Paleozoic cyclothems: American Association of Petroleum Geologists Bull., v. 40, no. 1, p. 17-50

Weller, J.M., 1957, Paleoecology for the Pennsylvanian Period in Illinois and adjacent states: Geological Society of America Mem., v. 67, no. 2, p. 325-364

Udden, J.A., 1912, Geology and mineral resources of the Peoria Quadrangle, Illinois: US Geological Survey Bull. 506

Zangrel, R., and Richardson, E.S., 1963, The paleoecological history of two Pennsylvanian black shales: Fieldiana-Geology Mem. 4

PENNSYLVANIAN GEOLOGY OF THE SAYLORVILLE EMERGENCY SPILLWAY

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INTRODUCTION

The strata visible and accessible in the Saylorville Dam emergency spillway after the 2008 flooding constitute the best exposure of Pennsylvanian Cherokee Group rocks in the State of Iowa, exposing over 60 vertical feet of the rock section from the basal portion of the Swede Hollow Formation through the unnamed limestone, shale, and mudstone units below Carruthers Coal of the Floris Formation. Three units have been named for type exposures in

Figure 1. View of the Lower Gorge of the Saylorville emergency spillway as exposed after the 2008 floods. Stop 1 of the field trip will be in this area.

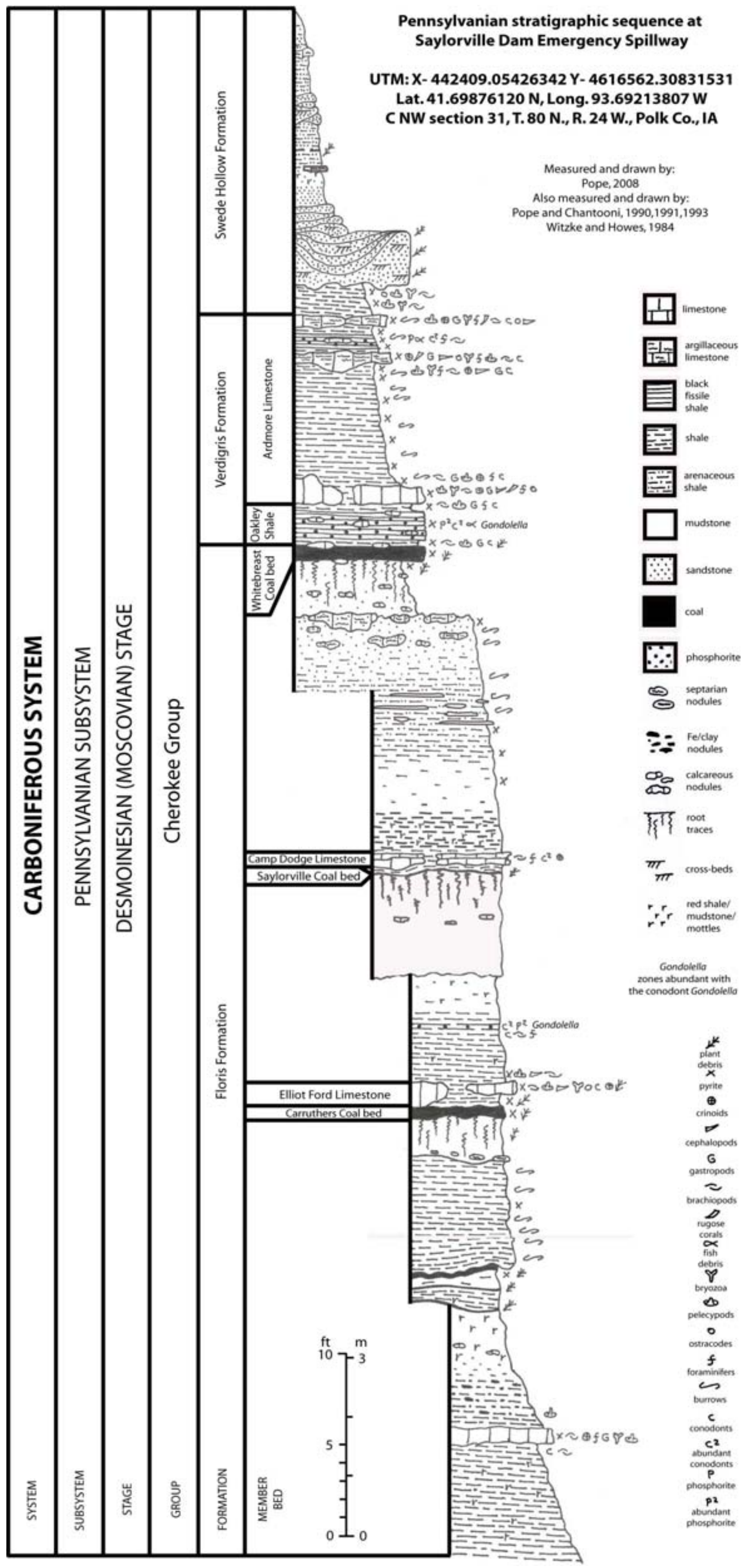

Figure 2. Graphic section of the Cherokee Group rocks exposed in the Saylorville emergency spillway. New stratigraphic units with type sections in the gorge including the Camp Dodge and Elliot Ford Limestone Members and the Saylorville Coal bed.

the Floris Formation. The field trip will begin in the lower gorge area (Fig. 1) where rocks of the Floris Formation (Fig. 2) are well exposed. The first stop of the field trip will be in the lower Saylorville canyon, the south end where the emergency spillway is most deeply incised. The first feature that will be encountered upon entering the spillway is an extensive boulder bar (Fig. 3) of large rocks ripped from the spillway as the flood waters cut down. Moving up the canyon the newly-named Elliot Ford Limestone Member can be accessed and examined above the Carruthers Coal in this area (Fig. 4), where it appears as a nodular limestone overlying the Carruthers Coal bed. Below the Carruthers a non-marine shale displays pedogenic structures and colors characteristic of a paleosol. A detailed description of the units displayed in the Saylorville gorge appears later in this article. A thin mud-cracked limestone (Fig. 5) near the base of the Floris Formation is a prominent feature at Stop 1. Another informative section in the lower gorge area of the Saylorville emergency spillway can be seen on the east wall of the

Figure 3. A large boulder bar was created in the lower gorge area at field trip Stop 1.

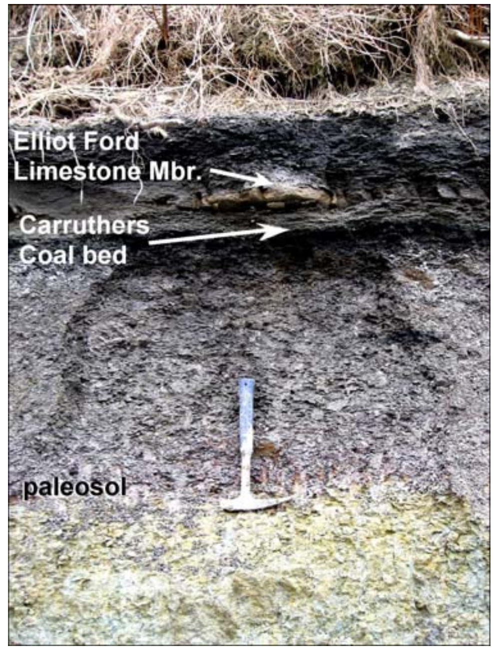

Figure 4. Newly-named Elliot Ford Limestone Member of the Floris Formation (the nodular limestone) overlies the Carruthers Coal bed and underlying paleosol at field trip Stop 1. Photo by Diana Pope.

Figure 5. An "unnamed" limestone near the base of the Floris Formation at Stop 1. High clay content and mud cracks suggest deposition in a shallow marine environment. Photos by Diana Pope.

spillway. Although accessing this section is very difficult and dangerous, key members and beds of the Floris Formation can be observed (Fig 6).

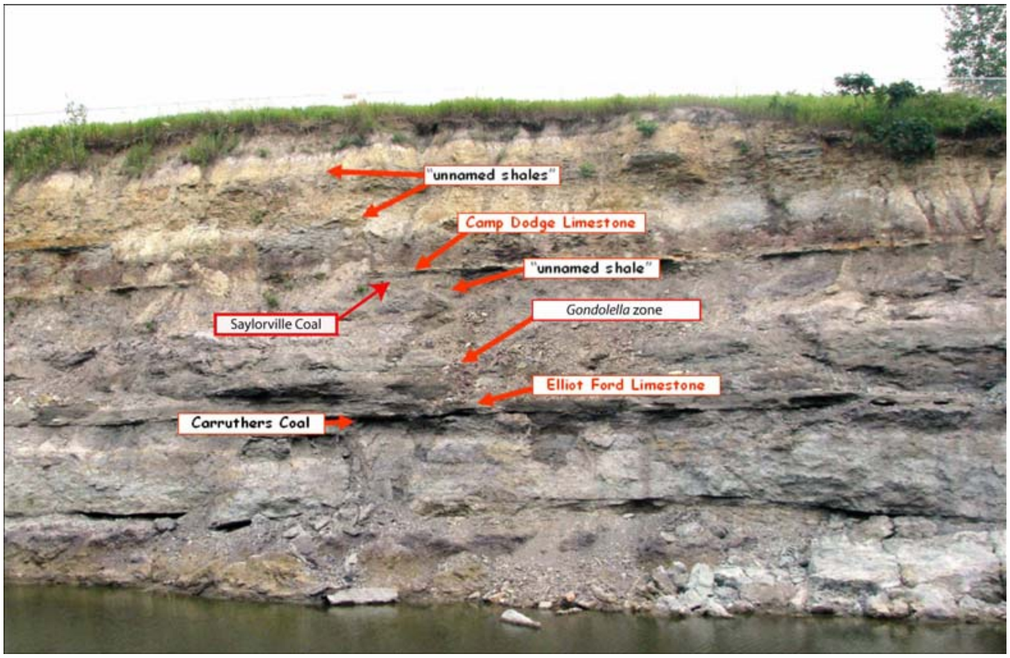

Figure 6. View of the east wall lower gorge of the Saylorville emergency spillway as exposed after the 2008 floods. Key members and beds of the Floris Formation can be seen in the wall exposure.

To get to the second stop of this field trip we will retrace our route back to the parking area and then follow trip leaders north along the emergency spillway to a point were the upper gorge can be accessed. In the upper Saylorville gorge area (Fig. 7) the lower units of the Swede Hollow

Figure 7. View of the Upper Gorge of the Saylorville emergency spillway as exposed after the 2008 floods. Stop 2 of the field trip will be in this area. The material in the lower right is concrete installed to stabilize the spillway after the 1993 floods. The structure in the background is concrete lip of the spillway.

Formation can be examined, as can the Ardmore Limestone and Oakley Shale Members of the Verdigris Formation and the Whitebreast coal bed of the Floris Formation. There are many interesting features to see in this area of the gorge. Figure 8 shows two-such features, molds of *Stigmaria* (roots of the lycopod *Lepidodendron*) preserved in an unnamed sandstone in the Swede Hollow Formation and sole marks (casts of grooves cut into the floor of Pennsylvanian rivers by large logs being swept downstream during floods). Two additional features that can be seen in the upper gorge of the Saylorville emergency spillway are shown in Figure 9, including two slabs of the Ardmore Limestone Member, one showing abundant whole-shell brachiopods of several


Figure 8. *Stigmaria*, roots of the lycopod *Lepidodendron*, with rootlets in silty facies of unnamed sandstone, at Stop 2 (left photo). Trenching tool over two feet in length. In the right photo sole marks in a block of unnamed Swede Hollow Fm. sandstone resting on the Verdigris Fm. Ardmore Limestone Member, which lies above the Oakley Shale Member.


Figure 9. Abundant brachiopods of several species can be found on the slab of Ardmore Limestone above. (photo by Diana Pope). On the right a block of lower Ardmore Limestone show a complex set of fractures or joints.

species. Brachiopods identified in the Ardmore include *Desmoinesia muricata, Wellerella osagensis, Mesolobus mesolobus, Punctospirifer kentuckyensis, Derbyia crassa, Neospirifer cameratus, Composita ovata, Crurithyris planoconvexa, Cleiothyridina orbicularis, Linoproductus platyumbonus, L. prattenianus*, and unidentified juvenile productids and chonetids. The photograph on the right (Fig. 9) shows fractures in the lower Ardmore Limestone. A pronounced perpendicular set of fractures is cut by a third set. Field trip leaders will point out these and other features of interest in the upper gorge area.

STRATIGRAPHY OF THE SAYLORVILLE EMERGENCY SPILLWAY

The Pennsylvanian stratigraphic nomenclature in Iowa is currently under review and revision by John Pope, Brian Witzke, Thomas Marshall, and Phil Heckel. The most current version of this revised nomenclature is detailed in a currently unpublished manuscript (Pope, 2009). Figure 10 compares the current version of Desmoinesian Stage Pennsylvanian stratigraphic nomenclature in Iowa to the previous nomenclature used by the Iowa Geological Survey (Ravn and others, 1984) and earlier historic nomenclature (Landis and Van Eck, 1965). An initial edition of this nomenclature will soon be published on the Iowa Geological and Water Survey web page (www.igsb.uiowa.edu) in the form of the Pennsylvanian portion of the Lexicon of Iowa Geology.

NEW PENNSYLVANIAN CHEROKEE NOMENCLATURE

Three new informally-designated units are first published in this guidebook. These units are all members or beds within the Floris Formation, and two have designated type sections in the Saylorville emergency spillway, including the Camp Dodge Limestone Member the underlying Saylorville Coal bed. The type section for the third, the Eliot Ford Limestone Member, is located along Saylorville Lake.

Camp Dodge Limestone Member

The Camp Dodge Limestone Member is a dense, thin, irregular, lenticular, grayish green to greenish gray skeletal lime mudstone. It is usually split by a thin, 0.13-1.3 cm (0.05-0.5 inches) medium dark gray to dark greenish gray shale. The lower limestone varies from 0-25 cm (0-10 inches) thick, while the upper limestone varies from 0-13 cm (0-5 inches) thick. In local areas, the middle shale is not present and the limestone occurs as a single bed.

Saylorville Coal bed

The Saylorville Coal bed is a smutty, very thin coal ranging from 0.13-1.3 cm (0.05-0.5 inches) in thickness, at the Spillway.

Elliot Ford Limestone Member

The Elliot Ford Limestone Member was first identified by Pope (2009) for exposures along the west side of Saylorville Lake in the NW NW section 14, T. 80 N., R. 25 W., Polk County, Iowa. The member is a lenticular limestone occurring above the Carruthers Coal at outcrops around Saylorville Lake and other locations in south-central and southeast Iowa. At the type section it is a thin-bedded, argillaceous, brachiopod/gastropod-rich packstone, with abundant carbonized wood fragments, and reaches 76 cm (2.5 feet) in thickness.

More formal and detailed descriptions of these new units are presented in the review of the Pennsylvanian stratigraphy at the Saylorville emergency spillway below.

THE DESMOINESIAN STAGE IN IOWA

The Desmoinesian Series was derived from the Des Moines Formation named by Keyes (1893) from outcrops along the Des Moines River in south-central and southeastern Iowa. No specific type section was ever designated. Jewett and others (1968) regarded the Desmoinesian as

Landis & Van Eck (1965)				Ravn and others (1984)					Pope (2009)						
				Midcontinent			Illinois		Midcontinent				Illinois		
Series	Group	Formation	Member	Group	Formation	Member	Formation	Member	Stage	Group	Formation	Member *bed*	Group	Formation	Member *bed*
Missourian	Pleasanton		Exline Ls Ovid C Chariton Congl	Bronson	Pleasanton	unnamed sh Exline Ls unnamed sh			MO	Bronson	Pleasanton	Shale Hill *Ovid C* Exline Ls Hepler Sh *Grain Valley C*	McCleansboro	Patoka	
Desmoinesian	Marmaton	Lenapah	Cooper Creek Ls	Marmaton		Cooper Creek Ls unnamed Sh Sni Mills Ls			Desmoinesian	Marmaton	Lost Branch	Cooper Creek Ls Nuyaka Creek Sh Sni Mills Ls		Shelbourn	
		Nowata Sh			unnamed Sh Lenapah Nowata Sh						Memorial Lenapah *Nowata*	*Dawson C* Norfleet			
		Altamont	Worland Ls Lake Neosho Sh Amoret Ls		Altamont	Worland Ls Lake Neosho Sh Amoret Ls					Altamont	Worland Ls Lake Neosho Sh Amoret Ls			
		Bandera Sh			Bandera Sh						Bandera	*McBride C* Farligton Ls *Mulberry C*			
		Pawnee	Coal City Ls Mine Creek Sh Myrick Station Ls Anna Sh		Pawnee	Coal City Ls Mine Creek Sh Myrick Station Ls Anna Sh					Pawnee	Coal City Ls Mine Creek Sh *Imes C* Myrick Station Ls Anna Sh unnamed ls			
		Labette Sh	Mystic C Marshall C		Labette Sh	Mystic C Marshall C					Labette	*Mystic C* *Marshall C*	unnamed	Carbondale	
		Fort Scott	Higginsville Ls Houx Ls		Mouse Crk	Higginsville Ls unnamed sh Houx Ls Little Osage Sh					Mouse Crk	Higginsville Ls Blackwater Crk Sh *unnamed coal* Houx Ls Little Osage Sh Clanton Crk Ls			
			Summit C		Morgan Sch	Summit C					Morgan Sch	*Summit C*			
			Blackjack Crk Ls			Blackjack Crk Ls Excello Sh						Blackjack Crk Ls Excello Sh unnamed ls			
	Upper Cherokee		Excello Sh Mulky C Pleasantview Ss Bevier C Wheeler C	Cherokee	Swede Hollow	Mulky C Bevier C Wheeler C				Cherokee	Swede Hollow	*Mulky C* Red Haw Ls *Bevier C* *Wheeler C*			
			Ardmore Ls Whitebreast C			Ardmore Ls Oakley Sh Whitebreast C					Verdigris	Ardmore Ls Oakley Sh Whitebreast C			
			Wiley C Seahorne Ls Munterville Ls Seville Ls Laddsdale C		Floris	Carruthers C unnamed C #5 Laddsdale C	"Spoon"				Floris	Camp Dodge Ls *Saylorville C* Eliot Ford Ls *Carruthers C* Olmitz Ls Belinda Sh *Thousand Acre C* *Laddsdale C*	Raccoon Creek	Tradewater	unnamed ss
	Lower Cherokee				Kalo	Cliffland C Blackoak C					Kalo	*Cliffland C* *Blackoak C*			
					Kilbourn	unnamed coals					Kilbourn	unnamed coals			
							Caseyville	Wyoming Hill C Wildcat Den C						Caseyville	*Wyoming Hill C* *Wildcat Den C*

Figure 10. Comparison of Desmoinesian Stage (Marmaton and Cherokee Groups) Stratigraphy used in Iowa historically (Landis and Van Eck, 1965), most recently (Ravn and others (1984), and new (Pope, 2009).

a stage (in Kansas) and Heckel and Watney (2002) regarded it as the Desmoinesian Stage of the Middle Pennsylvanian Series.

It comprises a succession of cyclic shales, coals, sandstones, and limestones (Heckel, 1999). It represents the lower Coal Measures of the upper Carboniferous (Keyes, 1893), and as he defined it the Desmoinesian was to include all strata from the base of the “great limestone of Winterset” or Bethany Limestone (now called Bethany Falls Limestone) down to the base of the Pennsylvanian (usually the top of the Mississippian) in Iowa. The Desmoinesian includes rocks of Morrowan and Atokan age (Ravn et al., 1984; Peppers, 1996). In Iowa the lower (Desmoinesian-Atokan) boundary was determined on the basis of palynomorphs (Ravn, 1981; Peppers, 1996; Peppers and Brady, 2007) and conodonts (Lambert and Heckel, 1990).

Moore (1932) redefined the upper boundary to coincide with a widespread unconformity (base of the Chariton Conglomerate where present) within the Pleasanton Group. Ravn and others (1984) placed the Desmoinesian-Missourian boundary at the top of the Cooper Creek Limestone (base of the Pleasanton Formation). In the Midcontinent of Kansas the upper (Desmoinesian-Missourian) boundary was placed by Heckel and others (1999) and Heckel and Watney (2002) between the Hepler and Shale Hill formations (base of the Exline Limestone) within the Pleasanton Group.

The Desmoinesian is characterized by the presence of the foraminifer *Beedeina* (=*Fusulina*), the brachiopod *Mesolobus*, coral-like chaetetid sponges (e.g. ‘*Chaetetes’*), the conodont *Neognathodus*, various ammonoids, and certain arborescent lycopods.

The Desmoinesian is perhaps 2700 m (9000 feet) thick in the Arkoma Basin of southeastern Oklahoma, ranging from 180-225 m (600-750 feet) along outcrop in eastern Kansas, and thinning slightly northward along outcrop into Iowa. It thickens into the subsurface in the Forest City Basin of Iowa, Nebraska, and Missouri to perhaps 290 m (950 feet). The Desmoinesian Stage overlies the Atokan Stage and underlies the Missourian Stage.

CHEROKEE GROUP

The Cherokee Group was named by Haworth and Kirk (1894) for exposures in Cherokee County in southeastern Kansas. In most of Iowa and the northern Midcontinent shelf, the Cherokee Group represents the basal major Pennsylvanian unit, lying above Mississippian and locally older strata and underlying the Marmaton Group. The Cherokee Group in Iowa encompasses strata of the Desmoinesian Stage and includes Atokan strata at its base.

In 1953, Searight and others adopted the Krebs and Cabaniss groups to replace the Cherokee Group, at a conference of several state geological surveys (Iowa, Kansas, Missouri, Nebraska, and Oklahoma), but Iowa did not fully agree with the classification. Despite ratification of the Krebs and Cabaniss groups, the Cherokee Group continued to be used in Iowa and throughout the Midcontinent. The Krebs and Cabaniss are still used as subgroups in Missouri.

The IGS Coal Survey Project, which ended in 1979, provided the first practical means of correlating beds in the Cherokee Group in Iowa. Ravn (1979), Ravn and others (1984), and Ravn (1986) established a biostratigraphic zonation in the group, based on palynology.

Prior to 1984 (e.g. Landis and Van Eck, 1965) the Cherokee-Marmaton boundary was placed at the base of the Blackjack Creek Limestone. Ravn and others (1984) placed the boundary at the base of the Excello Shale, the lowest recognized marine unit in the Marmaton. This was more consistent with other Marmaton Group and younger Pennsylvanian formations, which are divided on the basis of the cyclic nature of their sedimentation. These sedimentary cycles are usually divided into two formations: 1) a marine formation often dominated by limestones and marine shales and 2) a nonmarine formation dominated by nonmarine to marginal marine clastics.

The Cherokee Group has been divided into a number of cyclothemic successions in Missouri (Gentile and Thompson, 2004), but Ravn and others (1984) only designated four formations within the Cherokee Group of Iowa, similar to the divisions designated by the Kansas and Oklahoma surveys. Pope (2009) proposed five formations for the Cherokee of Iowa. In ascending order the formations in Iowa are the Kilbourn, Kalo, Floris, Verdigris and Swede Hollow.

The Cherokee Group averages about 122 m (400 feet) thick in its type region in Kansas to about 152 m (500 feet) in south-central Iowa, and is about 320 m (750 feet) thick in southwest Iowa. It thickens to over 244 m (800 feet) near the Iowa-Missouri-Nebraska border region in the Forest City Basin north of the Bourban Arch and east of the Nemaha Uplift. It also thickens south of the Bourbon Arch to at least 2700 m (9000 feet) in southeastern Oklahoma in the Arkoma Basin (Heckel, 1999).

The Verdigris/Ardmore cyclothem is the only highly recognizable major marine cyclothem within the group, being traceable from Iowa to Oklahoma. Several other minor and intermediate cyclothems (e.g. Carruthers; Bevier; some Laddsdales) contain conodont-rich zones and thin (often lenticular) limestones.

The Cherokee Group contains most of the coal resources of Iowa (Landis and Van Eck, 1965; Ravn, 1979) in the Midcontinent region. Major Cherokee Group coals in Iowa include the Blackoak, Cliffland, Laddsdale, Carruthers, Whitebreast, Wheeler, Bevier and Mulky, in ascending order.

Floris Formation

The Floris Formation includes strata from near the base of the Laddsdale Coal, just above the top of the Kalo Formation, to the base of the Oakley Shale Member of the Verdigris Formation (Pope, 2009). The type area for the Floris consists of a number of backslope cuts along a north-south road on the east edge of section 29, T. 72 N., R. 13 W., east of the town of Ottumwa, Wapello County, Iowa, but does not include the upper part of the Floris above and including the Carruthers Coal. It is named for the nearby town of Floris, in northeastern Davis County.

Ravn and others (1984) named two members in ascending order, Laddsdale Coal and Carruthers Coal, in the Floris Formation. The Laddsdale Member was redefined by Ravn and others (1984) to include one or more lenticular coals that are palynologically distinct from other Cherokee coals. The Carruthers is a single thin coal also distinguished by palynomorphs, and one or more unnamed coals occur both above and below the Carruthers. Many of these coals have lenticular marine limestones and shales associated with them (Cline, 1941). CP-7 (Wapello County) encountered eight Floris coals, the most noted in any of the 85 IGS Coal Survey Project cores.

The Floris type section is about 30.5 m (100 feet) thick, and includes seven coals, but the Carruthers Coal and overlying strata are not present. The lower six coals are assigned to the Laddsdale Coal, while the upper coal is palynologically distinct from the Laddsdale, but was unnamed by Ravn and others (1984).

In IGS Coal Survey Project cores, the Floris ranges from 20 m (65 feet) to 60 m (196 feet) in CP-53 (Monroe County), with the lower 42 m (140 feet) composed of sandstone. The thickest Floris sections are the result of sequences of sandstones (interpreted as having been deposited in river channels), which locally cut down into underlying Kalo and Kilbourn strata and occasionally into the Mississippian (e.g. CP-18, CP-53, CP-76). Some of these thick sandstones have not been named and others have been informally named: “Redrock Sandstone” (Keyes, 1891) for a series of sandstones that seem to occur at different stratigraphic horizons, around Red

Rock Reservoir, Marion County; "Cliffland Sandstone" (Leonard, 1901) near the town of Cliffland in Wapello County; "Redfield Sandstone" or "Hanging Rock Sandstone" near the town of Redfield, Dallas County; an unnamed sandstone in Ledges State Park, Boone County; an unnamed sandstone in Dolliver State Park, Webster County. There are several other similar subsurface sandstones known from cores and well logs in southeast, south-central and southwest Iowa. These sandstones may have depositional histories similar to those of the upper Tradewater ('Spoon') Formation sandstones in Scott and Muscatine counties.

In CP-41 (Marion County) the Floris contains five coals ranging in thickness from 17.8-50 cm (7-19 inches). In CP-7 (Wapello County) the Floris is 42 m (140 feet) thick and contains eight coals that range in thickness from 0.2-1.5 m (0.7-5 feet). The lower six coals are all assigned to the Laddsdale (Ravn et al., 1984), with three of the six coals associated with marine strata.

The Floris Formation underlies the Verdigris Formation and in most places in Iowa overlies the Kalo Formation, but may lie unconformably on Kilbourn Formation or Mississippian strata.

Shale below lower limestone

The lowest unit exposed in the gorge is about 1.8 m (6 feet) of blue gray (5B 6/1) to light olive (10Y 5/4), dark red (5R 3/6) to grayish red purple (5RP 4/2) mottled shales with scattered iron-clay nodules. The upper 10 cm (4 inches) is grayish green (10GY 5/2) and contains the conodonts *Adetognathus*, *Idiognathodus* and *Neognathodus*, along with linguloid brachiopods, Desmoinesia muricata and fish debris. Foraminifers include ammodiscoid, serpulopsid and earlandid forms. The lower part contains scattered clams.

These shales are interpreted as having been deposited in a marginal to shallow marine environment, where abundant clastic material was being carried in.

Lower limestone

The lowermost limestone is 20-30 cm (8-12 inches) of bioturbated skeletal lime mudstone to lime wackestone which weathers to a brownish yellow (10YR 6/8). The top is cracked into large polygonal blocks that are upturned on the edges. Cracks between the blocks are filled with shale and lime mud. Fossils include brachiopods: *Desmoinesia muricata, Derbyia crassa, Mesolobus mesolobus, Punctospirifer kentuckyensis, Neospirifer* sp., *Linoproductus* sp., *Composita ovata*, and *Crurithyris planoconvexa*; corals: *Stereostylus* sp.; gastropods: *Euphemites* sp., and unidentified internal molds, crinoid columnals, and foraminifers including unidentified small fusulinids and encrusting forms.

Hanley (2008) believes that the lowermost portion (including this limestone) of the Saylorville Dam Emergency Spillway exposure may be part of the Lower Tiawah cyclothem of Oklahoma, Kansas and Missouri, due to stratigraphic position. Initial biostratigraphic work on this interval yielded conodont faunas compatible to those of the Lower Tiawah cyclothem.

This limestone is interpreted to have been deposited in a shallow marine environment, away from clastic influx. The cracks and polygonal blocks on the top are probably desiccation cracks, formed when the lime mud was sub-aerially exposed.

Shale and mudstone between lower limestone and Carruthers Coal

Above the lower limestone is about 1.2 m (4 feet) of bluish gray (5B 6/1) shale with a grayish purple (5P 4/2) mottle in the upper half. The only fossils noted were the rare occurrence of unidentified clams. This unit may have been deposited in estuarine, or lagoon conditions. Above the bluish gray shale is 45 cm (1.5 feet) of yellowish brown (10YR 5/6) blocky mudstone with a grayish purple (5P 4/2) mottle and calcareous concretions, that grades into about 30 cm (1 foot) of grayish purple (5P 4/2) to dark red (10R 3/6) blocky mudstone. This unit is interpreted as being a paleosol developed on a well-drained paleosol, during marine lowstand.

The base of the next unit above the brown and purple blocky mudstone is about 15 cm (6 inches) of grayish green (5G 5/2) mudstone with a grayish purple (5P 4/2) mottle that grades upward to 45 cm (1.5 feet) of medium gray (N5) slickensided mudstone with two to three thin 0.13-1.3 cm (0.05-0.5 inches) coal smuts. This unit is interpreted as having been deposited on a floodplain as overbank deposits that periodically flowed into shallow swamps, during marine lowstand. The coaly zone grades upward to 30 cm (1 foot) of greenish gray (5GY 6/1) poorly bedded shale to mudstone with calcareous nodules, that in turn grades upward into 1.8 m (6 feet) of greenish gray (5GY 6/1) poorly bedded shale to mudstone with abundant vertical to subvertical tubes and calcareous nodules. This unit probably represents crevasse splay deposits that may have been deposited during a single flood event. The vertical tubes are interpreted as being crustacean burrows (similar to modern crawfish burrows) that have destroyed much of the bedding (bioturbation).

The greenish gray shale grades upward into 45-50 cm (18-20 inches) of very pale brown (10YR 7/3) to brownish yellow (10YR 6/8) blocky mudstone, with large (2-5 cm), vertically oriented pedogenic structures, and a grayish purple (5P 4/2) mottle in the lower 15 cm (6 inches). This mudstone grades upward into 65 cm (25 inches) of medium gray (N5) to dark gray (N3) mudstone with a moderate red (5R 4/6) mottle in the lower 25 cm (10 inches). Calcareous lenses and septarian nodules occur in the lower half and root traces occur in the upper half.

The upper unit is 5-10 cm (2-4 inches) of dark gray (N3) blocky mudstone with coal smuts and root traces which grades upward from the unit below. These units represent paleosols (underclays) developed on floodplain deposits. The upper parts show root casts from plants growing in the swamp, which eventually formed the overlying Carruthers Coal.

Carruthers Coal bed

The Carruthers Coal was named by Ravn and others (1984) for exposures in the east backslope along a gravel road in NW NW SE section 3, T. 73 N., R. 20 W., Lucas County, Iowa. Pope (2009) placed it in the SE SW NE section 3, T. 73 N., R. 20 W. The name is derived from Carruthers Creek, about 0.6 km (1 mile) to the southeast. The Carruthers Coal is relatively persistent in Iowa and ranges from a smut (CP-37, Clarke County and CP-44, Warren County) to 0.85 m (2.8 feet) in CP-24 (Davis County).

Historically the Carruthers Coal has been correlated with the Wiley Coal of Illinois (Weller et al., 1942), however Ravn (1986), using palynology, has shown that the unnamed coal below the Carruthers is probably equivalent of the Wiley Coal of Illinois. Cline (unpublished reports) and Landis and Van Eck (1965) used the name Wiley for the Carruthers Coal in Iowa. The Carruthers is correlative of the Greenbush Coal (southern and central) and Dekovan Coal (northern and western) of Illinois (Hopkins and Simon, 1975; Peppers, 1996). The Carruthers has also been known in Iowa, by the names ‘Dudley’, ‘Milo’, and ‘Crouch.’ Hanley (2008) correlated the Carruthers Coal with the “Scammon” Coal of Missouri and Kansas.

The Carruthers Coal bed varies from 5-15 cm (2-6 inches) with common fragments of pyrite replaced wood debris, and is locally interbedded at its top with the overlying shale or limestone. Melanterite ($FeSO_4 \cdot 7H_2O$) leaching out of the coal, is oxidized and hydrolyzed into limonite, forming a thick yellow (5Y 8.8) crust on the surface of the coal and underlying mudstone. A low diversity miospore assemblage (*Lycospora granulata, Densosporites sphaerotriangularis, D. triangularis, and Granasporites medias*) was reported in Coal Project cores in southeast Iowa, by Ravn (1986), but has not been examined at this location.

A reference section (Pope, 2009) is designated for exposures at Saylorville Dam Emergency Spillway in the C NW section 31, T. 80 N., R. 24 W., Polk County and an exposure exposures along the west side of Saylorville Lake in the NW NW section 14, T. 80 N., R. 25 W., Polk County (Elliot Ford Limestone type section). The Carruthers Coal is interpreted as having been deposited in a shallow swamp, formed by ponding of fresh water near the shoreline ahead of a relatively major marine transgression.

Elliot Ford Limestone Member

A lenticular limestone occurs above the Carruthers Coal at outcrops around Saylorville Lake and other locations in south-central and southeast Iowa. The Elliot Ford Limestone was first identified by Pope (2009) for exposures along the west side of Saylorville Lake in the NW NW section 14, T. 80 N., R. 25 W., Polk County, Iowa. At the type section it is a thin bedded, argillaceous, brachiopod/gastropod-rich packstone, with abundant carbonized wood fragments, and reaches 76 cm (2.5 feet) in thickness.

The Elliot Ford Limestone varies from 0-30 cm (0-12 inches) of light gray (N7) to medium gray (N5) skeletal lime mudstone to wackestone in the Spillway. At the Spillway cracks in the limestone are often filled with pink to red or translucent to white calcite and dolomite spar. Where the limestone thins it contains pyrite and limonite nodules. Where the limestone is not present, a light gray (N7) to medium light gray (N6) calcareous, highly fossiliferous shale occurs. Fossils include, brachiopods: *Desmoinesia muricata, Derbyia crassa, Mesolobus mesolobus, Composita ovata, Crurithyris planoconvexa, Juresania nebrascensis, Linoproductus* sp. (including juveniles with clasping spines), linguloids and orbiculoids; cephalopods: *Pseudorthoceras knoxense*; gastropods: *Trepospira* (*Trepospira*) sp., *Euphemites* sp., *Glabrocingulum* (*Glabrocingulum*) sp., and unidentified internal molds; clams: *Nuculopsis* sp., *Astartella* sp.; bryozoa: *Rhombopora* sp.; crinoids: columnals and cirri; foraminifers: *Serpulopsis* sp., encrusting forms and unidentified small fusulinids; fish debris; carbonized plant debris; ostracodes: *Bairdia*?, a geisinid and two unidentified genera; conodonts: *Idiognathodus* spp., *Adetognathus* sp.

According to Hanley (2008), the Elliot Ford Limestone would be equivalent to the upper split (equivalent to the limestone above the intraformational conglomerate at its type section in Rogers County, Oklahoma as reported by Marshall, 2002) of the Tiawah Limestone.

This limestone is interpreted as having been deposited in shallow open-marine conditions where carbonate was only partially produced or preserved, during a rise in sea level (transgressive limestone). It is possible that benthic carbonate production was smothered by clastic influx, which dominates the rest of the cyclothem.

A reference section (Pope, 2009) is designated for exposures in the Saylorville Dam Emergency Spillway in the C NW section 31, T. 80 N., R. 24 W., Polk County.

Shale and mudstone between Elliot Ford Limestone and *Gondolella* zone

Above the Elliot Ford Limestone is about 7.3 m (24 feet) of shale and mudstone with a lenticular carbonate and a thin coal near the top.

The lower 15 cm (6 inches), just above the limestone or equivalent shale, consists of light gray (N7) to medium dark gray (N4) shale. Fossils include; brachiopods: linguloids and juvenile productids attached to adult spines; crinoids: columnals and dorsal cup plates; foraminifers: *Serpulopsis* sp., *Tetrataxis* sp., *Endothyranella* sp., and ammodiscoid forms; echinoid spines; fish debris; sponge spicules; carbonized plant debris; unidentified internal molds of low and high spired gastropods; ostracodes: *Bairdia*?, a geisinid and two unidentified genera; conodonts:

Adetognathus spp., *Idiognathodus* spp., and *Neognathodus* spp. In the upper few centimeters of this unit *Adetognathus* disappears, but *Idioprioniodus* appears, along with abundant serpulopsid and ammodiscoid foraminifers. This shale is interpreted as being deposited in increasingly deeper water during sea level rise (transgression).

Gondolella zone

Next higher is a 2 cm (1 inch) thick greenish black (5GY 2/1) to black (N1) shale. It contains a few echinoid spines, gastropods, juvenile linguloid and orbiculoid brachiopods, and fish debris. *Idioprioniodus* becomes much more abundant along with *Idiognathodus* spp. and *Neognathodus* spp. *Gondolella pohli* appears as a rare constituent and *Adetognathus* and foraminifers are conspicuously absent. *Gondolella pohli* is a morphotype with a non-crenulated (smooth) platform.

Above this is about 4 cm (1.5 inches) of grayish olive green (5GY 3/2) shale. It contains an abundant conodont fauna with over 800 platform elements per kilogram. *Gondolella pohli*, *Idiognathodus* spp., *Neognathodus* spp., and *Idioprioniodus* are very abundant. Linguloid brachiopods and fish debris are rare, and *Adetognathus* and foraminifers are conspicuously absent.

Another 2 cm (1 inch) thick greenish black (5GY 2/1) to black (N1) shale occurs above this. It contains a few scattered nodules and often a thin but prominent laminae of phosphorite. The conodont fauna is very abundant with over 1200 platform elements per kilogram. Conodonts include *Idiognathodus* spp., *Idioprioniodus* spp., *Neognathodus* spp., *N. roundyi*, *Gondolella pohli*. Linguloid brachiopods and fish debris are rare, and *Adetognathus* and foraminifers are conspicuously absent. These black and greenish black shales are interpreted as having been deposited at marine highstand, during maximum transgression. The ocean bottom was probably very dysoxic below a pycnocline, as most fossils are pelagic forms. The conodont *Gondolella* was interpreted by Heckel and Baesemann (1975) as living in the water column, within or near the pycnocline.

Next higher is a medium gray (N5) shale about 2 cm (1 inch) thick. Conodont abundances drop considerably with only a few tens of platform elements per kilogram. The most common conodonts include *Idiognathodus* spp., *Neognathodus* spp., with rare *Idioprioniodus* spp. *Adetognathus* reappears along with ammodiscoid and serpulopsid foraminifers, but *Gondolella pohli* is absent. Linguloid and orbiculoid brachiopods also occur. This shale is interpreted as being deposited during early to late marine regression.

Shale and mudstone between *Gondolella* zone and Saylorville Coal

Above the darker shale of the *Gondolella* zone, is about 2.4 m (8 feet) of shale and blocky mudstone with small slickensides. The lower 45 cm (1.5 feet) is a medium gray (N5) to greenish gray (5GY 6/1) shale with very dusky purple (5P 2/2) to brownish yellow (10YR 6/8) mottling, and a small calcareous lens occurs near the top of the unit (near the northwest end of the lower gorge. Above this is 1.5 m (5 feet) of medium light gray (N6) to pale purple (5P 6/2) blocky mudstone to siltstone with scattered dark red (10R 3/6) hematite and very dusky red purple (5RP 2/2) goethite nodules. It is arenaceous and micaceous with calcite cement. The middle unit grades upward to 45 cm (1.5 feet) of medium dark gray (N4) rooted, blocky mudstone just below a thin coal (Saylorville Coal). Scattered large (> 15 cm) calcareous nodules occur near the base of this unit. Mottling in this unit often follows possible rooting structures and varies from reddish yellow (7.5YR 7/8) to blackish red (5R 2/2) to grayish green (10GY 5/2) and pale red purple (5RP 7/2). These shales and mudstones may have been deposited in a marginal marine to deltaic floodplain setting with a paleosol later developed on the deposits, during marine lowstand.

Saylorville Coal bed

The Saylorville Coal bed was first identified by Pope (2009) for exposures in the Saylorville Dam Emergency Spillway in the C NW section 31, T. 80 N., R. 24 W., Polk County, Iowa. The name is derived from Saylorville Lake, just west of the town of Saylorville in Saylor Township, north of Des Moines. The Saylorville Coal bed is a smutty, very thin coal ranging from 0.13-1.3 cm (0.05-0.5 inches) in thickness, at the Spillway.

The Saylorville Coal may be the same as the unnamed persistent coal that lies 2.4-5.2 m (8-17 feet) above the Carruthers Coal bed, which may correlate to the Abingdon Coal of northwestern Illinois (Cline and Cline and Stookey, unpublished manuscripts; Ravn, 1986). Hanley (2008) correlated the Saylorville Coal to the Mineral Coal of Oklahoma, Kansas, and Missouri.

The Saylorville Coal is interpreted as having been deposited in a shallow swamp, formed by ponding of fresh water near the shoreline ahead of a marine transgression (rise in sea level).

Above the Saylorville Coal bed is about 5 cm (2 inches) of brownish gray (5YR 4/1) shale. A few brachiopod fragments and ramiform conodont elements were recovered from this interval. This shale was probably deposited in a marginal marine to shallow marine setting during early marine transgression.

Camp Dodge Limestone Member

The Camp Dodge Limestone Member was first identified by Pope (2009) for exposures at the Saylorville Dam Emergency Spillway in the C NW section 31, T. 80 N., R. 24 W., Polk County, Iowa. The name is derived from Camp Dodge about 1.6 km (1 mile) to the west.

The Camp Dodge Limestone is a dense, thin, irregular, lenticular, grayish green (10GY 5/2) to greenish gray (5GY 6/1) skeletal lime mudstone. It is usually split by a thin, 0.13-1.3 cm (0.05-0.5 inches) medium dark gray (N4) to dark greenish gray (5G 4/1) shale. The lower limestone varies from 0-25 cm (0-10 inches) thick, while the upper limestone varies from 0-13 cm (0-5 inches) thick. In local areas, the middle shale is not present and the limestone occurs as a single massive ledge. The limestone contains rare brachiopods, including *Desmoinesia muricata* and *Mesolobus mesolobus*; conodonts: *Adetognathus* spp., *Idiognathodus* spp. and *Hindeodus* sp. The middle shale carries an extremely abundant conodont fauna of over 2300 elements per kilogram. This includes *Adetognathus* spp., *Idiognathodus* spp., *Neognathodus* spp., and possibly *Idioprioniodus* sp. Rare gastropods, ammodiscoid and serpulopsids foraminifers, linguloid brachiopods fish debris and carbonized wood fragments also occur.

Hanley (2008) believes that this unit is probably equivalent of the Russell Creek Limestone of Oklahoma, Kansas, and Missouri.

The Camp Dodge Limestone may represent later transgressive, highstand and early regressive deposits, of mostly carbonate, formed in open marine conditions.

Shale and mudstone between Camp Dodge Limestone and Whitebreast Coal

Just above the Camp Dodge Limestone is a very thin 1.3-3.8 cm (0.5-1.5 inches), irregular, clayey, medium light gray (N6) to greenish gray (5GY 6/1) shale that grades upward into a dark red (2.5YR 3/6) to dark reddish brown (2.5YR 3/4) clayey, shale with medium brownish gray (5YR 4/1) and very dusky purple (5P 2/2) mottling, about 0.76 m (2.5 feet) thick. The red shale was probably formed by the oxidation of marine shale during a period of subaerial exposure. The red shale grades upward into about 15 cm (6 inches) of medium gray (N5) shale with a dark red (2.5YR 3/6) and grayish green (5G 5/2) mottle. The medium gray shale in turn, grades upward into 60 cm (2 feet) of poorly bedded shale to mudstone. It is arenaceous and micaceous with thin, often rippled, lenticular interbeds of argillaceous sandstone. There are abundant granules of pyrite in the lower half, and the contact with the next higher unit is placed at the base of the lowest overlying sandy siltstone bed. The medium gray shale, just above the red shale, probably is at the stratigraphic horizon of the Fleming Coal (Hanley, 2008) seen in CP-79 Lucas County, Iowa.

The next higher unit is a light bluish gray (5B 7/1) arenaceous, micaceous shale interbedded with more resistant layers of sandy siltstone. This unit contains very abundant vertical to subvertical tubes which are filled with obliquely laminated, sandy, limonitic siltstone and argillaceous sandstone. The tubes can reach 10 cm (4 inches) in diameter and approach 40 cm (15 inches) in length. This unit probably represents crevasse splay deposits. The vertical tubes are interpreted as being crustacean burrows (similar to modern crawfish burrows) that have destroyed much of the bedding (bioturbation).

The burrowed unit grades upward into 15-45 cm (6-18 inches) of light gray (N7) to medium gray (N7) lenticular, arenaceous, micaceous, calcite-cemented siltstone and mudstone. The top of this unit grades into about 0.9 m (3 feet) of light gray (N7) to medium gray (N7) clayey, blocky, rooted mudstone. The bottom half of the unit contains abundant small (< 1 cm) calcareous nodules, below which lies a lenticular, light gray (N7), argillaceous, arenaceous limestone with vertical tubes. Scattered pyrite nodules and lenses occur at the top of this unit, just below the Whitebreast Coal. The mudstones and siltstones above the burrowed unit probably represent paleosols developed on deltaic floodplain deposits during sea level lowstand. The lenticular limestone, with dissolution tubes, and carbonate nodules represent caliche horizons developed within the paleosols.

Whitebreast Coal bed

In early reports St. John (1868) referred to what is now known as the Whitebreast Coal, as the 'A' coal. Later, St John (1870) named a coal the Panora Coal, for outcrops at Panora Mills on the Raccoon River, near the town of Panora in section 31, T. 80 N., R. 30 W., Guthrie County. Another one of St. John's (1870) sections contained both the Panora and Wheeler coals, and was described as being in "the immediate vicinity of Wheeler's Mill" on Whitebreast Creek in the NE section 33, T. 73 N., R. 22 W., Lucas County. Lugn (1927) described a section about 0.8 km (0.5 mile) south of St. John's section, south of Wheeler's bridge near the middle of the same section [33], and renamed the Panora Coal the 'White Breast' [Whitebreast] Coal. The name was derived from White Breast (Whitebreast of some maps) Creek. Hall (1969) relocated Lugn's type section about 366 m (400 yards) south of the bridge over White Breast Creek in the SW SW NE section 33, T. 73 N., R. 22 W.

Ravn and others (1984) redescribed the Whitebreast Coal at exposures in a series of streamcuts, at their Swede Hollow type section, in sections 33 and 34, T. 73 N., R. 22 W. and section 3, T. 72 N., R 22 W., Lucas County, Iowa. The Whitebreast Coal Member occurs at the top of the Floris Formation and underlies the Oakley Shale Member of the Verdigris Formation.

The Whitebreast Coal has been correlated to the Lower Ardmore Coal of Missouri (Hinds, 1912); Colchester (No. 2) Coal of Illinois (Hopkins and Simon, 1975); Croweburg Coal, Pioneer Coal, and Williams Coal of southeastern Kansas and southwestern Missouri (Howe, 1956; Gentile and Thompson, 2004); Croweburg Coal of Oklahoma (Wilson and Hoffmeister, 1956); Colchester (IIIa) Coal of Indiana (Peppers, 1970); Schultztown Coal of western Kentucky (Peppers, 1970); and the Lower Kittanning Coal of the Appalachian Basin (Hopkins and Simon, 1975; Heckel, 1994, 1999). The name Panora has priority over Whitebreast (Cline, 1938), but the name Whitebreast has been firmly entrenched in the literature and will be retained. Pope (2009) removed the Whitebreast Coal from the Swede Hollow Formation and placed it at the top of the underlying Floris Formation in Iowa.

At the Spillway, the Whitebreast Coal is about 25 cm (10 inches) thick with well-preserved wood and plant fragments. Cracks are filled with gypsum, pink and white calcite and pyrite. A low diversity miospore assemblage that includes the first appearance of several taxa occurs in the Whitebreast Coal. These include *Schopfites dimorphus*, *Raistrickia subcrinita* and *Triquitrites spinosus*. It also marks a large decrease in *Densosporites* species, with *Lycospora granulata* as the dominant form. This flora was reported in Coal Project cores in southeast Iowa, by Ravn (1986), but has not been examined at this location.

The Whitebreast Coal is interpreted as having been deposited in a shallow swamp, formed by ponding of fresh water near the shoreline ahead of a major marine transgression.

A reference section (Pope, 2009) is designated for exposures at Saylorville Dam Emergency Spillway in the C NW section 31, T. 80 N., R. 24 W., Polk County.

Verdigris Formation

The Verdigris limestone was originally named on a published geologic map from exposures along the Verdigris River in southern Rogers County, Oklahoma (Smith, 1928), and is essentially equivalent to what is now called the Ardmore Limestone. The Verdigris formation of Searight and others (1953), Searight (1955), Searight and Howe (1961) and Thompson (1995) lay between the Croweburg and Bevier formations, and included an unnamed basal shale, the Ardmore Limestone, the Wheeler Coal bed and an unnamed upper member, in ascending order. Gentile and Thompson (2004), in Missouri, used the same units, naming the lower shale the Oakley of Ravn and others (1984) and the upper shale an unnamed member the Wheeler Formation.

Pope (2009) proposed restricting the Verdigris Formation in Iowa to only include the unnamed lower Verdigris marine interval (part of the Oakley Shale), the Oakley Shale Member and overlying Ardmore Limestone Member, of Ravn and others (1984) and Gentile and Thompson (2004). Pope (2009) also proposed placing the underlying Whitebreast Coal bed (Croweburg Coal of Missouri) in the unnamed shale at the top of the underlying Floris Formation.

In Iowa, the Verdigris Formation overlies the Floris Formation and underlies the Swede Hollow Formation. There appears to be a lenticular limestone between the Whitebreast Coal bed and the Overlying Oakley Shale Member in Iowa, but it has only been seen on outcrop at the Saylorville Dam Emergency Spillway in Polk County. Locally large (> 15 cm; 6 inches, in diameter) light gray (N7) to medium gray (N5) concretions of lime mudstone occur in the Oakley shale in Iowa and Missouri (similar to those seen in the Excello Shale), but they do not represent a transgressive limestone.

Unnamed lower Verdigris marine interval

At most locations in the Spillway gorge (Pope and Chantooni, 1996) the black fissile facies of the Oakley Shale rests directly on the Whitebreast Coal, but in some areas it is separated by 1-2 cm (0.4-0.8 inches) of medium gray (N5) shale or lenses of limestone. The unnamed, lenticular, carbonized wood-rich, gastropod-rich, lime wackestone to packstone has only been observed by the authors at this location in Iowa. Only two lenses of the limestone are visible in the outcrop at this time, and in thin section are seen to be almost entirely replaced by pyrite with abundant carbonized wood fragments (Fisher and Pope, 2009). The gastropods are replaced by dolomite and pyrite. No conodonts were recovered from this unit. Pope and Chantooni (1996) recovered a few brachiopod fragments, gastropods, clams, and foraminifers from the thicker part of the gray shale. At this time, this interval is considered as part of the Oakley Shale.

This unit is interpreted as being deposited in shallow open-marine conditions where carbonate was only partially produced or preserved, during a rise in sea level (transgressive limestone). It is possible that benthic carbonate production was 1) reduced, due to acidic or dysoxic conditions on top of the underlying Whitebreast Coal; or, 2) sea level rise was too rapid to allow the bottom to stay within the photic zone long enough to produce carbonate; or, 3) carbonate was produced, but not preserved due to geochemical conditions on the bottom that dissolved lime mud.

Oakley Shale Member

The Oakley Shale was named by Ravn and others (1984) for exposures in a series of streamcuts at the Swede Hollow type section in sections 33 and 34, T. 73 N., R. 22 W. and section 3, T. 72 N., R 22 W., Lucas County, Iowa. It is named for the nearby town of Oakley in northern Lucas County. The Oakley Shale overlies the Whitebreast Coal bed of the Floris Formation and underlies the Ardmore Limestone Member.

The Oakley Shale averages about 45 cm (1.5 feet) in thickness in Iowa. There may be a thin light-gray (N7) shale above the Whitebreast Coal, but usually the black (N1) fissile facies rests directly on the coal, and contains carbonized wood debris in its lower part. The black (N1) fissile shale also usually contains numerous spherical non-skeletal phosphorite nodules less than 2.5 cm (1 inch) in diameter and locally large (greater than 15 cm; 6 inches in diameter) light gray (N7) to medium gray (N5) concretions of lime mudstone.

In CP-78 (Wayne County) and CP-79 (Lucas County) the black (N1) fissile phosphatic facies becomes dark gray (N3) and thickens to 0.91 m (3 feet) thick. It is separated from the Whitebreast Coal by carbonaceous medium-gray (N5) shale and siltstone up to 7.5 m (25.1 feet) thick. Cline (unpublished papers) correlated the lower medium-gray (N5) shale facies with the Francis Creek Shale of Illinois from which the Mazon Creek fossils were described. A similar fauna of fern leaves and a xiphosuran (*Euproöps danae*) in siderite and clay-iron concretions, have been described from this facies at the old Redfield clay pit (Case, 1982), Dallas County.

The main body of the Oakley Shale is a black, organic-rich, nonsandy, black fissile shale with abundant phosphorite lenses and laminae. Only a few conodonts (*Gondolella pohli*, *Neognathodus* spp., *Idiognathodus* spp., and *Idioprioniodus* sp.) and fish remains were recovered from the shale, but no radiolarians were seen. Where it rests directly on the coal the lower few centimeters of the black fissile facies contains abundant carbonized wood debris. The black fissile facies may be the equivalent of the Mecca Quarry Shale in northeastern Illinois (Hopkins and Simon, 1975; Ravn et al., 1984).

The dolomitic lime mudstone concretions in the Oakley Shale vary from a few centimeters to over 30 cm in diameter. They are often lens shaped with slickensided black shale draped around them. Common phosphorite laminae that occur in the black shale continue through the concretions. Numerous dolomite and pyrite replaced radiolarians were etched from these concretions; they include the elongate pseudoalbaillellids and spherical spumellarians (Fisher and Pope, 2009). Most are poorly preserved and only a few are moderately well preserved. In thin section, numerous calcispheres (some partially replaced with pyrite) are seen, that probably represent spumellarians along with fortuitous longitudinal sections through pseudoalbaillellids. Triaxon sponge spicules replaced by pyrite and dolomite were observed. Numerous conodonts and fish remains, as in the black shale, were also recovered. The calcareous concretions also contain conodonts (mainly *Gondolella pohli*); *Petrodus patelliformis*, cladodont teeth, *Petrodus* sp., fin spines, paleoniscid fish teeth and scales; brachiopods: *Lingula carbonaria* and *Orbiculoidea missouriensis*; scolecodonts; and unidentified burrows and trails.

The small phosphatic nodules were often barren of fossils, but rare nodules contain pyrite replaced radiolarians (that were excellently preserved including complete spines and porous outer shell structure), fish remains, sponge spicules, and the ammonoid cephalopod *Eoasianites* sp.

Above the black fissile facies is about 8-10 cm (3-4 inches) of light gray (N7) to medium gray (N5) shale with an abundant and diverse open marine fauna like that found in the overlying basal limestone of the Ardmore Limestone Member.

The black, fissile facies of the Oakley Shale is interpreted as being deposited during maximum marine transgression (highstand) in relatively deep water far offshore. Here the bottom was probably below a pycnocline where the water was anoxic and sediment influx was very low (sediment starvation). This allowed pelagic organisms (conodonts, radiolarians, fish debris, etc.) to become concentrated in the sediments. The phosphorite nodules are interpreted as being syndepositional with the black fissile shale. They probably formed as non-skeletal phosphate precipitated out of cold, deep ocean water during an upwelling event at sea level highstand. Many nucleated around pelagic phosphatic organisms, but some contain non-phosphatic pelagic organisms. The calcareous concretions are interpreted as early diagenetic growth of calcium carbonate within the shale, which preserved tiny microfossils such as the radiolarians. The dolomite and pyrite replacement of siliceous (originally opal-A) radiolarians and sponge spicules possibly occurred later than concretion precipitation, but the timing of the dissolution and replacement of the fossils has not been worked out. The upper light gray facies suggests deposition in more oxygenated water above the pycnocline, but below the photic zone, during early marine regression.

A reference section (Pope,2009) is designated for exposures at Saylorville Dam Emergency Spillway in the C NW section 31, T. 80 N., R. 24 W., Polk County and for the 328.1-353.2 foot interval of CP-78 (Wayne County).

Ardmore Limestone Member

The Ardmore Limestone was named by Gordon (1893, name formally published in 1896) in the same area where he had named the Lower Ardmore Coal. Cline (1941) redefined the Ardmore to include all of the limestone and shale beds from the base of the 'Whitebreast caprock' upward to the top of the highest marine limestone below the Wheeler Coal. McQueen (1943) designated a type section for roadcuts near the town of Ardmore immediately west of C E line section 24, T. 56 N., R. 15 W., Macon County, Missouri. It has also been called the Rich Hill Limestone in western Missouri by Greene and Pond (1926). Abernathy (1937) redefined the Ardmore as the "Ardmore cyclothem" with the Ardmore limestone as one of the more characteristic units within the cyclothem. Searight and others (1953) formally proposed that Abernathy's "cyclothem" be called the Verdigris Formation, identifying the prominent limestone member as the Verdigris limestone member. Since two rock units (Ardmore Formation and Member) should not have the same name, Searight and Howe (1961) proposed the present nomenclature: Ardmore Limestone Member of the Verdigris Formation. The Ardmore Limestone Member overlies the Oakley Shale Member and underlies the Swede Hollow Formation.

The lower Ardmore (the single limestone just above the Oakley Shale) was often called the 'diamond rock' (in reference to the joint pattern) and 'Whitebreast caprock' by early miners. It ranges from 0-46 cm (0-18 inches) in thickness and averages 15 cm (6 inches) thick. In some core and outcrop it is not present or only occurs as a layer of limestone nodules in shale. The shale between the lower and upper limestone beds averages about 1.8 m (6 feet) in thickness, but may exceed 4.6 m (15 feet). It varies from medium dark gray (N4) to dark gray (N3) to black (N1) in color, and often contains selenite crystals on weathered surfaces and pyrite-filled burrows.

The upper Ardmore (often two layers of argillaceous limestone separated by a thin, black (N1) *Crurithyris planoconvexa*-bearing, phosphatic, conodont-rich shale) was called the 'Two-Layer Limestone' by Lugn (1927) for exposures at the type section of the Whitebreast Coal, and the 'Bevier Sump Rock' by early miners in northern Missouri. In some outcrops in Dallas County several thin argillaceous limestones separated by shale, up to 2.4 m (8 feet) thick, may be present. In the Glen-Gerry Redfield clay pit in the NW NW section 8, T. 78 N., R. 29 W., Dallas County, the upper Ardmore is represented by 0.76 m (2.5 feet) of light-gray (N6) fossiliferous shale overlain by 15 cm (6 inches) of algal-coated, abraded-grain, skeletal lime grainstone.

Moore (1936) recognized that the Ardmore Limestone is essentially the equivalent of the Verdigris Limestone of Oklahoma, which was named from exposures along the Verdigris River in Rogers County, Oklahoma (Smith, 1928). The Ardmore has also been correlated to the Oak Grove Limestone of Illinois (Hopkins and Simon, 1975), and the Columbiana Limestone of the Appalachian Basin (Heckel, 1994).

At the Saylorville Dam Emergency Spillway the Ardmore Limestone Member contains three limestone beds and two prominent shales. The lower limestone bed becomes lenticular to the southwest side of the gorge, and varies in thickness from 0-46 cm (0-18 inches). Common in thinner areas, but seen in areas where the limestone is thicker, there are “windows” into the underlying Oakley Shale. Where the limestone is not present, the overlying shale rests directly on the Oakley Shale. The lower limestone is mainly a skeletal lime mudstone to lime wackestone, but locally is a lime packstone. The surface is usually quite flat, but in some areas becomes hummocky. The hummocks are low rounded areas of fossiliferous packstone and lime wackestone, often with branching sinuous grooves in the top. Rhombic jointing occurs across the entire outcrop and slickensides, due to minor movement, occur along some joints. Pyrite replaces or coats many fossils, and along with dolomite and calcite fills cracks. The ledge is resistant to erosion and forms a major bench in the gorge. Fossils seldom weather free from the matrix, but almost all of the nautiloid cephalopods found in the Ardmore Limestone, come from this unit. Fossils include, brachiopods: *Desmoinesia muricata, Wellerella osagensis, Mesolobus mesolobus, Punctospirifer kentuckyensis, Derbyia crassa, Neospirifer cameratus, Composita ovata, Crurithyris planoconvexa, Cleiothyridina orbicularis, Linoproductus platyumbonus, L. prattenianus*, and unidentified juvenile productids and chonetids; gastropods: *Straparollus* (*Amphiscapha*) sp., *Trepospira* (*Trepospira*) sp., *Bellerophon* (*Pharkidonatus*) sp., *Anematina*?, *Goniasma*?, many unidentified internal molds; clams: *Allorisma terminale*, *Nuculopsis* sp., *Astartella* sp.; cephalopods: *Pseudorthoceras knoxense*, *Ephippioceras* sp., *Domatoceras* sp., several unidentified nautiloids; bryozoan: *Rhombopora* sp.; corals: *Stereostylus* sp.; foraminifers: *Endothyranella* sp., *Serpulopsis* sp., ammodiscoid and earlandid forms; crinoids: columnals, cirri, cup plates; echinoids: teeth, lantern plates, spines; ostracodes: *Bairdia*?, a geisinid; holothuroids: sieve and wheel sclerites; conodonts: *Idiognathodus* spp., *Neognathodus* spp., and *Adetognathus* sp.

The lower limestone is interpreted as having been deposited in open marine conditions during early regression, as the ocean bottom came into the photic zone and benthic algal growth resumed. We interpret that the hummocky appearance and ‘windows’ through the limestone (and possibly the lenticular nature of the limestone) is due to dissolution of the carbonate. This may have occurred after deposition of at least some of the overlying black shale, which may have caused bottom waters to become acidic.

Above the lower limestone bed is about 1.8 m (6 feet) of grayish black (N2) to black (N1) thin bedded to laminated, semi-fissile, organic-rich shale. Common pyrite-filled vertical tubes and laminae occur, but fossils are very rare. The top of the unit is a 5-25 cm (2-10 inches) thick light gray (N7) calcareous shale, commonly with interlaminations of black (N1) shale. It has a fauna similar to the overlying middle limestone. This shale was possibly deposited by influx of terrestrial organic material which was carried into an interdistributary bay during regression, as distributary channels shifted and the shoreline moved closer to the area as water shallowed.

The middle limestone bed is the most fossiliferous, both in terms of diversity and abundance, of the three Ardmore limestones. It consists of an argillaceous, bioturbated, skeletal lime mudstone to lime wackestone, with local zones that are packstones. It is also locally interbedded with grayish green (10G 4/2) to dark gray (N3) fossiliferous shale. It averages about 10 cm (4 inches) thick in the gorge, but increases to 45 cm (18 inches) toward the northwest end. Pyrite is very abundant and is present on almost every fossil. Some fossils are so coated as to almost be unrecognizable. Common fossils are, brachiopods: *Desmoinesia muricata, Wellerella osagensis, Mesolobus mesolobus, Punctospirifer kentuckyensis, Derbyia crassa, Neospirifer cameratus, Composita ovata, Crurithyris planoconvexa, Crania modesta, Linoproductus platyumbonus, L. prattenianus, Juresania nebrascensis, Leptalosia ovalis, Orbiculoidea missouriensis*, juvenile linguloids, productids and chonetids; gastropods: *Glabrocingulum* (*Glabrocingulum*) sp., *Straparollus* (*Amphiscapha*) sp., *Trepospira* (*Trepospira*) sp., *Bellerophon* (*Pharkidonatus*) sp., *Euphemites* sp., *Anematina*?, *Goniasma*?, *Meekospira*?, many unidentified internal molds; clams: *Allorisma terminale*, *Nuculopsis* sp., *Astartella* sp., *Phestia* sp., *Parallelodon* sp., *Aviculopecten* sp.; cephalopods: *Pseudorthoceras knoxense*, *Metacoceras* sp.; foraminifers: *Endothyranella* sp., *Tetrataxis* sp., *Serpulopsis* sp., ammodiscoid and earlandid forms; crinoids: columnals, cirri, cup and arm plates; echinoids: teeth, lantern and interambulacral plates, spines; ostracodes: *Bairdia*?, *Kellettina*?, a geisinid; holothuroids: sieve and wheel sclerites; bryozoa: *Rhombopora* sp.; corals: *Stereostylus* sp.; scolecodonts; fish debris; conodonts: *Idiognathodus* spp., *Neognathodus* spp., and *Adetognathus* sp. This limestone was probably deposited as delta distributary channels shifted again, as water deepened during a reversal of sea level and the area became more open marine.

Above the middle limestone is about 45 cm (18 inches) of shale. The lower 10 cm (4 inches) is light greenish gray (5G 7/1) shale with numerous calcareous lenses. Fossils are very abundant, with a fauna similar to the middle limestone. It grades upward into about 25 cm (10 inches) of blackish gray (N2) to black (N1) semi-fissile to fissile shale. This facies contains scattered nodules and laminae of phosphorite. The black facies contains numerous fossils including, brachiopods: *Desmoinesia muricata, Wellerella osagensis, Mesolobus mesolobus, Punctospirifer kentuckyensis, Derbyia crassa, Composita ovata, Crurithyris planoconvexa, Leptalosia ovalis, Orbiculoidea missouriensis*, juvenile linguloids, productids and chonetids; gastropods: *Trepospira* (*Trepospira*) sp., *Straparollus* sp., several unidentified low-spired internal molds; cephalopods: *Pseudorthoceras knoxense*; foraminifers: *Endothyranella* sp., *Tetrataxis* sp., *Serpulopsis* sp., ammodiscoid and earlandid forms; crinoids: columnals, cup plates; echinoids: interambulacral plates, spines; ostracodes: *Bairdia*?, *Kellettina*?, a geisinid; holothuroids: sieve, hook, wheel sclerites; fish debris: *Petrodus patelliformis*, *Petalodus* sp., *Holmesella* sp., paleoniscid teeth and scales; scolecodonts; carbonized wood fragments; unidentified invertebrate burrows and trails; conodonts: *Adetognathus* sp., *Idiognathodus* spp., *Neognathodus* spp., and possibly *Idioprioniodus* sp. The black shale in turn grades upward into a 5-8 cm (2-3 inch) light gray (N7) shale. The upper part of this shale is fossiliferous and contains a fauna similar to the overlying limestone. This phosphatic black shale probably represents another condensed interval as water deepened and the bottom was once again below the photic zone and a pycnocline.

The upper limestone bed is an argillaceous, skeletal lime mudstone to lime wackestone and averages about 20 cm (8 inches) thick. It varies from 10 cm (4 inches) to 45 cm (18 inches) in thickness. It is the least fossiliferous of the three limestone beds in the Ardmore Limestone. Only minor amounts of pyrite occur. Fossils are mainly brachiopods and gastropods, and include, brachiopods: *Desmoinesia muricata, Wellerella osagensis, Mesolobus mesolobus, Derbyia crassa, Composita ovata, Crurithyris planoconvexa, Leptalosia ovalis, Crania modesta, Linoproductus platyumbonus, L. prattenianus*; gastropods: *Glabrocingulum* (*Glabrocingulum*) sp., *Trepospira* (*Trepospira*) sp., *Bellerophon* (*Bellerophon*) sp., *Euphemites* sp., *Naticopsis* sp., *Ianthinopsis* sp., *Anematina*?, *Goniasma*?, several unidentified internal molds; clams: *Allorisma* *terminale*, *Nuculopsis* sp., *Astartella* sp., *Phestia* sp., several unidentified internal molds; foraminifers: *Endothyranella* sp., *Tetrataxis* sp., *Serpulopsis* sp., ammodiscoid and earlandid forms; crinoids: columnals, cirri, cup plates; cephalopods: *Pseudorthoceras knoxense*; ostracodes: *Bairdia*?, a geisinid; bryozoan: *Rhombopora* sp.; unidentified invertebrate burrows and trails. This limestone was deposited in open marine conditions similar to those in which the middle limestone was deposited.

Swede Hollow Formation

The Swede Hollow Formation was named by Ravn and others (1984) for a series of streamcuts along a tributary (Swede Hollow) to Whitebreast Creek in sections 33 and 34, T. 73 N., R. 22 W. and section 3, T. 72 N., R 22 W., Lucas County, Iowa. The original definition of the Swede Hollow was all strata between the base of the Whitebreast Coal and the base of the Excello Shale, which is the boundary between the Cherokee Group and overlying Marmaton Group (Ravn et al., 1984). The Swede Hollow, as defined by Pope, (2009), spans strata from the top of the Ardmore Limestone to the base of the Excello Shale, after placing the Oakley Shale and Ardmore Limestone in the newly erected Verdigris Formation. The Swede Hollow Formation overlies the Verdigris Formation and underlies the Mouse Creek Formation of the Marmaton Group.

At this time only relatively continuous limestone and coal units within the Swede Hollow Formation will be named, in descending order: Mulky Coal bed, Red Haw Limestone Member, Bevier Coal bed, and Wheeler Coal bed. These units are important in developing a cyclothemic framework for the Pennsylvanian Cherokee Group of Iowa, and are relatively easily recognized in core and outcrop. Because of the uncertainty involved in correlating laterally discontinuous and highly variable sandstone bodies and shales, the units between the above named members and beds will not be named.

Shale and mudstone between Ardmore Limestone and unnamed sandstone

Above the upper Ardmore Limestone bed is 2 cm (1 inch) of light greenish gray (10GY 7/1) shale that grades into about 25 cm (10 inches) of medium dark gray (N4) shale and mudstone. It contains scattered pyrite nodules, several genera of clams (including a *Pteronites*-like form), *Rhombopora* sp., *Desmoinesia muricata*, and other marine fossils. Ostracodes and spirorbid worm tubes are very abundant locally, in some horizons. This unit grades upward into 25 cm (10 inches) of light greenish gray (10GY 7/1) mudstone. Localized zones near the base have a slight moderate red (5R 4/6) mottling. Common ostracodes occur near the base. These shales were probably deposited in marginal marine conditions.

Unnamed sandstone

Above the ostracode-rich mudstones is a weathered sandstone that ranges from a brownish yellow (10YR 6/8) to moderate yellowish brown (10YR 5/4) to dark yellowish brown (10YR 3/4). It varies from 0.2-1.5 m (0.7-4.8 feet) thick, is fine to medium grained, micaceous, locally silty, and is cemented with calcite and iron oxides. Where the sandstone is well-cemented it is very dense and hard. Unweathered sandstone is usually a light gray (N7) color.

In Iowa the sandstone(s) at below the Marmaton Group was/were usually called the 'Pleasantview' (Weller et al., 1942), a name applied by Ekblaw (1931) for a sandstone occupying the same stratigraphic position near the town of Pleasantview, Schuyler County, Illinois. Landis and Van Eck (1965) also used the name Pleasantview, but it was misprinted as Pleasantville in their stratigraphic column (Landis and Van Eck, 1965, Fig. 4, p. 19). In Iowa and Missouri, the Pleasantview was normally considered the first sandstone below the Mulky Coal or sometimes below the Breezy Hill Limestone. Other workers have used the name Pleasantview for sandstones occurring below the Bevier Coal (Bevier Coal of today's definition) and possibly below the Wheeler Coal. Ravn and others (1984) dropped the name Pleasantview from Iowa nomenclature, because of the uncertainty involved in correlating laterally discontinuous sandstone bodies, especially from basin to basin (Illinois Basin to Midcontinent Basin).

The sandstone has several channel structures oriented northeast-southwest (azimuth trends on the three easternmost channels are 215, 230, and 260), with current and interference ripples and often drag marks on the bottoms. Several (at least seven can still be seen) open or partially sand-filled channel structures have been noted in the gorge. Adjacent to some of the channel structures are trough-cross bedding features, but recent weathering, flood events, and spillway construction has markedly eroded these features. The thicker areas between the channel structures are interpreted to have been deposited as migrating longitudinal river bars or small dune and vegetation covered island in a braided river system, possibly in a delta distributary. This river probably flowed from the northeast to southwest across the area. The base of the sandstone has scoured into the underlying mudstone to various depths and most overturned blocks show a wide variety of sole marks. These include small to large groove casts (probably caused by partially floating logs being dragged along the bottom of the channels), possible current lineations, and other small tool marks. Stigmaria (root casts) of arborescent lycopods and other tress and plants, that were probably growing sections on the bars and islands between channel structures, can be seen in transverse sections. One root cast on the present surface is over 9 m (30 feet) in length, with many of the side 'rootlets' preserved, is probably in life position where it grew. Other 'rootlets' in a cross section of sandstone after the 1991 flood were over 1 m (40 inches) in length. This block was destroyed by the 1993 flood event. Ferns and fern-like plants (e.g. seed ferns), *Calamites*, and carbonized plant fragments also occur in the sandstone.

Joints in the sandstone are bordered by alternating parallel bands of limonite and other iron (and manganese?) oxide minerals. These features are called metachromatic (Liesegang) bands that formed when iron mineral saturated water flowed along the joints, and iron and other minerals were left behind in the sandstone. Each band may represent a separate flow event, which probably happened well after lithification of the sediment.

The sandstone is very resistant to erosion, except along the joints. Undercutting of the mudstone beneath it and plucking of the sandstone blocks by currents during flood events, has allowed many large blocks, some over 3 m (10 feet) across, to fall onto lower units or be pushed into somewhat imbricated piles.

Near the washed out roadway, the sandstone is less weathered and is more of a grayish blue green (5BG 5/2) color. Here it grades upward into 30 cm (1 foot) of friable argillaceous sandstone to siltstone. This grades upward into 38 cm (15 inches) of arenaceous grayish green (5G 5/2) blocky mudstone with a dark red (10R 3/6) mottle at the top. Above this is about 0.9 m (3 feet) of blocky dark red (10R 3/6) mudstone with a grayish green (5G 5/2) mottle throughout. Near the top of the red mudstone is a lenticular 15-25 cm (6-10 inches) limestone. The red mudstone is probably a paleosol with caliche horizons developed on a well-drained floodplain during sea level lowstand. The uppermost strata reported by Pope and Chantooni (1996) near the concrete weir are no longer exposed.

REFERENCES

Abernathy, G.E., 1937, The Cherokee group of southeastern Kansas, *in* Guidebook, 11th Regional Field Conference, Kansas Geological Society, Southeastern Kansas and northeastern Oklahoma. p. 18-23.

Case, G.R., 1982, A pictorial guide to fossils: Van Nostrand Reinhold Company, New York, 515 p.

Cline, L.M., 1938, Correlation of Pennsylvanian Des Moines series of southern Iowa and northern Missouri: Bulletin of Geological Society of America (abstract), v. 49, p. 1973.

Cline, L.M., 1941, Traverse of upper Des Moines and lower Missouri series from Jackson County, Missouri,to Appanoose County, Iowa: American Association of Petroleum Geologists Bulletin, v. 25, p. 23-72

Ekblaw, S.E., 1931, Channel deposits of the Pleasantview Sandstone in western Illinois: Illinois Academy of Science Transactions, v. 23, p. 391-399.

Fisher, and Pope, J.P., 2009, Paleontology, Petrology and Petrography of early diagenetic calcareous concretions in the Oakley Shale Member of the Verdigris Formation at Saylorville Dam Emergency Spillway, Polk County, Iowa: South-Central Geological Society of America Abstracts with Programs, v. 41, no. 2, p. 10.

Gentile, R.J., and Thompson, T.L., 2004, Paleozoic succession in Missouri, Part 5, Pennsylvanian Subsystem: Missouri Geological Survey, Report of Investigations 70, 1225 p.

Gordon, C.H., 1896, A report on the Bevier sheet, *in* Keyes, C.R., Reports on areal geology: Missouri Geological Survey, v. IX, 1st Series, Sheet Report Part 2 (1893), 75 p.

Greene, F.C., and Pond, W.F., 1926, The geology of Vernon County: Missouri Bureau of Geology and Mines, v. 19 (2nd series), 152 p.

Hall, S.A., 1969, Nomenclature of some Pennsylvanian upper Cherokee (Desmoinesian Series) coals of Iowa: Iowa Academy of Science v. 76, p. 275-281.

Hanley, K.D., 2008, Sequence Stratigraphy and correlation of middle Cherokee Group cyclothems (Middle Pennsylvanian, early Desmoinesian) from Oklahoma to Iowa: Unpublished Ph D. Thesis, University of Iowa, Iowa City, 163 p.

Haworth, E., and Kirk, M.Z., 1894, A geologic section along the Neosho River from the Mississippian formation of the Indian Territory to White City, Kansas, and along the Cottonwood River from Wycoff to Peabody: Kansas University Quarterly, v. 2, p. 104-115.

Heckel, P.H., 1994, Evaluation of evidence for glacial-eustatic control over marine Pennsylvanian cyclothems in North America and consideration of possible tectonic effects: *in* Dennison, J.M., and Ettensohn, F.R., eds., Tectonic and Eustatic Controls on Sedimentary Cycles: SEPM Concepts in Sedimentology and Paleontology, no. 4, p. 65-87.

Heckel, P.H., 1999, Overview of Pennsylvanian (Upper Carboniferous) stratigraphy in Midcontinent region of North America; *in* Guidebook for XIV-ICCP Field Trip #8: Middle and Upper Pennsylvanian (Upper Carboniferous) cyclothem succession in Midcontinent Basin, U.S.A., Heckel, P.H., editor: Kansas Geological Survey Open-file Report 99-27, p. 68-102.

Heckel, P.H., Boardman, D.R., Watney, W.L., Barrick, J.E., and Pope, J.P., 1999, Description of field trip stops; *in* Guidebook for XIV-ICCP Field Trip #8: Middle and Upper Pennsylvanian (Upper Carboniferous) cyclothem succession in Midcontinent Basin, U.S.A., Heckel, P.H., ed., Kansas Geological Survey Open-file Report 99-27, p. 13-67.

Heckel, P.H., and Watney, W.L., 2002, Revision of stratigraphic nomenclature and classification of the Pleasanton, Kansas City, Lansing, and lower part of the Douglas groups (lower Upper Pennsylvanian, Missourian) in Kansas: Kansas Geological Survey Bulletin 246, 69 p.

Heckel, P.H., and Baesemann, J.F., 1975, Environmental interpretation of conodont distribution in Upper Pennsylvanian (Missourian) megacyclothems in eastern Kansas: American Association of Petroleum Geologists Bulletin, v. 59, p. 486-509.

Hinds, H., 1912, The coal deposits of Missouri: Missouri Bureau of Geology and Mines, v. 11, 2nd series, 503 p

Howe, W.B., 1956, Stratigraphy of pre-Marmaton Desmoinesian (Cherokee) rocks in southeastern Kansas: Kansas Geological Survey Bulletin 123, 132 p.

Hopkins, M.E., and Simon, J.A., 1975, Pennsylvanian System, *in* Willman, H.B., et al., Handbook of Illinois stratigraphy: Illinois Geological Survey Bulletin 95, p. 163-201.

Jewett, J.M., O'Conner, H.C., and Zeller, D.E., 1968, Pennsylvanian System, *in* Zeller, D.E., ed., The stratigraphic succession in Kansas: Kansas Geological Survey Bulletin 189, p. 21-43.

Keyes, C.R., 1891, The Redrock Sandstone of Marion County, Iowa: American Journal of Science, v. 141, p. 273-276.

Keyes, C.R., 1893, Geological formations of Iowa: Iowa Geological Survey, v. 1, 144 p.

Lambert, L.L., and Heckel, P.H., 1990, The Atokan/Desmoinesian boundary in North America: preliminary considerations for selecting a boundary horizon: Courier Forschunginstitut Senckenberg, v. 130, p. 307-318.

Landis, E.R., and Van Eck, O.J, 1965, Coal resources of Iowa: Iowa Geological Survey Technical Paper 4, 141 p.

Leonard, A.G., 1901, Geology of Wapello County: Iowa Geological Survey Annual Report, v. XII, p. 440-511.

Lugn, A.L., 1927, Geology of Lucas County: Iowa Geological Survey Annual Reports for 1925 and 1926, v. 32, p. 101-237.

McQueen, H.S., 1943, Geology of the fire clay districts of east central Missouri, with chapters on the results of X-ray analyses of the clays and the results of firing behavior tests, by P.G. Herold: Missouri

Geological Survey and Water Resources, v. 28, 2nd series, 250 p.

Marshall, T. R., 2002, Outcrop based cyclic stratigraphy of the Cherokee Group (Desmoinesian, Pennsylvanian): Unpublished MS Thesis, Oklahoma State University, Stillwater, OK

Moore, R.C., 1932, A reclassification of the Pennsylvanian system in the northern mid-continent region: *in* Guidebook, 6th Regional Field Conference, Kansas Geological Society, p. 80-97.

Moore, R.C., 1936, Stratigraphic classification of the Pennsylvanian rocks of Kansas: Kansas Geological Survey Bulletin 22, 256 p.

Peppers, R.A., 1970, Correlation and Palynology of coals in the Carbondale ad Spoon formations (Pennsylvanian) of the northeastern part of the Illinois Basin: Illinois State Geological Survey Bulletin 93, 173 p.

Peppers, R.A., 1996, Palynological correlation of major Pennsylvanian (Middle and Upper Carboniferous) chronostratigraphic boundaries in the Illinois and other coal basins: Geological Society of America, Memoir 188, 111 p.

Peppers, R.A., and Brady, L.L., 2007, Palynological correlation of Atokan and Lower Desmoinesian (Pennsylvanian) strata between the Illinois Basin and the Forest City Basin in eastern Kansas: Current Research in Earth Sciences, Bulletin 253, part 1, (http://www.kgs.ku.edu/Current/2007/Peppers/index.html), 21 p.

Pope, J.P. 2009, Description of Units, Revision of Stratigraphic Nomenclature, and Reclassification of the Morrowan, Atokan, Desmoinesian, Missourian, and Virgilian stages

(Cherokee, Marmaton, Bronson, Kansas City, Lansing, Douglas, Shawnee, and Wabaunsee groups) in Iowa. unpublished manuscript, Iowa Geological and Water Survey, Iowa City, Iowa, 69 p.

Pope, J.P., and Chantooni, A.M., 1996, Pennsylvanian geology of the Saylorville Dam emergency spillway after the floods of ’93: Prepared for the Army Corps of Engineers, Saylorville Dam, 114 p.

Ravn, R.L., 1979, An Introduction to the stratigraphic palynology of the Cherokee Group (Pennsylvanian) coals of Iowa: Iowa Geological Survey Technical Paper, no. 6, 117 p.

Ravn, R.L., 1981, Stratigraphy, petrology and depositional history of the Hertha Formation (Upper Pennsylvanian), Midcontinent North America: Unpub. Ph.D. thesis, University of Iowa, 274 p.

Ravn, R.L., 1986, Palynostratigraphy of the Lower and Middle Pennsylvanian coals of Iowa: Iowa Geological Survey Technical Paper, no. 7, 245 p.

Ravn, R.L., Swade, J.W., Howes, M.R., Gregory, J.L., Anderson, R.R., and Van Dorpe, P.E., 1984, Stratigraphy of the Cherokee Group and revision of Pennsylvanian stratigraphic nomenclature in Iowa: Iowa Geological Survey Technical Information Series No. 12, 75 p.

St. John, O.H., 1870, Geology of the middle region of western Iowa and other counties: *in* White, C.A., Report on the geological survey of the State of Iowa: v. 2, p. 1-200.

Searight, W.V., 1955, Lexicon of pre-Marmaton terms with notes, *in* Guidebook for field trip, Second Annual meeting, Association of Missouri Geologists: Missouri Geological Survey and Water Resources Report of Investigations no. 20, p. 30-42.

Searight, W.V., and Howe, W.B., 1961, Pennsylvanian System (revised, Thompson, T.L., 1995), *in* The stratigraphic succession in Missouri: Missouri Geological Survey and Water Resources, v. 40, 2nd series, p. 78-122.

Searight, W.V., Howe, W.B., Moore, R.C., Jewett, J.M., Condra, G.E., Oakes, M.C., and Branson, C.C., 1953, Classification of Desmoinesian (Pennsylvanian) of northern Mid-Continent: American Association of Petroleum Geologists Bulletin, v. 37, no. 12, p. 2747-2749.

Smith, C.D., 1928, Geologic map of Claremore Quadrangle, *in* Woodruff, E.C., and Cooper, C.L., Geology of Rogers County: Oklahoma Geological Survey Bulletin 40-U, Map (reprinted in Bulletin 40, v. 3, p. 269-288, Map no. 26).

Thompson, T.L., 1995, The stratigraphic succession in Missouri: Missouri Department of Natural Resources Division of Geology and Land Survey, v. 40 (revised), 189 p.

Weller, J.M., Wanless, H.R., Cline, L.M., and Stookey, D.G., 1942, Interbasin Pennsylvanian correlations, Illinois and Iowa: American Association of Petroleum Geologists Bulletin, v. 26, p. 1585-1593.

Wilson, L.R., and Hoffmeister, W.S., 1956, Pennsylvanian plant microfossils of the Croweburg Coal in Oklahoma: Oklahoma geological Survey Circular 32, 52 p.

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