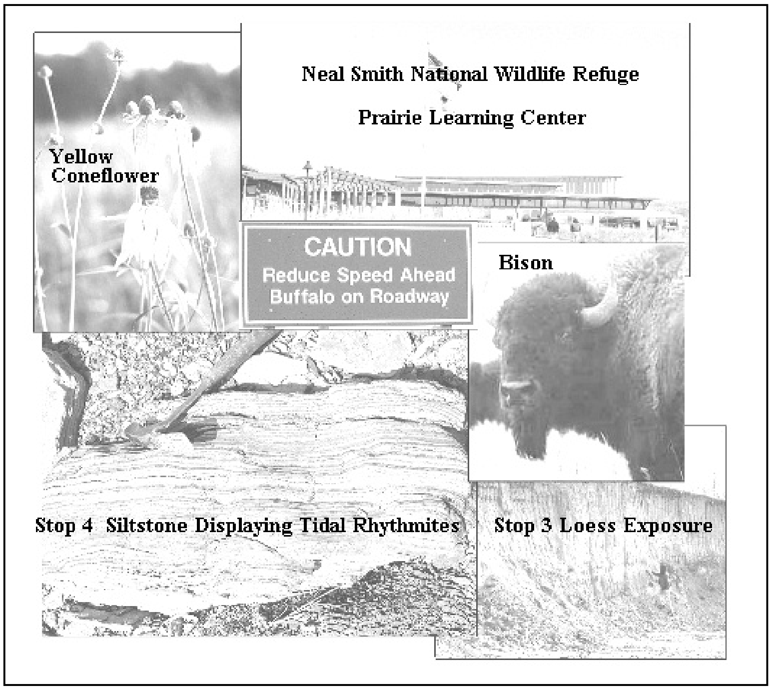
PRAIRIES TO COAL SWAMPS: GEOLOGICAL FEATURES IN SOUTH-CENTRAL IOWA

edited by Raymond R. Anderson

Geological Society of Iowa

April 27, 2002 Guidebook 73



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PRAIRIES TO COAL SWAMPS: GEOLOGICAL FEATURES IN SOUTH-CENTRAL IOWA

INTRODUCTION TO THE FIELD TRIP

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The Spring 2002 Geological Society of Iowa field trip provides participants with an opportunity to observe several aspects of geoscience in south-central Iowa. We will begin the day at the U.S. Department of Fish and Wildlife's Neal Smith Wildlife, southwest of Prairie City in Jasper County. The refuge is the largest prairie reconstruction project in the United States, and will include 8,000 acres when completed. We will meet at the refuge's beautiful and informative Prairie Learning Center, where we will learn about the great tallgrass prairie that once covered much of Iowa, including Jasper County, and the efforts of the people at Neal Smith to restore that prairie. Following a brief tour of the Prairie Learning Center, Keith Schilling (Iowa Geological Survey Bureau) will discuss his activities monitoring Walnut Creek, the principal stream in the refuge. Keith has been recording the changes in water quality and other parameters related to the transformation of much of the creek's drainage basin from agricultural row crop to native prairie. Following his discussion, Keith will lead us to Stop 1, an area of the creek that he has been actively monitoring, and we will see how he collects this important data. Then we will return to our vehicles and take a motor tour of the refuge. We will drive past the US Geological Survey Gaging Station on the south end of the refuge, then return to the heart of the facility where we will a drive through the area where bison and elk have been introduced to the prairie. ***THE ANIMALS ARE DANGEROUS, SO PLEASE STAY IN YOUR CARS AND TAKE PHOTOGRAPHS THROUGH YOUR WINDOWS.*** After the drive through the refuge, we will return to the Prairie Learning Center for a short hike on the Prairie Overlook Interpretive Trail, if time allows then lunch at the Center.

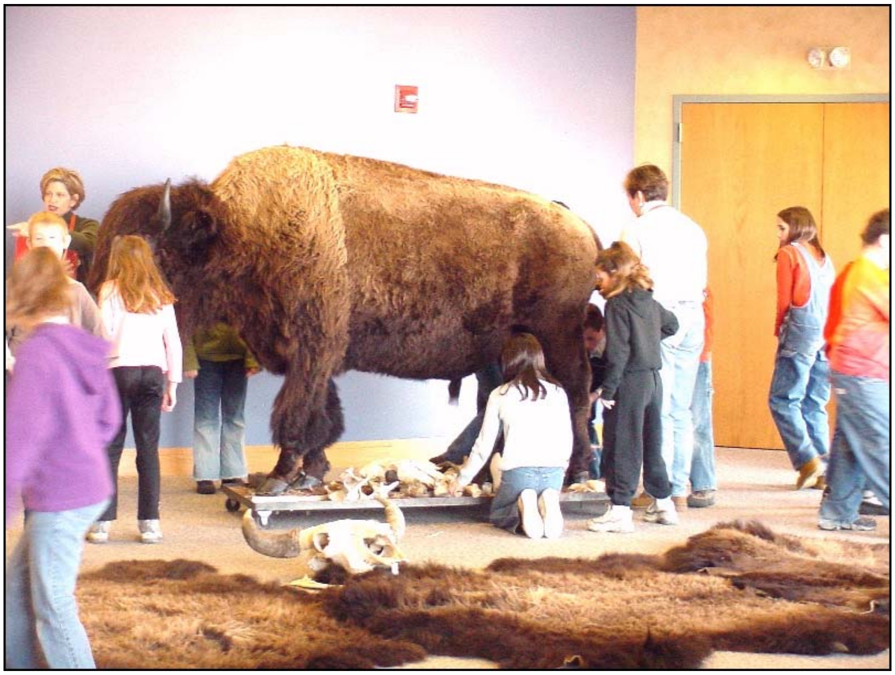


Figure 1. Children study a mounted bison at the Prairie Learning Center.

After lunch we will return to the cars for a drive south and east to Red Rock Lake, by way of Monroe and Highway 14. We will cross Red Rock Lake, Iowa's largest lake, on the Highway 14 bridge, locally known as the *one mile bridge*, then continue south for about 2 miles where we will take a side road west of the highway just prior to the bridge over the White Breast Creek arm of the lake. At the lake, John Pope (University of Iowa Geoscience graduate student) will lead us to Stop 2 where we will observe Pennsylvanian river channel sandstones, displaying a variety sedimentologic features and plant fossils, and overlying shales deposited by the subsequent marine transgression. Features in the shales include enigmatic cone-in-cone structures. At Stop 3, very near Stop 2, Stephanie Tassier-Surine will show us a very interesting exposure of Quaternary Loess and related paleosols. About ¼ mile from these stops, John Pope will lead an investigation of Stop 4, Pennsylvanian units stratigraphically above the Stop 2 shale. These units include marine shale, a terrestrial under clay displaying spherosiderorites, and a thin coal. For the final stop of the day we will drive through Knoxville, then east and north to the White Breast campground on the south shore of Lake Red Rock. We will park at the campground, then hike down to the lake on the White Breast Creek side of the peninsula. At the lake we will see Stop 5, a fascinating sequence of rocks including a suite of thin silt and clay beds, probably deposited by the daily waxing and waning of the tides in the Pennsylvanian seas 300 million years ago, features known as tidal rhythmites. These rhythmies were deposited in a drowned river valley and are capped by a thick sandstone that represents the channel sands that were deposited where the river emptied into the sea. Also visible at the site is a Pennsylvanian paleosol, a soil developed on the banks of the ancient river.

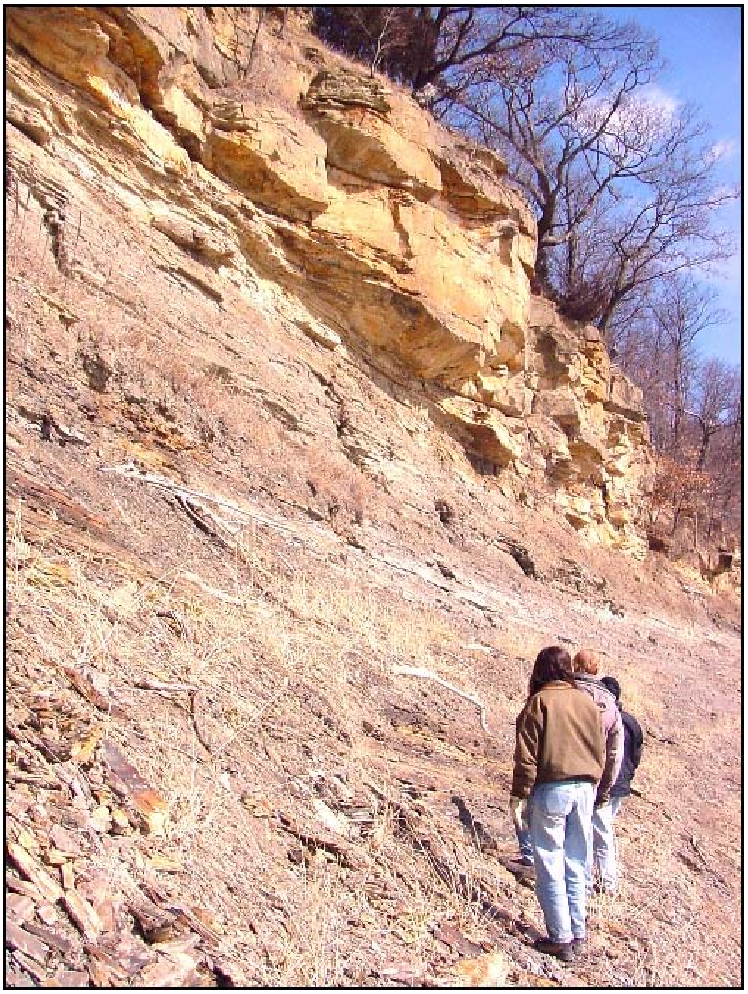
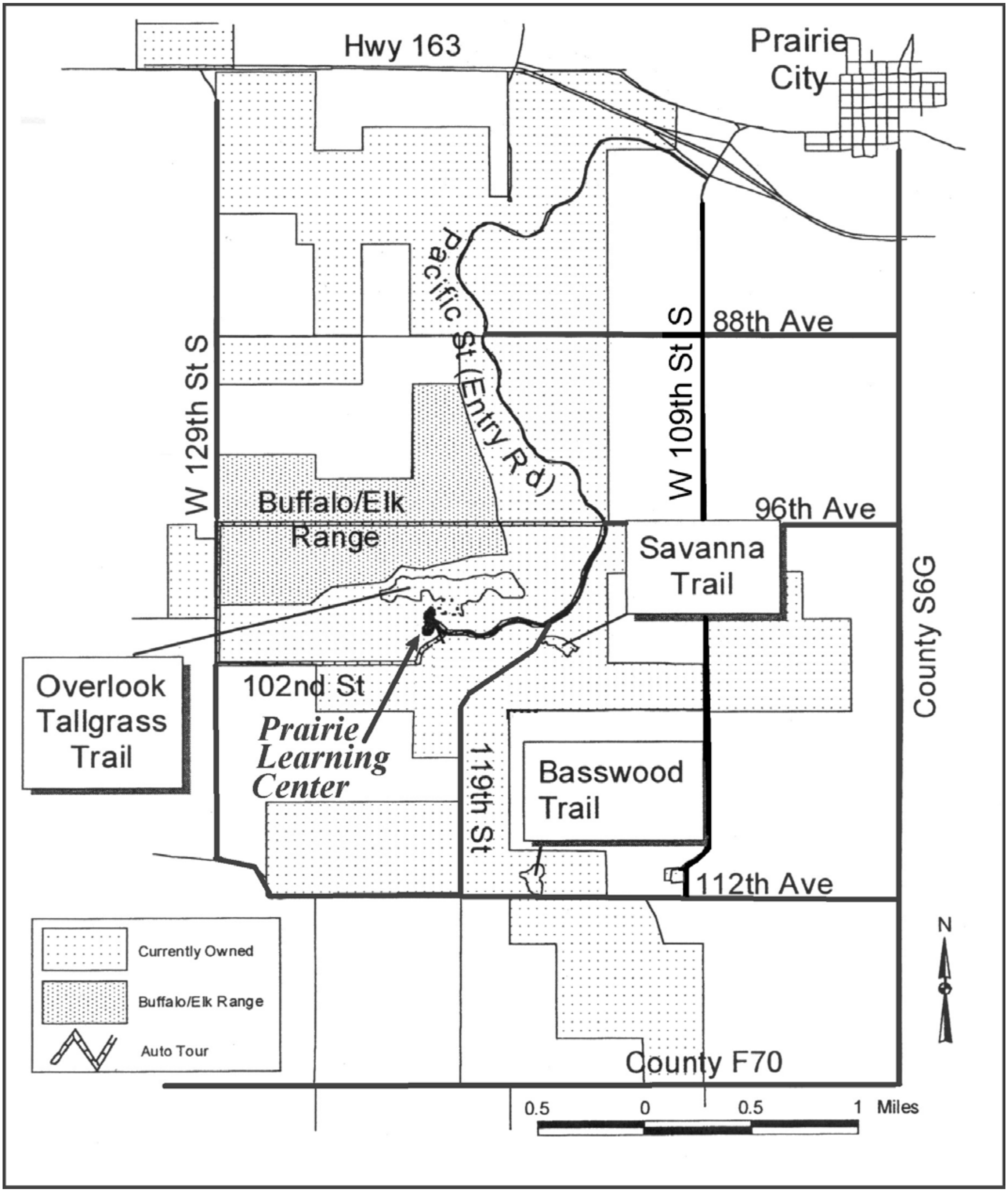


Figure 2. Field trip leaders examine the Pennsylvanian tidal rhythmites and overlying sandstone at Stop 5.

This field trip will provide participants with a look at a variety of geologic features of varying ages. We will be able to observe and compare ancient soils (paleosols) of Quaternary age (Yarmouth-Sangamon and Farmdale Soils at Stop 3) and much older Pennsylvanian paleosols (at Stop 5). I hope that everyone enjoys it and learns a little about past and current geologic processes in Iowa.



Map of Neal Smith National Wildlife Refuge

THE NEAL SMITH NATIONAL WILDLIFE REFUGE

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INTRODUCTION

The Neal Smith National Wildlife Refuge (formerly Walnut Creek), located in Jasper County, Iowa, is a unit of the National Wildlife Refuge System administered by the Department of the Interior's U.S. Fish and Wildlife Service. The refuge is the largest re-creation of the tallgrass prairie ecosystem anywhere in the United States. One hundred fifty years ago, tallgrass prairie covered 85% of Iowa's 36 million acres. Today, only one-tenth of one percent of that prairie remains. The near extinction of this ecosystem was one of the arguments that encouraged the Congress of the United States, in 1990, to pass the act that will eventually re-create an 8,000-acre area of tallgrass prairie and oak savanna, the plant communities that existed in central Iowa prior to Euro-American settlement in the 1840's. Native grasses and prairie flowers are being nurtured, and more than 200 types of prairie seeds have been replanted. In addition, the animals that inhabited these ecosystems are being reintroduced in controlled areas of the preserve. Bison and elk have been introduced, to join white tail deer, badgers, and other native species still living in the area. Additionally, a world-class prairie exhibit and education center, the Prairie Learning Center (Fig. 1), was constructed at the refuge. The low-lying, modern structure blends neatly into the prairie landscape and includes a 13,000 square foot exhibition hall, with an associated theater, meeting rooms, offices, picnic facilities, and the Prairie Point Book Store.

Figure 1. The Prairie Learning Center at Neal Smith National Wildlife Preserve.

HISTORY

The Original Prairies of the Great Plains

The Great Plains of North America is a roughly triangular area covering 1.4 million square miles that extends for about 2,400 miles (3,870 km) from Alberta, Saskatchewan, and Manitoba southward through Texas into Mexico and approximately 1,000 miles (1,612 km) from foothills of the Rocky Mountains eastward to Indiana. As prevailing westerly winds, rich with moisture from the Pacific Ocean, rise up over the mountains, they are cooled, releasing most of their moisture in the form of rain on the western slopes. Now dry, the winds blow down the eastern slopes and out onto the Great Plains. The vegetation of these plains are, of necessity, low moisture plants, including prairie grasses and flowering plants. The Western Great Plains stretch from the Rocky Mountains to the east as a nearly treeless landscape. This *shortgrass prairie* is typical of the western portion of what is called the "prairie wedge." As the westerlies continue east, they collide with the moisture-rich winds sweeping up from the Gulf of Mexico and rainfall grows more plentiful. On the western edge of this central Great Plains region a *mixed-grass prairie* developed, and as more moisture became available, the prairie species gradually changed from mixed-grass species in Nebraska to the *tallgrass* species of Iowa and Illinois (Fig. 2). The tallgrass prairies provided a diversity of wild life, with hundreds of plant species, over 350 species of birds, nearly 100 species of mammals, scores of amphibians and reptiles and fish, and uncounted thousands of insect species. Today, these three original prairie types largely correspond to the western rangelands, the wheat belt, and the corn/soybean area, respectively[1]. Annual production of wheat, oats, barley, rye, sorghum and corn in the region is greater than 334 million tons - roughly 25% of the world's total production of these grains. The Great Plains are becoming increasingly rural because of emigration of human populations away from farms to urban centers. Although the Great Plains encompasses about 20% of the landmass of the lower 48 states, the population is only about 2% of the U.S. total. With a population of approximately ten million, it is one of the least densely populated agriculturally productive areas in the world.

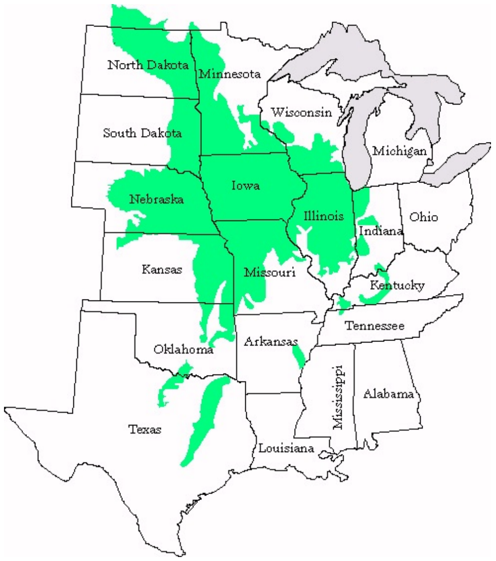

Figure 2. Map of the original Great Plains tallgrass prairie.

> *"No living man will see again the long-grass prairie, where a sea of prairie flowers lapped at the stirrups of the pioneer..."* [Aldo Leopold, 1949]

What is a Prairie

modified from Robertson (2002)

Prairies are a type of grassland, a landscape dominated by herbaceous plants, especially grasses. Trees are either absent or only widely scattered on the landscape. Grasslands occur in many regions, such as the llanos of Venezuela, the pampas of Argentina, the cerrado and campos of Brazil, the steppes of central Asia, the veldt and savannas of Africa, and the grasslands of Australia. Approximately 32 to 40% of the world's land surface is, or was, covered by grasslands. Today, grasslands are extremely important for agriculture, and approximately 70% of the food produced for humans comes from these regions. Grasslands are the largest vegetation type in North America, covering approximately 15% of the land area. Prairies are the grasslands found in the central part of the North American continent, the Great Plains.

Iowa lies within an area called the *prairie peninsula* (Fig. 2), an eastward extension of prairies that borders deciduous forests to the north, east, and south. This is part of the tallgrass prairie region, sometimes called the true prairie, with the landscape dominated by grasses such as big bluestem and Indian grass as well as a large number of other species of grasses and wildflowers, the latter called forbs. The vegetation sometimes reaches a height of 10 feet or more.

Prairies are one of the most recently developed ecosystems in North America, formed after the period of Pleistocene glaciation. Although glaciers were present in north-central Iowa as recently as about 12,000 years ago, the southern Iowa region that includes the Neal Smith National Wildlife Refuge last saw glacial ice more than 500,000 years ago. During the coldest periods following the retreat of the glacial ice, the area was covered by spruce and pine forests. As the climate became warmer and drier, between 14,000 and 10,000 years ago, a cool mesic hardwood forest with ash, oak, elm, maple, birch, and hickory trees replaced the spruce forest. About 8,300 years ago, the climate became substantially warmer and drier, and within the relatively short time of 500 to 800 years, most of the forests in Iowa died out, except along stream banks, and prairies spread over the landscape. Prairie fires kept most of the forest at bay, however certain trees could survive some of the fires and grew widely-spaced, intermingling with the prairie, and creating savannas.

Prairies developed and were maintained under the influence of three major non-biological stresses: *climate*, *fire*, and *grazing*.

Climate

Occurring in the central part of North America, prairies are subject to extreme ranges of temperatures, with hot summers and cold winters. There are also great fluctuations of temperatures within growing seasons. Rainfall varies from year to year and within growing seasons as well. The prairie region is also subject to droughts. The summer months typically include prolonged dry periods, and major droughts lasting for several years occur every 30 years or so.

Fires

Prairie fires, started either by lightning or by Native Americans, were commonplace before Euro-American settlement. Any given parcel of land probably burned once every one to five years. These fires moved rapidly across the prairie, so damaging heat from the fire did not penetrate the soil to any great extent. The fires kill most saplings of woody species, remove thatch that aids nutrient cycling, and promote the early flowering of spring species. Controlled fires are used today at many prairie areas, including the Neal Smith National Wildlife preserve to control non-native herbaceous species that can invade prairie remnants.

Grazing

A considerable portion of the above ground biomass of a prairie was consumed each year by the grazing of a wide range of browsing animals, such as bison, elk, deer, rabbits, and grasshoppers. This grazing was an integral part of the prairie ecosystem, and therefore grasslands and ungulate mammals coevolved together. Grazing increases growth in prairies, recycles nitrogen through urine and feces, and the trampling opens up habitat for plant species that prefer some disturbance of the soil.

Prairie plants have adapted to these stresses by largely being herbaceous perennials with underground storage/perennating structures, growing points slightly below ground level, and extensive, deep root systems. The tender growing points of prairie plants occur an inch or so below ground and are usually not injured by browsing animals. During droughts, the deep roots of prairie plants are able to take up moisture from deep in the soil.

Euro-American Settlement of the Great Plains

modified from Robertson (2002)

When the first European settlers moving westward from the forested regions of the eastern United States they encountered the prairies, which they likened to a vast ocean of grass. The wind caused waves on the surface of the shimmering grasses. One type of wagon used by the pioneers was the *prairie schooner*, a reference to a sailing vessel that further added to the analogy of the prairie as a large inland sea of grasses. It was easy to get lost in the prairie, especially since there were few trees or other natural features to act as landmarks. Even when on horseback, it was often not possible to see across the prairie to the horizon. These settlers found the prairies to be rather frightening. They were not used to the hordes of biting insect, intense summer heat and high humidity, bleak, windy winters, and periodic raging prairie fires. Because no trees grew on the prairie, they first considered the prairies to be infertile. This, plus the need for firewood and construction timber prompted them to build homes at the edges of the prairies and along rivers, where trees persisted. It was not long, however, before the settlers discovered that the prairie soil was more fertile than forest soil, and these Iowa soils were among the richest and most productive in the world.

One difficulty the settlers encountered was that their plows, made for forest soils, were not able to cut through the dense prairie sod. It was not until 1837, when John Deere invented the self-scouring, steel-bladed plow in Grand Detour, Illinois, that it was possible to break the prairie sod and farm the prairie on a large scale. Then, in a remarkably short period of perhaps 50 years, the vast majority of the prairie in Iowa was plowed and converted to agriculture. Prior to settlement, tallgrass prairie covered 85 percent of Iowa's 36 million acres before it yielded to man's influence and was converted to farms, gravel roads and highways, towns and cities. Today, less than one percent of that prairie remains.

Figure 3. The John Deere self-cleaning plow.

The History of the Neal Smith National Wildlife Refuge

In the 1980s, Iowa Congressman Neal Smith began to promoting the idea of a wildlife refuge and prairie restoration project in central Iowa. About that same time 3,600 acres of land in Jasper County, near Prairie City, Iowa, was made available for the project. The land was originally purchased in the early 1970s by a utility company, with the intended purpose of constructing a nuclear power plant on the site. By the 1980s, it was apparent that they would not proceed with additional nuclear power, and a company vice president, who was also involved with one of the advisory groups looking for a preserve location, offered the property for the restoration project, to be developed by the U.S. Department of the Interior.

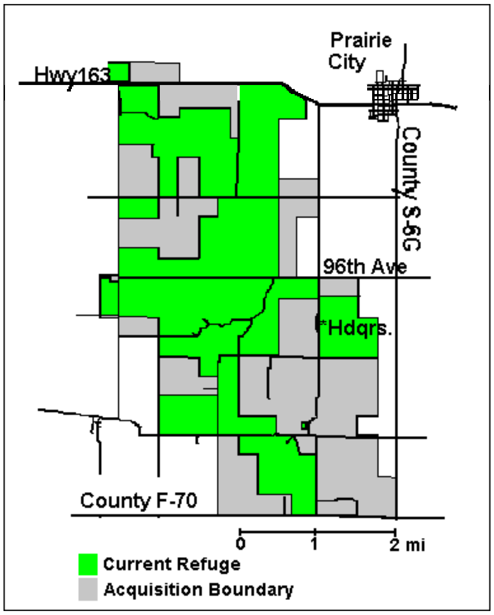

Figure 4. Map of the Neal Smith National Wildlife Refuge showing current land and future acquisitions.

Congress formally approved the Iowa tallgrass prairie restoration project on September 5, 1990, authorizing the purchase of 8,654 acres for the creation of the Walnut Creek National Wildlife Refuge (named for the creek that drains most of the refuge land). The first parcel of land was purchased in April 1991, and in September of 1991, the U.S. Fish and Wildlife Service purchased the 3,622 acres originally slated for the nuclear power plant from Redlands Corporation, a subsidiary of Iowa Power (now Mid-American Energy). To date, about 5,000 acres (of the 8,654 acres approved by Congress) have been purchased. The map on the left (Fig. 4) shows the area of the current preserve and the additional land to to be acquired. In 1993, the *Friends of the Prairie Learning Center* was formed to support refuge activities. In 1996, the Prairie Learning Center building was completed, earning MidAmerican's Energy Efficiency Design Award. The Walnut Creek National Wildlife Refuge had its official grand opening in

1997, with former Vice President Al Gore and Iowa Congressman Neal Smith presiding at the dedication.

In 1998 Neal Smith retired from Congress, and the name of the refuge was changed to the Neal Smith National Wildlife Preserve, to honor the man who was the driving force behind the creation of the refuge.

Goals of the Neal Smith National Wildlife Refuge

The Neal Smith National Wildlife refuge has four major goals:

- to increase biodiversity by restoring and reconstructing tallgrass prairie and savanna habitats
- to increase public knowledge and understanding of prairie through environmental education
- to increase scientific knowledge and understanding of the prairie and savanna through ongoing research
- to provide a diverse recreational landscape for public use and education

These goals are being realized by:

- **restoring** small prairie patches that were left, including some savannas and small prairies
- **reconstructing** prairies by planting prairie seeds, many collected by volunteers from tiny remnants in cemeteries, roadsides, and railroad tracks in south-central Iowa
- **reintroducing** a herd of bison and elk herds to help understand their roles in shaping the tallgrass prairie
- **reconstructing** by taking out trees that don't belong and using fire to encourage prairie and control unwanted weeds and other nonnative plants and restoring oak savanna by removing trees that don't belong

Bison (*Bison bison)* Facts

(from Friends of the Prairie Learning Center, 2002)

- Male buffalo often weigh 2,000 lbs. or more and stand 5 to 6 feet high at the shoulders
- The huge head and great hump are covered with dark brown wooly hair that contrasts with their relatively small hips
- Despite their great size and bulk, buffalo have amazing mobility, speed, and agility and are able to sprint at speeds of 30 mph
- Buffalo have cloven hoofs. Both male and female have a single set of hollow, curved horns
- Buffalo have a life expectancy of about 20 years
- In 1806, Lewis and Clark wrote, "*The moving multitude...darkened the whole plains*"
- As the American frontier expanded westward, a systematic reduction of the buffalo began around 1830
- Organized groups of hunters killed buffalo for hides and meat, often killing up to 250 buffalo a day
- Estimates indicate there were once between 30 to 75 million buffalo in North America, but the great herds were reduced to less than 300 buffalo by 1900
- Today, buffalo populations are strong once again, with an estimate of 200,000 buffalo roaming the plains, many at National Wildlife Refuges, National Parks, and private herds
- During the winter months, buffalo use their massive heads as shovels to dig through snow to uncover dried grasses
- Bison have an excellent sense of hearing and smell
- Buffalo cannot see very well, so an entire herd can stampede if it is startled
- In the spring, buffalo shed their heavy winter coats
- To hasten shedding and to relieve their itching skin, buffalo rub against large stones and trees
- Soon their dark brown wooly winter coats hang in tatters
- Bison wallow in the dust and mud to keep cool and to sooth irritating insect bites
- Male buffalo try to prove themselves the most fit by charging each other and butting heads
- The bulls bellow hoarsely, lower their heads, and paw the earth defiantly
- Bulls rarely fight to the death
- Males live alone most of the year, but during the breeding season, mid-to-late summer, the bulls join the cows and young bison herd
- Buffalo usually give birth every year to a tawny to buff-colored calf
- Most calves are born between the middle of April and the end of May, but some arrive as late as October
- Buffalo begin grazing (primarily on grasses) while still very young but some calves continue to nurse until they are nearly a year old
- Calves are tended by the female cow
- At birth, the calves have only a faint suggestion of the hump that they will begin to develop at 2 months
- Usually a calf stands up about 30 minutes after birth and can keep up with the herd several days later

Reconstructing the Prairie

The original tallgrass prairies of the Midwest, including the prairie that existed in Jasper County 200 years ago, hosted a great diversity of wild life, including hundreds of plant species, over 350 species of birds, nearly 100 species of mammals, scores of amphibians and reptiles and fish, and uncounted thousands of insect species. In order to reproduce as closely as possible the prairie/savana ecosystem that existed prior to Euro-American settlement of the area, the biota that is being introduced from outside the refuge boundaries originates from natural community remnants within a 38-county range in southern and central Iowa (Drobney, 1994). This range includes most of the counties in the Southern Iowa Drift Plain but excludes counties along the Mississippi and Missouri rivers (where the natural commuinities have developed under a different set of ecological conditions). In selected cases (such as with bison and elk) none of the desired species existed in this nearby area, so these were imported from other regions.

The Prairie Vegetation

So far the Neal Smith National Wildlife Refuge has reconstructed approximately 2,000 acres of land to prairie vegetation, and restored an additional 1,000 acres of existing prairie remnants. Seeds from over 200 species of prairie plants and grasses have been planted by employees and volunteers at the Neal Smith National Wildlife Refuge, as they attempt to recreate this diversity. Recently, a reduced work force at the refuge has limited the amount of prairie reconstruction to about 100 acres per year. This work is done primarily by volunteers who regularly collect seed of prairie species that typify good prairie remnants. In 1997, the refuge became independent of outside prairie seed sources when 20,000 pounds of prairie seed and other material was harvested from plantings on the refuge (Schilling and others, 1998).

The Bison

Bison once roamed the Great Plains in prodigious numbers. In a talk to the Chicago Corral of The Westerners in 1980, Craig Eben noted that "*In 1851 there was an estimate of 75 to 100 million buffalo. . .(with) Some estimates. . .as low as 30 million or as high as 200 million*" (Merkes, 1989). Herds of 500,000 animals were described as covering fifty square miles. Individual herds are thought to have reached 4 million animals or more. While the preserve is not large enough for such great herds to exist, a limited number of bison were introduced to the reserve. In 1996, 25 head of bison were imported from the Fort Niobrara National Wildlife Refuge in Nebraska, Witchita Mountain National Wildlife Refuge in Kansas, and the National Bison Range in Mountana. As in natural herds, equal numbers of male and female bison were introduced to the refuge. The bison adapted to their new home even better than anticipated, with 16 calves born in the summer of 2000 and 17 more born in 2001. Last October the swelling bison population reached 74, too large for the 740 acres that the reserve has fenced in for the bison and elk, and a number of bison were rounded up and shipped to new homes on tribal lands of the Red Lake Chippewa in Minnesota and the Winnebago tribe in Nebraska. Additionally one went to live at Mariposa Park, 7 miles northeast of Newton, and two were sent to Black Hawk County and one to Buchanan County. The Neal Smith National Wildlife Refuge bison herd currently numbers 37 (Fig. 5), and refuge officials anticipate that 8 to 10 animals will be sold in succeeding years.

Elk Facts

(from Friends of the Prairie Learning Center, 2002)

- Elk have a coat of deep copper brown to light tan, depending on the season
- Their legs and neck are often darker than their body, with a light beige rump
- Newborn calves weigh about 35 lbs, the cow - 500 lbs., and the bull - 700 lbs.
- Bulls measure 8 feet from nose to tail
- U.S. elk population is 1 million
- Antlers are fast-growing bone that male elk shed every spring
- Testosterone is the hormone that holds the antlers secure
- Every October, the testosterone level of the male begins to drop, until early spring when the antlers snap off
- While new antlers are growing, a soft covering called velvet protects the antlers and carries blood to the growing bone tissue
- Antlers grow from bony bumps on the elk skull called pedicles (bones shaped like cups and covered with skin)
- An antler can grow up to 1 inch a day during the summer
- Antlers are often branched, but the number of points does not signify age
- Teeth are a better gauge to an elk's age than antler size
- Elk eat grasses, tree limbs and bark, and low-growing, soft-stemmed plants
- Herds eat and watch for predators at the same time - at least one animal is looking up while others are eating
- Elk's eyes are designed to detect movement over long distances & they have a superb sense of smell

The Elk

A few years ago the refuge began a program to reintroduce elk into their native habitat. Four bulls and six females were intitially moved to Neal Smith from the National Bison Range in Montana. After three intitial mortalities, several additional elk were acquired, and subsequently three calves were born. Although their introduction to the refuge has not been as successful as the bison, efforts continue to build a sustainable elk herd, and currently 14 elk (Fig. 5) reside at the Neal Smith refuge.

The refuge currently has 740 acres fenced for the bison and elk range, with plans to expand this area to 2,000 acres as the remainder of the refuge land is acquired. It is possible that some day fritillary butterflies, northern harriers, upland sandpipers short-eared owls, glass lizards, sedge wrens, pocket mice, speckled snakes, and spotted skunks (all original inhabitants of the area) will once again live at Neal Smith National Wildlife Refuge.

Figure 5. Elk and Bison at the Neal Smith National Wildlife Refuge

The Prairie Learning Center

One of the features that makes the Neal Smith National Wildlife Refuge unique is the Prairie Learning Center (Fig. 1). Teeming with fascinating exhibits, the Prairie Learning Center offers a 13,000 square foot exhibition hall with world-class prairie and wildlife displays and a prairie maze for kids, a theater for films and lectures, meeting rooms with audio-visual facilities, and the Prairie Point Bookstore and gift shop. The Center features acclaimed video and exhibits that explain the beginnings of the prairie grass preserve. With its eco-friendly design features, the Center is an integral part of the Neal Smith Refuge. The Center is open year round, Tuesdays-Saturdays, 9 a.m. to 4 p.m. and Sunday 12:00 - 5:00. Admission is free.

Operating the Prairie Point Bookstore is one of the major activities of the Friends of the Prairie Learning Center, an organization that coordinates volunteer work at the Refuge. Proceeds from the bookstore are used to fund projects at the Refuge. The Bookstore offers specialty items for sale including books on prairies and wildlife, Iowa art work, prairie photographs, children's books and toys, and Refuge T-shirts.

The Bookstore is open on Tuesday–Saturday from 9:00 a.m. to 4:00 p.m., and on Sunday, 1:00 p.m. - 4:00 p.m.

Refuge Trails

The Neal Smith National Wildlife Refuge features 5 miles of walking trails in 4 formal trail areas.

Tallgrass Trail is a two-mile long trail that wanders through reclaimed prairie beginning at the Prairie Learning Center (Fig. 6). It has a black-top surface and benches about every 1/3 mile on which hikers can rest and watch the prairie life around them. It has long, gradual slopes that extend to the banks of Walnut Creek. This trail is accessible to everyone, including those in wheelchairs, walkers, or on crutches, though it does require some endurance. The trail features 6 interpretive stations that are well described in the Refuge pamphlet *The Tallgrass Trail; Back to the Future?*

Savanna Trail is a half-mile gravel trail winding through ancient oaks in a reclaimed Savanna area near the location of the Walnut Creek groundwater monitoring wells that we will visit on this field trip.

Prairie Overlook Intrepretive Trail is an ADA (Americans with Disabilities Act) accessible paved trail that serves as a portion of the larger Tallgrass Trail (Fig. 6). Beginning at the Prairie Learning Center, the trail is about 1/3 mile long and offers views of prairie plantings, buffalo, and oak savanna

Basswood Trail is the newest of the Refuge trails, located just off 112th Avenue about 1¼ miles southeast of the Prairie Learning Center. The trail has a mowed grass surface and passes through a wooded region of the Refuge.

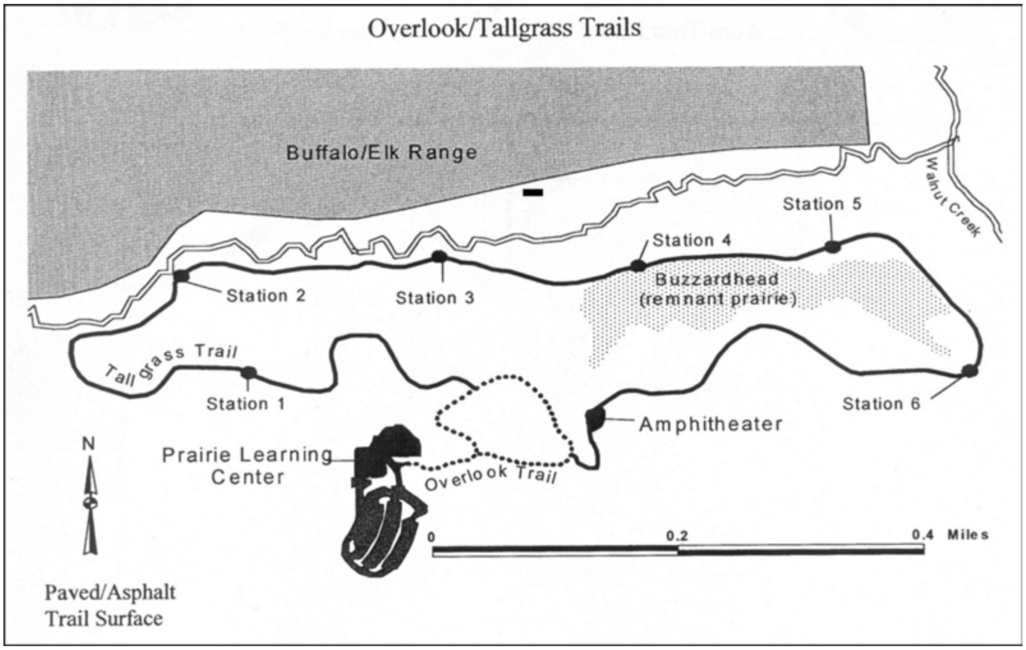

Figure 6. Map of the Overlook and Tallgrass Trails

CONCLUSIONS

Neal Smith offers a rare peek at this incredible variety of life we call the tallgrass prairie. You can take a driving tour through this developing remnant of our history. Or search for the bison or elk herd in their native tallgrass habitat. Wander through the myriad of prairie blooms with a new show each week during the growing season. Lend a helping hand by helping plant some of prairie seeds in the spring. Take a walk among the open-grown oaks of the oak savanna with the ghosts of thousands of elk.

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CORNFIELDS TO PRAIRIES; LAND-USE AND WATER QUALITY; THE WALNUT CREEK WATERSHED MONITORING PROJECT

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INTRODUCTION

Nonpoint source pollution is a major cause of impairment to water quality in Iowa. Recent assessments suggest that agricultural land use is the source of diffuse, nonpoint source pollution (NPS) affecting approximately 96% of Iowa's streams and the majority of lakes and wetlands. In southern Iowa, more than 30 lakes and wetlands, and several river or stream segments, have been listed as impaired on the State of Iowa's 1998 303(d) list due to excessive sediment, nutrients, pesticides and animal waste runoff.

Numerous programs employing a variety of best management practices (BMPs) have been implemented in Iowa to mitigate NPS pollution from agriculture. However, monitoring NPS water-quality improvements resulting from BMPs has rarely been done because it is not an easy task. NPS pollution results from runoff across a landscape with varied land-management practices. The resultant NPS impacts measured in perennial streams are typically a mix of effects from many different parcels of land and many different components of management, integrated over many time scales. Hence, it is difficult to document the relationship between improvements in water quality and changes in management practices on a watershed scale. Many projects implemented under Section 319 of the Clean Water Act have had little or no monitoring associated with them. Water quality improvements are generally assumed rather than measured, or estimated using field-scale or watershed models.

The Walnut Creek Watershed Restoration and Water-Quality Monitoring Project are providing a valuable opportunity to measure quantitatively, on a watershed scale, water quality improvements resulting from large-scale land use changes. The Walnut Creek Watershed Monitoring Project was established in 1995 as a NPS monitoring program in conjunction with watershed habitat restoration and agricultural management changes implemented by the U.S. Fish and Wildlife Service (USFWS) at the Neal Smith National Wildlife Refuge and Prairie Learning Center (Refuge) in Jasper County Iowa (Fig. 1). A large portion of the Walnut Creek watershed is being restored from row crop agriculture to native prairie and/or savanna. Riparian zones and wetlands are being restored in context, with riparian zones grading from prairie, to savanna, to timbered stream borders (Drobney 1994). Although it is not expected that large-scale prairie restoration will ever be used as a nonpoint source management practice, the magnitude of the land use changes within the Walnut Creek watershed is large compared to other watershed projects. This project is forming a baseline against which to set expectations for other watershed improvement projects and for establishing the amount and location of non-agricultural land that might be placed in watersheds to reach a given water quality objective.

The Walnut Creek Monitoring project was approved in 1996 by the U.S. Environmental Protection Agency (EPA) as a Section 319 National Monitoring Program project. The project is supported, in part, by a Nonpoint Source Program (Section 319, Clean Water Act) grant from the EPA, Region VII. National Monitoring Program projects comprise a small subset of NPS pollution control projects funded under the Clean Water Act. The goal of the national program is to support 20-30 watershed projects nationwide that meet a minimum set of planning, implementation, monitoring, and evaluation requirements designed to lead to successful documentation of project effectiveness with regard to water quality protection or improvement.

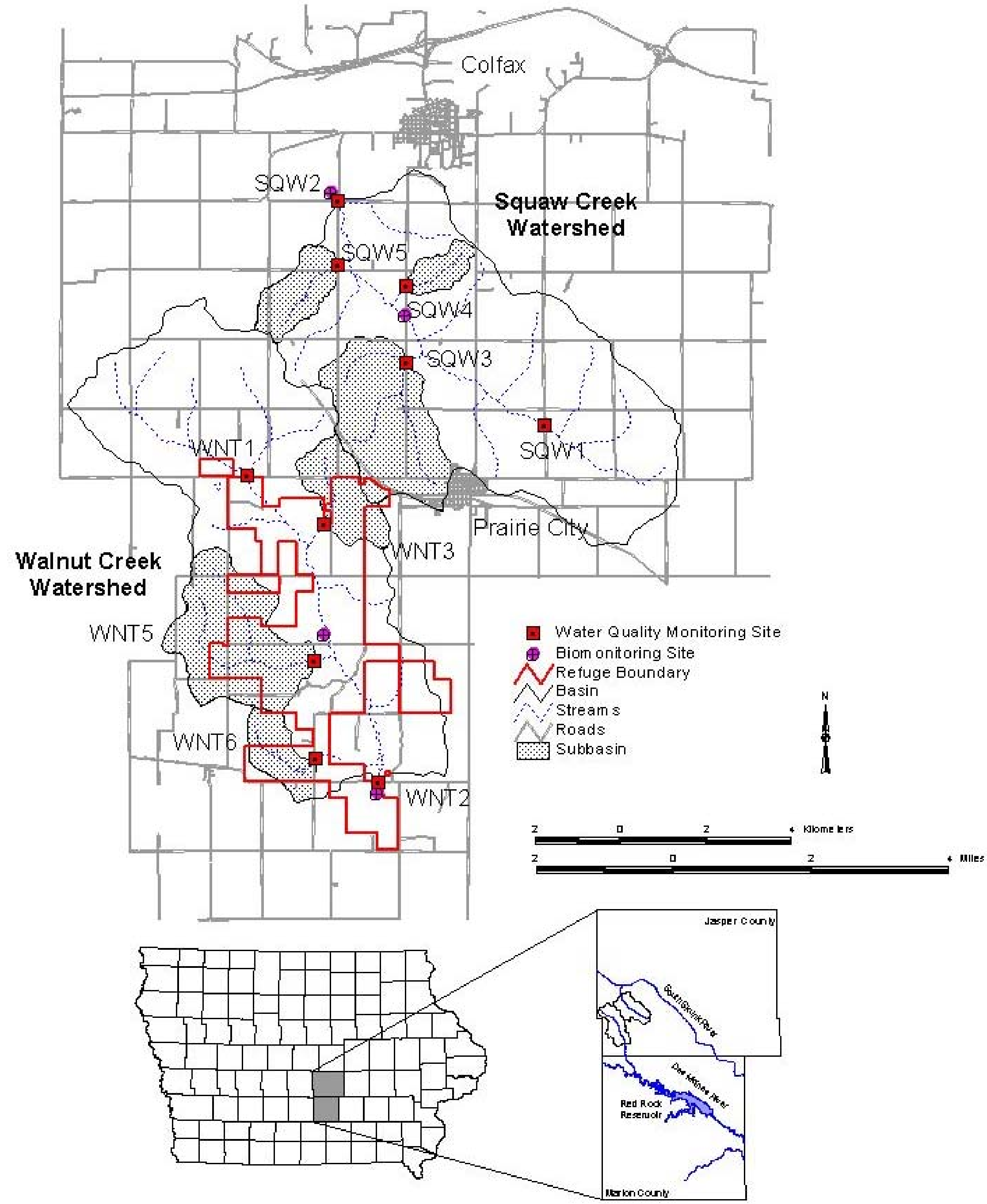


Figure 1. Location of Walnut and Squaw Creek watersheds.

Monitoring of both land treatment and water quality to document improvement is necessary to provide decision-makers with information on the effectiveness of NPS control efforts. Currently there are 22 projects, including Walnut Creek, in the national program.

The monitoring project utilizes a paired-watershed approach (Walnut and Squaw creeks) as well as upstream/downstream comparisons (Walnut Creek only) for analysis and tracking of trends (Fig. 1). The Walnut Creek watershed is paired with the Squaw Creek watershed, which shares a common basin divide with Walnut Creek, to minimize precipitation variation. Several subbasins are also being monitored in each watershed to allow comparisons of differential implementation over time and for analyzing their incremental contributions to the overall watershed response.

Land restoration activities began in the Walnut Creek watershed in 1992, and by 1993 full scale restoration and improved agricultural management were implemented on Refuge-owned lands. Monitoring in the Walnut Creek and Squaw Creek watersheds began on a limited basis in 1994 and full-scale monitoring commenced in 1995. Four basic components have comprised the project: 1) tracking of land cover and land management changes within the basins, 2) stream gauging for discharge and suspended sediment at two locations on Walnut Creek and one on Squaw Creek, 3) surface water quality monitoring of Walnut and Squaw Creeks, and 4) biomonitoring for aquatic macroinvertebrates and fish in Walnut and Squaw Creeks (Fig. 1).

Watershed Attributes

Walnut and Squaw Creeks are warm-water streams located in Jasper County, Iowa (Fig. 1). Walnut Creek drains 30.7 $mi.^2$ (19,500 acres) and discharges into the Des Moines River at the upper end of the Red Rock Reservoir. Only the upper part of the watershed (12,890 acres) is included in the monitoring project because of possible backwater effects from the reservoir. The Squaw Creek basin, adjacent to Walnut Creek, drains 25.2 $mi.^2$ (16,130 acres) above its junction with the Skunk River. The watershed included in the monitoring project is 18.3 $mi.^2$ (11,714 acres) and does not include the wide floodplain area near the intersection with the Skunk River. Basin characteristics of the Walnut Creek and Squaw Creek watersheds are very similar and make them well suited for a paired watershed design (Table 1).

Table 1. Summary of basin characteristics of Walnut and Squaw Creek watersheds.

BASIN CHARACTERISTICS	**Walnut Creek**	**Squaw Creek**
Total Drainage Area (sq mi)	20.142	18.305
Total Drainage Area (acres)	12,890	11,714
Slope Class:		
A (0-2%)	19.9	19.7
B (2-5%)	26.2	26.7
C (5-9%)	24.4	25.0
D (9-14%)	24.5	22.2
E (14-18%)	5.0	6.5
Basin Length (mi)	7.772	6.667
Basin Perimeter (mi)	23.342	19.947
Average Basin Slope (ft/mi)	10.963	10.981
Basin Relief (ft)	168	191
Relative Relief (ft/mi)	7.197	9.575
Main Channel Length (mi)	9.082	7.605
Total Stream Length (mi)	26.479	26.111
Main Channel Slope (ft/mi)	11.304	12.623
Main Channel Sinuosity Ratio	1.169	1.141
Stream Density (mi/sq mi)	1.315	1.426
Number of First Order Streams (FOS)	12	13
Drainage Frequency (FOS/sq mi)	0.596	0.710

The Walnut Creek and Squaw Creek watersheds are located in the Southern Iowa Drift Plain, an area characterized steeply rolling hills and well-developed drainage (Prior, 1991). The soils and geology of the two watersheds are similar. Soils within the Walnut and Squaw Creek watersheds fall primarily within four major soil associations: Tama-Killduff-Muscatine; Downs-Tama-Shelby; Otley-Mahaska; and Ladoga-Gara (Nestrud and Worster, 1979). These soil taxa account for 82% of the soils found in the Walnut basin and 78% of the soils found in the Squaw basin. Tama and Muscatine soils are found primarily in upland divide areas, whereas Ackmore soils are associated with bottomlands. Killduff, Otley and Ladoga-Gara soils are found developed in slope areas. Most of the soils are silty clay loams, silt loams, or clay loams formed in loess and till. Moderate to high erosion potential characterizes many of the soils, and both watersheds contain equal amounts of highly erodible land.

Loess mantled pre-Illinoian till typifies much of the geology of the Walnut and Squaw creek watersheds. Both watersheds are mantled primarily by loess in upland areas. Outcrops of pre-Illinoian till and Late Sangamon paleosols are occasionally found in hillslope areas, whereas alluvium dominates the shallow subsurface of the main channels and second-order tributaries. Pre-Illinoian till underlying most of the watersheds is 20 to 100 feet thick. Bedrock occurs at elevations varying between about 850 to 700 feet above mean sea level and is primarily Pennsylvanian Cherokee Group shale, limestone, sandstone, and coal. In the drainageways of Walnut and Squaw Creeks, Holocene alluvial deposits consist of stratified sands, silts, clays and occasional peat. In the Walnut Creek drainageway, post-settlement alluvial and colluvial materials deposited in the stream valley range from approximately two to six feet in thickness.

Land Use Changes

Prior to land restoration activities in 1992, land use in the Walnut Creek watershed consisted of approximately 69 percent row crop and 27 percent grass. These values were similar to row crop and grass percentages measured in Squaw Creek (71% and 27%, respectively). From 1992 to 2000, 2,341 acres of land was converted from row crop to native prairie in the Walnut Creek watershed, representing 18.2 percent of the watershed (Fig. 2). Overall row crop land use in the watershed decreased from 69 to 61 percent. From 1992 to 2000, an average of approximately 260 acres of prairie have been planted each year, with areas planted in 1994 and 1995 exceeding 400 acres. During this same time period from 1992 to 2000, row crop land use in the Squaw Creek watershed increased from 71 to 79 percent row crop (Schilling et al., 2002).

In addition to the land conversions, 579 acres of refuge-owned lands in the Walnut Creek watershed (4.5% of the watershed) have remained in row-crop production during the restoration period and are farmed on a cash-rent basis by local farmers. In these areas, improved agricultural management practices are mandatory, and all chemicals and application rates are approved prior to application to minimize adverse impacts on non-target plants and animals. In accordance with the Cropland Management Plan for the refuge: 1) no fall application of fertilizer is allowed; 2) a maximum of 45 kg of nitrogen per acre is allowed on conventional rotation corn acres; and 3) no pre-emergent herbicide is allowed (this includes common Iowa herbicides atrazine, cyanazine, metolachlor, alachlor, metribuzin, and acetochlor) (Schilling and Thompson, 1999; 2000).

Combining the prairie planting areas and restricted application areas, land use changes have been implemented on 22.4% of the Walnut Creek watershed. The remainder of USFWS land in the watershed consists of areas that have remained unchanged since refuge activities began in 1992. These lands consist of mainly grass or woods and comprise another 11.3% of the watershed. Overall, the USFWS controls 1,759 ha, or 33.7%, of the Walnut Creek watershed above the WNT2 gauging station.

Beginning in 1993, with adoption of the Cropland Management Plan, pesticide and nitrogen use on refuge-owned lands was drastically curtailed. From 1992 to 2000,

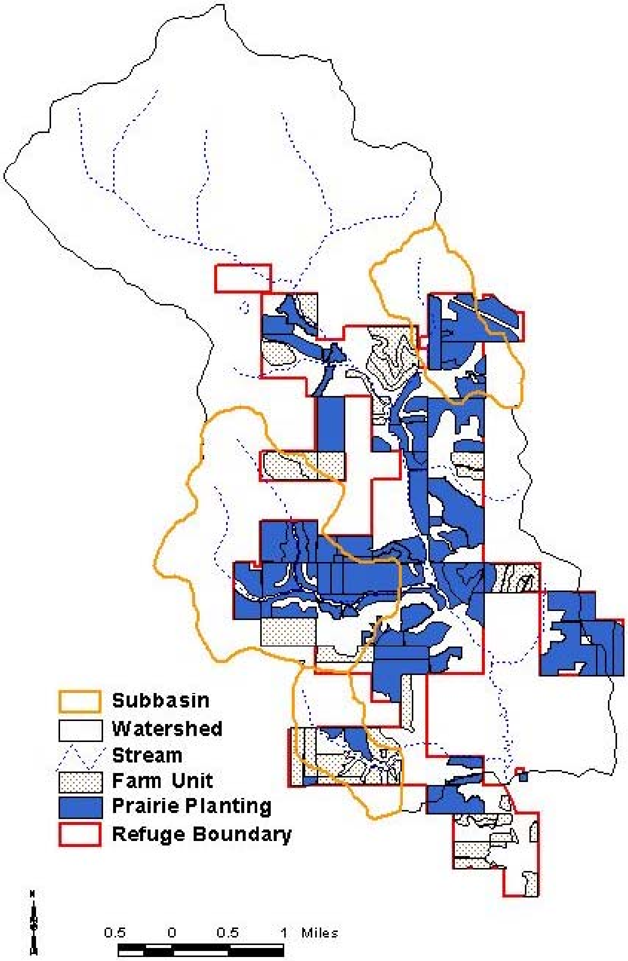


Figure 2. Location of prairie plantings and rental farm lands in Walnut Creek watershed.

nitrogen applications in the Walnut Creek watershed were reduced by approximately 12 to 37% (Schilling et al., 2002). Pre-emergent pesticide use was eliminated on refuge-owned lands in 1993, reducing pesticide application in the watershed by an estimated 28%.

WATER QUALITY MONITORING RESULTS

Nitrate

Nitrate-N concentrations have ranged between 0.8 to 13.0 mg/l at the downstream Walnut Creek station (WNT2) and 2.1 to 15.0 mg/l at the downstream Squaw Creek stations (SQW2) (Table 1). Both basins show a similar temporal pattern of detection and an overall reduction in nitrate-N concentrations from upstream to downstream monitoring sites (Fig. 3). Higher concentrations are noted in the spring and early summer months coinciding with periods of application, greater precipitation and higher stream flows.

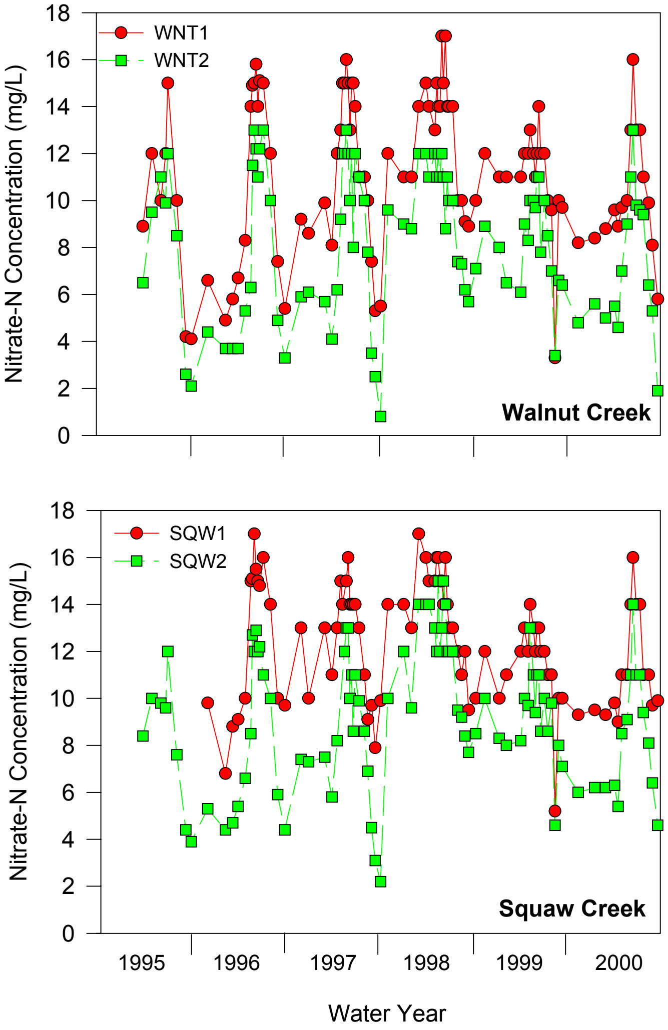


Figure 3. Nitrate concentrations at upstream and downstream sampling sites in Walnut and Squaw creeks for water years 1995 to 2000.

A t-test found a significant difference between the nitrate concentration means of the Walnut and Squaw creek data sets from 1995 to 2000 (n = 97, $p < 0.05$) with the overall mean nitrate concentration in Walnut Creek substantially lower than Squaw Creek (8.19 mg/l and 9.20 mg/l, respectively). Regression analysis was performed to determine if a change has occurred over time in the relationship of nitrate concentrations in the treatment watershed (Walnut) and the control watershed (Squaw). Nitrate has decreased by 0.0028 mg/l/week over 326 weeks, equivalent to 0.912 mg/l over the entire sampling period. Considering a mean value of the control watershed (9.20 mg/l), nitrate has decreased from 9.19 mg/l to 8.28 mg/ in the treatment watershed over the entire sampling period during the growing season (May-August), and from 8.06 mg/l to 7.15 mg/l during the non-growing season (Schilling, 2000a; 2000c).

Analysis of nitrate concentration data between upstream (WNT1) and downstream (WNT2) locations on Walnut Creek was conducted using the same regression procedure. When analyzed as an upstream/downstream design, a slight decreasing trend in nitrate concentrations at WNT2 was evident (P = 0.19) but was not statistically significant at the P = 0.05 level.

Table 2. Summary of water quality analyses (1995 to 2000).

	n	range	mean	sd	Quartile 25th	50th	75th
Nitrate-Nitrogen (mg/l)							
WNT1	99	2.3-17	11.1	3.3	9.1	11	14
WNT2	99	0.8-13	8.2	3.1	5.9	8.8	11
SQW1	90	5.2-17	12.4	2.5	10	13	14
SQW2	97	2.1-15	9.2	3.0	7.2	9.5	11
Atrazine (µg/l)[1]							
WNT1	50/59	<0.1-3.4	0.47	0.63	0.20	0.29	0.46
WNT2	47/59	<0.1-5.0	0.57	0.81	0.22	0.33	0.54
SQW1	45/60	<0.1-7.7	0.73	1.33	0.29	0.36	0.59
SQW2	50/60	<0.1-8.1	0.69	1.26	0.23	0.34	0.60
Fecal Coliform (counts/100 ml)							
WNT1	98	<10-7,600,000	105,300	780,291	410	1200	3700
WNT2	98	10-150,000	7,988	24,992	288	980	2875
SQW1	91	10-250,000	9,048	39,400	165	570	1100
SQW2	99	10-13,000,000	138,425	1,306,493	350	870	2250

[1] Summary statistics for detections only.

Pesticides

Six different compounds and two degradation products were detected between 1994 and 2000 in Walnut and Squaw Creek surface waters. Atrazine was by far the most frequently detected compound, as is true across Iowa, with the frequency of detection ranging between 75% to 85% in the main channels (Table 1). Concentrations ranged between <0.1 to 5.0 µg/l at Walnut Creek and <0.1 to 8.1 µg/l at Squaw Creek, with median concentrations at the downstream stations nearly equal (0.33 µg/l vs. 0.34 µg/l, respectively) (Schilling, 2000a; 2000c).

Atrazine concentrations were highest in May and June of each year during periods of high stream flow associated with rainfall runoff (Fig. 4). Following peak events, atrazine concentrations decreased in the late summer and fall. The timing of peak concentrations in the late spring/early summer with high streamflow events is consistent with the "spring flush" described by Thurman et al. (1991).

After atrazine, cyanazine was the most frequently detected pesticide with median concentrations less than 0.3 µg/l. Detection frequencies of cyanazine were nearly the same for both downstream main stem sites (36 to 40%). Both degradation products of atrazine were found with desethylatrazine (DEA) more commonly detected than deisopropylatrazine (DIA). Concentrations for both degradation products were generally below 0.2 µg/l. Acetochlor was detected at approximately the same frequency in both basins with median concentrations from 0.20 to 0.26 µg/l

For statistical analyses of atrazine concentration data over time, concentrations reported as <0.1 µg/l were considered to be one-half the detection limit (0.05 µg/l). Atrazine data were highly skewed and required log transformation before regression analyses were conducted.

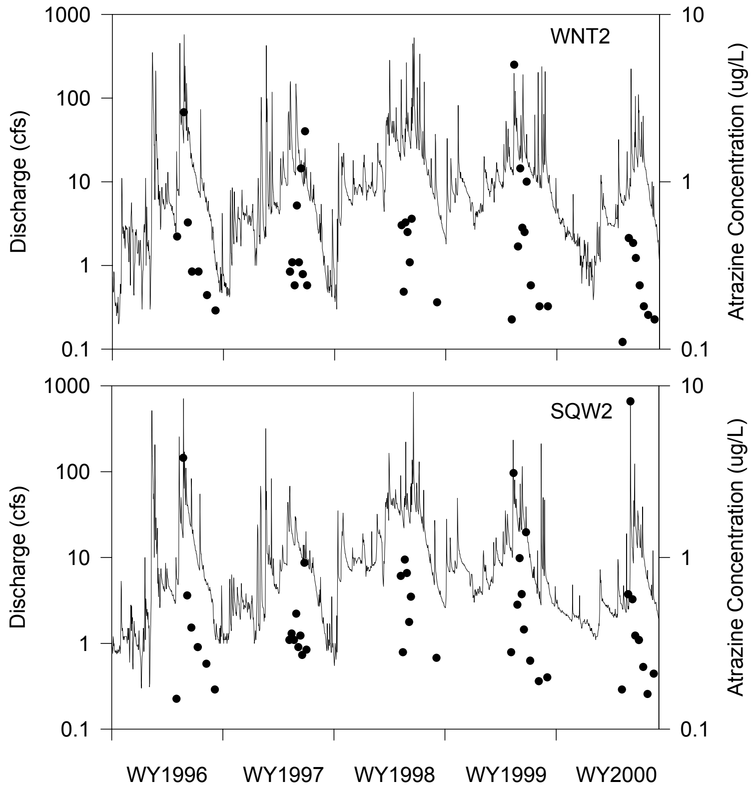


Figure 4. Atrazine concentrations (points) versus discharge (continuous line) at WNT2 and SQW2 sites for water years 1996 to 2000.

Sampling was done primarily in the summer, so no effort was made to stratify the values into growing and non-growing seasons. A general decrease in atrazine concentration was noted at the outlet of Walnut Creek while adjusting for the control, however, the trend was not significant at p=0.05 (95% significance). It was nominally significant at a 90% significance (p=0.10). The mean decrease over the entire sampling period was –0.126 log units. Using the mean log value of Squaw Creek (-0.551) and taking the antilog to obtain an untransformed answer, atrazine decreased from 0.3080 to 0.230 µg/l over the entire 326 week sampling period (Schilling et al., 2002).

Fecal Coliform

Fecal coliform counts varied widely among sampling sites and water years, ranging from less than 10 counts/100 ml to 13 million counts/100 ml at SQW2 (Table 1). In general, highest levels of fecal coliform bacteria occurred in spring and early summer months during high stream flow periods associated with rainfall runoff. There was no statistically significant trend in fecal coliform over time (p=0.246). Attempting to base the regression analysis on greater seasonal variability, monthly data were grouped into “grazing” versus “non-grazing” seasons. This comparison was nominally significant (p=0.07). A reduction of 0.35 log units of fecal coliform over the sampling period (326 weeks) translated to an average change from 3.444 to 3.095 log units during the “grazing season” and a change from 2.828 to 2.468 during the “non-grazing” season; or 2780 mpn/100 ml to 1245 mpn/100 ml and 673 mpn/100 ml to 294 mpn/100 ml, respectively. When evaluated as an upstream/downstream design there was no statistically significant trend in fecal coliform over time (p=0.60). The same holds true when month was introduced into the analysis (Schilling, 2001a; Schilling et al., 2002).

Nitrate Loading Patterns

In an effort to identify sources of nitrate concentrations in Walnut Creek watershed, two synoptic surveys were conducted. The first survey was conducted in May 1999 and focused exclusively on Walnut Creek watershed. The second survey performed in October 2000 involved sampling in both Walnut and Squaw creek watersheds.

In May 1999, a baseflow survey of 81 tributary creeks and drainage tiles showed major differences in pollutant loading rates within the Walnut Creek watershed (Schilling, 2001b; Schilling and Wolter, 2001). Concentrations of nitrate (<1 mg/l), atrazine (<0.1 µg/l) and chloride (<3 mg/l) were lowest in creeks and tiles draining restored prairie areas. In contrast, water draining row crop areas had elevated nitrate (>10 mg/l), atrazine (0.3 µg/l) and chloride (>12 mg/l) concentrations. Results showed that nine headwater subwatersheds, consisting of 90% row crop land use, contributed more than half the total nitrate export load from the watershed while comprising only one-third the land area (Fig. 5; Schilling, 2001). Results further showed that 84% of the nitrate load in surface water originated on non-refuge land. However, the results of this study were applicable only to Walnut Creek watershed and questions remained whether headwater areas exerted a proportionally large influence on water quality in Squaw Creek watershed where row crop land use does not vary substantially from the core of the watershed to headwater areas.

In October 2001, a second baseflow survey of tributary creeks was conducted to: 1) determine the sources of elevated concentrations and loads of agricultural pollutants in Walnut and Squaw Creek watersheds and 2) determine if differences in pollutant loading patterns were a response to prairie restoration in the Walnut Creek watershed. Stream discharge and water chemistry was measured at 41 sites in Walnut and Squaw Creek watersheds when flow in the creeks was at a low baseflow condition. (Fig. 6).

If the streams were flowing, discharge measurements were made at the outlets of most first and second-order streams in the watersheds. Discharge at most sites was measured using methods similar to those used by Gburek and Folmer (1999). A small dam was constructed across the stream using a combination of sand bags and clay bank material, and a PVC pipe was sealed into the top of the dam to provide a defined water outlet. After each small impoundment had reached equilibrium, a bucket was placed beneath the drainage tube and flow was measured using a graduated bucket and stopwatch. Following several consistent time-to-fill measurements, the dam was removed and the area restored to previous conditions. The accuracy of the discharge measurement technique was not assessed; Gburek and Folmer (1999) reported an accuracy of ±10% with their approach. We estimated our measurement accuracy was probably within ±25% due to differences in dam construction and flow measurements provided by three different field crews. Errors were minimized to the extent practicable by repeated measurements. At larger midreach and tributary creek sites, surface water discharge was measured using a standard Price AA meter set at a depth ratio of 0.6 measured from the water surface.

Two methods were used to estimate baseflow from riparian corridors where discharge could not be directly measured: 1) a watershed flow budget; and 2) a regression equation related to the amount of alluvial soils present. The first method involved calculating a water budget for the riparian area where discharge inputs from all contributing watershed areas were summed, then subtracted from the measured discharge at the main stem site. The second method of estimating baseflow discharge along riparian corridors considered the relationship between the amount of alluvial soils present in a subwatershed and the volume of streamflow produced by a subwatershed. GIS was used to select all soil series formed in recent and older alluvium in the subwatersheds (Ackmore, Colo, Nodaway, and Zook soil series, alluvial land) and intersect these

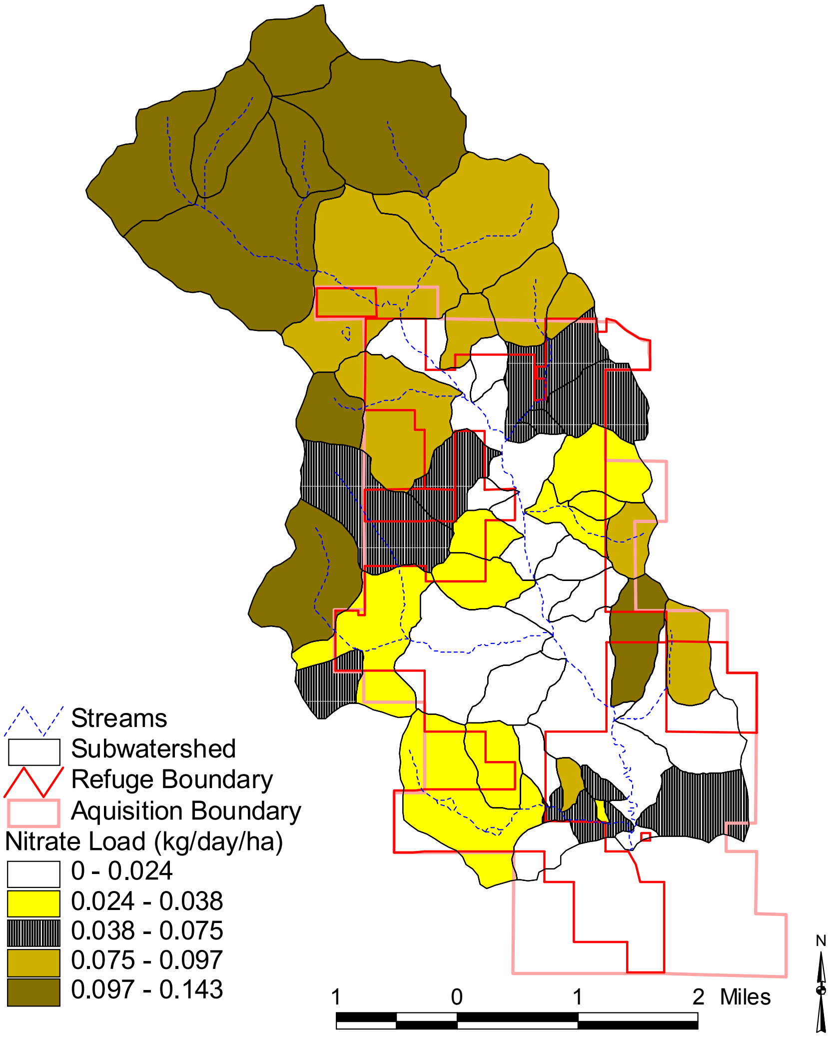


Figure 5. Nitrate loads per hectare in Walnut Creek subwatersheds (May 1999).

areas with subwatershed boundaries. The amount of alluvial soils present in a subwatershed (in hectares) was found to be significantly related ($p<0.05$) to the volume of baseflow discharged from a subwatershed (in L/s) according to the equation: Q (L/s) = 0.06 Ha of alluvium + 0.4. In many cases, baseflow estimated with this approach was consistent with the watershed budget method. Regardless of the method used, diffuse groundwater discharge along major tributary corridors was found to be the major source of streamflow and pollutant loading in both watersheds.

Concentrations of atrazine (<0.05 to 0.24 µg/l), nitrate (<0.05 to 14 mg/l) and chloride (6.2 to 34 mg/l) varied but were highest in water draining predominantly row crop areas. Nitrate, atrazine and chloride concentrations tended to be highest in groundwater draining subwatersheds dominated by row crop land use. Nitrate concentrations were less than 1 mg/l in samples collected from interior watershed areas draining restored prairie areas. Along the riparian corridor of Walnut Creek, nitrate concentration decreased from upstream to downstream locations (5.8

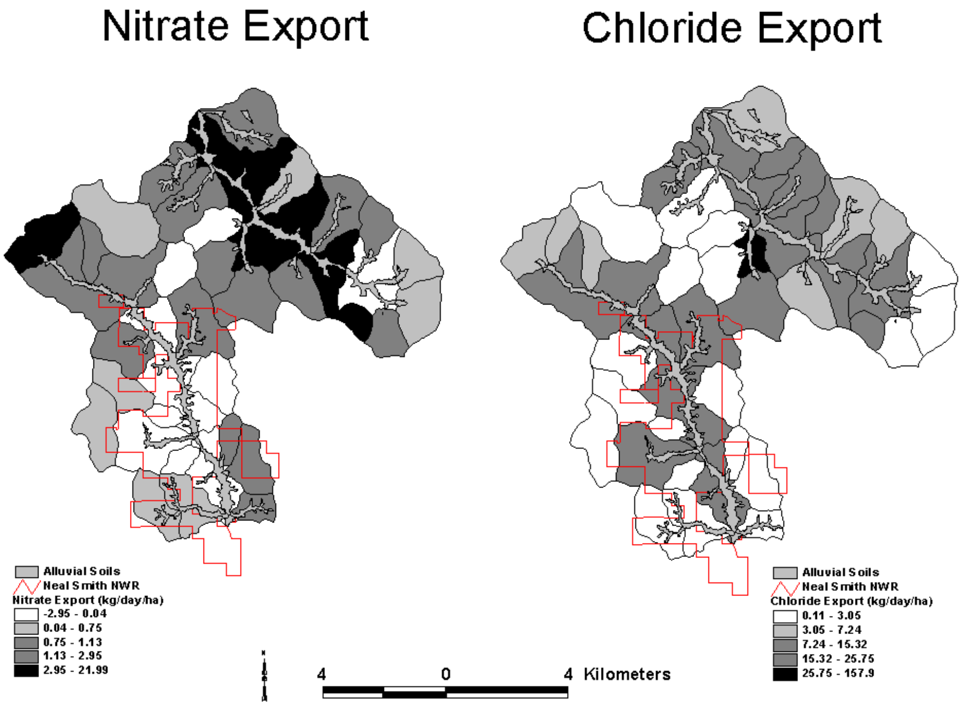


Figure 6. Nitrate and chloride export in Walnut and Squaw Creek watersheds (October 2001).

mg/l at WNT1 to 1.1. mg/l to WNT2). In contrast, nitrate concentrations in Squaw Creek, increased from 1.8 mg/l (SQW1) to 4.2 mg/l (SQW2) from upstream to downstream.

Prairie restoration concentrated in the riparian corridor of the Walnut Creek watershed has produced a different pollutant-loading pattern compared to Squaw Creek. In Walnut Creek watershed, baseflow from interior watersheds and riparian corridor areas exported very little nitrate (<0.04 kg/day/ha). Nitrate losses occurred primarily in headwater drainages dominated by row crop, especially noticeable in areas above WNT1 (Fig. 6). Thus, nitrate concentrations decreased downstream in Walnut Creek watershed as baseflow from restored prairie areas in the riparian corridor areas diluted stream nitrate levels. On the other hand, chloride export in Walnut Creek appeared to essentially “follow the water,” with greater chloride transport associated with areas producing higher streamflows. Some dilution of chloride concentrations occurred but not to the same degree as nitrate.

In Squaw Creek, fewer differences in nitrate export are noted among the subwatershed areas (Fig. 6). Greatest nitrate losses occurred primarily from middle and lower riparian corridor areas. In Squaw Creek watershed, these riparian corridors are dominated by row crop agriculture up to the streambank. Thus, nitrate concentrations in Squaw Creek increased downstream as baseflow containing elevated nitrate concentrations discharged from riparian row crop areas. Chloride export was more evenly distributed in the Squaw Creek watershed.

SUSPENDED SEDIMENT TRANSPORT STUDIES

Introduction

Sediment has been identified as the major pollutant affecting Iowa's streams. Approximately 45% of the impaired water bodies on Iowa's 1999 303(d) list were listed because of excessive siltation or turbidity. Silt, delivered to streams and rivers through nonpoint source runoff and streambank erosion, can degrade aquatic habitat through covering of coarse substrates, deposition in pools, and through increased turbidity that can interfere with the growth and reproduction of fish and other aquatic life.

Much of the cause of excess siltation can be traced to the introduction of European farming techniques more than a century ago, which forced major channel adjustments in watersheds draining the newly cultivated land (Knox, 1977, Trimble and Lund, 1982, Trimble, 1983). Soil erosion in the uplands from intensive row crop agriculture mobilized a tremendous volume of sediment into the stream valleys. Much of this historical sediment remains stored on the floodplain (Happ et al., 1940; Knox, 1977, Trimble, 1983). In an attempt to increase the number of tillable acres on floodplains, practices such as stream channelization, removal of riparian vegetation and agricultural tiling, also had profound affects on hydraulic characteristics and morphology of alluvial systems (Simon 1989; Hupp, 1992).

As the agricultural community has become more aware of the problems of upland soil erosion and modifications in channel hydrology, farming methods and land use practices have been developed that substantially reduce the amount of sediment delivered to streams. These methods include contour planting, terracing, grassed waterways, no till planting and riparian buffer systems. Although the rate of sediment remobilization and transport down the drainage system can be improved by land management practices, the fact remains that the historical sediment accumulation and hydraulic modifications represent conditions of instability that require time to overcome.

In the Walnut and Squaw creek watersheds, research as part of the Walnut Creek Watershed Monitoring Project is focused on monitoring daily discharge and suspended sediment in paired agricultural watersheds (Schilling, 2000). Since both Walnut and Squaw creek watersheds have been intensely row-cropped and tile drained, and both stream channels have been extensively channelized, the watersheds are typical of much of rural Iowa and offer opportunities to evaluate natural variations in discharge and suspended sediment transport in small Iowa watersheds.

Methods

Stream discharge and suspended sediment are monitored daily at upstream and downstream USGS stations in Walnut Creek and at a downstream USGS station in Squaw Creek (Fig. 1). At USGS gauging stations, stage is monitored continuously with bubble-gage sensors (fluid gages) and recorded by data collection platforms (DCP) and analog recorders (Fig. 7) (Rantz, 1982). The DCPs digitally record rainfall and stream stage at 15-minute intervals. The recording instruments are housed in five feet by five feet metal buildings. The equipment is powered by 12 volt gel-cell batteries that are recharged by solar panels or battery chargers run by external power. Stream discharge is computed from the rating curve developed for each site (Kennedy, 1983). The stream gauging and calibration is performed by USGS personnel, using standard methods (Rantz et al., 1982; Kennedy, 1983). Current meters and portable flumes are used periodically to measure stream discharge and refine the station rating curve. Suspended sediment samples are collected daily by local observers and weekly by water quality monitoring personnel. The observers collect depth integrated samples at one point in the stream using techniques described by Guy and Norman (1970). Samples are collected daily at all three stations. During storm events, suspended sediment samples are collected with an automatic water-quality sampler installed by the USGS at the gauging stations. Sampling is initiated by the DCP when the stream rises to a pre-set stage, and terminates when the stream falls below this stage. Suspended sediment concentrations are determined by the USGS Sediment Laboratory in Iowa City, Iowa, using standard filtration and evaporation methods (Guy, 1969).

Monitoring Results

Daily discharge and suspended sediment transport in both watersheds tends to be very flashy, responding rapidly to precipitation and snowmelt events. Peaks in discharge and sediment loads occur most often in February, May and June, although rapid increases have also occurred in other months. Streamflow typically decreases from seasonal highs of greater than 100 cfs in May and June to less than 1 cfs in September and October. Sediment loads during high-flow events occasionally exceed 100 tons/day in the period between February through July. Sediment loads typically decrease more rapidly than discharge following peak events and were generally less than 1 ton/day between August and January (Schilling, 2000).

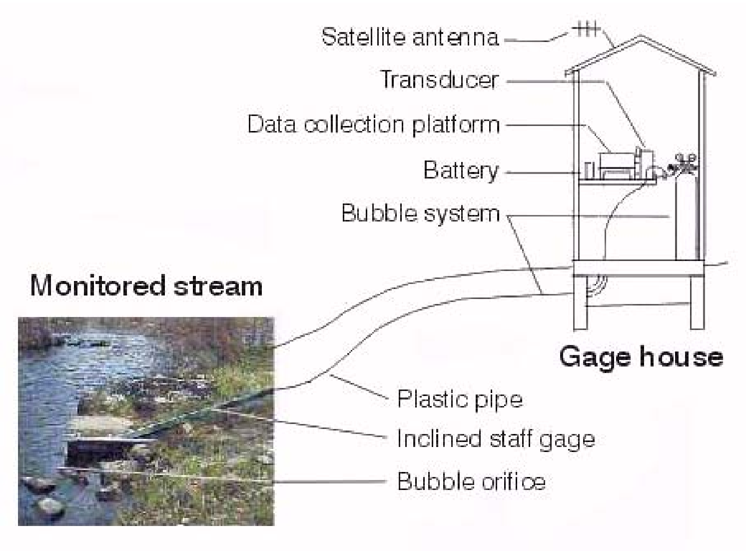


Figure 7. Typical USGS stream gauge. From U.S. Geological Survey, 2002.

In any given year, as much as 25% of the annual sediment load is transported out of the watershed in a single day, and five days account for as much as 80% of the annual sediment load. Twenty non-consecutive days in any given year will account for 90% of the annual sediment load. Discharge and suspended sediment loads are highest in May and June, which account for 40 to 50% of the annual discharge and approximately 60% of the annual sediment total (Fig. 8). The February to July period accounts for 98% of the annual suspended sediment load in most years. Approximately 10,000 to 20,000 tons of sediment are transported downstream in both watersheds each year (Schilling and Wolter, 2000a). Previous research suggests that maximum peak flows and sediment loads and a higher proportion of annual sediment loads migrating during one- and five-day periods occur in Squaw Creek. Watershed morphology and land use differences, including prairie restoration in Walnut Creek, may contribute to these differences.

The pattern of rapid conveyance of discharge and sediment loads is typical of incised channels (Happ et al., 1940; Knox, 1987; Shields et al., 1995; Faulkner and McIntyre, 1996). In incised channels, flood events peak higher and faster as more water is contained within the channel, promoting efficient transport of suspended sediment downstream. Channel incision in the Walnut and Squaw Creek watersheds probably contains all but the most exceptional flood flows and contributes to the rapid downstream conveyance of sediment.

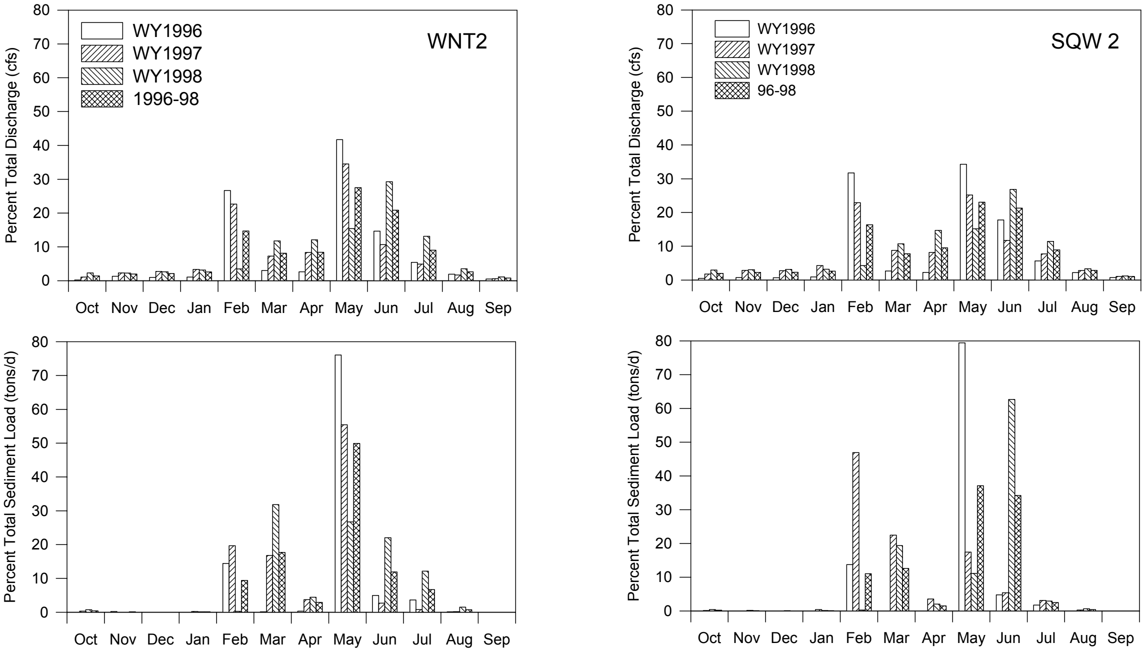


Figure 8. Monthly discharge and suspended sediment loads in Walnut and Squaw Creek watersheds (water years 1996 to 1998).

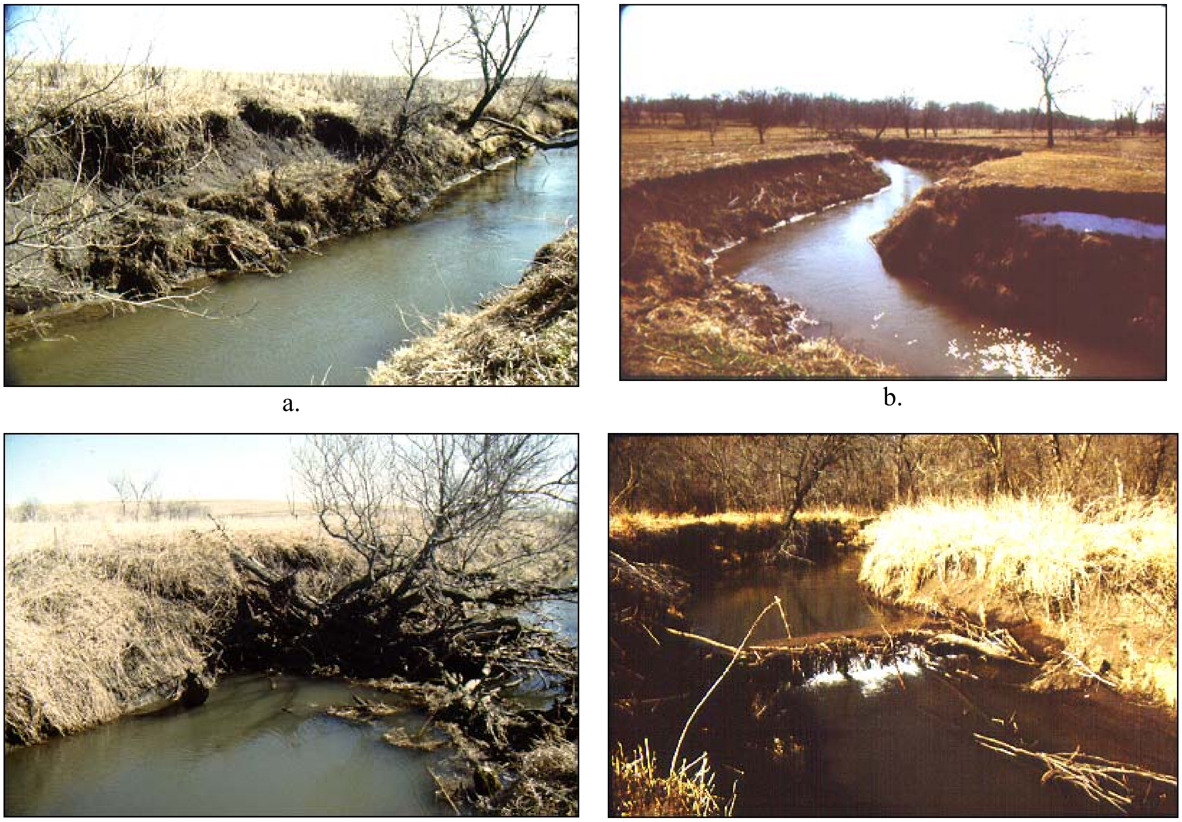
Channel incision of Walnut and Squaw Creek probably occurred quite rapidly after initiation of intensive row crop production and modification of stream channel morphologies. The relationship between stream power (discharge and gradient) and the ability to move sediment (sediment discharge) has been described as a "dynamic equilibrium" (Happ et al., 1940):

$$QS \sim Q_s d_{50}$$

where bankfull discharge (Q) and channel gradient (S) balance with bed-material discharge (Qs) and median grain size of the bed material (d_{50}). An increase in stream power or changes in sediment discharge quantity or character can disrupt this balance and result in a stream incising into its floodplain. In the case of Walnut and Squaw Creeks, this balance was disrupted significantly in the past when stream channels were straightened (resulting in increased stream gradients) and much of the watersheds were row cropped and tile drained (resulting in increased flow to the channel). The stream channels subsequently moved toward equilibrium by incising into their channels and increasing sediment loads through downcutting and widening. If Walnut and Squaw Creeks behaved similar to other Midwestern watersheds, much of the disruption probably occurred during the early part of the 20th century. Trimble and Lund (1982) noted that pervasive land deterioration occurred in the Coon Creek watershed in southeastern Wisconsin primarily between 1910 and 1940. Aerial photographs of Walnut Creek watershed showed little evidence of modern conservation practices placed on the landscape by 1940, perhaps suggesting that intensive erosion in Walnut Creek extended into the latter half of the 20th century (Schilling, 2000).

Stream Survey

An intensive survey of Walnut Creek was completed in October 1999 using a combination of Global Positioning System (GPS) equipment and GIS software (Schilling and Wolter, 1999; 2000b). Channel features were located and described, including streambank conditions, streambed material and thickness, debris dams, drainage tiles, cattle crossings and cross-section measurements (Fig. 9).



a.

b.

c.

d.

Figure 9. Walnut Creek stream conditions: a) streambank slumping; b) grazed pasture; c) debris dam; and d) beaver dam.

A major source of sediment in Walnut Creek watershed is streambank erosion of Holocene alluvium and post-settlement materials. Streambank erosion was observed to be particularly severe at many outside meander bends, debris dams, and cattle access areas. Severe bank erosion is typified by bare or exposed soils, obvious slope failures, and mature trees falling into the stream. Debris dams consisted of the fallen trees, beaver dams, or large piles of debris that diverted streamflow into bank sides and result in increased erosion. The percentage of total annual suspended sediment load derived from streambank erosion was estimated to be approximately 50%. Channel incision has occurred primarily through post-settlement materials and Holocene alluvium, which lack the cohesive strength of the underlying till. In particular, Historical post-settlement alluvium (Camp Creek Member) would be easily remobilized by streambank erosion because these materials lack internal structure provided by buried soil horizons developed during the Holocene.

Streambed degradation of the underlying till is not believed to be a significant sediment source in the watersheds. Despite evidence for active downcutting in several straightened reaches of

Walnut Creek (evidenced by narrow, V-shaped channel cross sections and a channel bottom consisting of bare or thinly mantled till), base level is controlled by resistant pre-Illinoian till and Roberts Creek Member alluvium. Stream mapping in Walnut Creek showed little or no streambank erosion occurring in these straightened reaches. To the contrary, downcutting appears to have been slowed by the resistant bottom that has allowed streambanks to become relatively stable and well vegetated. Streambanks in channelized segments showed little sign of recent mass wasting or undercutting. Most severe streambank erosion in Walnut Creek was concentrated in meandered areas, debris dam areas and cattle access points. Other sources of sediment in the watersheds include concentrated flow erosion from gullies and tributaries and sheet and rill erosion from upland sources. In the Walnut Creek watershed, these sediment sources combine to contribute the remaining 50% of the annual sediment loads. Future work in both Walnut and Squaw Creek watersheds will focus on developing a sediment erosion model that incorporates all sediment sources, including streambanks, gullies and sheet and rill erosion.

Silt, derived from local glacial and loess deposits, is the dominant streambed material in Walnut Creek, and it tends to accumulate behind debris dams and at cattle crossings. At some locations, silty muck in the streambed was more than 1 to 2 feet deep. In channelized segments of Walnut Creek, surface water often flows on top of dense alluvium or glacial till with little or no loose streambed material present. Increased water velocity in straightened reaches scours the streambed and prevents accumulation of streambed materials. Eroded sediment that reaches the main channels of Walnut or Squaw creeks does not necessarily exit the watersheds immediately. Stream mapping in Walnut Creek indicated that sediment often accumulates in the channel behind logs, debris dams or other impediments. Others have observed that these features can provide temporary base levels in the stream and temporary storage sites of sediment for long periods (Mosley, 1981; Trimble 1983). When these temporary storage sites are destroyed or disrupted, stored sediment becomes available again for transport and is eventually flushed from the watershed. Thus, streambed sediment stored in the channel bottom can also provide an ongoing source of sediment downstream. Mapping data was used to estimate the total mass of sediment contained within the Walnut Creek channel. Based on annual averages of stream discharge and suspended sediment concentrations, and assuming no additional sediment inputs, it would take approximately *nine years* to flush the sediment stored in the channel bottom from the watershed.

Channel cross-section measurements were made at 31 locations in Walnut Creek. Channel width averaged 32 feet whereas channel depth averaged about nine feet. Channel depth and width increased downstream with a width-to-depth ratio on the order of 3 to 4. Stream sinuosity was often less than 1.1 in many stream segments.

Restoration Timeframe

Other sediment transport studies conducted in the upper Midwest have indicated that there may be significant time lag before changes in land use in Walnut Creek watershed translate to reduced discharge and suspended sediment. Often a long-term monitoring record is needed to factor out influences of climate and historical sediment storage in watersheds. Trimble and Lund (1982) looked at more than 100 years of land use and sedimentation records and noted a lag time (or “hysteresis”) of 10 years between 1930 and 1940 in the Coon Creek watershed in Wisconsin before improvements in land use resulted in decreases in erosion and sedimentation. In the Buffalo River watershed in west-central Wisconsin, Faulkner and McIntyre (1996) investigated the persistence of high sediment yields despite decades of erosion control and land use changes. They found that channel incision migrating into tributary streams increased conveyance capacities of sediment downstream.

Detecting changes in the Walnut Creek watershed in a reasonable timeframe (i.e., years) must be cautioned. First, climatic effects, including variable location and intensity of precipitation within a watershed or between watershed pairs, can completely overwhelm and mask any reductions in discharge and sediment loads for many years. Climate is a main reason other watershed sediment reduction projects require decades to observe improvements. Compounding climatic variability are difficulties in comparing improvements between paired watersheds with very similar, yet different morphologies and land use histories. Small differences in channel sinuosity and slope may translate to significant differences in discharge and sediment transport. While similar in a general sense, historical land use in the Walnut and Squaw Creek watersheds has probably resulted in variable amounts and distribution of sediment stored on the floodplain. Considering that streambank erosion can contribute up to 50% of the annual load, and gullies may contribute additional loads, land use changes in the uplands may be difficult to detect above these sediment sources. Most of the sediment available for sediment migration in channels and gullies is derived from sediment storage. Within the channel itself, temporary sediment storage can effect long-term sediment yields. As Schilling and Wolter (2000) noted, based on the amount of sediment stored in the Walnut Creek channel, up to a decade may be needed to remove the sediment from the channel with no additional inputs.

ALLUVIAL FLOODPLAIN HYDROLOGY SITE

In May 2001, a hydrologic investigation was initiated in a riparian corridor at the Neal Smith National Wildlife Refuge. The objectives of this investigation were to 1) document the Holocene alluvial stratigraphy; 2) evaluate the interaction of groundwater and surface water in a typical southern Iowa riparian corridor dominated by reed canary grass; and 3) monitor potential hydrologic changes as the area is restored from reed canary grass to native floodplain vegetation.

A series of 35 shallow, nested groundwater monitoring wells were installed in a transect across the Walnut Creek floodplain. The entire transect of wells spans a distance of 1800 feet from upland landscape positions on both sides of the floodplain (Fig. 10). A series of wells were installed at regular intervals from the upland positions to locations in close proximity to the Walnut Creek channel. Most of the wells were nested, that is, several wells were installed side-by-side at different depths, to evaluate vertical hydraulic gradients and the three-dimensional groundwater flow system. The locations of the wells were positioned on either side of the

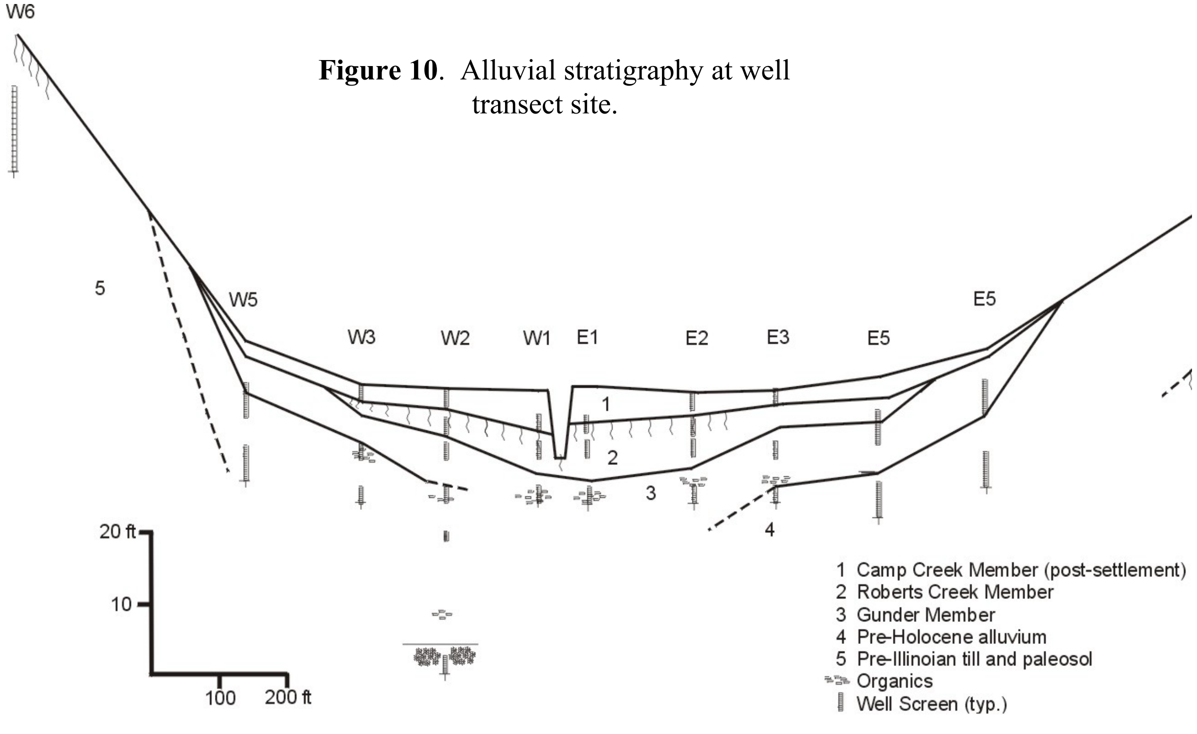


Figure 10. Alluvial stratigraphy at well transect site.

floodplain to be mirror equivalents. This was done in order to establish a paired groundwater study, so that hydrologic effects brought on by actions taken to eradicate reed canary grass on one side of the riparian corridor may be compared to a control on the other side of the corridor. In addition to the wells located along the transect, a three-well nest is located off the line of the transect on both sides of the stream in order to establish horizontal groundwater flow directions and gradients.

Most of the wells nearest the stream channel were installed using hand augers in May and June of 2001. Upland wells (5, 6 and 7 well clusters) were installed in August using a Geoprobe, a truck mounted hydraulic probing unit. In November, a deeper monitoring well (W2 location) was installed using the Geoprobe on the west side of the floodplain to a depth of 40 feet.

Geology

The alluvial stratigraphy in the riparian corridor is probably similar to other third- and fourth-order watersheds in the Southern Iowa Drift Plain landscape region. In the drainageway of Walnut Creek, Holocene alluvial deposits of the DeForest Formation (Bettis, 1990; Bettis et al., 1992) consist of stratified sands, silts, clays and occasional peat. The DeForest Formation was designated by Bettis (1990) to contain all the fine-grained Holocene alluvium in the state. Three members of the DeForest Formation were observed at the site (Camp Creek Member, Roberts Creek Member and Gunder Member). A fourth Holocene or pre-Holocene alluvial unit is also present at depth at the site. A summary of the Holocene stratigraphic units is as follows:

CAMP CREEK MEMBER: Very dark grayish brown to yellowish brown (10YR3/2-5/4) silt loam to loam; noneffervescent; unit is usually horizontally stratified where it exceeds 0.75 m in thickness; base of unit usually overlies buried A horizon of the presettlement soil; thickest in the floodplain area (where it buries the Robert Creek Member) and at the base of steep slopes where row-cropped fields are upslope; ranges in age from 400 years before present (BP) at base to modern at top.

ROBERTS CREEK MEMBER: Very dark gray to dark gray (2.5YR3/0, 10YR3/1-4/1) silty clay loam, loam or sandy loam; noneffervescent; thick sections are horizontally stratified at depth; unit has relatively thick A-C soil profile developed into its upper part; found within the present low floodplain, usually roughly paralleling the modern channel; unit ranges in age from about 3000 to 500 years BP.

GUNDER MEMBER: Brown to yellowish brown (10YR5/3) silt loam with common fine yellow brown mottles, occasional evidence of vertical burrowing with dark brown silty clay fill (Roberts Creek Member); stratified zones of abundant organic-rich muck, wood, preserved plant material common; unit ranges in age from about 10,500 BP at its base to about 3000 BP at the top of the unit.

PRE-GUNDER SILT LOAM: Dark gray (10YR4/4), reduced, unmottled and unleached, few plant remains, appears to be reworked loess, small white concretions, occasionally laminated with sandy loam, prominent organic-rich deposits; part of bar complex?; Late Wisconsinan to Early Holocene age.

PRE-ILLINOIAN DEPOSITS: In the uplands (W6 and E7 well locations), pre-Illinoian deposits consisting predominantly of basal tills were deposited during several glacial and interglacial episodes between 2.2 million and 500,000 years ago (Hallberg, 1980; Kemmis et al., 1992). Soil development that occurred on the pre-Illinoian landscape, which was subsequently buried by Wisconsinan loesses, is referred to as Sangamon Soil. At the well transect, Sangamon Soil developed in oxidized pre-Illinoian till at higher landscape positions but may be laterally replaced by pedisediment at lower elevations. Sangamon Soil is yellowish-red (5YR5/6) medium subangular blocky, with some sand and pebbles, and commonly contains iron and manganese accumulations along roots and joints. Oxidized pre-Illinoian till is dark yellowish brown (10YR4/6) with common grayish brown mottles (10YR5/2), variably leached of carbonates, and contains abundant joints and roots coated with Fe and Mn accumulations.

Hydrology

Water levels have been monitored in the wells on a weekly to biweekly basis since their installation. From wetter conditions in May and June, through dry conditions in late summer and fall, water levels have fluctuated substantially (Fig. 11). The wells closest to the stream (W1 cluster) showed a decrease in the water table of approximately three feet from June to August whereas the water table at the W2 cluster decreased more than five feet in the three-month period. The water table monitored at W3A showed less fluctuation throughout the summer than the W2 wells; this area probably receives recharge from upslope regions.

An interesting aspect of this study is the role that the incised Walnut Creek channel plays in the relation of water table depths to the elevation of the stream. Water levels at the 1 and 2 locations nearest the stream were relatively high in May and June in relation of the stream level when conditions were wet; during the subsequent dry months, groundwater contained in these alluvial sediments apparently drained to Walnut Creek at different rates (see the spreading of the range of water level elevations over time).

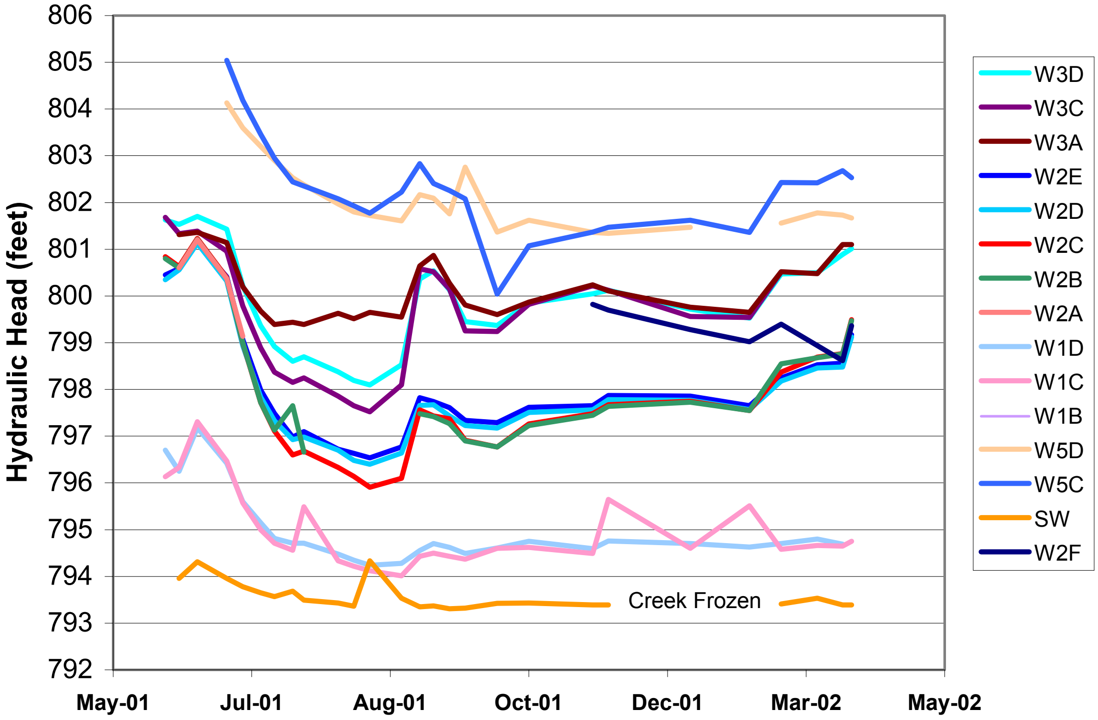


Figure 11. Water level fluctuations measured in western portion of monitoring well transect.

Groundwater flows at the transect from higher landscape positions towards Walnut Creek. Hydraulic head data suggest that groundwater flow is predominantly lateral through the Holocene alluvium in the Walnut Creek drainageway. Lack of significant vertical hydraulic gradients at multiple well nests, in relation to horizontal gradients, indicates that horizontal groundwater flow dominates the three-dimensional flow system at both nests. An upward hydraulic gradient from the lowermost sand (W2F well) to the shallow C and D wells suggests that Walnut Creek is a discharge zone for local groundwater flow. The hydraulic head in W1 and E1 wells is also higher than surface water level in Walnut Creek, indicating groundwater discharge to surface water.

Water samples were collected from the transect wells in October 2001 for field parameters, nitrate, chloride and sulfate. Although it was apparent that some well screens were compromised by bentonite leaking into the well screen from the seal (high specific conductance and sulfate concentrations in water), results for dissolved oxygen, nitrate and chloride were interesting. Chloride concentrations tended to reflect the relative age of the water, with chloride concentrations in groundwater at the water table much lower than concentrations measured in deeper nested wells. Low chloride concentrations at the water table reflected the recharge of recent precipitation into the groundwater system.

Nitrate-N concentrations were not detected above laboratory detection limits in any of the alluvial wells. While this may be a result of prairie restoration serving to remove the source of high nitrate from recharge water (replacement of row cropped fields with native grasses), dissolved oxygen measurements suggest other contributing factors. In particular, dissolved oxygen concentrations were less than 1 mg/l in many monitoring wells screening the organic-rich Roberts Creek and Gunder Members, suggesting that denitrification may be helping to reduce nitrate-N in shallow groundwater in this area. It is possible that the organic-rich horizons screened by some nested wells are providing a carbon source for denitrifying reactions occurring in the aquifer. Deeper monitoring wells installed through stratified silts, sands and clays may contain less organic carbon available for denitrification. In nested monitoring wells installed in the Walnut Creek alluvium located approximately one mile north of the well transect, concentrations of nitrate in the deeper alluvial well (screened 25 to 30 feet below ground surface) ranged between 11 and 28 mg/l whereas the shallow well (10-15 feet deep) of the well nest showed non-detectable nitrate concentrations (<0.5 mg/l) (Schilling and Thompson, 1999).

Results at this stage are very preliminary. We have only recently completed all well installations and are continuing to gather baseline water level and water quality data. The baseline data will be critical in the future to establish baseline conditions between treatment and control sides of the floodplain. In the spring of 2002, we anticipate burning the west side of the riparian corridor and taking other actions to eradicate reed canary grass on this side of the channel. Hydrologic conditions will then be monitored to detect possible changes in groundwater levels and flow. Other research in this area will involve installing continuous water level recorders in several of the wells in the transect in the spring to monitor the effects of high streamflows on the groundwater flow and quality in the riparian zone.

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LOESS DEPOSITS NEAR RED ROCK LAKE

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INTRODUCTION

At Stop 3 (Fig. 1) we will see a 15' loess-paleosol section. The top of the section exposes Peoria Formation deposits. Peoria Formation materials overlie the Pisgah Formation, with the Farmdale Soil developed in its upper part. The Sangamon Geosol is present at the base of the section. Based on the near proximity to the outcrops observed at Stop 2, Pennsylvanian lithologies are presumably not too far beneath the base of the section.

Figure 1. The author at the Stop 3 loess exposure near Red Rock Lake.

PEORIA FORMATION

The name Peoria Formation (named for the Peoria of Illinois) was proposed by Bettis (1990) for the loess that had previously been referred to as the Wisconsin loess in Iowa. Other names found in the literature for these materials include the Peoria Loess, Peoria Silt, and Peorian loess. The Peoria Formation deposits are the youngest Wisconsin loess in the Central Lowland, and accumulated during and after the last glacial maximum (LGM). The Peoria Formation in Iowa consists of two facies (a silt facies and a sand facies) of wind-deposited sediments (Bettis et al., 1996), and is typically described as a light-brown massive silt loam (Muhs and Bettis, 2000).

Stratigraphically, the Peoria of Iowa grades into the Peoria of Illinois and has a similar mineralogy (Bettis, 1990). The Peoria occurs throughout Iowa, and ranges in thickness with proximity to the source. It is the thickest (up to 48m) and most extensive loess of the Great Plains (Muhs and Bettis, 2000). Near the Missouri Valley in western Iowa, the formation is usually more than thirty meters thick, and on the Des Moines Lobe the thickness ranges from a few centimeters to about three meters (Bettis et al., 1996). The Peoria Formation typically occurs at the land surface and unconformably overlies older Quaternary formations and associated paleosols (Bettis et al., 1996). The contact with underlying units is marked by an abrupt change in unit characteristics (texture, structure, color, weathering features, etc.).

Generally speaking, Peoria Formation materials in Iowa were deposited between 25,000 and 12,500 years ago. The Peoria Formation is time transgressive with the silt facies being deposited between 22,000 and 12,500 RCYBP on the Des Moines Lobe. The sand facies was deposited contemporaneously with the silt facies and into the Holocene (Bettis et al., 1996). In western Iowa, radiocarbon ages of basal Peoria loess are as old as 27,000 to 24,000 RCYBP and thermoluminescence (TL) ages indicate deposition between 22,000 and 18,000 cal yr B.P. (Forman et al., 1992). Data from western Iowa indicate that loess deposition could have ended as early as 14,000 RCYBP, but certainly ended before approximately 11,000 RCYBP (Muhs and Bettis, 2000).

FARMDALE SOIL

The Farmdale Soil is the name proposed by Bettis (1990) for the interstadial soil developed in the upper part of the Pisgah Formation. It is in the same stratigraphic position as the Farmdale Soil of Illinois (Hall and Anderson, 2000). The Farmdale was formerly referred to as the basal Wisconsin soil or the basal loess paleosol in Iowa (Bettis, 1990). Interstadial soils are typically much less well developed than interglacial soils. The Farmdale occurs as a weak pedogenic alteration in the top of the Pisgah Formation, mostly as organic matter accumulation (Muhs and Bettis, 2000).

This Middle Wisconsinan soil is the most widespread interstadial soil in the central United States (Hall and Anderson, 2000). The Farmdale Soil is well-known in Illinois and is present in places in southwestern and western Indiana. In eastern and southeastern Indiana, the term Sidney Soil is used (Hall and Anderson, 2000; Hall et al., 1988) following Forsyth (1965) and Gooding (1975).

Data published by Forman et al. (1992) for western Iowa give radiocarbon ages ranging from approximately 34,000 (shell) to 31,000 yr B.P. (disseminated organic matter); and TL ages of ~30,000 and ~23,000 cal yr B.P. (Muhs and Bettis, 2000).

PISGAH FORMATION

The name Pisgah Formation was proposed by Bettis (1990). These deposits were previously referred to as the basal Wisconsin sediment or the basal Wisconsin loess in Iowa, and occupy the same stratigraphic position as the Roxana Silt of Illinois and the Gilman Canyon Formation of Nebraska. Other terminology previously used for the Pisgah Formation includes the Late Sangamon Loess (Smith, 1942) and the Farmdale Loess (Leighton and Willman, 1950).

The Pisgah Formation includes loess, colluvium, slope deposits, and mixing zone materials. The Pisgah Formation is typically buried by Peoria Formation materials and overlies the Sangamon Geosol that is developed in a variety of older deposits. The Farmdale Soil is commonly observed to be developed in the upper part of the Pisgah Formation.

The Pisgah Formation was deposited between about 55,000 and 23,000 BP. The basal age decreases with distance from source areas (Kleiss, 1973; Ruhe, 1976; Johnson and Follmer, 1989). Minimum ages taken from soil organic matter from the upper horizons of the Farmdale soil (radiocarbon dates) indicate 27,000 to 25,000 BP as a minimum age.

SANGAMON GEOSOL

The Sangamon was first recognized as a soil by Worthen in 1873, and was later named by Leverett (1898) to define the weathering zone between the Iowan loess and the Illinoian till sheet. The early concept and specific definition of the Sangamon has changed with time, but most generally it represents the last interglacial soil in the midcontinent and is estimated to have developed from 55,000 to 125,000 years ago in Iowa. The Sangamon soil is time-transgressive, and although the age is not precisely defined it can be said that it formed between the Wisconsinan and Illinoian (Follmer, 1979).

The Sangamon Geosol is the last interglacial soil, is overlain by Wisconsin age materials, and overlies a variety of older deposits. This buried soil is usually thick (2-3m), with 7.5YR or 5YR hues, well developed angular blocky or prismatic structure, continuous clay films in the Bt horizon, and is leached of carbonates.

STOP 3- DESCRIPTION

At Stop 3, we will see a 15' loess section. Units exposed at the site include the Peoria Formation loess, the Pisgah Formation with the Farmdale Soil developed in its upper part, and the Sangamon Geosol. Access to the middle part of the Peoria Formation is difficult, but horizon boundaries may be observed by the gradual color change. A generalized section description from a reconnaissance on April 2, 2002, is found below. A more detailed description follows in the text.

Base of Section	
0-4'	Sangamon Geosol- variable in character (texture, color, etc.)
4-5.2'	Pisgah Formation
5.2-5.5'	Farmdale Soil
5.5-10'	Peoria Formation
10-14.7'	Bt?
14.7-15'	A- modern soil

The Sangamon Geosol extends from the base of the section to approximately 4'. The Sangamon is highly variable in character. The texture ranges from silt loam to sandy loam. The structure is strong fine to medium subangular to angular blocky. Continuous clay coatings are common on ped faces throughout the Sangamon. The entire profile is leached.

Color ranges throughout the profile. The upper portion (~3.5' to ~4') is dark yellowish brown (matrix 10YR 4/4 and mottles 10YR 4/6), and the central portion of the Sangamon Geosol (approximately 11.5' to 13') is mottled light olive brown (2.5Y 5/3), yellowish brown (10YR 5/6), and dark yellowish brown (10YR 4/4). Beginning at approximately 2' (2' below the Sangamon/Pisgah contact) the matrix colors become grayish brown (2.5Y 5/2) with few fine light olive brown (2.5Y 5/3) and dark yellowish brown (10YR 3/6) mottles. To the base the matrix is grayish brown (2.5Y 5/2). Dark brown (7.5YR 3/4) medium and coarse iron accumulations are common to very common towards the base of the section.

Immediately above the Sangamon Geosol is the Pisgah Formation. The Pisgah is approximately 1.5' thick, but varies across the section. The Farmdale Soil is formed in the upper part of the unit. The Farmdale ranges in thickness from 2 to 6" and has a wavy abrupt (broken in some areas) contact with the overlying and underlying units. The Farmdale is very dark gray (10YR 3/1- moist) with common black (10YR 2/1) fine charcoal throughout the unit. The Pisgah is a yellowish brown (10YR 5/4- moist) silt loam, with moderate fine to medium subangular blocky structure and few fine root traces throughout.

The Peoria Formation comprises the upper 9.5' of the section. Near 10' from the base of the section a gradual color change is noted from yellowish brown (10YR 5/4- dry) to light yellowish brown (2.5Y 6/4- moist); however the contact cannot be accessed along the full length of the section. From 5.5' to 10' the

Peoria Formation is exposed as a light yellowish brown massive silt loam. The deposit is uniform, has fine root traces throughout, dark yellowish brown (10YR 4/4- moist) coatings, and is leached.

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OVERVIEW OF LOWER DESMOINESIAN (PENNSYLVANIAN) STRATIGRAPHY IN SOUTH-CENTRAL IOWA

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PENNSYLVANIAN PALEOGEOGRAPHY AND THE MIDCONTINENT BASIN

During the Pennsylvanian or Late Carboniferous, Euramerica (North America and Europe) were joined to the rest of the continents in the south (Gondwana) by the Appalachian-Hercynian Orogenic belts. The Caledonian Mountains extended from the northern Appalachians thru the present day United Kingdom, Greenland, and Norway (Fig. 1). Together, Euramerica and Gondwana comprised the assembling supercontinent of Pangea, with most of its land area in the southern hemisphere. During this time, most of the midcontinent lay within a few degrees south or north of the equator (Heckel, 1999).

The sediments deposited during the Pennsylvanian are now exposed in several structural basins including the Appalachian, Michigan, Illinois, and Midcontinent (Fig. 2). In addition, there were a number of smaller tectonic basins in the western United States.

The Midcontinent or Western Interior Basin (Fig. 2) extends from southwest Iowa, northwest Missouri, and Nebraska in the north, to central Oklahoma to the south. It extends westward from west-central Arkansas to eastern Colorado at essentially the position of the present day Front Range of the Rocky Mountains. The northern part of the basin is known as the Northern Midcontinent Shelf and contains three main structural features: the Nemaha Uplift, the Bourbon Arch and, the Forest City Basin. The southern part of the basin contains the forearc Anadarko and Arkoma basins, north of the Arbuckle-Wichita-Amarillo uplift and the Ouachita uplift, respectively. During times of low sea-level stand, the Midcontinent Basin was open to the Panthalassa Sea (Protopacific Ocean) thru the Oklahoma basins and the Midland Basin of western Texas, but most of the area north and east of the Oklahoma basins was subaerially exposed. During times of high sea-level stand, most of the present United States north of the Ouachita Mountains and west of the Appalachian Mountains was covered by a relatively shallow epiric sea (Heckel, 1999).

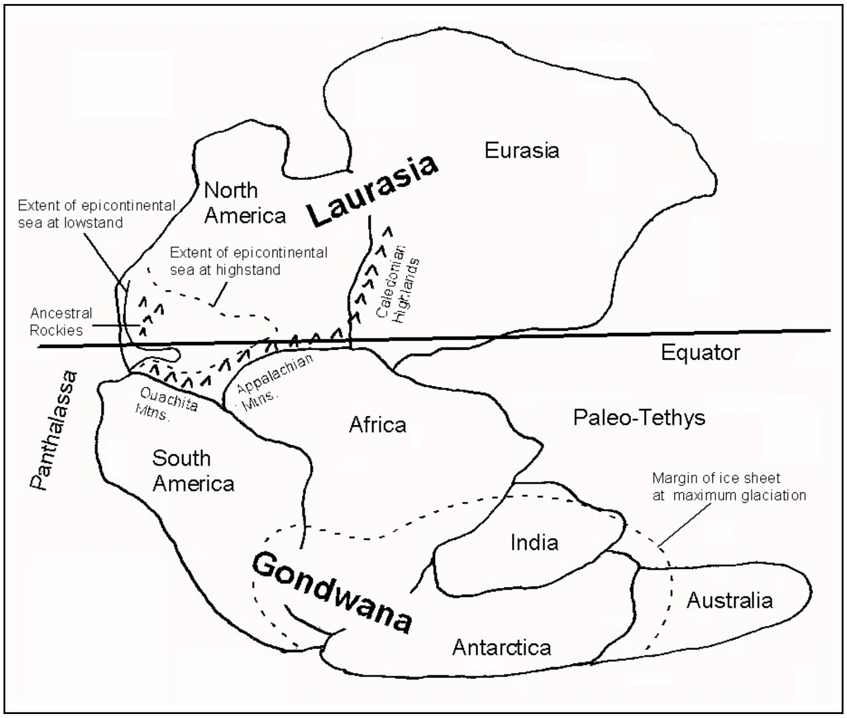

Figure 1. Paleogeography of the assembling supercontinent of Pangea. The outline of the North American Epicontinental Sea is shown at lowstand and highstand, as well as the maximum extent of glaciation in Gowganda. Modified from Heckel (1995) and Scotese (2000).

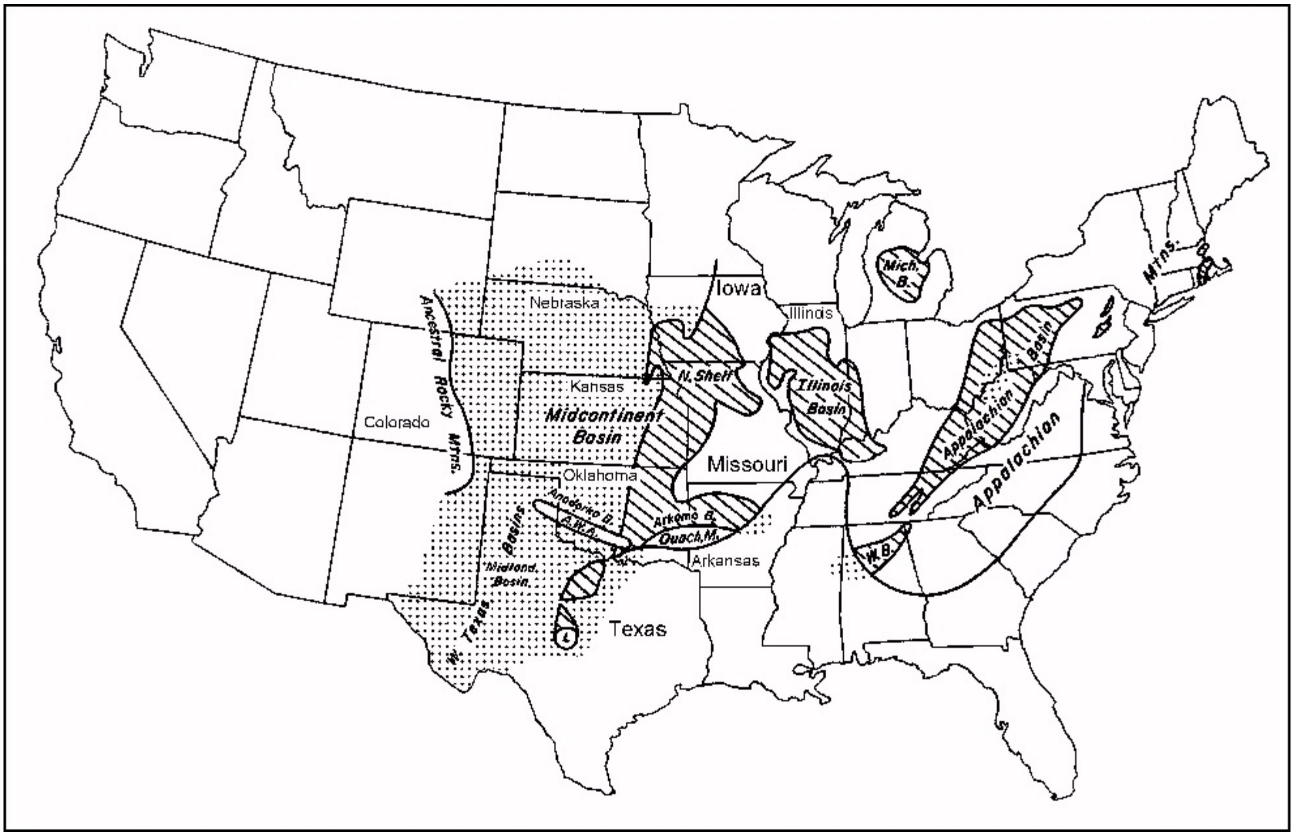

Figure 2. Pennsylvanian Structural Features of the United States (modified from Heckel (1999).
AWA = Amarillo – Wichita – Arbuckle Uplift, L = Llano Uplift, WB = Warrior Basin,
lined area = outcrop, dots = subsurface.

REGIONAL STAGES AND THE DESMOINESIAN STAGE

The Midcontinent Basin is the area in which the North American regional stage names were established. They are in ascending order: Morrowan, Atokan Desmoinesian, Missourian, and Virgilian. The Morrowan is lower Pennsylvanian, the Atokan and Desmoinesian are middle Pennsylvanian, and the Missourian and Virgilian are upper Pennsylvanian. This part of the fieldtrip will highlight selected exposures of the Desmoinesian Stage near Red Rock Lake in Marion County of south-central Iowa.

In Iowa, the major area of deposition and present exposure of Pennsylvanian sediments is the Forest City Basin that occupies about the southwestern third of the state. Here Pennsylvanian strata unconformably overlie Mississippian carbonates and generally dip to the south and west. Nearly 1700 feet (520 m) of Pennsylvanian sediment are known in the subsurface of southwestern Iowa. To the northeast successively older Paleozoic strata are exposed, while to the north and northwest the Pennsylvanian deposits are unconformably overlain by Cretaceous deposits of the Dakota Formation.

The Desmoinesian Stage was derived from the Des Moines formation named by Keyes (1893) from outcrops along the Des Moines River in Iowa. In Iowa, it is comprised of a succession of cyclic shales, sandstones, coals, and rare limestones. It is generally less than 940 feet (285 m) thick in Iowa, but thickens to about 6600 feet (2000 m) in the Arkoma Basin of Oklahoma (Heckel, 1999).

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

Cherokee and Marmaton Groups

The Desmoinesian Stage is subdivided lithostratigraphically into the Cherokee and Marmaton Groups in ascending order (Fig. 3). Only sediments of the Cherokee Group will be examined during this trip.

The Marmaton Group encompasses the uppermost Desmoinesian and is comprised of several limestone-dominated cyclothems representing more open marine conditions than those conditions represented by Cherokee cyclothems. The marine units are separated by locally thick shales, mudstones, sandstones, and some coals.

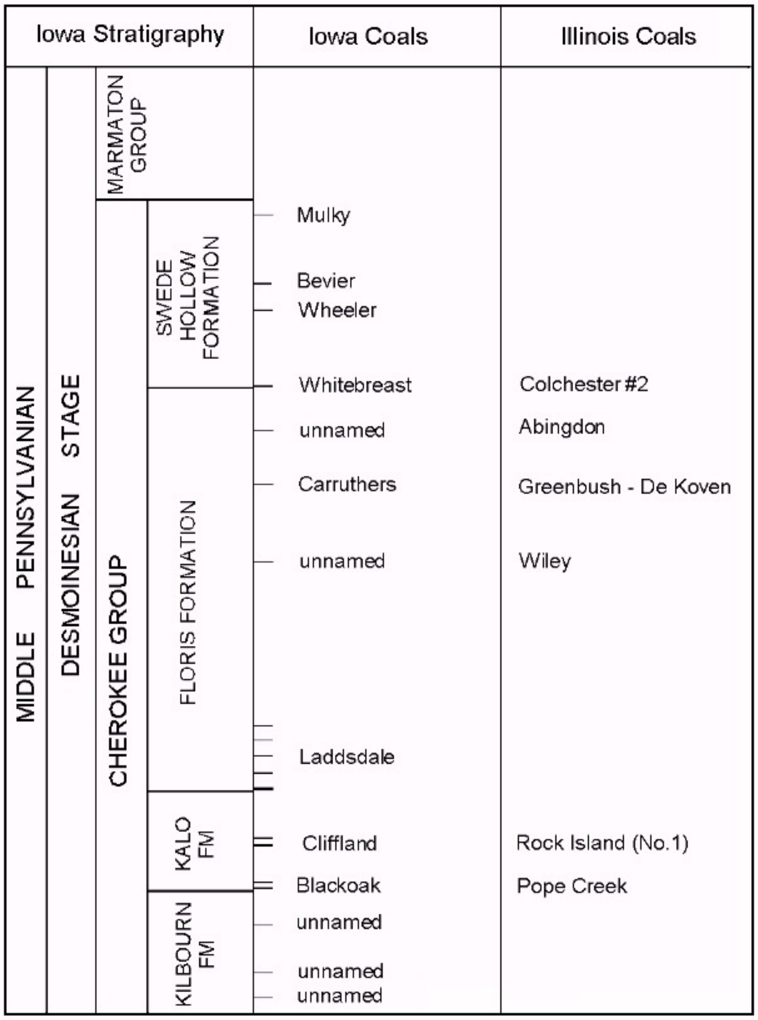

Figure 3. Cherokee Group coals of Iowa and Illinois (modified from Ravn, 1986).

The Cherokee Group was named by Haworth and Kirk (1894) for exposures in Cherokee County, Kansas. It comprises a succession of shale-dominated, coal bearing cyclothems, with locally prominent sandstones and rarer thin limestones. It is about 800 feet (245 m) thick in extreme southwest Iowa, but thins to the east in the outcrop belt of south-central Iowa to 500 feet (150 m). The Cherokee contains most of the coal resources of Iowa.

The Cherokee Group appears to represent four major episodes of sedimentation, with each major episode comprised of several minor, intermediate, and in one case a major scale cyclothem (a transgressive-regressive allostratigraphic unit mainly resulting from the glacial-eustatic rise and fall of sea-level) (Ravn et al., 1984). In ascending order these major lithostratigraphic packages, each delineated by certain characteristics, are designated the: Kilbourn, Kalo, Floris, and Swede Hollow formations (Fig. 3).

In Iowa, the Cherokee is divided into a lower and upper part. The Kilbourn, Kalo, and Floris formations from the Mississippian-Pennsylvanian unconformity to the base of the Whitebreast Coal comprise the lower Cherokee Group. The Swede Hollow Formation includes strata from the base of the Whitebreast Coal to the base of the Excello Shale and comprises the upper Cherokee Group. The Swede Hollow includes the only major marine cyclothem of the Cherokee Group and generally records a period of increasing marine influence on sedimentation in southern Iowa (Pope, and Chantooni, 1996). This field trip will focus on the lower Cherokee formations, especially the Floris Formation, but may include some of the upper Kalo Formation.

Kilbourn Formation

The Kilbourn Formation was named for exposures near the town of Kilbourn in Van Buren County, Iowa by Ravn et al. (1984). It comprises basal Cherokee Strata that rest unconformably upon Mississippian rocks and extends upward to the base of the Blackoak Coal of the Kalo Formation. The Kilbourn represents initial deposition on the land surface that was being developed on argillaceous Mississippian carbonates. Stream incision on these carbonates had produced a surface of considerable relief and irregularity (Fig. 4). The distribution and orientation of these stream valleys was controlled by regional dip, structural trends, outcrop distribution and karst development. Kilbourn deposition was the result of gradual subsidence in the Forest City Basin in combination with several eustatic marine transgressions and regressions (Ravn et al., 1984). This deposition predominantly took place in the incised paleovalleys during rise in relative sea-level while pedogenesis (soil formation) and erosion continued on the interfluves. As many as seven depositional cycles are encountered in the subsurface of south-central Iowa, dominated by nonmarine sandstones, shales, siltstones, and coals. Thin marine shales and limestone were deposited in the distal ends of estuaries and river systems during maximum transgression. Most of the sediments are thin and discontinuous, but eventually filled in the paleovalleys that had developed on the Mississippian erosional surface and nearly leveled the topographic relief (Fig. 5).

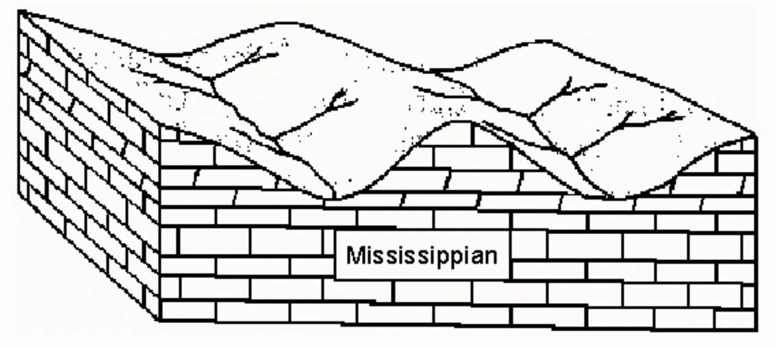

Figure 4. Block diagram showing relief on the Mississippian surface prior to Kilbourn deposition (modified from Ravn, 1984).

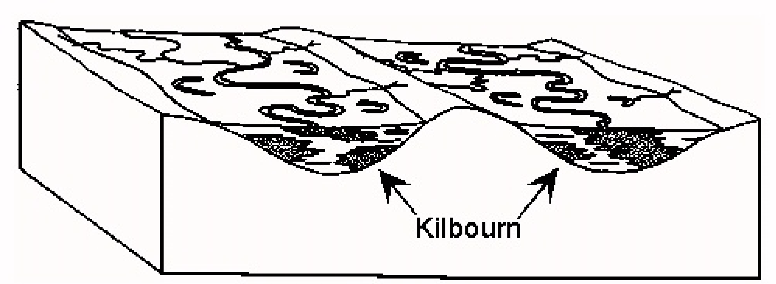

Figure 5. Block diagram showing mode of Kilbourn deposition (modified from Ravn, 1984).

Kalo Formation

The Kalo Formation was named for exposures near the town of Kalo in southern Webster County in north-central Iowa by Ravn et al. (1984). It includes strata from the base of the Blackoak Coal to the base of the Laddsdale Coal in the overlying Floris Formation. Two major coals, the lower Blackoak and the upper Cliffland, are the only two named members of the Kalo Formation in Iowa. Because of the leveling of the Mississippian erosional surface by Kilbourn deposition, the first widespread episodes of coal deposition occurred in Iowa (Fig. 6). The widespread occurrence of Kalo coals suggest that peat deposition resulted from a eustatic rise in sea-level that allowed swamp conditions to develop over a wide area of the state. As sea-level continued to rise, the swamps kept pace with the transgression allowing marine units to be deposited over the peat swamps to the southwest, where the topography was lower. Widespread occurrence of the marine facies was prevented by local development of delta lobes prograding seaward and delta switching as the result of differential compaction. Stream gradients, though, apparently remained low as thick fluvial channel-fill sandstones are less abundant than in the underlying Kilbourn Formation or the overlying Floris Formation (Ravn et al., 1984).

The Blackoak Coal is equivalent to the Pope Creek Coal of Illinois, which is considered to be upper Atokan in age. The Cliffland Coal is equivalent to the Rock Island (No. 1) Coal of Illinois and is considered to be lower Desmoinesian in age. Thus the Atokan-Desmoinesian boundary should be placed in the middle of the Kalo Formation between the Blackoak and Cliffland coals (Ravn et al., 1984).

Floris Formation

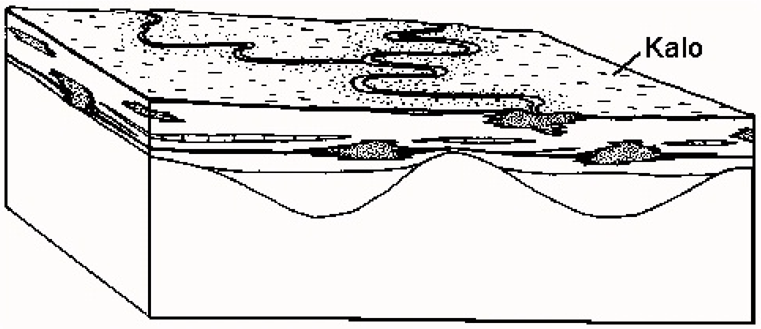

Figure 6. Block diagram showing mode of Kalo deposition (modified from Ravn, 1984).

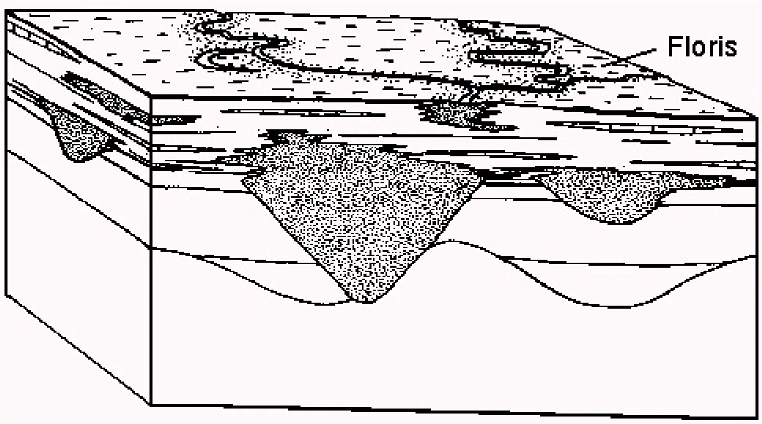

Figure7. Block diagram showing mode of Floris deposition (modified from Ravn, 1984).

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

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

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

In general the Floris represents a transition from nonmarine fluvial and deltaic processes to more marine processes (Pope, and Chantooni, 1996). Major incised valleys and their associated thick sandstone fills probably occurred before deposition of the Carruthers Coal. These sequences of sandstone, 140 feet (42 m) or more thick, cut downward into the underlying Kalo and Kilbourn formations, and occasionally into the Mississippian (Fig.7). Keyes (1891) proposed the name Redrock Sandstone for calcite cemented, brown, red, and orange iron oxide stained sandstones near the former town of Red Rock just west of the north end of the mile long bridge on Highway 14 across Red Rock Lake in Marion County, Iowa. The name Cliffland has been used for similar sandstones along the Des Moines River in Wapello County.

Generalized Floris Formation Depositional Environments in a Sequence-Stratigraphic Framework

In siliciclastic depositional regimes in a relatively high shelf setting, sequence boundaries can be represented by subaerial exposure and erosional truncation. During times of low sea-level stand, incised streams produce erosional truncation (Eble et al., 2002). These erosional surfaces pass laterally into paleosols on the interfluves formed during subaerial exposure (Fig.8a). The paleosols and areas of low deposition to erosion represent the lowstand systems tract (LST). Due to low rates of deposition or nondeposition, the paleosols represent condensed intervals formed in a terrestrial environment, usually during times of a low water table. The paleosols are usually strongly developed due to long exposure times and rapid rates of weathering in a humid tropical environment. They often contain sphaerosiderites that formed later when the water table was high. In a vertical sequence, they are often overlain by a coal and subsequently overprinted by a histosol, which in turn may be overlain by estuarine, fluvial, deltaic, and/or marine facies during sea-level rise and highstand.

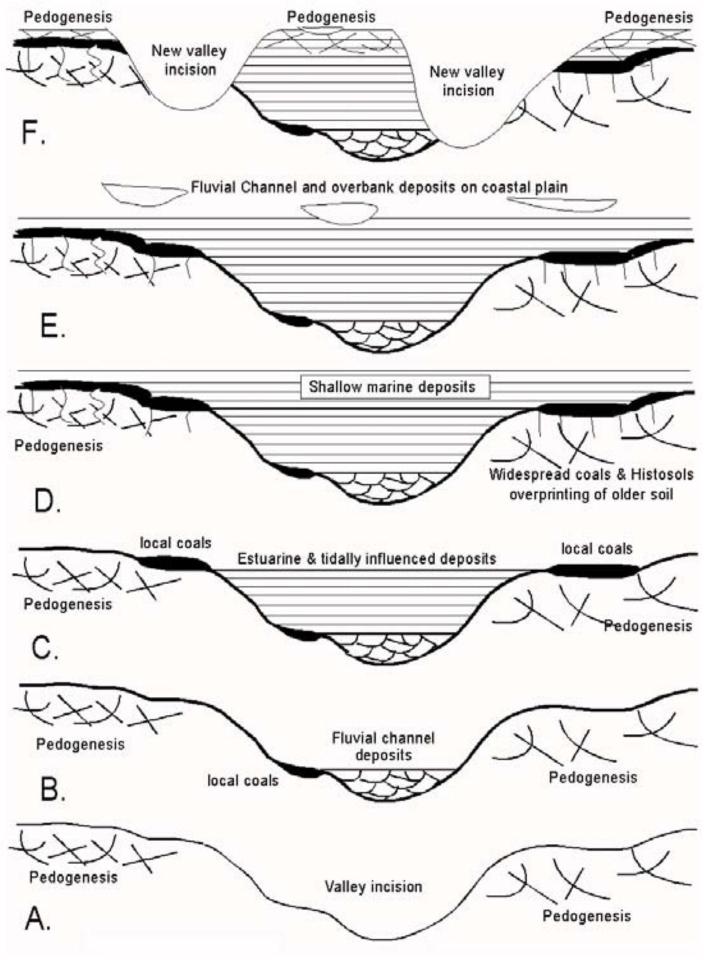

Figure 8. Siliciclastic depositional regimes in a high shelf setting during a single transgressive-regressive sequence (modified from Eble et al., 2002).

During sea-level rise (transgression), valley fills are often aggregating (Fig.8b) and prograding coarsening upward sequences produced by fluvial filling of the drowning valley (estuary), while pedogenesis proceeds on the interfluves (Eble et al., 2002). Tidally influenced deposits often overlie fluvial deposits (Fig.8c). Ponding of fresh water ahead of rising sea-level produces peat accumulation in areas of low clastic influx and shales, siltstones, and sandstone in areas of higher clastic influx. This can result in laterally discontinuous coals developed as narrow lenses in the proximal parts of the estuaries and marine facies developed in the more distal (seaward) regions of the estuary. Eventually, if sea-level continues to rise and the estuaries completely fill, sediments spread out over the interfluves (Fig. 8d). This can result in more widespread coals and marine facies resting on paleosols. The above described deposits represent the transgressive systems tract (TST).

During sea-level highstand, low gradient streams can produce isolated fluvial channel deposits adjacent to finer overbank deposits as the coastal plain experiences rapid aggradation due to increased accommodation space (Fig. 8e). At maximum highstand, deltas can prograde over earlier deposited marine facies, because estuaries are filled. These are called highstand system tract (HST) deposits.

As sea-level falls (regression), fluvial incision once again starts to erode valleys and subaerial exposure leads to soil development on shallow marine and coastal plain sediments (Fig. 8f). This results in an upper sequence boundary for the underlying depositional package and a lower sequence boundary for the overlying depositional package (Eble et al., 2002).

Incised valley fills are larger than single channel fills. Valley fills produced during a transgression often include amalgamated fluvial channel deposits overlain by estuarine facies of various types, often capped by tidally influenced fluvial or shallow marine facies. In valley fills produced by more than one transgressive-regressive cycle, complex compound fills may be found. They often show multiple episodes of incision and filling. In isolated outcrops of small lateral extent, the intricate relationship of these deposits may not be readily apparent. Some outcrops exposing strata in incised valleys may contain more cycles of deposition than the outcrops exposing strata deposited on the interfluves, and younger strata deposited in the incised valleys may lie adjacent to and below older strata on the interfluves. Laterally extensive exposures are relatively rare in the Pennsylvanian of Iowa. Stop 5 of this field trip affords an excellent opportunity to observe several hundred lateral feet and nearly a hundred vertical feet of complex terrestrial, fluvial, deltaic, estuarine, and marginal marine deposits. This is but one of several related exposures around the shores of Red Rock Lake.

COMMON LAND PLANTS FROM THE RED ROCK LAKE AREA

True ferns (Division Pteridophyta; Bold et al., 1987) were common in the Pennsylvanian. They reproduce by spores contained in sporangia arranged on the underside of leaves. Groups of sporangia are known as sori. Most have highly elaborate compound leaves or fronds. The petiole or stalk extends into the leaf blade as the rachis. From this arise pinnae or primary leaf divisions. Pinnules are the secondary divisions of pinnae. Stems may be trunk-like or rhizomes (underground horizontal stems).

Modern tree ferns exceed 20 m (66 ft.) in height. The unbranched trunks lack secondary xylem (wood) and are covered by a mantle of adventitious roots that helps support the main stem. The top of the stem supports a crown of leaves, which in some modern species may reach 4 m (13 ft.) in length. *Psaronius* was one of the most common of the tree ferns in the Pennsylvanian. *Pecopteris* (Fig. 9) is a common leaf form genera associated with *Psaronius*.

The Division Arthrophyta (Bold et al., 1987) is represented by herbaceous *Sphenophyllum* and arborescent *Calamites*, a large tree-like form related to the modern *Equisetum*. *Equisetum* is familiarly known as “horsetails” (branching species) and “scouring rushes” (unbranched species). The latter name comes from the fact that the epidermal cells are heavily silicified. Some Pennsylvanian forms may have reached 30 m (98 ft.) in height and 40 cm (15 in.) in diameter.

The stem of *Calamites* grew from a large horizontal underground rhizome. Both the aerial stem and rhizome have well-defined nodes and internodes. From the stem nodes leaves and branches grew and from the rhizome nodes roots grew. Stems were hollow, usually with a very large pith region. During fossilization the pith cavity often filled with sediment and a “pith cast” was formed (Fig. 10). Grooves in the pith cast correspond to separate primary xylem strands, while the ridges are vascular rays between the xylem strands. Horizontal grooves are the result of parenchymous pith diaphragms that occurred at the nodes. Leaves are assigned to the organ genera *Annularia* (Fig. 11a, b) and *Asterophyllites*.

Some species of *Sphenophyllum* may have been vine-like while others had several dichotomous branching, meter long stems, growing upward from a rhizome. Instead of having a hollow pith like *Calamites*, there was a triarch protostele of primary xylem surrounded by secondary xylem. Some had small webbed leaves (Fig. 12).

Lycopods ranged from small herbaceous plants to subarborescent forms to immense arborescent trees, with some exceeding 50 m (165 ft.) in height. Lycopod trunks had a small pith surrounded by generally thin primary and secondary xylem. The rest of the trunk is composed of an inner and outer cortex. The cortex may have provided support, considering the relatively small amount of xylem tissue. The root system, known by the form genus *Stigmaria* (Fig. 13), consists of rhizophores. They branched dichotomously in a nearly horizontal plane and bore small roots on the distal parts. The roots, like the

Figure 9. Terminal part of two pinnae of *Pecopteris*, associated with the tree fern *Psionius*. *Longer specimen 13 cm (5 in.) in length.*

Figure 10. Pith cast of *Calamites*. Note the short internodes and numerous nodes. *Length 20 cm (8 in.)*.

a.

b.

Figure 11.a) Leaves of *Calamites*, **.b)** Incomplete leaf whorl. Width 2.5 cm (1 in.). *Width 5 cm (2 in.).*

Figure 12. Sphenophyllum leaf whorl. Width 1.5 cm (0.6 in.).

Figure 13. Lycopod rhizophore (*Stigmaria*). Note the root scars arranged in spiral rows. *Length 25 cm (10 in.)*

Figure 16. Vertical rows of leaf cushions of *Sigillaria*. *Length 15 cm (6 in.).*

Figure 14. Unidentified lycopod stem compression showing spiral arrangement of horizontally elongate leaf cushions. Note probable outer cortex between widely separated leaf cushions. *Width 10 cm (4 in.).*

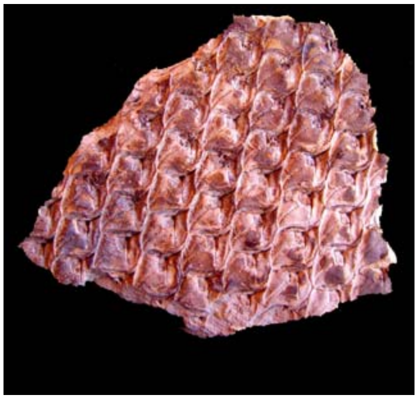

Figure 15. *Lepidodendron* stem compression. Leaf cushions are elongated vertically. *Width 10 cm (4 in.).*

Figure 17. Unidentified fern-like leaf of a probable seed fern. *Length 2.5 cm (1 in.).*

leaves, are arranged in spiral rows and may be over a meter (3.3 ft.) in length. Lycopod rhizophores and roots are a common component of rooted paleosols below coals. Detached leaves are known by the form genera *Lepidophylloides*. Figure 14 shows a compression fragment of an unidentified lycopod from Pella, Iowa.

Lepidodedron and *Lepidophloios* were two common lycopods that are inferred to have inhabited swampy areas. The root system had aerenchymatous tissues to help in gas exchange, and the cortex had a resin-like substance that was inferred to help "waterproof" the tree (Eble et al., 2002). Both trees bore leaves in a spiral arrangement and as the stems matured the leaves fell off exposing a rhomboidal leaf cushion elongated in the vertical direction in *Lepidodedron* (Fig. 15) and in the horizontal direction in *Lepidophloios*. Only the upper few meters of the aerial trunks were branched.

Sigillaria was another arborescent lycopod similar to *Lepidodedron* and *Lepidophloios. Sigillaria*, though, has the leaf cushions in vertical rows (Fig. 16) and the aerial trunk is unbranched or divides one or two times. They exceeded 30 m (98 ft.) in height and 1 m (3.3 ft.) in diameter at the base. *Sigillaria* is inferred to have inhabited drier areas than most other lycopods (Eble et al., 2002).

Gymnosperms are represented by the Division Coniferophyta, Order Cordaitales (cordaites) and the Division Pteridospermophyta (seed ferns) (Bold, et al., 1987). Gymnosperm ("naked seed") generally refers to a seed plant lacking an enclosing structure for the seeds.

Cordaites were a diverse group of trees that attained maximum heights of 5-30 meters (16-98 ft.), while at least one species may have been a shrub-like plant (Stewart, 1983). Most species had large (up to a meter long), simple, stemless, strap-like leaves borne in a spiral arrangement. The shorter species had stilt-like roots resembling those of modern mangroves and probably inhabited swamps along rivers, marine shores, and estuaries. Other species may have inhabited a variety of environments, including drier uplands.

The stems of cordaites resemble those of conifers quite closely (Bold, et al., 1987), consisting of a pith, small primary xylem strands, secondary xylem tissue (wood), and tracheids with circular, bordered pits on the radial walls. Because of differential growth between the pith and the rest of the stem the pith became septate, alternating with air chambers and plates of parenchyma tissue. The distinctive cast of the pith is known by the generic name *Artisia*, the leaves *Cordaites*, the roots *Amyelon*, the reproductive structures *Cordaianthus*, and the seeds *Cardiocarpus*.

Seed ferns (Pteridospermophyta) were plants with fern-like foliage (Fig. 17) that bore seeds on the fronds instead of sporangia. Many of the so called 'ferns' from the Pennsylvanian are now known to be seed ferns, but it is still nearly impossible to determine if some foliage is fern (Pteridophyta) or seed fern (Pteridospermophyta). Seed ferns ranged from vine-like (*Callistophyton*) to tree-like (*Medullosa*) forms. *Neuropteris* and *Alethopteris* are two common leaf form genera of probable medullosan affinities.

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SPHAEROSIDERITES IN PALEOSOLS OF THE PENNSYLVANIAN CHEROKEE GROUP OF SOUTHERN IOWA: PHYSICAL AND GEOCHEMICAL TRACERS OF EQUATORIAL PALEOPRECIPITATION

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INTRODUCTION

Participants on today's field trip will have an opportunity to examine relict sphaerosiderites in diagenetic calcite concretions within several underclays of the Pennsylvanian Cherokee Group. Subtle sedimentologic features that are easily overlooked, sphaerosiderites are millimeter-scale spherulites of pure siderite ($FeCO_3$) that form in the reducing groundwaters of wetland soils in siliciclastic sediments (Ludvigson et al., 1998). Research experience has consistently shown that the stratigraphic occurrence of coals is a reliable predictor of the occurrence of sphaerosiderites in associated sediments, as they are related by shared paleohydrologic and paleoenvironmental requirements.

ZONAL CLIMATIC BELTS AND THEIR CHARACTERISTIC PEDOGENIC CARBONATES

The formation of calcareous soils is generally well known in the soil science and geologic literature (Birkeland, 1999, p. 127-132). Calcareous soils accumulate in regions of precipitation-evaporation deficit, where groundwater infiltration is insufficient to leach calcite from the soil profile, and there is net evaporative accumulation (Goudie and Kenneth, 1983). The term "pedogenic carbonate" is often used as a synonym for pedogenic calcite, but such usage fails to account for the common occurrence of siderite as a pedogenic mineral, and the extensive reaches of the globe in which it accumulates in soils. While the zonal dry belts do cover a substantial portion of the globe, they are by no means ubiquitous to the terrestrial paleoenvironments that are preserved in the sedimentary record.

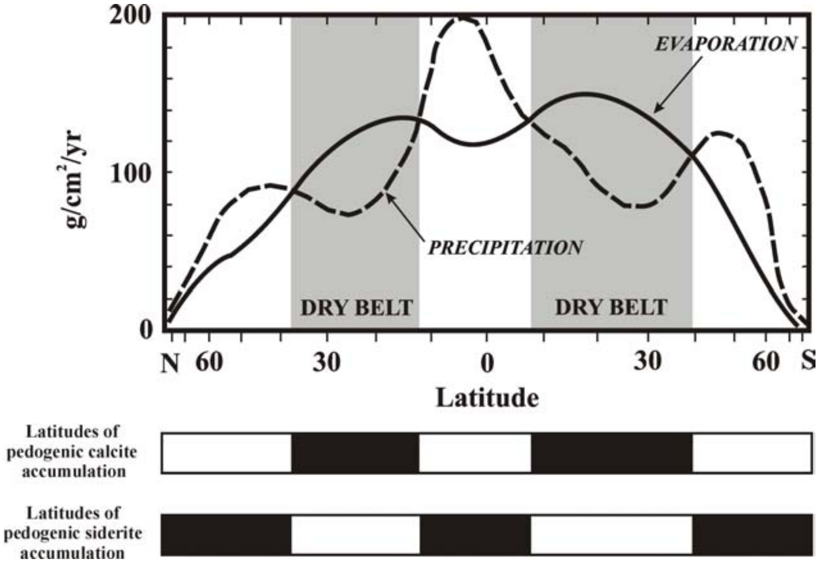

Figure 1. Zonal distribution of climatic belts (in black) that are dominated by accumulation of pedogenic calcite (calcretes) and siderite (sphaerosiderites). The zonally averaged precipitation and evaporation rates are from the modern climate system, and are modified from Barron and Moore (1994).

Hard-cemented calcareous soils, or calcretes, accumulate in continental deposits that are largely confined to the subtropical dry belts (Fig. 1), with the exceptions related to “rain shadow” orographic effects. Over the remainder of the globe where there is precipitation excess, calcite commonly is chemically leached from soil profiles. Within the humid belts, in poorly-drained soils that remain saturated through most of the year, oxidation of soil organic matter leads to the development of strong vertical redox gradients within soil waters, and the presence of reducing groundwaters near the land surface. In these settings, dissolved Fe^{2+} that is released from the cannibalization of detrital or pedogenic ferric oxides by reducing groundwaters is taken up by the formation of siderite. Sphaerosiderite, a morphologically distinct millimeter-scale spherulitic form of siderite, is common in buried soils in the geologic record (Retallack, 1981). Ludvigson et al. (1998) showed that sphaerosiderites from a given paleosol have a characteristic carbon and oxygen isotopic signature that they referred to as ***meteoric sphaerosiderite lines*** (MSLs; see Fig. 2). They argued that the invariant $\delta^{18}O$ values in MSLs are determined by the $\delta^{18}O$ values of soilwaters (i.e. the weighted mean annual $\delta^{18}O$ of local paleoprecipitation) and local mean annual temperature, and that the highly variable $\delta^{13}C$ values are determined by differing biogeochemical processes that produce dissolved inorganic carbon in wetland soils (aerobic oxidation of organic matter; methanogenesis; methane oxidation; see Fig. 3). Paleogeographic and stratigraphic variations in MSL values in Cretaceous mid-latitude paleosols have recently been utilized for the development of dramatic new insights on sequence stratigraphy and continental-scale paleoclimatology (Ludvigson et al., 1998; White et al., 2001; Ufnar et al., 2001).

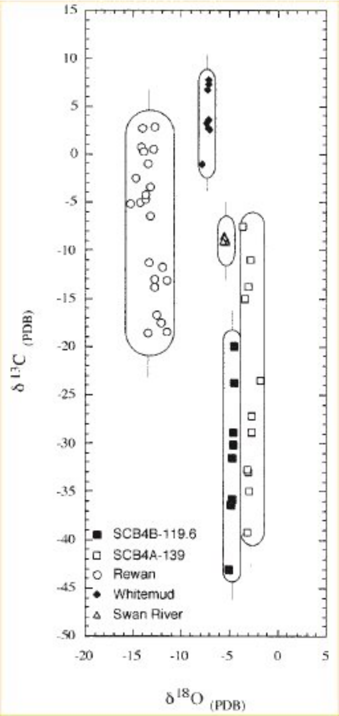

Figure 2. Carbon and oxygen isotope plot showing the characteristic diagenetic trends of meteoric sphaerosiderite lines. From Ludvigson et al. (1998).

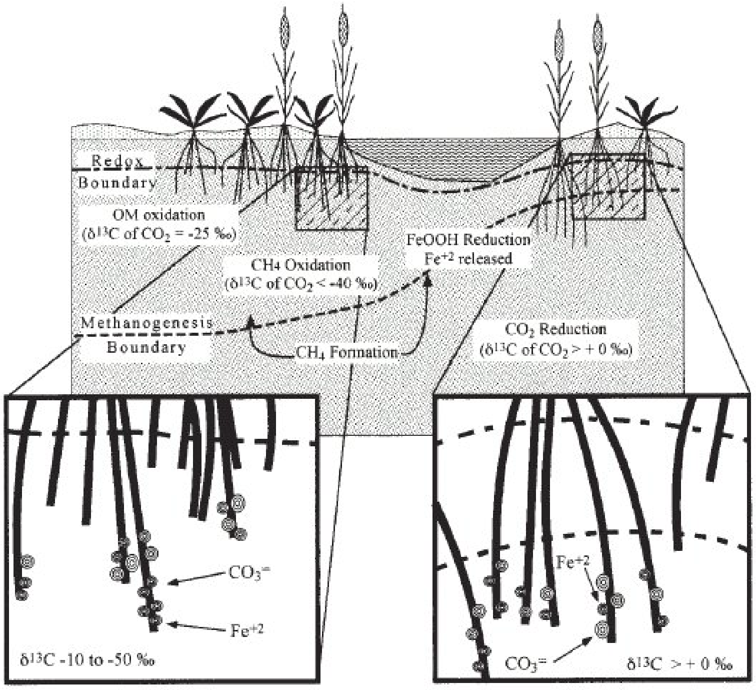

Figure 3. Schematic drawing illustrating the formation of sphaerosiderites arrayed along root traces in a wetland setting, and the geomicrobiological processes controlling $\delta^{13}C$ variations in meteoric sphaerosiderite lines. From Ludvigson et al. (1998).

MODERN EXAMPLES OF PEDOGENIC SIDERITE

Siderite has not been commonly reported as a pedogenic mineral in modern hydromorphic soils, but this general oversight is probably related to the microscopic size of siderite crystals found in modern occurrences, and sampling difficulties related to the chemical instability of reduced iron minerals in wet soil samples once they are exposed to the oxidizing atmosphere. Stoops (1983) and Llanduydt (1990) provided some of the first micromorphologic descriptions of Holocene sphaerosiderites, with maximum diameters in the 200 micron range. They often are associated with the chemically unstable reduced iron phosphate mineral vivianite, and also fine-grained pyrite in wetland settings influenced by infiltration of brackish fluids. Kim et al. (1999) reported on sphaerosiderites in Early Holocene paleosols with diameters up to 300 microns. Other reports of siderite accumulation in Holocene wetland sediments include Postma (1981), Moore et al., (1992), Virtanen (1994), McMillan and Schwertmann (1998), Aslan and Autin (1999), and Ellis (2001).

PALEOGEOGRAPHIC SETTING OF SPHAEROSIDERITE-BEARING PENNSYLVANIAN PALEOSOLS IN NORTH AMERICA

It has been the senior author's experience that many sedimentologists who have worked on coal-bearing Pennsylvanian strata in North America commonly are aware of the occurrence of sphaerosiderite in underclays—the clay-enriched gleyed silicilastic mudstone paleosols that typically occur beneath coal beds. Scal (1990, p. 96-107) described and illustrated sphaerosiderites in Desmoinesian sandstone units in Iowa. Browne and Kingston's (1993) descriptions of sphaerosiderites in Westphalian paleosols from maritime Canada are the best-known published examples to date. Recalling the aforementioned relationship between coals and sphaerosiderites, it is instructive to consider the paleogeographic distribution of mid-Pennsylvanian coals with reference to the paleoclimatic setting of the Cherokee Group in Iowa. Witzke's (1990) reconstruction for the Westphalian (Fig. 4), using climatically-sensitive lithic data, established a paleogeographic scheme that has not changed with subsequent work, and clearly places Iowa astride the mid-Pennsylvanian paleoequator.

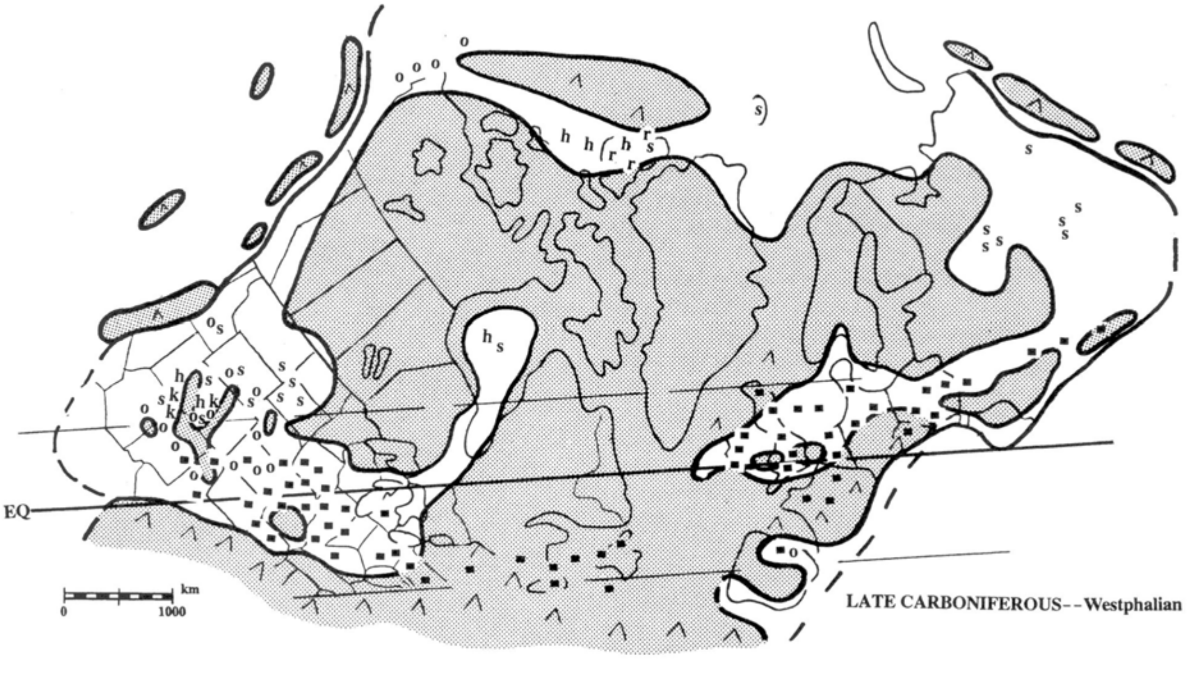

Figure 4. Interpreted North American and European paleogeography for the Westphalian (Morrowan, Atokan, Desmoinesian, mid- to late Baskirian, and Moscovian). Square symbols represent occurrences of coal in the equatorial humid belt, whereas sulfate (s), halite (h), and potash (k) evaporite occurrences denote a contemporaneous dry belt. From Witzke (1990).

The paleogeographic scheme shown in Figure 4 was specifically designed to place coal-bearing strata from the mid-continent United States and maritime Canada in the equatorial high precipitation belt (see Fig. 1), with a relatively sharp boundary with dry belt paleoenvironments at approximately 10° N paleolatitude.

SPHAEROSIDERITES IN THE PENNSYLVANIAN CHEROKEE GROUP OF IOWA

Figure 5. Photograph of hand sample of calcite concretion with contained sphaerosiderites visible as dark spots from their contained pseudomorphic iron oxides. From Melcher-Dallas locality in southwestern Marion County, Iowa. This sample comes from a siliciclastic mudstone paleosol (underclay) in the Laddsdale coal interval from the lower Floris Formation (Desmoinesian) of the Cherokee Group.

Continuing field studies in south-central Iowa, in support of new bedrock geologic mapping, has resulted in the discovery of some remarkable occurrences of sphaerosiderites in underclays of the Cherokee Group. These sphaerosiderites are preserved in larger calcite concretions within underclay units, and remain as partially intact siderite with pseudomorphic ferric oxides (Fig. 5). Intact sphaerosiderites very seldom are found in field exposures, with the exceptions occurring in new excavations in operating clay pits, or in actively-spalling cutbanks. In the case of these concretions, sphaerosiderite engulfment by later diagenetic calcite nodules apparently has partly protected them from oxidation by modern weathering processes.

In thin section view, sub-millimeter scale sphaerosiderites and their pseudomorphing iron oxides float in a mudstone matrix with grey-speckled birefringence. Both of these components are engulfed and superimposed by 1.5 mm- to 2 mm-diameter calcite spherulites that coalesce to form the body of the calcite concretions within the underclay unit. The petrography of the calcite spherulites in these calcite concretions very closely resembles that shown by Siewers et al. (2000) from

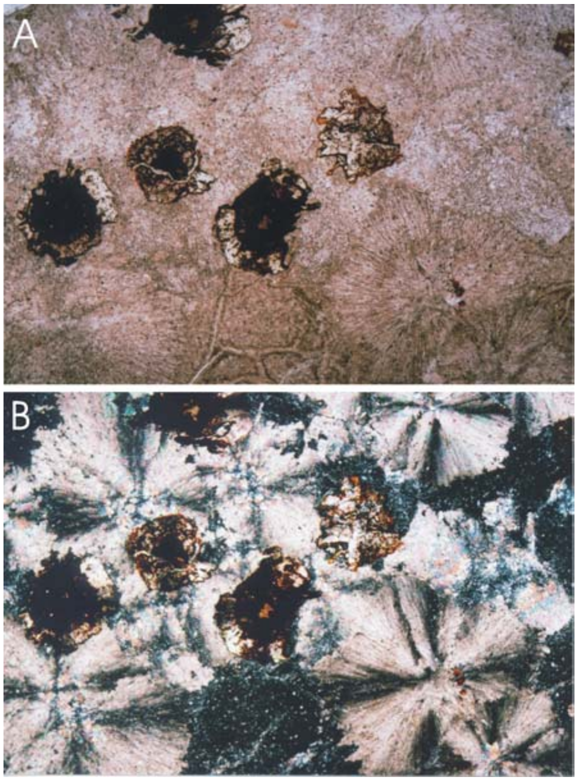

Figure 6. Thin section photomicrographs from the hand sample shown in Figure 5. Partially intact sphaerosiderites and pseudomorphic ferric oxides stand out in relief against surrounding background of calcite spherulites and mudstone matrix. A. Plane-polarized light. Note corroded margins of siderite spherulites. B. Same view in cross-polarized light. Note "pseudo-uniaxial cross" extinction pattern in both the siderite and calcite spherulites. Mudstone matrix has grey speckled birefringence. Horizontal field of view is 3.2 mm.

Pennsylvanian coal balls, which are early diagenetic, pre-compaction calcite concretions in coal beds that delicately preserve the cellular microstructure of vascular coal-swamp plants. Inspection of acetate peels taken from coal balls collected from Iowa coal mines in the Cherokee Group shows that these spherulitic calcite cements are common to all such concretions that we have examined so far. On the basis of these initial observations, it appears that the underclay and coal-ball concretions with spherulitic calcite cements may be products of the same early diagenetic processes.

A GENERAL THEORY FOR EARLY CARBONATE DIAGENESIS IN PENNSYLVANIAN COALS AND UNDERCLAYS IN IOWA

Gerdon et al. (1997) reported that Late Paleozoic coal balls from North American and European deposits are principally cemented by radial-fibrous (i.e. spherulitic) low magnesium calcite, with 2-9 wt. % Fe and 0.3-2 wt. % Mn substitution for Ca in the calcite lattice. They further reported highly variable $\delta^{13}C$ values ranging between –40 to –5 ‰ PDB, relatively invariant $\delta^{18}O$ values averaging around –9 ± 2 ‰ PDB, and $^{87}Sr/^{86}Sr$ ratios suggesting a radiogenic strontium source. They also noted that these data collectively indicate that coal balls were principally formed by early meteoric phreatic diagenesis, with dissolved carbonate produced from the decay of organic matter in the hosting peat deposits. Given that all of the deposits in question accumulated in the equatorial humid belt (see Fig. 4), the relatively depleted $\delta^{18}O$ values of these early meteoric phreatic calcites is highly suggestive of oxygen isotopic rainout effects resulting from high precipitation rates along the paleoequator (Rozanski et al., 1993).

The formation of sphaerosiderites in Pennsylvanian underclays, and their subsequent engulfment by spherulitic early meteoric phreatic calcite cements that apparently precipitated in both overlying coal and underlying underclay beds suggests that all of these phenomena might be related to the paleohydrologic effects of rising local base levels. Micromorphologic studies of many sphaerosiderite-bearing paleosols have shown that meteoric phreatic sphaerosiderites are often superimposed on earlier pedogenic features that developed in formerly oxidizing vadose soil profiles (McCarthy and Plint, 1998; Ufnar et al., 2001).

The most parsimonious interpretation is that underclay paleosols like that shown in figures 5 and 6 might have originally developed as oxidizing vadose soil profiles, and that sphaerosiderites formed from the cannibalization of earlier pedogenic iron oxides by reducing groundwaters during the gleization of the profiles as the local water table passed upward through the soil profile during base level rise. Continuing base level rise and the eventual establishment of perennial standing water would lead to the deposition of coal swamps, and the rapid accumulation of histosol soils (peats). The early meteoric phreatic precipitation of spherulitic calcite concretions in the histosols (coal balls) and underlying gleyed siliciclastic mudstone paleosol (underclay concretions) could have resulted from the production of dissolved carbonate from the decay of organic material in the histosol, in a more iron-limited groundwater flow system. Why are spherulitic calcite morphologies shared among all these early diagenetic products? Do high concentrations of organic acids play a role? Alternatively, Gonzalez et al. (1992) indicated that radial-fibrous morphologies in low-Mg calcites can result from high rates of fluid flow. Perhaps these calcite fabrics resulted from vigorous groundwater flow systems that developed in domed peats as they rapidly aggraded in the tropical paleoenvironments of the Pennsylvanian equatorial belt.

ACKNOWLEDGMENTS

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Field Photograph of coal and underlying gleyed underclay at Stop 4. Darker-toned rocks littering the slope on the underclay are fragments of calcite concretions containing sphaerosiderites.

LAKE RED ROCK AND ELK ROCK STATE PARK

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Lake Red Rock

Lake Red Rock is Iowa's largest flood control reservoir with 19,000 surface acres (USA Corps of Engineers, 2002). The reservoir is operated by the U.S. Corps of Engineers on the Des Moines River, in Marion County about 5 miles north of Knoxville (Fig. 1). Lake Red Rock is Iowa's largest single expanse of public lands with over 50,000 acres. The reservoir is a multi-use area: with camping, hiking, biking, nature areas and a visitor information center. The area encompasses 47,610 acres of U.S. government lands managed by the Corps of Engineers, 25,572 acres under long-term lease to the Iowa Department of Natural Resources (DNR) as a wildlife management area (the Red Rock Wildlilfe Unit – one of the largest in the state), as well as 2,218 acres managed by the DNR as Elk Rock State Park on the southern edge of Lake Red Rock. Additionally, the Corps leases 2,622 acres to the Marion County Conservation Board, which manages the area as Roberts Creek and Cordova County Parks, north of the lake.

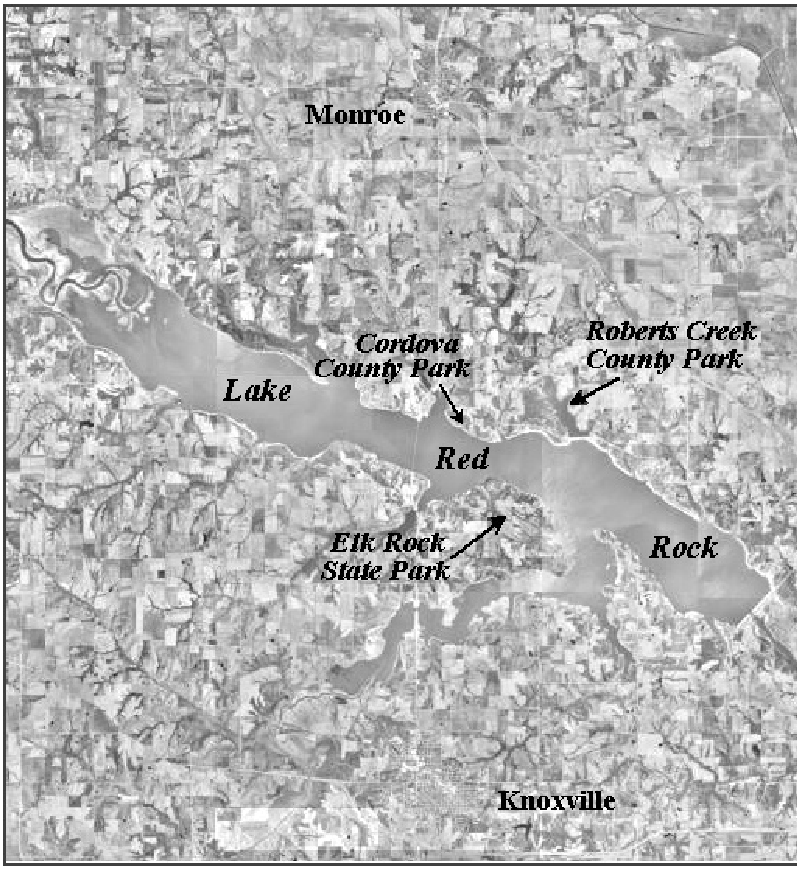

Figure 1. Composite of Digital Orthophoto Quadrangles of the Lake Red Rock Area (from Iowa Geographic Image Map Server).

The Red Rock Dam was authorized by the Congress for flood control purposes. After nine years of construction, the U.S. Army Corps of Engineers completed the mile-long earthen dam (Fig. 2) in 1969. The dam is constructed of **embankments** made of slowly-permeable clay material with a sand layer that allows for drainage of seepage water. Large blocks of limestone, called rip rap**,** protect the embankments from wave action on the lake side of the dam. The downstream or riverside of the embankment is covered with a layer of topsoil and seeded with grass. Fourteen hydraulically-operated **Sluice Gates** (Fig. 3) located inside the dam control structure move lake water past the dam to continue the flow of the Des Moines River. Each gate is five feet wide and nine feet tall and are used when lake outflow is less than 38’000 cubic feet per second (one cubic foot is equal to 7.5 gallons of water). When greater water

Figure 2. Photograph of the Red Rock Dam.

discharges are desired, the water flows over a **controlled spillway**, which unlike most dam spillways is capable of controlling the amount of water that passes over the dam. The spillway water is controlled by a series of **Tainter Gates** (Fig. 3), each 41 feet wide and 45 feet tall that allow control of the flood pool level. Water from both the Sluice Gates and the Tainter Gates empty into a **Stilling Basin**. The Stilling Basin acts to slow the velocity of the water coming through and over the dam, reducing downstream bank erosion. To slow the water, 25 **baffles** were placed in two rows in the basin, each baffle the size of a passenger van.

At the lake's standard elevation of 742 feet above sea level, it has a surface area of 19,000 acres of water. When heavy rains occur in the lake's 12,000 square-mile watershed, the lake can triple in size. Flooding in 1993 pushed the lake to a height of 782.67 feet above-sea-level, creating a lake with an area greater than 70,000

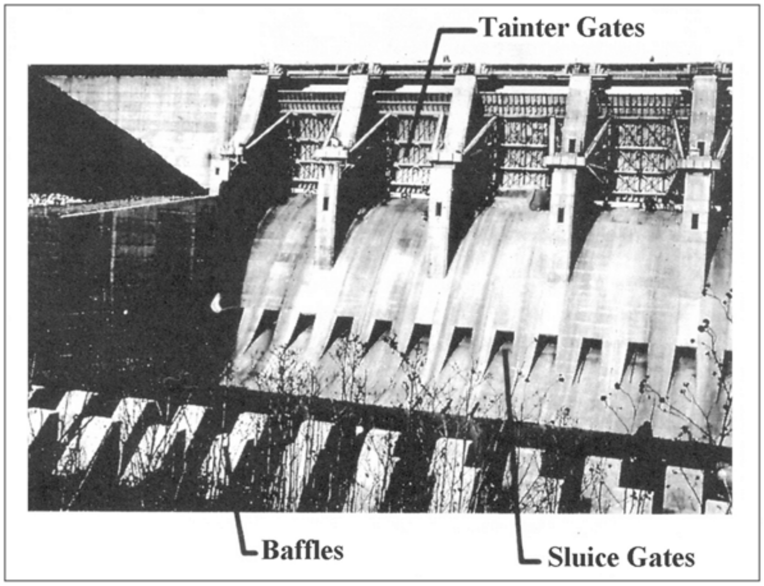

Figure 3. Photo of Red Rock Dam Control Structure showing Gates and baffles. Photo from US Army Corps of Engineers.

acres. It is interesting to note that the normal maximum pool level for Red Rock Lake is 780 feet, but the lake's spillway is controlled and allows an emergency flood pool level of 791 feet. The Corps owns land around the lake up to the 783 foot level, and could presumably be liable for damages by flood above that level, so they are would be very reluctant to allow waters to rise above that level. Iowa State Highway 14 crosses the lake on the "mile long bridge" (Fig. 4). The field trip route crosses the bridge.

Figure 4. Photograph of the Highwy 14 "mile-long bridge".

While the primary purpose of the dam is controlling water levels on the Des Moines River, another important purpose has evolved over the last two decades. Lake Red Rock has become a premier location for enjoying uncrowded outdoor recreation opportunities. Over 50,000 acres of diverse habitat, from sandy shoreline to wooded rocky bluffs, provides homes to hundreds of wildlife species. Large numbers of whitetail deer can be seen throughout the lake area and river otters are seen occasionally along the shoreline. The large area of open water and extensive associated habitat attracts large numbers and varieties of birds, both permanent inhabitants and migrators. In her web publication on ***Birding the Red Rock Area***, Ann Johnson (2002) stated that "*Although by most standards this area has been under-birded, about 300 species of birds have been found here in the past 20 years. With better coverage, who knows what might be found!*" She goes on to mention a number of the bird species that have been reported in the area and she suggests the best localities to observe them. Birds identified in her article include loons, grebes, herons, cormorants, ducks, pelicans, and gulls. Scarlet Tanagers, Kentucky Warblers Willow Flycatchers, Yellow Warblers, Bell's Vireos, Red-breasted Nuthatches and Long-eared Owls have also been observed. She mentions shorebirds such as Buff-breasted and Baird's sandpipers, Sanderling and Ruddy Turnstones. Ms. Johnson notes that Peregrines Falcons are seen nearly every fall, and a Cooper's Hawk nested near the lake a few years ago. White pelicans migrate through the Lake Red Rock area every spring and fall, and large numbers of waterfowl migrate through the lake every spring and fall.

Also present in large numbers are bald eagles, observed in particularly large numbers during winter months (November through March). Eagles were well on their way to extinction and were eventually included on the federal list of endangered species. But since the 1972 federal ban of the use of the pesticide DDT (which produces thin-shelled eggs in many bird species), bald eagles have been making a huge comeback in Iowa and nationally. Iowa did not have a nesting pair of the eagles for 70 years before one was spotted in 1977, and a second pair was not seen until 1982. Then populations expanded rapidly, with five to 10 nesting pairs appearing in the state every year. Today Iowa Department of Natural Resources biologists estimate the state now has 130 nesting pairs in 54 counties.

Elk Rock State Park

Elk Rock State Park is located on southern shore of Lake Red Rock, just east of Iowa Highway 14 (Fig. 5). The park includes 2,218 acres, and along with the traditional camping, hiking, and fishing facilities, the park features an equestrian campground with 13 miles of equestrian trails. The park also allows mountain bikes on the trails.

The area in and around Elk Rock State Park was inhabited by American Indians for more than five thousand years, back to the Archaic Culture. In 1842, the Sac and Fox Indians granted white settlers right to this land. The name "Elk Rock" has been attributed to the unusual rock formation, which is located on the south side of the river in the park. With the influx of Euro-American settlers and traders, many small towns sprung up along the Des Moines River in the Red Rock area. They included: Cordova, Cunreath, Fifield, Percy, Red Rock and Raouseau. All these settlements existed in the area now covered by Lake Red Rock.

The State once leased land both north and south of the lake. The lease on the land north of the lake, known as North Elk Rock, was not renewed by the state because of the difficulties in managing two non-adjacent areas. That northern area is now managed by Marion County as Cordova County Park. In 1978, the state obtained a lease for property on the south shore of the reservoir. This land became known as South Elk Rock. Today Elk Rock State Park comprises the main southern Elk Rock Park area, which has both day and night facilities, and the bridge area that is a day use picnic area (Iowa DNR, 2002).

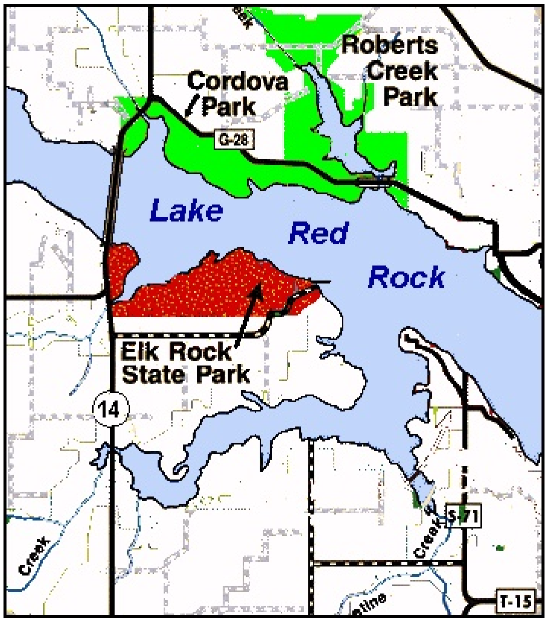

Figure 5. Location of Elk Rock State Park and Roberts Creek and Cordova County Parks.

Cordova and Robert's Creek County Parks

Cordova County Park is located on the north side of Lake Red Rock, off County Road G-28 (Fig. 5). Managed by the Marion County Conservation Board, the park boasts 7 cabins for rent year-round. The park also offers a nature trail, picnic facilities, and a boat ramp. A new observation tower is also open throughout the year.

Robert's Creek County Park is also located on the north side of Lake Red Rock, just east of Cordova Park (Fig. 5). Managed by the Marion County Conservation Board, the park provides two camping areas, a hiking trail, and two boat ramps with access to Robert's Creek. (from Lake Explorer, 2002).

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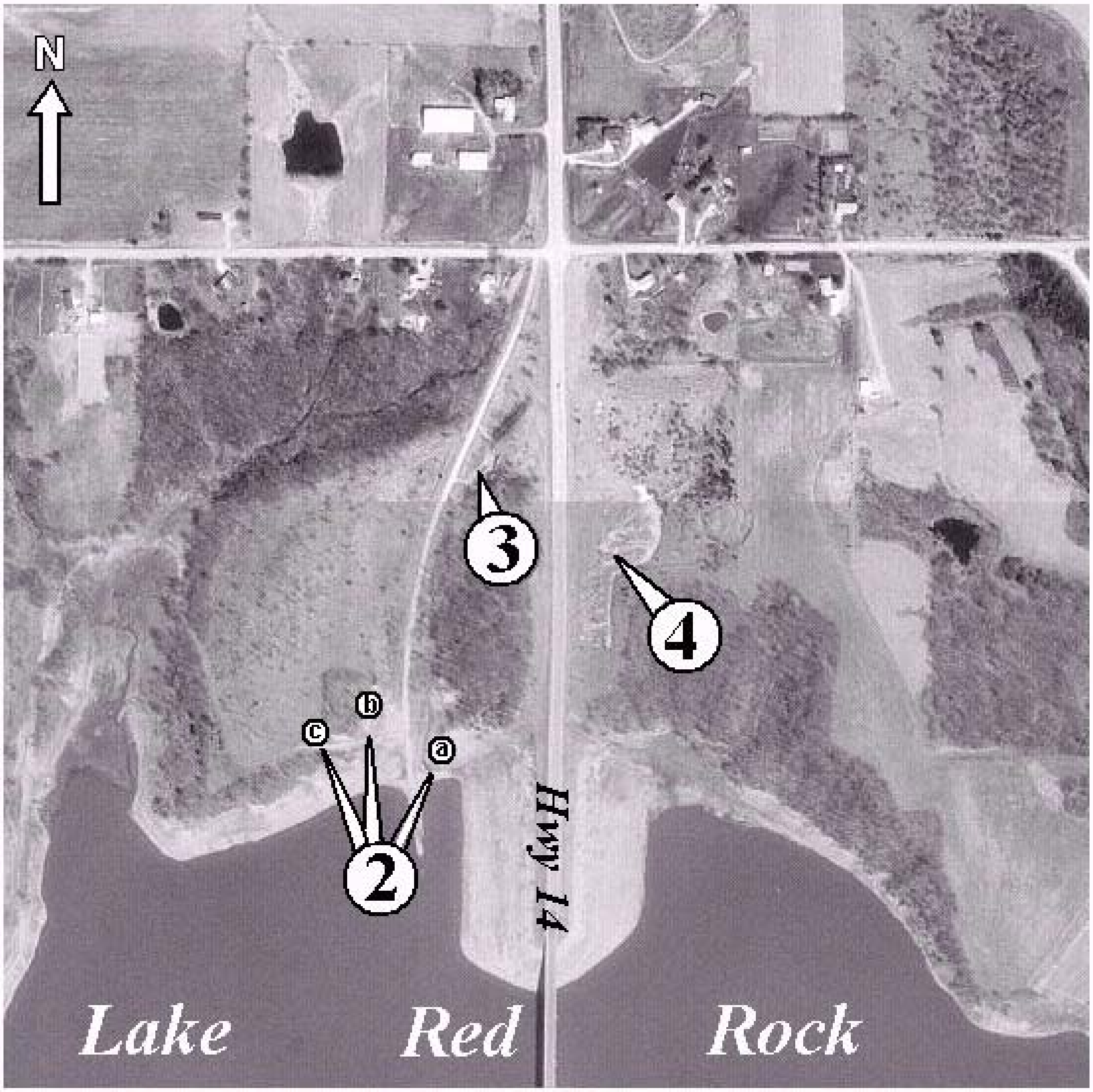
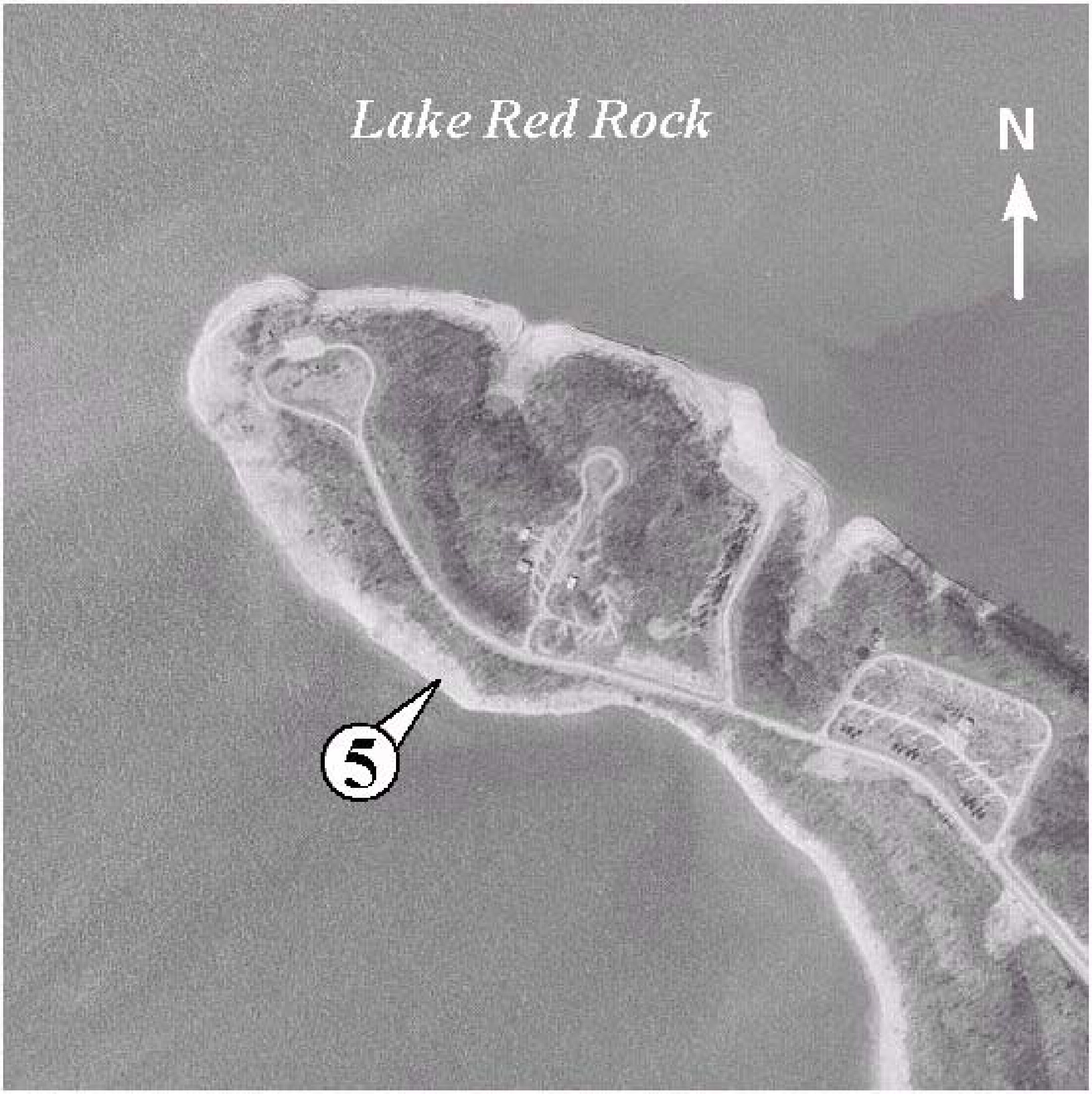
AERIAL PHOTOGRAPHS OF AFTERNOON FIELD TRIP STOPS



Aerial Photograph of field trip Stops 2, 3, and 4, just north of White Breast Creek arm of Lake Red Rock.



Aerial photograph of Whitebreast Campground and location of field trip Stop 5.

STRATIGRAPHY AND PRELIMINARY INTERPRETATION OF DEPOSITIONAL ENVIRONMENTS FOR FIELDSTOPS IN THE FLORIS FORMATION, RED ROCK LAKE, MARION COUNTY, IOWA

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STOP 2A, B, C; (SEE FIGURE 2)

Abandoned Highway 14 Sections
NE SE NW Sec. 24, T. 76 N., R. 20 W.

STOP 2A

Stop 2a (Fig. 1) affords an opportunity to observe minor lateral lithologic changes in isolated outcrops over relatively short distances. These changes are interpreted to reflect depositional environment lying adjacent to each other in a fluvial system.

The lower sandstone at consists of three stacked, fining-upward clastic sequences. Each sequence grades upward from thick cross-bedded medium quartz sand to sandy shale. The upper two sequences are elongated bodies each with their axis trending NE-SW. In all three, the foresets of most of the cross-beds dip steeply to the southwest. The basal sand beds of each sequence erosionally truncate the underlying sandy shales of the next lower sequence.

The lower sequence is much thicker than the upper two with several massive beds. The upper surfaces of two of the massive beds have current ripples and FeO/clay drapes, often containing pyrite nodules. It has not yet been determined if the FeO/clay drapes are original clay deposits within the sand or later diagenetic features. Some beds contain centimeter scale armored mud balls. *Lepidodendron* log casts and molds, *Sigillaria*, *Stigmaria*, and ferns leaves (may include seed ferns) and other wood casts are common.

Figure 1. Photograph of field trip Stop 2a.

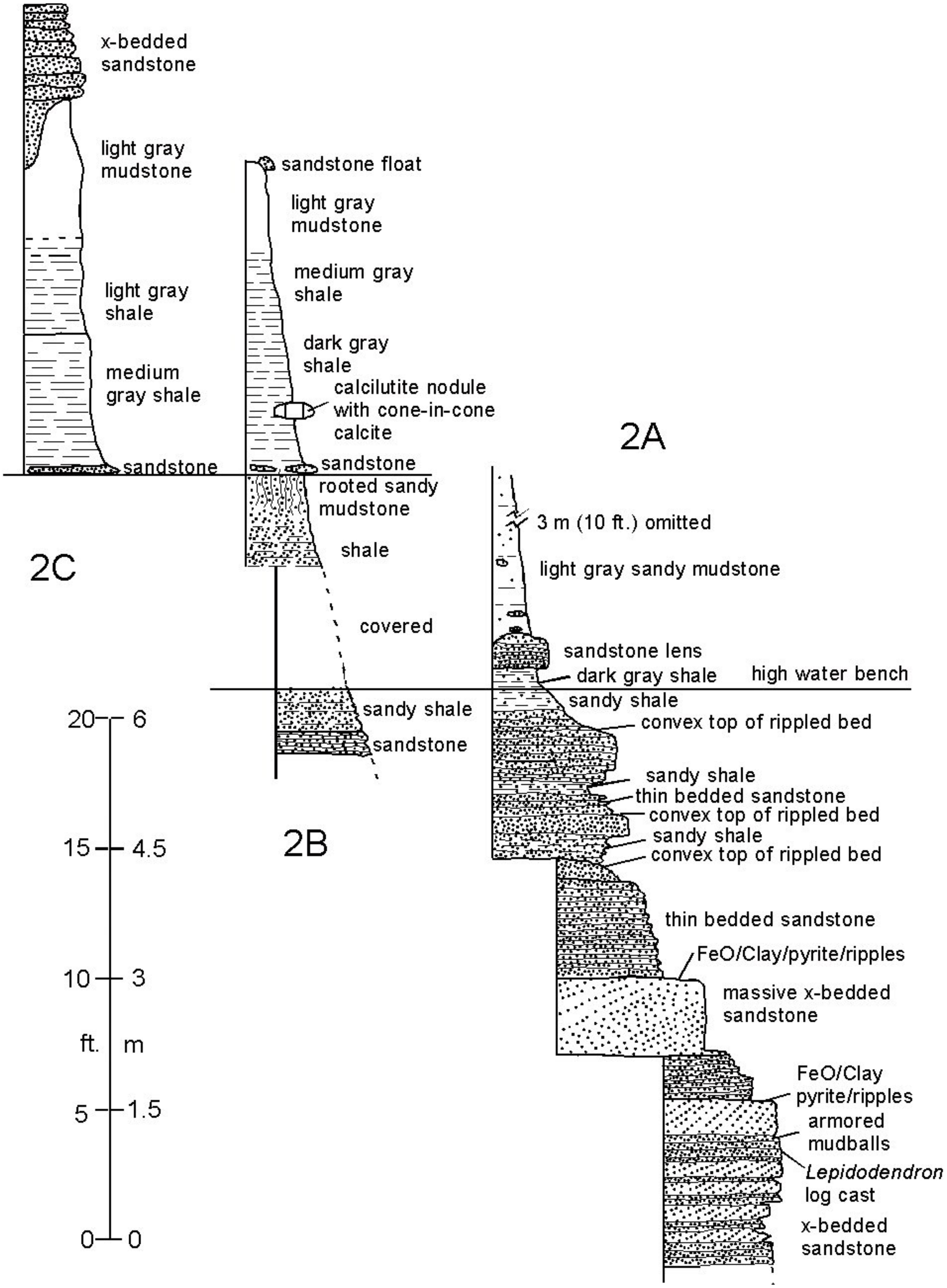


Figure 2. Graphic Sections for field trip Stop 2, NE, SE, NW, Sec. 24, T. 79 N., R. 20 W., Marion County.

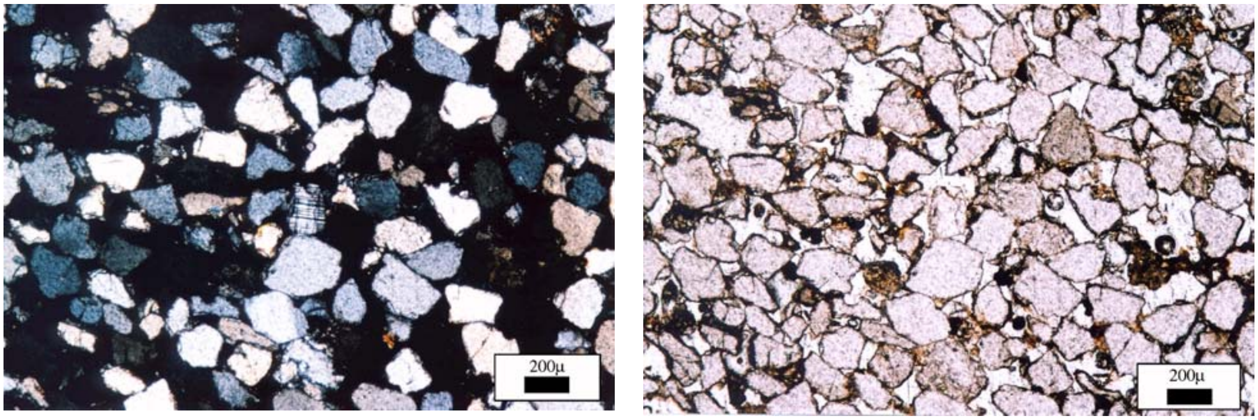
Petrographically the lower beds are a well sorted fine to medium grained quartz arenite using the terminology of Folk et al. (1970). Monocrystaline quartz showing normal extinction (Fig. 3a;) is the most common constituent with minor amounts of polycrystalline quartz, microcline feldspar (Fig 3a;), muscovite, and schistose rock fragments. Most quartz grains are angular to subrounded. Contacts between quartz grains show both point-to-point contacts and suturing. Cement is rare usually occurring as thin bands of low birefringent clays and iron oxides that tend to coat grains (Fig. 3b;). The thin bands of cement occur in cross beds with an average dip of 40 degrees. Clays are common along cleavage planes in the feldspars and muscovite.

The basal sand beds of the upper two sequences and the top sand beds of the lower sequence have current-rippled convex upper surfaces. They thin away from the NE-SW axis while the upper sandy shale of each sequence thickens away from the axis.

The upper sequence grades upward into several feet of poorly exposed sandy mudstones and shales with lenses of sandstone. The relationship between these upper beds and those at stops 2B and 2C have not been definitely determined. In a ravine to the north and several feet above exposure 2A are mudstones and shales overlain by a thick cross-bedded sandstone. This is probably the same sandstone that is seen at the top of stop 2C and may be the lower sandstone seen in the east road ditch at stop 3.

STOP 2B

The base of stop 2B is gray shale that grades upward into a sandy, rooted, light gray, blocky mudstone overlain by a few inches of bioturbated sandstone. Several feet of dark gray shale with large dark, dense calcilutite nodules, in its base, occurs above the sandstone. The nodules partially consist of cone-in-cone calcite (Fig. 4). The dark shale grades upward into medium and light gray shale.



a.

b.

Figure 3. Photomicrographs of lower sandstone at Stop 2a. a.) cross-polarized light; b.) plane polarized light.

STOP 2C

Figure 4. Calcareous shale displaying cone-in-cone structure, from Stop 2b.

At Stop 2C the thin sandstone seen at stop 2B is at the base of the section. This is overlain by several feet of medium to lite gray shale that grades upward to several feet of light gray blocky mudstone. This is in turn overlain by at least 1.2 m (4 ft.) of cross-bedded sandstone with a sharp basal contact.

The upper sandstone is a calcite cemented medium sorted very fine to medium grained quartz arenite (Fig. 5). Monocrystaline quartz with normal or undulose extinction is the most common grain type with polycrystalline quartz, feldspars, and muscovite also present in minor amounts. Most quartz grains are angular to rounded (Fig. 5). Microcline, orthoclase and plagioclase comprise the feldspars found in this sandstone. Clays are common along cleavage planes in the feldspars and muscovite.

Calcite cement is pervasive, and many feldspars show areas replaced by calcite. Low birefregent clays and iron oxides are also present as cement between grains. Most quartz grain contacts are point-to-point with only a few contacts being sutured.

Interpretation

Both sandstones (base of 2A designated lower, and top of 2C designated upper) are relatively well sorted quartz arenites suggesting long periods of transport, which destroyed most other grains. Quartz grains are highly resistant to either mechanical or chemical weathering and when found in abundance suggests that the source was far away or that the climate was hot and humid which can chemically degrade less resistant grains. The degraded nature and the limited amount of feldspars present also suggest that the ultimate source for the feldspars was some distance from Iowa. The upper sandstone also contains more quartz grains showing undulose extinction possibly indicating a slightly different source area for the two sandstones.

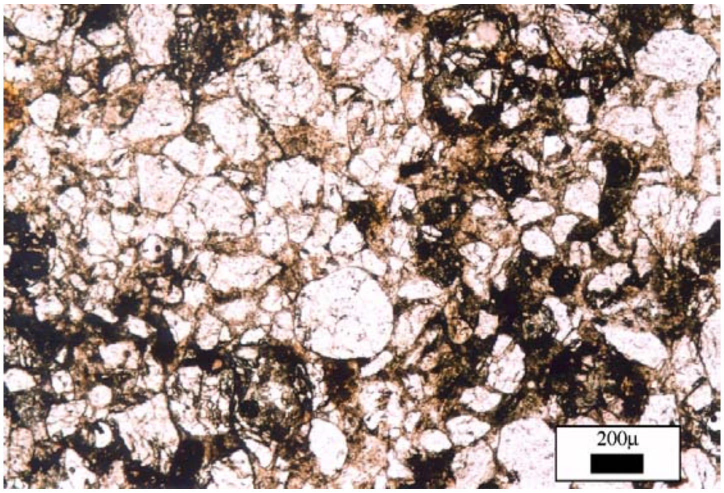


Figure 5. Photomicrograph of upper sandstone from Stop 2c, using plane polarized light.

The lower sandstone has abundant pore space and very little cement. This may have been caused by modern, low pH, lake waters dissolving carbonate cements that may have originally been present in the rock. The sample was taken several feet below the high water level of Red Rock Lake, and the water of the Des Moines River probably has relatively high levels of aliphatic acids derived from decaying organic material. The upper sandstone has abundant pore space filled with calcite cement. The low number of sutured contacts indicates that the calcite cement most likely represents a relatively early digenetic event where water saturated with $CaCO_3$ flowed through the rocks pores, cementing the grains before they had time to compact against each other. The lower sandstone shows more suture contacts suggesting greater compaction before whatever cementation it underwent.

The lower sandstone is interpreted to have been deposited by a stream or river flowing to the southwest from the northeast. The lower sandstone may represent aggrading fluvial channel sediments deposited in relatively low accommodation space. The upper mudstones and shales may represent overbank deposits on a flood plain with some relief. Soils may have formed on higher areas, while dark organic-rich shales and coaly shales were deposited in lower areas where more organic material was preserved. The deposits from the bottom of the lower sandstone to the base of the upper sandstone may represent a rise in base level that provided accommodation space for the sediments to accumulate. This was terminated by a fall in sea-level, erosion and paleosol formation represented by the upper blocky mudstone. The upper sandstone may represent another rise in base level.

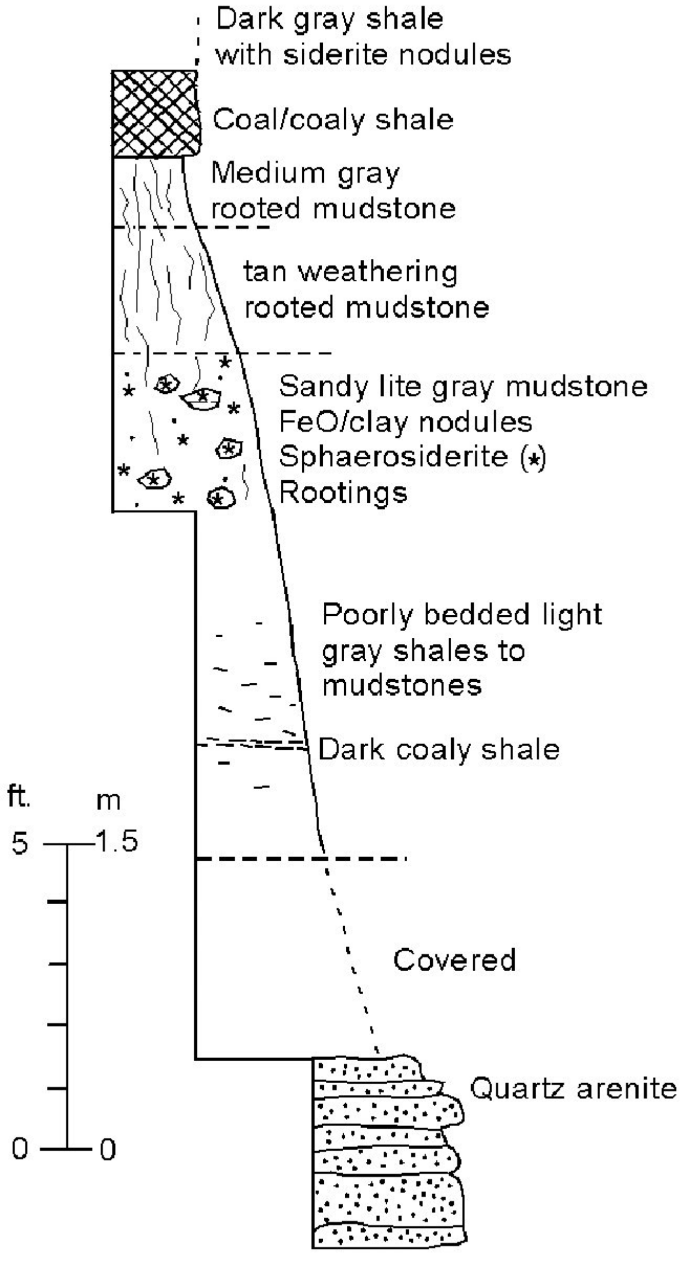


Figure 6. Graphic Section for field trip Stop 4; SW, NW, NE, Sec. 24, T. 76 N., R. 20 W, Marion County.

Archer and Greb (1996) hypothesized that an early Pennsylvanian river system with headwaters in the eastern Canadian Shield or the northern Appalachians moved sediments from these areas to the Mississippi Embayment area during sea-level low-stand. Similar river systems could have deposited the sands that now form most of the Middle Pennsylvanian sandstones in Iowa. Archer and Greb (1996) calculated that some of these rivers could have been comparable to the modern Amazon in size, although the rivers that deposited the thick sandstones in the Red Rock Lake area were probably much smaller than the modern Amazon.

STOP 4, (SEE FIGURE 6)

Highway 14 Section
SW NW NE Sec. 24, T. 76 N., R. 20 W.

Stop 4, (see Fig. 7) in contrast to stop 2 and later stop 5, exhibits very few lateral changes. This may reflect more widespread environments of deposition.

The sandstone in the east road ditch may be the top of the sandstone exposed at the top of the 2C section. The upper 1.2 m (4 ft.) is a

Figure 7. Photograph of field trip Stop 4.

fine to medium grained quartz arenite with calcite and iron oxide cements. Quartz grains are angular to subrounded with very few sutured contacts. There is some high birefringent clay matrix, organics, and probable siderite present. Above this is 90 cm (3 ft.) of covered interval and 90 cm (3 ft.) of exposed section consisting of light gray to nearly white poorly bedded shale and mudstone with a thin dark gray coaly shale near the top. This is overlain by 2.4 m (8 ft.) of light to medium gray blocky mudstone containing numerous root molds, FeO/clay nodules, and oxidized sphaerosiderites. The upper part has scattered pyrite replaced rhizophores (*Stigmaria*) of lycopod trees. The uppermost unit of the outcrop is the lower part of a black coaly shale to coal with only about 46 cm (1.5 ft.) exposed. The coal has an apparent dip to the east.

Numerous large, round, flattened siderite nodules are found on the surface of the mudstone directly below the coal. These nodules are actually weathering from a shale in the grassed over interval above the coal. About 9 km (5.6 mi.) to the southwest in a railroad cut near the town of Donnelley, a similar section has a 76 cm (2.5 ft.) coal overlain by 5.8 m (19 ft.) of medium to dark gray shale. The upper 3.7 m (12 ft.) contains numerous siderite nodules like the ones resting on the mudstone at stop 4.

Palynological work has not been done on the coal at stop 4, but due to its position relative to other known coals in Marion County, it is inferred to be one of the Laddsdale coals or possible the unnamed coal above the Laddsdale (pers. comm. Mary Howes, 2002).

STOP 5, (SEE FIGURE 9)

Coal Ridge Southside Section

S1/2 NE NW Sec. 15, T. 76 N., R. 19 W.

The section exposed at stop 5 is unusual in south-central Iowa in that it is almost 30 m (100 ft.) high and nearly 0.8 km (0.5 mi) long. It is a very complex exposure showing major lateral lithologic changes, as seen in the diagrammatic cross section. Three vertical transects that illustrate the lateral variability within the exposure will be discussed here, one on the western end, one near the center, and one at the eastern end of the outcrop. The elevation of the lake at normal pool level is used as the main datum and a high water bench approximately 7.6 m (25 ft.) above this is used as a secondary datum. All descriptions will be from bottom to top starting at the lake level datum.

At the western end of the outcrop the lower 2.1 m (7 ft.) is covered. Above this is 4.3 m (14 ft.) of light gray to nearly white blocky mudstone. Within this mudstone are several irregular zones of large cacilutite nodules. The upper zone of nodules is imbedded in a sandy, calcite-cemented, rooted siltstone and can reach 0.9 m (3 ft.) in thickness. Within these nodules are zones of centimeter sized spherulitic radial-fibrous calcite, some of which also show concentric banding. The top of this zone has an apparent dip to the east where at it lowest point, it is overlain by 1.5 m (5 ft.) of medium to dark gray shale with stringers of iron-rich siltstone.

The mudstone is interpreted to be a soil horizon with pedogenic carbonate zones. The dark shale above this, which thins over highs in the soil, could be overbank fines deposited in low areas that preserved organic material, during a rise in base level or sea-level.

Near the center of the exposure on a small point extending into the lake, the outcrop becomes highly complex. The base of this section is a coal exposed just above lake level. Above this is a rooted, sandy, blocky mudstone to rooted sandstone and another coal, all of which have an apparent dip to the west. The upper coal thins up-dip to less than 2.54 cm (1 in.) and thickens to over 46 cm (1.5 ft.) down-dip in about 4.6 m (15 ft.) of horizontal distance. Overlying this coal is about 2.7 m (9 ft.) of laminated black shale and sandstone that grades upward into a laminated sandstone (Fig. 9). The same mudstone with carbonate nodules seen at the western section is seen a few feet above the laminated sandstone, but here it has an apparent dip to the west. The eastern end of this central part of the outcrop seems to have a surface that truncates the coals, laminated shale and sandstones, and the upper mudstone with carbonate nodules. The truncation surface has a high angle dip to the east. This surface is overlain by blocky mudstone and

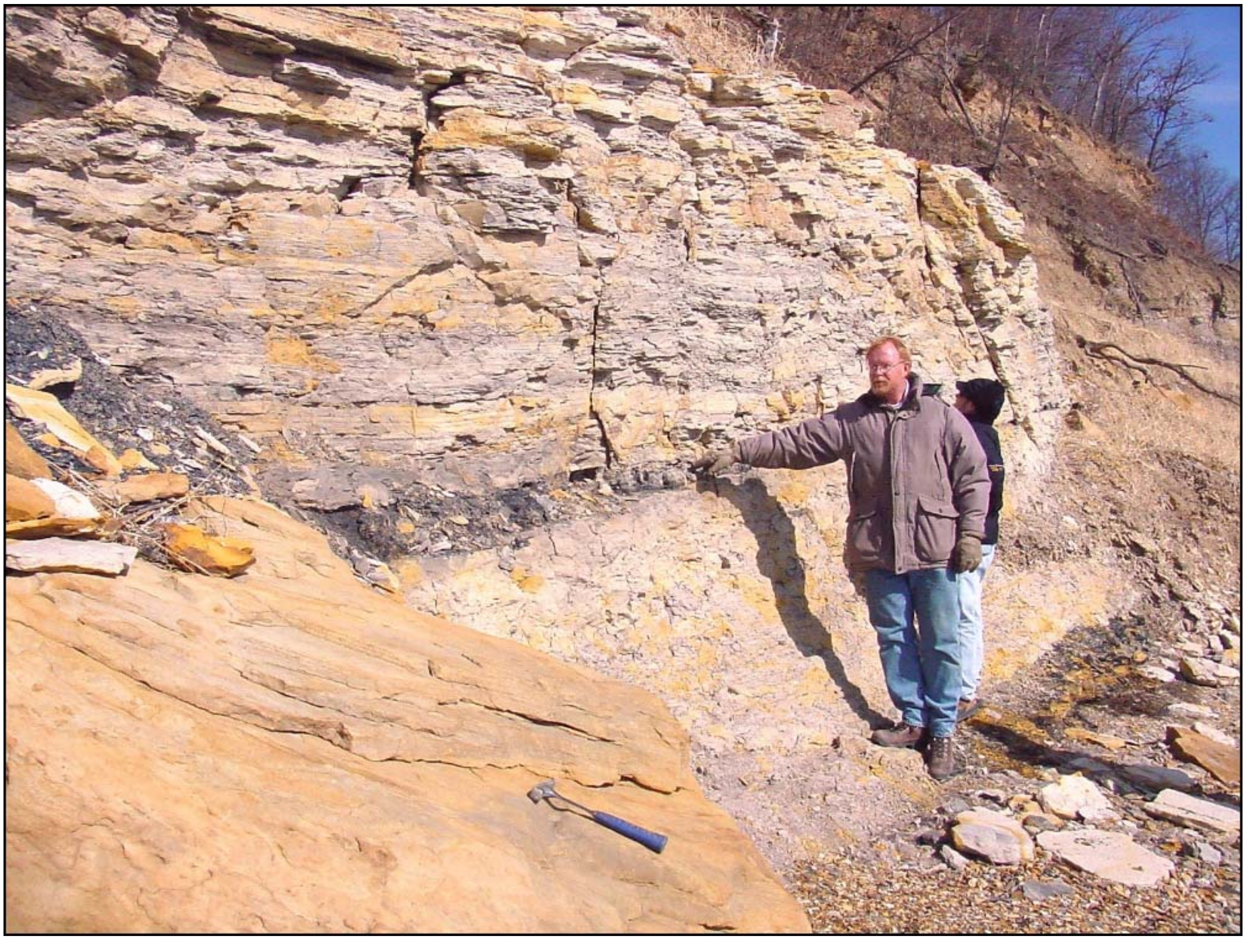


Figure 8. Photograph of center of the exposure at Stop 5. Trip leader John Pope is standing on the lower coal and pointing at the upper coal. The tidal rhythmites are exposed above the upper coal.

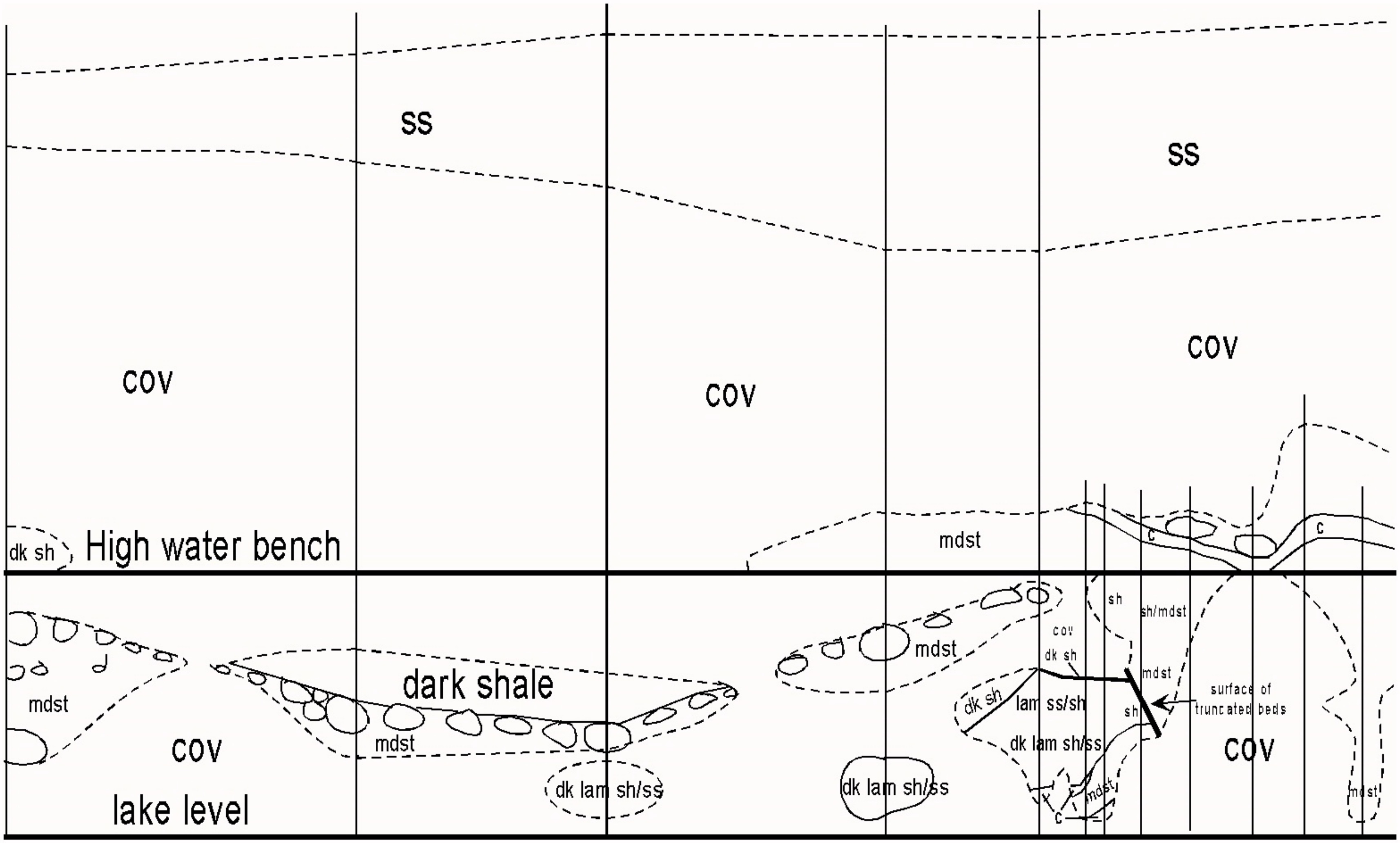
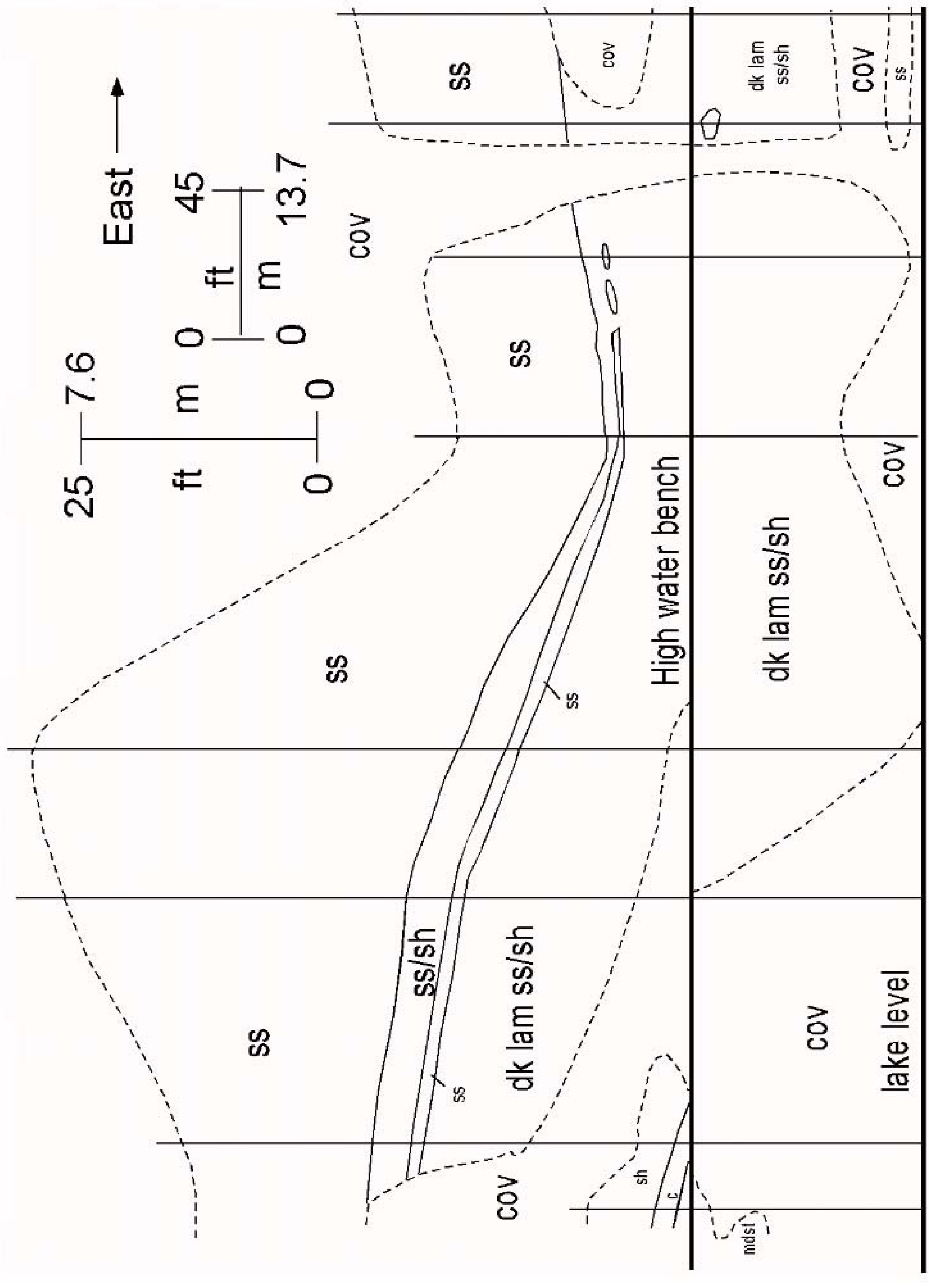


Figure 9. Diagrammatic cross –section of the rocks exposed at stop 5. This page illustrates west end of exposure; facing page illustrates east end of exposure.


East
25
ft
0
7.6
m
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poorly bedded shale that thicken to the east. Above this is an undulose coaly shale to coal that attains a maximum thickness of 30 cm (1 ft.). It contains numerous compressions of 'fern' leaves and *Calamites* and disappears below a covered interval as it dips to the east. In low areas on top of the coaly zone are concretions and shale with an abundant fauna of gastropods, clams including pectin-like species, ostracodes, and spirorbid worm tubes. A covered interval of about 7.6 m (25 ft.) extends upward to a thick (at least 6 m (20 ft.) is exposed) sandstone exhibiting both trough and planar cross-bedding.

The lower part of this section is interpreted to be an incised paleovalley filled during a probable rise in sea-level that flooded the valley. The coals may represent ponding of fresh water during initial sea-level rise. The laminated shale and sandstones that coarsen upward are most likely estuarine fills deposited as a bay-head delta prograded into the estuary. These deposits are probably tidally influenced. Figure 10 shows several features interpreted by Dr. Steve Greb (personal communication, 2002) as evidence of probable tidal deposition. The alternating black and white arrows show alternating thin and thick layers of siltstone and sandstone versus shale. The shales were likely formed as clay drapes when tidal currents slowed and clays dropped out of suspension. The diamond shapes indicate areas where there are couplets of laminae that are vertically thickening and thinning and which could be interpreted as neap-spring deposited layers. The circles indicate areas where bioturbation has possibly disrupted the tidally deposited laminae.

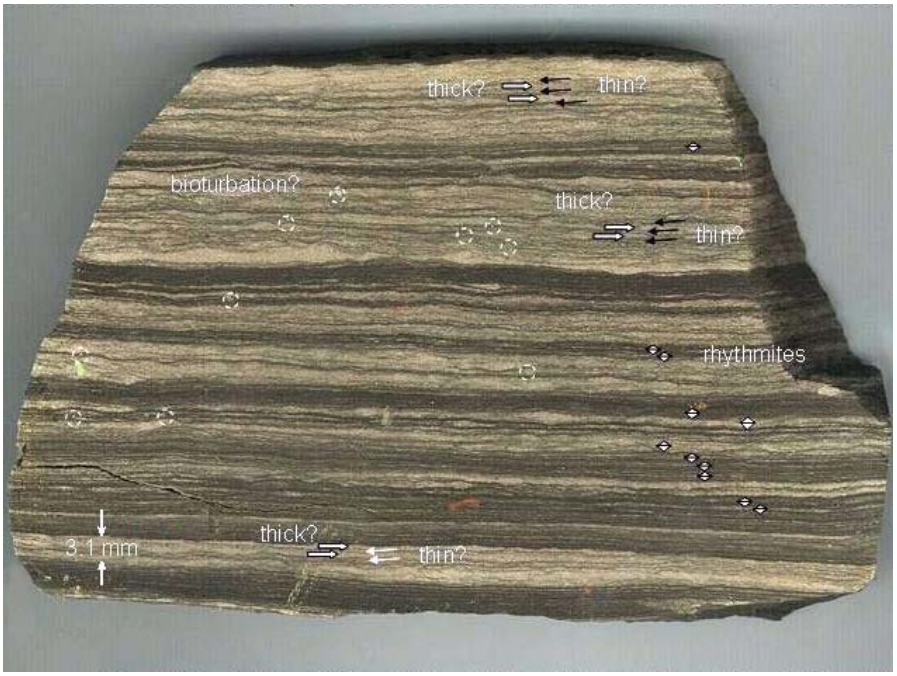

Figure 10. Tidal rhythmite from Stop 5 showing features interpreted as evidence of probable tidal deposition by Dr Steve Greb (personal communication, 2002).

Overall the sandier intervals and the shaly intervals taken together are probably arranged in an annual cycle with the finer laminae forming incomplete records of monthly and neap-spring tides.

When sea-level later fell, paleosols developed on the upper surface of these deposits. The truncation surface is interpreted to be the part of the formation of another large incised paleovalley cut into the previous paleovalley fill, during regression and a low stand of sea-level (Fig. 8F, page 46).

The upper coaly shale and overlying massive sandstone are most likely related to the deposits seen in the eastern part of the outcrop. The fossiliferous zone above the coaly probably represents deposition in brackish water marginal marine conditions.

In the eastern one half of the outcrop (Fig. 11) the deposits seem to be less complex and the extensive exposures allow for better understanding of both vertical and horizontal relationships. In the extreme eastern part the top of a 0.8 m (2.5 ft.) thick cross-bedded sandstone is exposed at lake level. This is overlain by 12 m (40 ft.) of coarsening upward laminated shale and sandstone with abundant carbonized plant debris. These laminated deposits have an apparent dip component to the west.

Figure 11. Photograph of tidal rhythmites overlain by massive bay-head delta sandstones at Stop 5.

To the west, near a ravine that heads near the road at the top of the exposure, they flatten out. Even farther west they exhibit an apparent dip to the east. The upper unit is a thick cross bedded sandstone with irregular intervals of laminated sand and shale in the lower one half.

The eastern part of the outcrop is interpreted to have been deposited during a rise in sea-level that provided accommodation space in another incised valley, forming an estuary. The lower sand may represent aggrading fluvial sediments deposited during initial transgression. The lower sandstone may be underlain by the undulose coaly shale seen above the truncation surface near the center of the outcrop, but this relationship is not readily apparent due to covered parts of the outcrop. The laminated sandstone and shale that coarsen upward into the massive upper sandstone, again is interpreted to be a bay head delta prograding into the estuary. The upper part of the laminated sandstone and shale and the lower part of the upper massive sandstone show probable tidal reworking of the deposits.

Palynological work has not been done on any of the coals at this outcrop. In relation to other outcrops in the area it is inferred to be in the lower Floris and perhaps the upper Kalo formations (per. Comm.. Mary Howes, 2002).

RECOGNITION OF TIDALLY INFLUENCED ESTUARINE DEPOSITS

Pennsylvanian age rivers (similar to those seen at stop 2) have been recognized to incise valleys during regression and low sea-level stand, and later form estuaries during the next transgression (sea level rise) (Archer et al., 1994). Clifton (1982) describes an estuary as a marginal-marine semi-enclosed body of water that is measurably diluted by fluvial discharge [i.e. a drowned river valley]. Sediments found in estuaries can be influenced by a complex combination of tides and currents, waves, river discharge, temperature, precipitation, and many other factors (Clifton, 1982).

According to Archer et al. (1994) estuaries are commonly sites of tidal amplification and tide-mediated deposition. Course sediments are primarily deposited in the narrow upper parts of estuaries where fluvial processes begin to merge with estuarine processes. In the middle of the estuary bottom currents are weak and muds are deposited. Most of the suspended mud is deposited during slack water at the high and low tides. Muddy tidal flats can be well developed in the middle estuary consisting of sand layers deposited during maximum tidal velocities and clay drapes formed during slack water. The modern vertical sequence of facies usually begins with a fluvial sand deposited on an incised surface, followed by sandy and muddy estuarine facies capped by a bay head delta sand.

Kvale et al. (1999) stated that records of daily tidal deposition are an order of magnitude larger than that attainable from large-scale tidal bundle deposits, and are preserved in the form of tidal rythmites. Kvale et al. (1998) described how synodic (new moon to new moon) tides form. Daily high tides are higher when the Earth, Moon, and Sun are aligned (full or new moon) and lower when the Sun and Moon are at right angles to the Earth (1st or 3rd quarter phases). Tides during full or new moon are referred to as spring tides, and tides at quarter phases are referred to as neap tides. The synodic month has a modern period of 29.53 days and contains two neap-spring cycles. Kvale et al. (1999) described how to recognize these features:

Tidal rythmites include structures consisting of: 1) stacked sets of clay–draped ripples that as cosets can be classified as lenticular, wavy, and flaser bedding; and 2) flat laminated siltstone and silty claystone with thin intercalated claystone layers. These layers drape essentially horizontal reactivation surfaces forming the small scale equivalent of large-scale tidal bundles. The tidal influence on the origin of these rhythmites is indicated by the progressive thickening and thinning of individually accreted packages or bundles in response to changing current velocities associated with lunar cycles.

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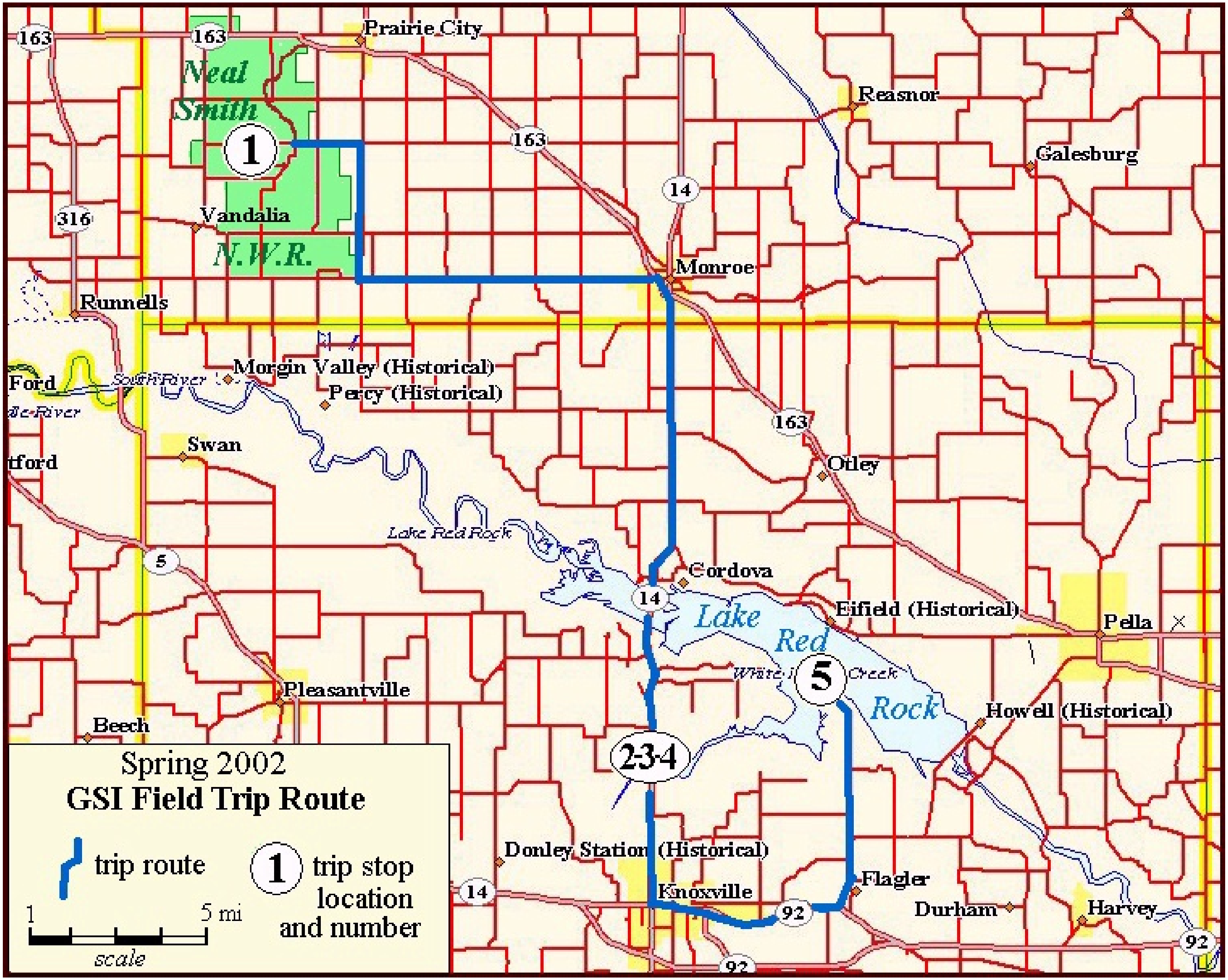
Spring 2002
GSI Field Trip Route
trip route
1 trip stop location and number
1
5 mi
scale
1
2-3-4
5
Neal Smith N.W.R.
Prairie City
Reasnor
Galesburg
Vandalia
Monroe
Runnells
Morgin Valley (Historical)
Percy (Historical)
Ford
South River
Swan
Otley
Lake Red Rock
Cordova
Eifield (Historical)
Pella
White Creek
Howell (Historical)
Pleasantville
Beech
Donley Station (Historical)
Knoxville
Flagler
Durham
Harvey
163
316
14
5
92