WINDOWS INTO MISSISSIPPI'S GEOLOGIC PAST

David T. Dockery III

Illustrations by Katie Lightsey

CIRCULAR 6

MISSISSIPPI DEPARTMENT OF ENVIRONMENTAL QUALITY
OFFICE OF GEOLOGY

S. Cragin Knox
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Jackson, Mississippi

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Cover: A look into the past with something looking back at us. A Triassic dinosaur peering through foliage at Lake, Mississippi, 220 million years ago as drawn by Katie Lightsey.

Illustrations:

Most of the illustrations in this book are by Katie Lightsey, a student at St. Andrew's Episcopal School, Ridgeland, Mississippi. The pictures were drawn while she was in the 5th and 6th grades under the supervision and encouragement of her science teacher John D. Davis.

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WINDOWS INTO MISSISSIPPI'S GEOLOGIC PAST

David T. Dockery III

GEOLOGIC TIME IN PERSPECTIVE

Picture yourself at the Jackson International Airport. The geologic epoch is the Holocene or Recent. Children and adults stare out plate-glass windows as a Boeing 727 races down the runway gaining speed. The long-bodied jet lifts its nose and, with engines roaring, quickly climbs into the sky. The moment delights the onlookers and is a testament to the wonderful technical age in which we live. This event, the takeoff of a 727, was only possible after 1969 when the 727 came into commercial use. Once the 727 is discontinued, it will cease. Thus, airborne 727's characterize a brief span of Earth history.

As the jet banks towards its destination, it passes an old homestead and cemetery. Genealogists and archeologists use such monuments for historic studies. Their builders and occupants knew times before air travel, times of the horse and buggy. What a difference only a hundred years has made. Headstones in the cemetery give birth and death dates for the deceased. Could the late Harold Jones have known Lewis Evans? The dates will tell. Could Mr. Jones have driven a car or flown in a plane? Again, the dates will tell.

Underlying the landscape and vegetation is an even older feature, the soil. This thin layer has supported forests for thousands of years and contains the artifacts and remains of Mississippi's aboriginal population. Artifacts consisting of small arrowheads of the Woodland Period are hundreds of years old. Fluted points of the Early Archaic Period are thousands of years old.

Excavations near the airport cut through the brown loamy soil into a bed of blue-gray clay. Remains of white, chalky seashells are everywhere. A hard object stops the penetration of the backhoe. With care, the operator unearths a log-size vertebra, the remains of the ancient whale *Basilosaurus cetoides.*

The duration of the species *Basilosaurus cetoides* marks the later part of a geologic time known as the Eocene Epoch. This duration is not measured in tens, hundreds, or thousands, but in millions of years. Basilosaurs inhabited a tropical ocean that covered Mississippi between 34 and 40 million years ago. Sediments of this ocean are over 400 feet thick and are formally known as the Yazoo Clay. It is this clay that is responsible for much of Jackson's foundation problems. Could our basilosaur have attacked a dinosaur wading along an ancient shoreline? No, dinosaurs became extinct 65 million years ago at the end of the Cretaceous Period. Basilosaurs and dinosaurs never met. A geologic time scale recognizes eras, periods, and epochs that help us keep Earth's history in perspective.

A geologist among the airport crowd has a special appreciation of the setting. After spectators have left the window and the jet is on its way, the silent, rolling hills of the Jackson Prairie remind him of Eocene times. Times when the hills were rolling waves, the playground of large whales and giant sharks. Or, perhaps Cretaceous times when Jackson was an island volcano, belching fire and brimstone down its forested slopes. These eruptive events made even the fearsome dinosaurs to flee and flying pterodactyls to seek safe haven. To keep all of these ancient times in perspective, their duration in millions of years (Ma) is given in the geologic time chart on the facing page.

Division of Earth history into eras, periods, and epochs is based on the occurrence of fossil remains of ancient creatures. The beginning of the Paleozoic Era is marked by the first appearance of segmented animals with three axial lobes, called trilobites. The end of this era is marked by their extinction. The Mesozoic Era is characterized by the appearance of dinosaurs, and its end is marked by their extinction. The Cenozoic Era in which we live is marked by a diversity of mammals. The last period of this era, the Quaternary, is marked by the ice age and the appearance of man.

ERA	PERIOD	EPOCH	DURATION IN MA
Cenozoic			
	Quaternary		
		Holocene	0 - 0.01
		Pleistocene	0.01 - 1.7
	Tertiary		
		Pliocene	1.7 - 5.3
		Miocene	5.3 - 23.8
		Oligocene	23.8 - 33.7
		Eocene	33.7 - 54.5
		Paleocene	54.5 - 65
Mesozoic			
	Cretaceous		65 - 144.2
	Jurassic		144.2 - 205.7
	Triassic		205.7 - 245
Paleozoic			
	Permian		245 - 290
	Pennsylvanian		290 - 323
	Mississippian		323 - 363
	Devonian		363 - 409
	Silurian		409 - 439
	Ordovician		439 - 510
	Cambrian		510 - 570

USE OF "WINDOWS" AS AN ACTIVITY BOOK

"Windows" is a collection of short stories on Mississippi's geologic history written for classroom readings in grades K-5 and perhaps middle school. However, these stories should be of interest to older students and adults as well. Each story concerns a period or epoch of geologic time and is preceded by a description of the geologic facts upon which the story is based. Illustrations accompanying these stories were done by Katie Lightsey during her 5th and 6th grade years. These may be photocopied and passed out to the class to be colored in pencil, crayon, water color, or other media. Please send any artwork you find exceptional to David Dockery, Mississippi Office of Geology, P.O. Box 20307, Jackson, MS 39289-1307 (artwork will not be returned). Selected artwork will be collected for a possible color edition of this book in the future with credits given to the young artists.

Figure 1 is a geologic map of Mississippi as digitized and printed by David Thompson of the Office of Geology. It shows the surface exposures (called outcrop belts) of formations and groups (a group contains two or more formations). The legend shows the oldest formations of the Mississippian and Devonian periods at the bottom and the youngest at the top. On the map, the oldest formations are in the northeast corner and the youngest along the coast and Mississippi River flood plain (locally called the Delta). As an activity, students can color the legend, giving a different color to each box, and then match that color to outcrop belts on the map. Colored pencils are best for this exercise as they can follow the fine detail of the map. A faster exercise is to select and color just one formation or group to highlight its areal distribution. The Midway Group of the early Tertiary Period is recommended for this purpose.

Figures 2 and 3 show an oblique block diagram of the state geologic map sliced along the 35th, 34th, 33rd, and 32nd parallels. These figures show the structure of geologic strata below the surface, which dip to the west toward the axis of a structural trough called the Mississippi Embayment and then rise toward the surface in neighboring Arkansas and Louisiana. The axis of this embayment dips to the south as can be seen by comparing the base of the Midway Group at different parallels. At 35° latitude, the base of the Midway Group along the axis of the Mississippi Embayment dips to about 2,500 feet; at 34°, it dips to about 3,500 feet; at 33°, it dips to about 4,300 feet; and at 32°, it dips to about 7,800 feet. Color the Midway Group on the oblique surface geologic map and then in the four cross sections along the parallels.

Figure 4 is a structural features map of Mississippi. The heavy line labeled A-A' connects oil or test wells in eastern Mississippi. The vertical distribution of strata along this cross section is shown in Figure 5. This cross section extends to a greater depth (33,000 feet) than those in figures 2 and 3 (13,000 feet along the 32nd parallel).

Prominent structures shown in Figure 4 include the buried roots of the Appalachian (eastern Mississippi) and Ouachita (western and central Mississippi) mountain ranges. North of these buried ranges is the Black Warrior Basin. Running east-west near the southern limit of the combined Appalachian and Ouachita belts (also called the Central Mississippi Ridge) is the Pickens Gilbertown Fault System. It is near or on this fault zone in Clarke County that some 12 earthquakes have occurred in the last 20 years. The most recent on March 25, 1996, was captured on Katie Underwood's 9th-grade science fair project, a homemade seismograph. Her record of this earthquake (shown in Figure 6) made the newspaper and appeared on local television newscasts, making Katie an instant celebrity.

South of the Pickens-Gilbertown Fault

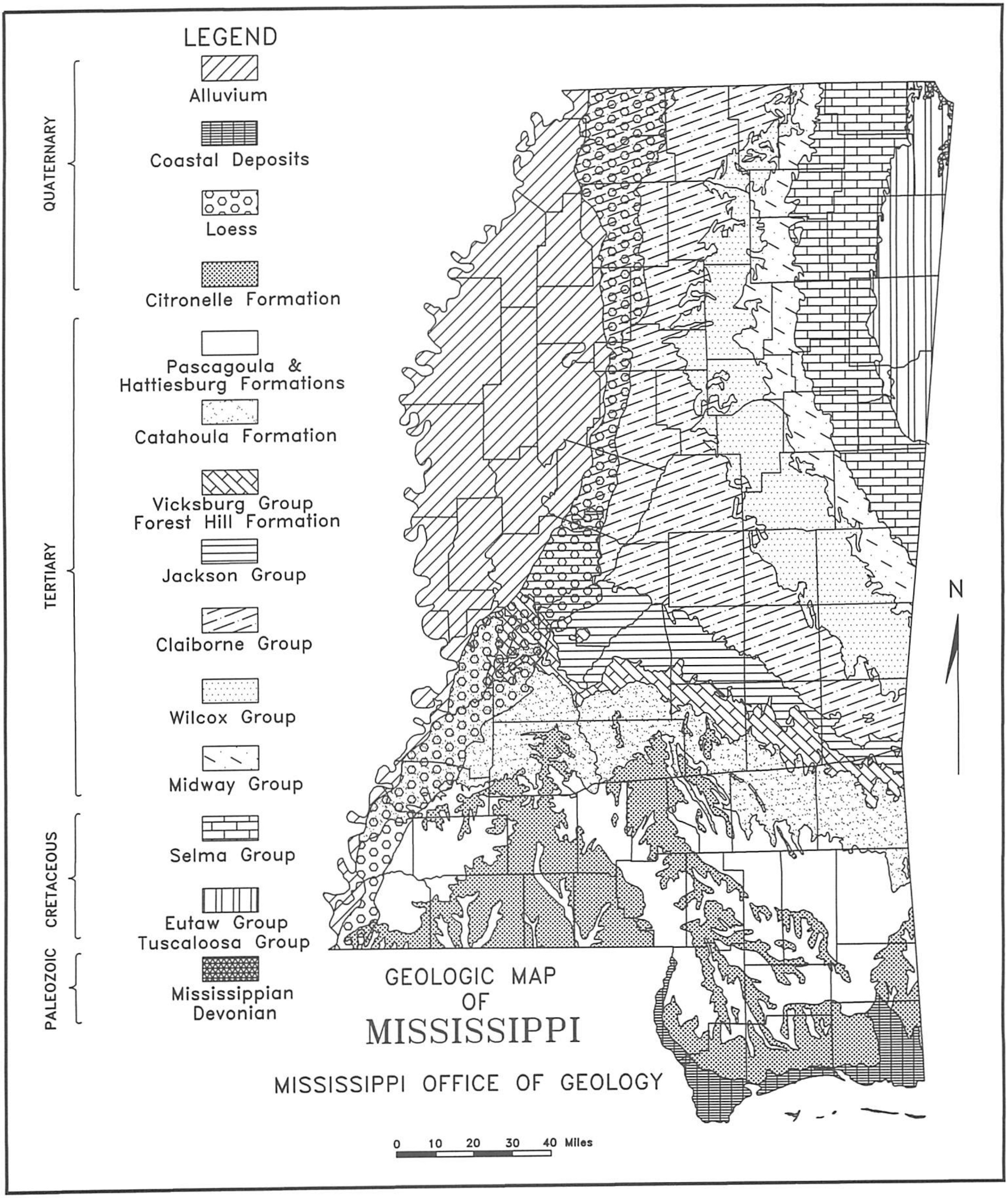
System is the Mississippi Salt Basin. Buried deep within this basin is a thick sequence of the Louann Salt of Jurassic age. Because salt is lighter than other sediment and not as compressible, its buoyancy produces diapiric structures that push their way toward the surface. We call these structures salt domes, and some 49 are indicated on Figure 4 by small circles. Color these circles green. You will note that the cross section A-A' crosses one in Perry County. Now find the "Jurassic Salt (JS)" in Figure 5 and color it green. You will see how the Richton Salt Dome in Perry County punches through some 20,000 feet of sedimentary rock.

Bordering the southern edge of the Mississippi Salt Basin are the Wiggins Anticline and Hancock Ridge. Collectively these structures are part of the Wiggins Uplift. At the core of the uplift, as shown in Figure 5, is a chunk of Paleozoic-age granite ripped away from the Appalachian belt when South America and Africa split away from North America in the Triassic Period. Earlier, in the Permian Period, this block of granite was at the core of a mountain range.

In west-central Mississippi, the Mississippi Salt Basin is interrupted by two buried volcanic terranes, the Jackson Dome and the Sharkey Platform. Both structures supported active volcanoes in the Late Cretaceous Period. The axis of the Mississippi Embayment runs between these structures. This axis can be seen in the basal dip of the Midway Group in the cross section along the 33rd parallel in Figure 3. However, the Midway Group shows a double trough along the 32nd parallel, the hump in the middle being an extension of the Jackson Dome.

The following accounts are imaginative recreations of days in Mississippi's geologic past. They are based on rocks and sediments and the remains of living things (fossils) found in the rock record. From these we can infer the ancient terrain, geologic processes, and the plant and animal life. Taking our journey through time, we will begin with the older geologic localities that offer us a window into the past and continue through the younger. These localities are plotted and numbered from oldest to youngest in Figure 7. After reading a story, the students may want to find the corresponding geologic formation in the stratigraphic columns of Appendix 1. They may use the geologic systems column on the left and the numerical time scale column in the middle of these charts to locate the formation.

Figure 1. Geologic map of Mississippi as digitized and printed by David E. Thompson of the Mississippi Office of Geology. Color the Midway Group in the legend and find the outcrop belt on the map with the same pattern and color it the same color; then, if time allows, color the remaining map in like manner, being careful to match colors with the legend.


LEGEND
QUATERNARY
Alluvium
Coastal Deposits
Loess
Citronelle Formation
TERTIARY
Pascagoula & Hattiesburg Formations
Catahoula Formation
Vicksburg Group Forest Hill Formation
Jackson Group
Claiborne Group
Wilcox Group
Midway Group
CRETACEOUS
Selma Group
Eutaw Group Tuscaloosa Group
PALEOZOIC
Mississippian Devonian
N
GEOLOGIC MAP OF MISSISSIPPI
MISSISSIPPI OFFICE OF GEOLOGY
0 10 20 30 40 Miles

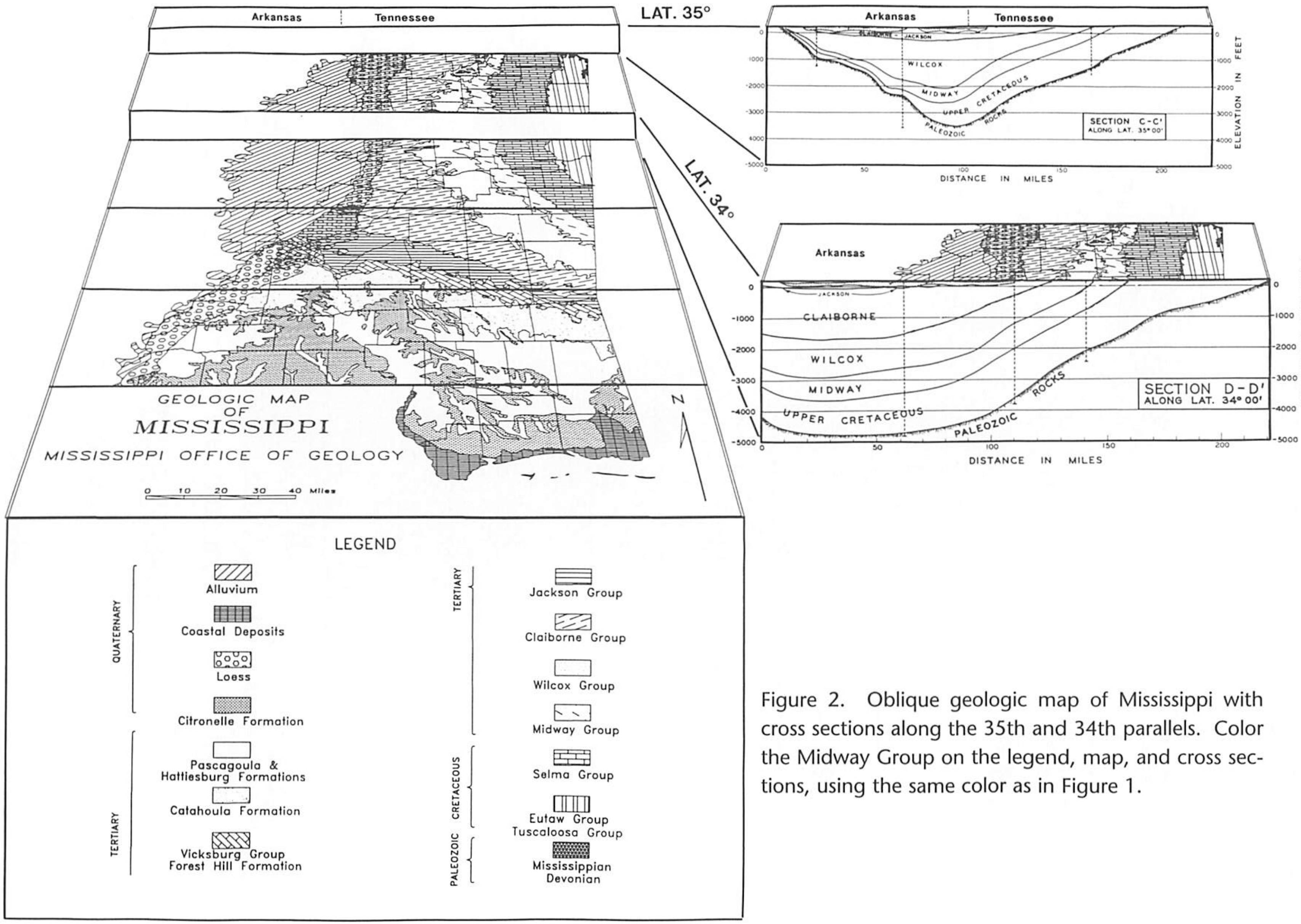


Figure 2. Oblique geologic map of Mississippi with cross sections along the 35th and 34th parallels. Color the Midway Group on the legend, map, and cross sections, using the same color as in Figure 1.

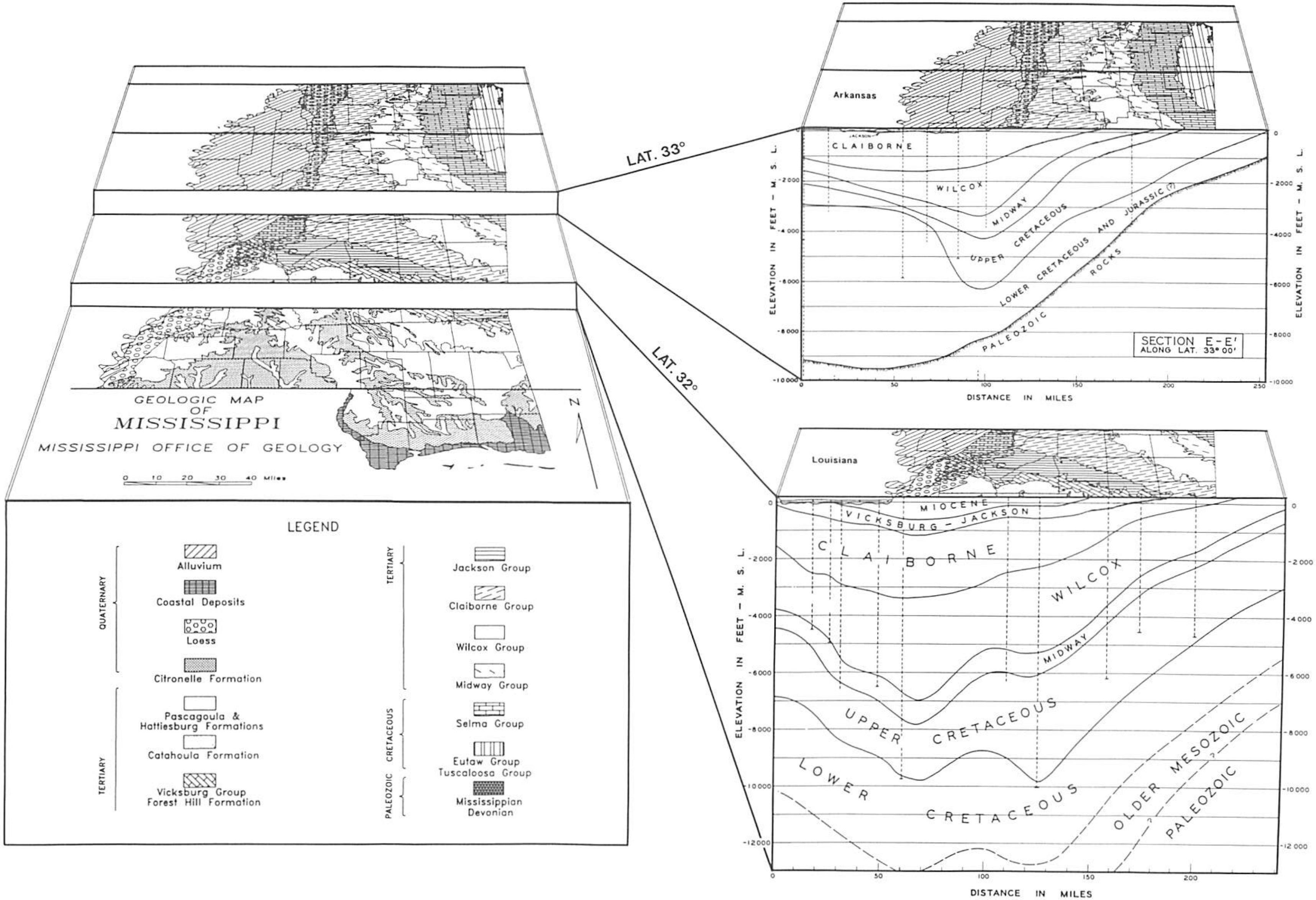


Figure 3. Oblique geologic map of Mississippi with cross sections along the 33rd and 32nd parallels. Color the Midway Group on the legend, map, and cross sections, using the same color as before.

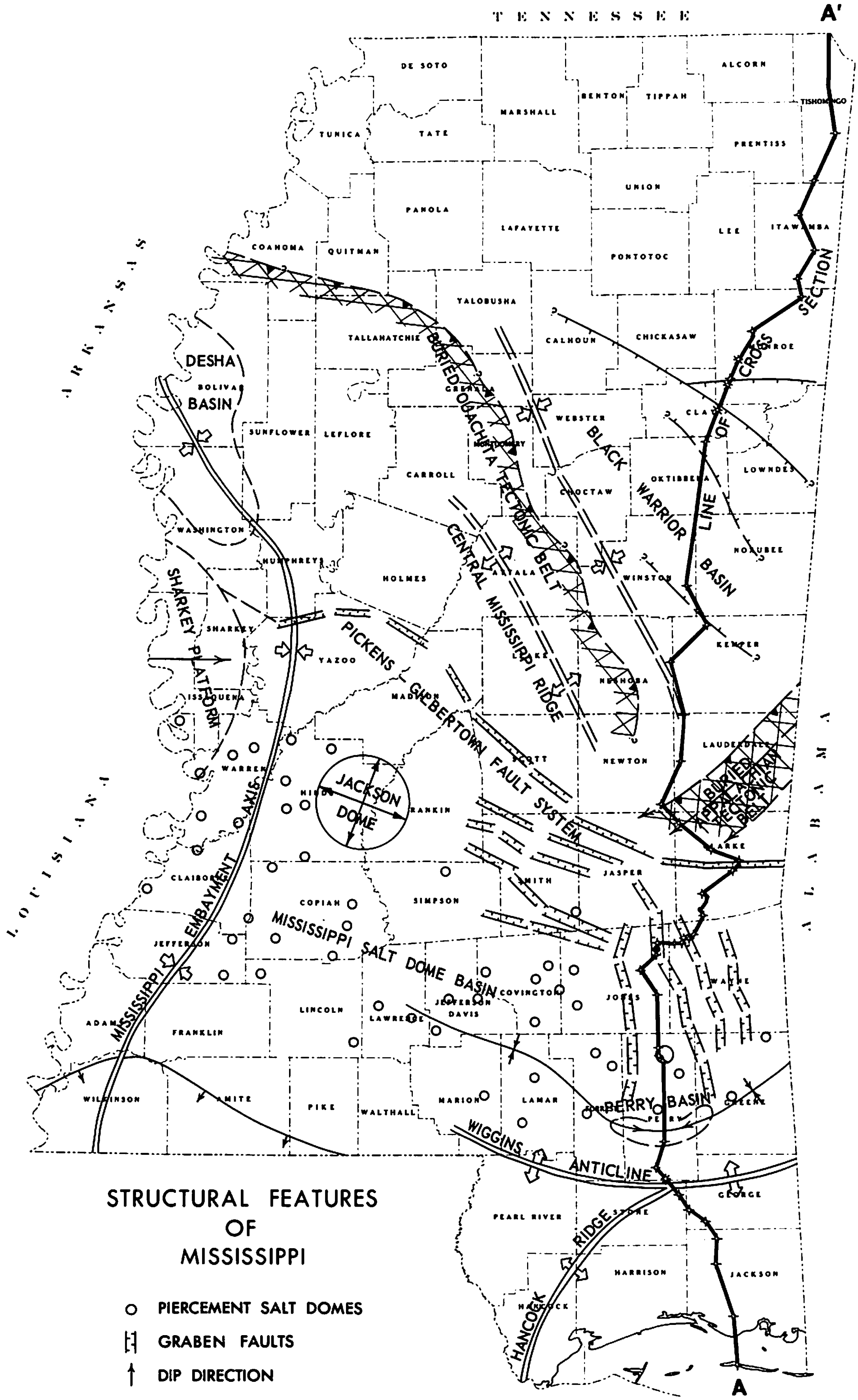


Figure 4. Structural features map of Mississippi from Williams (1969). Color the piercement salt domes (shown as circles) of the Mississippi Salt Basin green.

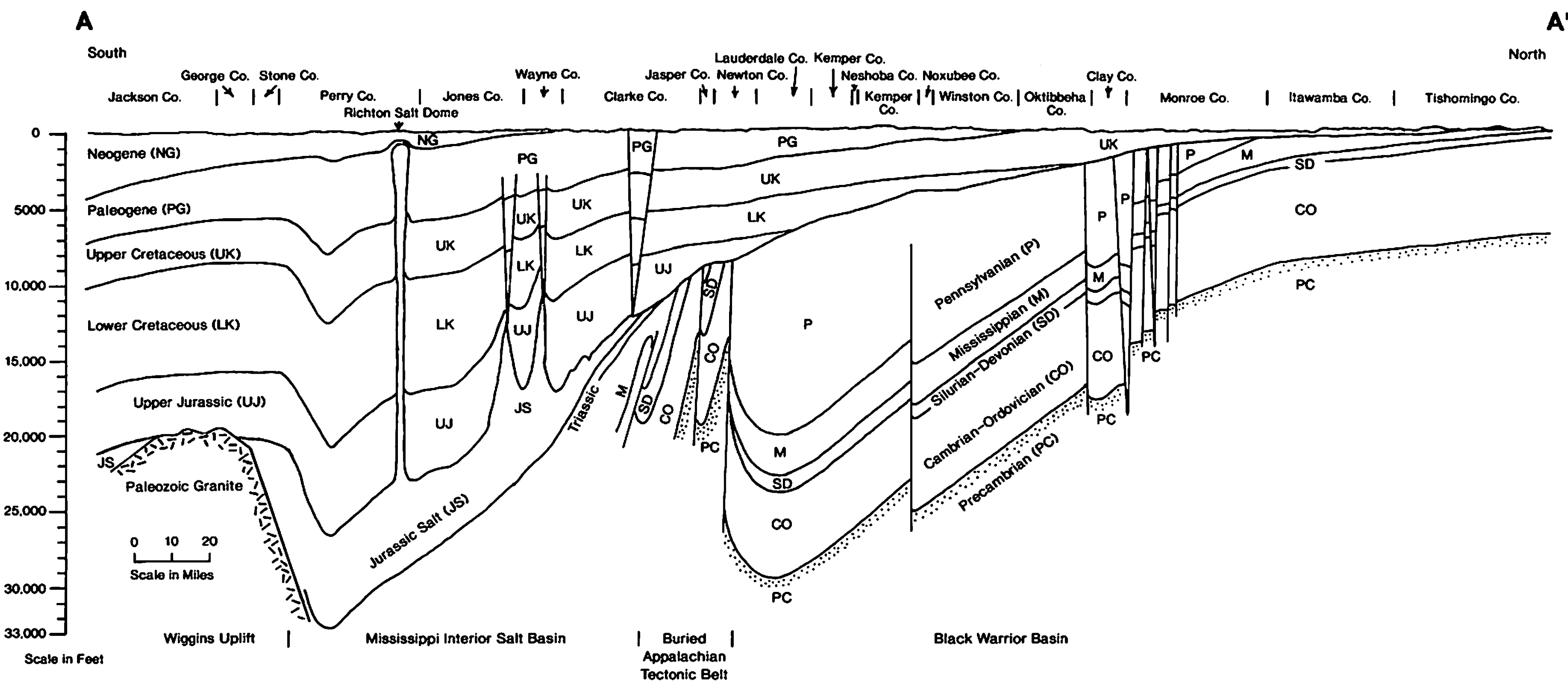


Figure 5. North-south Cross Section A-A′ from the Mississippi-Tennessee State Line to Horn Island in the Gulf of Mexico, modified from Williams (1969). Color the Jurassic Salt green to better see the Richton Salt Dome.

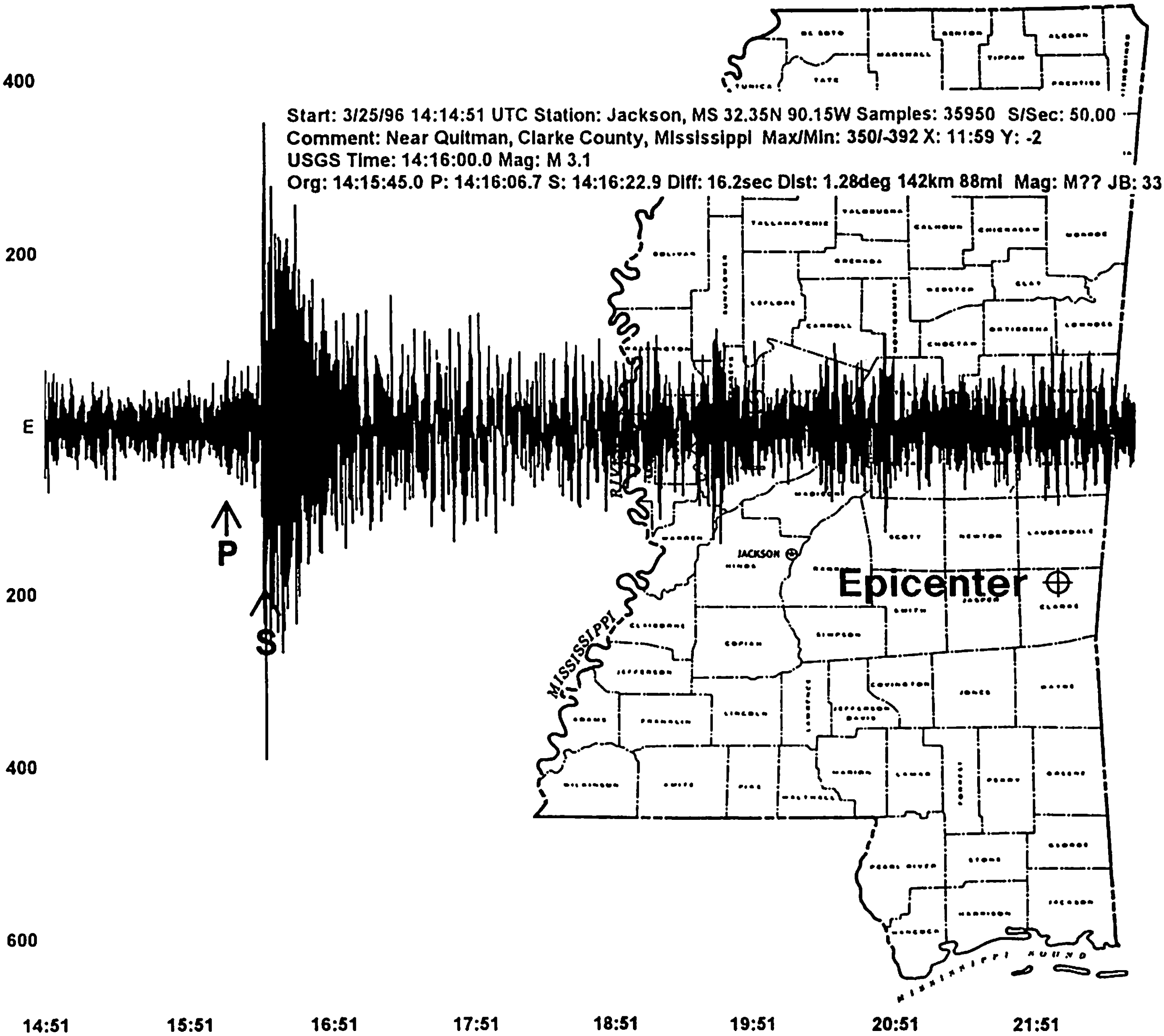


Figure 6. Seismic record and location of the March 25, 1996, Quitman earthquake measured by Katie Underwood's 9th-grade science fair project, a homemade seismograph.

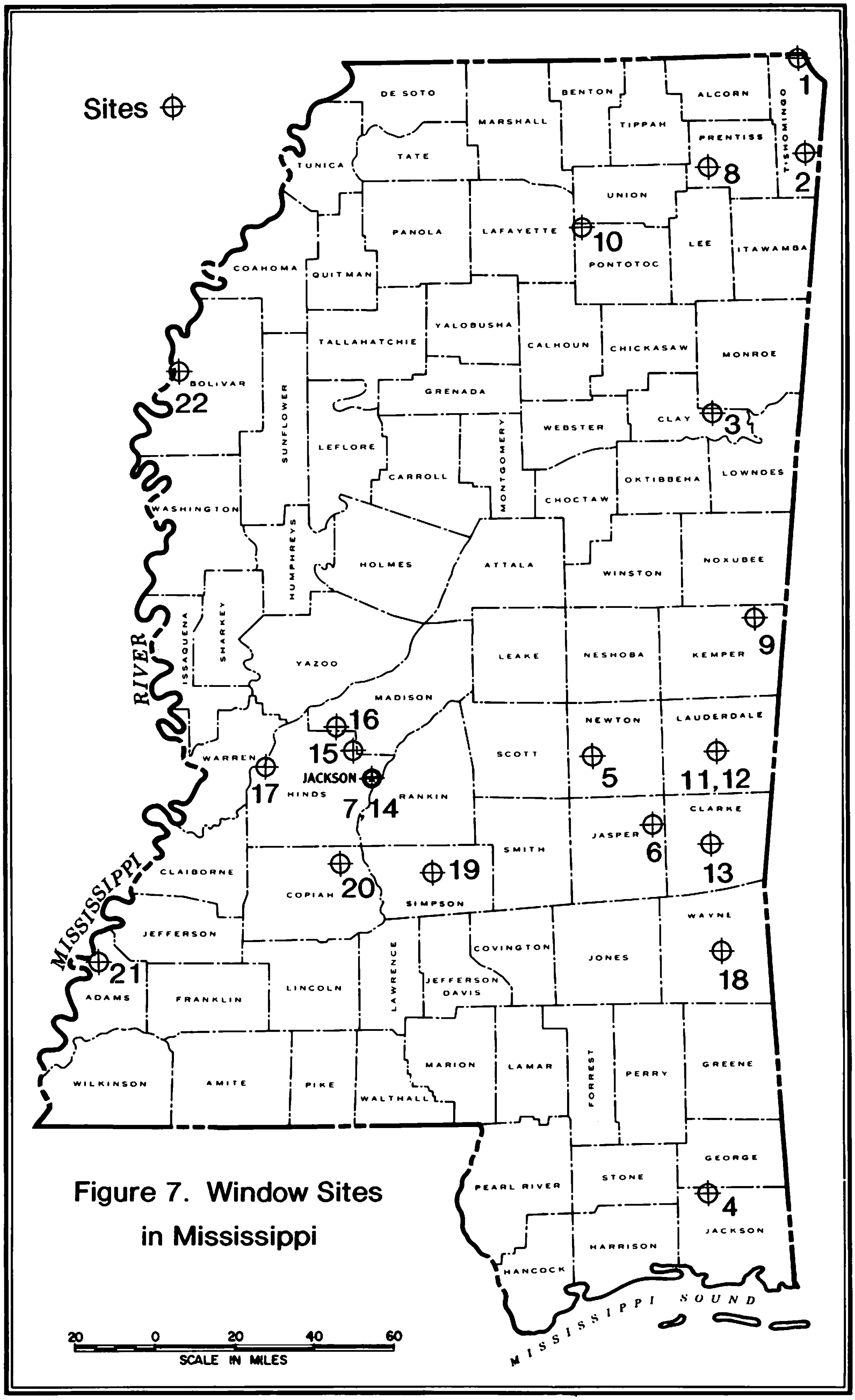


Figure 7. Window Sites in Mississippi

SITE 1: WINDOW INTO THE DEVONIAN

Time of Silica-Rich Tropical Oceans and Armored Fish

Devonian Site

Today the sediments of the ancient Devonian sea are exposed in the rocky core of a small anticline on the north side of a remote island in Pickwick Lake. To reach them we put in our boat at J. P. Coleman State Park in Tishomingo County in the northeastern corner of the state. Here hard rocks of the Fort Payne Chert border the landing at water's edge. These rocks are of Mississippian age. The Devonian rocks we seek lie below. They are the oldest rocks exposed in the state. Based on fossils and radiometric ages they are placed in the Helderbergian Stage of the Lower Devonian at 400 million years old. Thick beds of Devonian cherts in the subsurface of northern Mississippi indicate that the state was covered by a silica-rich ocean at that time.

Leaving the docks of J. P. Coleman State Park, we take our boat north along the western shore of Pickwick Lake's Indian Creek embayment. We continue north along the lake's main channel. Here the rocky hills rise steeply above the water. After some travel we pass a cove named Cooper Hollow. It is a picturesque place. We see a large sailboat anchored opposite a forty-foot waterfall that spills over layers of hard rock. All of this rock is Fort Payne Chert. Though the rocks of the waterfall are older (lower within the formation) than those at the park landing, they are still younger than our Devonian objective.

Our course continues up the lake and into a western embayment until we come to an island known as Island Hill. Here the Fort Payne Chert and underlying Chattanooga Shale arch upward to expose Mississippi's oldest rocks, the fossiliferous cherts of the Devonian Ross Formation. This locality is unique in that it is the only site in Mississippi where a fossil collector has a good chance of finding trilobites. Large specimens of *Huntonia* and medium-sized *Paciphacops* are moderately common here. They are present on bedding planes and may be found in blocks of chert pried up from the bedrock or in the chert shingles that litter the shore and are present just below water level. Also present are an abundance of brachiopods, corals, and bryozoans. The compound eyes of trilobites peering from the Ross chert are in full view of a marina on the opposite shore. They bring to mind a poem of 19th century paleontologist Timothy A. Conrad:

> The race of man shall perish, but the eyes
> Of trilobites eternal be in stone,
> And seem to stare about in mild surprise
> At changes greater than they have yet known.

Trilobites characterize the Cambrian, Ordovician, Silurian, and Devonian periods. They were diverse and common in the Early Devonian, but a series of extinctions reduced them to a minor element of later Mississippian, Pennsylvanian, and Permian faunas.

A Day in the Early Devonian of Mississippi:

Pickwick Lake 400 Million Years Ago

To experience a day in the Early Devonian of Mississippi a time traveler would need scuba gear as the whole state was most likely under water. The Ross Sea in northeastern Mississippi was shallow and contained a diverse invertebrate assemblage. Swaying in its currents were the tentacle-like arms of crinoids atop long flexible stalks. The bottom would have been littered with the dead and living shells of brachiopods.

A diver in these waters would see trilobites and other arthropods scurry for cover as his shadow traversed the bottom. Trilobites would dig into the mud or perhaps hide among the corals and the fronds of fenestrate bryozoans. Small, armored, jawless fish called ostracoderms would also seek shelter on the bottom. Swimming above the bottom are small sharks and armored fish with jaws called placoderms. A person swimming this sea would be the largest and most fearsome creature around—unless a large placoderm arthrodire appeared. This fish had a bony shield covering the head and fang-like bony teeth. The largest arthrodires, *Dunkleosteus* and *Gorgonichthys*, inhabited the waters of North America and grew to be 30 feet long. They were perhaps the largest predators of their time.

The previously described ecosystem is based in part on that given by Greb et al. (1993, see figure 35) for the Devonian section on the Falls of the Ohio at Louisville, Kentucky.

Figure 8. A day in the Early Devonian of Mississippi. Pickwick Lake 400 million years ago by Katie Lightsey, St. Andrew's Middle School 5th grade.

SITE 2: WINDOW INTO THE MISSISSIPPIAN

At Last, a Sandy Beach and Some Land

Mississippian Site

The Mississippian Period is not a namesake of the State but was named for exposures in the upper Mississippi River Valley. Just the same, it is appropriate that at least some strata of this age are exposed in Mississippi. These strata show a shallowing of the ocean toward the top of the section. It is at the top, in the Hartselle Sandstone, that we select a good place to look back on the state's ancient past. Here, perhaps, we have the first opportunity during that period to put our feet on dry land and stay within the boundaries of the present state.

To reach our Mississippian site we travel to Tishomingo State Park, in Tishomingo County, Mississippi. As we enter the park, we note the large rectangular sandstone boulders in the bed of a stream. Part of this stream flows across the park entrance, and we are obliged to splash through it in our vehicle. The park's stately buildings are constructed of this native rock. This rock is the Hartselle Sandstone, a 330 million-year-old sandstone in the Chesterian Series of the Mississippian System. The Mississippian System refers to present-day rock strata, while Mississippian Period refers to a duration of geologic time.

The park ranger unlocks the cable to a gravel side road leaving the park. We take this road to a badly gullied dirt road that leads to an old sandstone quarry. The floor of the quarry is flat, with intersecting rectangular joints. On it are the sinuous trails of ancient marine creatures. In a big block of sandstone nearby is the ancient log of a giant scale tree. The blocky quarry wall is a light brown with some shades of pink and purple. We can see why it was once prized as a building stone.

The mix of fossil trees and marine organisms found in the quarry indicates an ancient shoreline—just the setting we want for our visit to the Mississippian Period.

A Day in the Mississippian of Mississippi:

Tishomingo State Park 330 Million Years Ago

Swash from the surf rises and falls at our feet as we walk along a sand beach for which we can see no end. Shells stranded along the high tide mark are different than those we are accustomed to today. They are disarticulated (separated pairs) valves that are lightweight and translucent. Some have broad hinge lines with ribs radiating from a central beak. These are the spirifer brachiopods. Others have shorter hinge lines with delicate spines extending from their radial ribs. These are the productid brachiopods. Brachiopod shells greatly outnumber the few clam and snail shells we find. The latter are characteristic of modern beaches.

Other items we find washed up on the beach resemble a segmented flower with tentacles rather than petals. These tentacles are lined with even finer tentacles. Together they form quite a tangle at the end of a long segmented stem. At the stem's opposite end is what appears to be a system of roots. These items are crinoids (sometimes called sea lilies) that have been dislodged from the sea floor and stranded on the beach to die. Other similar forms have stalks with ovate heads having a five rayed, petal-like structure opposite the stalk. These are blastoids, a relative of the crinoid. The beach is littered with their bits and pieces.

A log stranded on the beach is different than any we've seen. Its straight, non-tapering trunk is like that of a modern palm tree. The surface has a regular pattern of diamond-shaped scars where leaves once grew. This strange log calls another difference to mind; there are no grasses anchoring the shifting sand of the beach. A few ferns take their place.

Looking away from the ocean, we see the tops of trees beyond the sand dunes in a swamp on the opposite side. These, like the stranded log, are scale trees of the genus *Lepidodendron*. Their trunks extend to great heights before the first branches appear as they compete with each other for sunlight. A gust of wind stirs the treetops and sends a yellow cloud our way. Some sneeze as the musky-smelling cloud arrives. It is full of microscopic spores.

Flying among the trees are the largest dragonflies we've ever seen. Their wingspan reaches three feet. They have aerial superiority as there are no birds or other winged vertebrates to challenge them. Our walk is interrupted as one buzzes us overhead. While it means no harm, its presence is intimidating. We take leave of the beach and encounter the first land animal, a large labyrinthodont. This alligator-like amphibian greets us with open jaws studded with sharp teeth. It's the largest predator on the beach, but fortunately it isn't very fast.

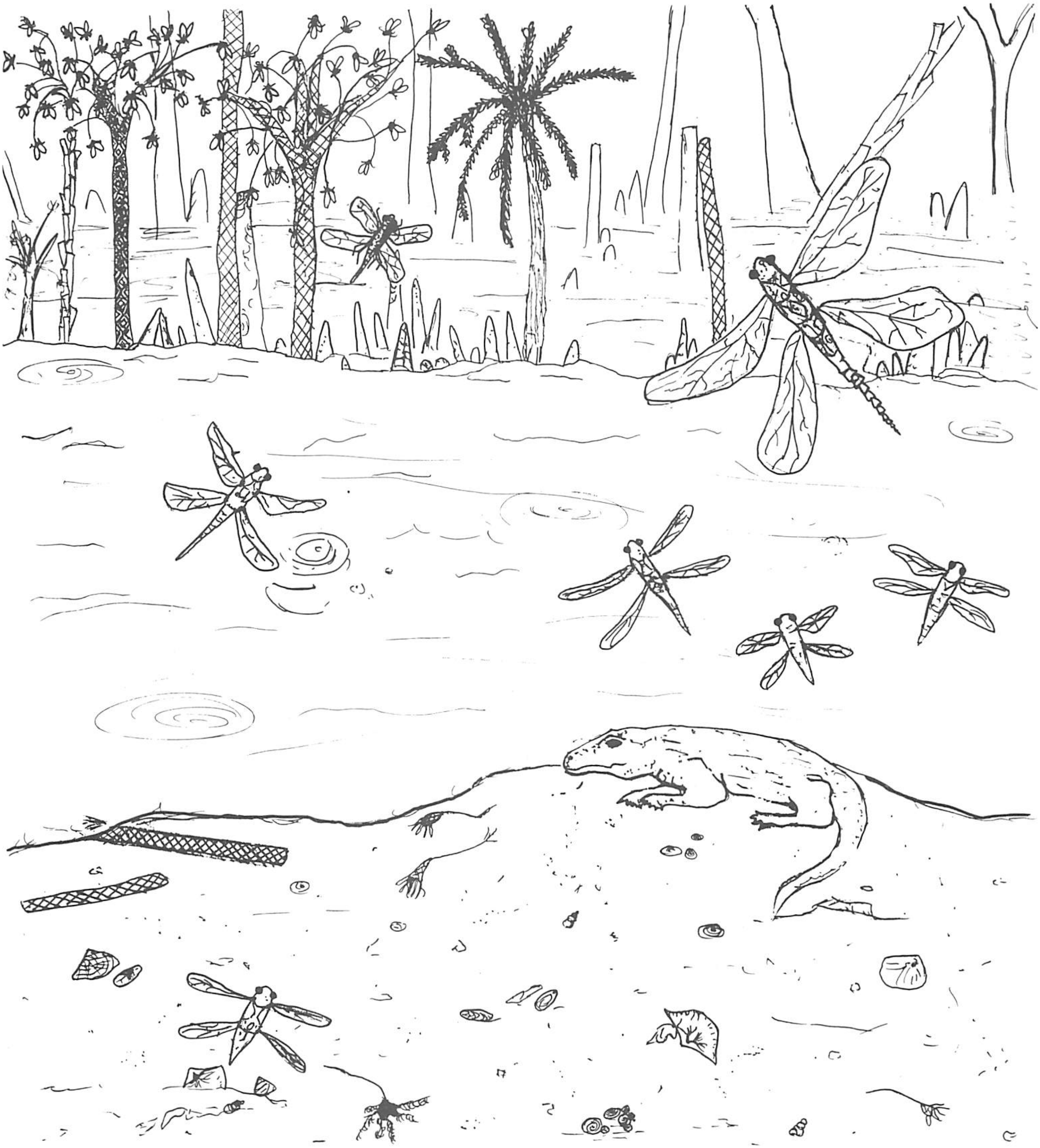


Figure 9. A day in the Mississippian of Mississippi. Tishomingo State Park 330 million years ago by Katie Lightsey, St. Andrew's Middle School 5th grade.

SITE 3: WINDOW INTO THE PENNSYLVANIAN

A Time of Fern Trees, Giant Amphibians, Swamps, and Mountains

Pennsylvanian Site

No rocks of Pennsylvanian age are exposed at the surface in Mississippi. They were stripped away by erosion in the Late Cretaceous Period, exposing the Mississippian rocks below. Overlying this erosional unconformity are thick gravels of the Tuscaloosa Formation. However, thick deposits of the Pennsylvanian Pottsville Formation were preserved in the Black Warrior Basin of northern Mississippi and are present below Tuscaloosa gravels. The Pottsville Formation is a sequence of sedimentary rocks deposited by ancient rivers and deltas that reaches thicknesses of 5,900 to 9,180 feet in Oktibbeha County, Mississippi (Thomas and Osborne, 1987).

Our Pennsylvanian site is the Plantation Petroleum #1 Allen core hole in Section 27, T. 16 S., R. 6 E., in Clay County, Mississippi, just north of the West Point city limits. Here the 315 million-year-old rocks of the Pottsville Formation are buried below 1,820 feet of Cretaceous sediments. At 2,270 to 2,507 feet below the surface we encounter the first coal seams, which are called the West Point Group. According to Ericksen (1992), these coals were deposited in the fresh water of a deltaic plain. This depositional environment was similar to what we find today in the swamps of southern Louisiana, except the plants and animals were different. These swamps may have contributed to an increased oxygen level in the Pennsylvanian as indicated by the period's giant insects (Graham et al., 1995).

One interesting note before we visit the West Point coals. The thick sediments of the Pottsville Formation were derived from a southwestern source, the rising Ouachita and Appalachian orogenic belts. These young mountains crossed central Mississippi from Lauderdale County on the southeast to Coahoma County on the northwest. They were pushed up as North America collided with Europe, Africa, and South America.

A Day in the Pennsylvanian Coal Swamps of Mississippi:

West Point 315 Million Years Ago

A mist rises from the stagnant water as our southern Louisiana guide poles our pirogue between the large trunks of giant scale trees. Our Cajun guide feels quite at home in this swamp and has plenty of energy due to the increased Pennsylvanian oxygen level. The water below is murky with tannin from decaying plant debris. Overhead, giant insects fill the air, with the larger ones preying upon the smaller ones. Spiders crouch on the trunk of a dead tree. They scatter as a 6-inch cockroach runs by. A lungfish splashes nearby as it surfaces for a gulp of fresh air.

Looking up through a parting in the mist, we see the height of the towering scale trees. Their trunks appear as stately columns supporting leafy foliage only at the tops. Above is the blue sky with puffy cumulus clouds. The swamp is immense, and we can see no end to it. Pairs of eyes watch from fallen logs. They belong to alligator-sized amphibians with sharp teeth. Two of these beasts hit the water and swim toward our pirogue.

We are prepared for this moment. Our guide has a spray gun with a nonlethal, but noxious, solvent that will irritate the amphibians' eyes and delicate skin. He sprays both with a liberal dose. The solvent works instantly, and the 500-pound animals thrash about violently in the water. Their commotion attracts other amphibians that swim our way. Our guide sprays some but others are coming at us from below the water's surface.

Well versed in swamp life, our Cajun friend is unalarmed by the dangerous creatures below. He calmly pops the lid on a plastic bucket of stale cheese. The stench is nauseating. He then throws the bucket overboard, and the amphibians are drawn to it like a magnet. The bucket is instantly shredded as the animals fight over the rancid prize. We escape unnoticed.

Figure 10. A day in the Pennsylvanian coal swamps of Mississippi. West Point 315 million years ago by Katie Lightsey, St. Andrew's Middle School 5th grade.

SITE 4: WINDOW INTO THE PERMIAN

A Time of Continental Collisions, High Mountain Ranges, Deserts, and Large Reptiles

Permian Site

The only Permian rocks known from Mississippi are metamorphic rocks from the core of the Wiggins Uplift in southern Mississippi. These rocks were encountered southeast of the town of Vestry when Champlin Oil Company drilled a wildcat well, the #1 International Paper Co., over a structural high on the Wiggins Uplift in Jackson County. At 18,354 feet, rather than finding oil-bearing Jurassic limestone as hoped for, the cuttings contained quartz grains, feldspar, and hornblende. An eleven-foot core was taken from 18,678 to 18,689 feet. To the chagrin of Champlin geologists and to the delight of academia, the core barrel returned with metamorphic rock from the uplift's basement. Radiometric analysis of a sample from 18,678-18,679 feet gave an age of 282 ± 14 million years. This age is similar to the 272 million-year age of basement rock from the nearby Amoco No. 1 Cumbest well (Harrelson and Jennings, 1990).

The radiometric ages found in the Wiggins basement are believed to have been reset in the Permian due to metamorphism and recrystallization. This metamorphism was associated with mountain building as North America collided with Europe, Africa and South America, forming one supercontinent. The parent basement rock was probably a much older granite associated with the Appalachian trend. This basement complex was torn from the Appalachians during rifting in the Late Triassic and stranded beneath southern Mississippi as Africa and South America moved south. Thus, in the Permian, the basement rock under Vestry may have been as far north as Jasper County.

A Day in the Permian Mountains of Mississippi:

Vestry 282 Million Years Ago

In my childhood days as a proud Mississippi native, I was disappointed that the state lacked the prominence of a high peak, some lofty monument that could be seen for miles around. I could only imagine the mist-covered slopes of such a peak in the forms of distant clouds. Had I been born 282 million years earlier, I would have had my wish. However, it would be granted at a tremendous cost—the loss of things (e.g. the Gulf of Mexico) that make the state the lush green place it is today.

Vestry, Mississippi, seems an unlikely place for the center of a mountain chain. It is located on the flat flood plain of Red Creek and is only fifty feet above sea level. However, the eroded core of an ancient mountainous terrain lies below.

Turning the clock back some 282 million years, we climb southward up a mountain pass between the high peaks surrounding Vestry. Only the highest peaks have fields of snow. The others show barren rocky faces against a blue sky. What little vegetation is present is confined to the mountain's northwestern slopes and the valleys that drain them. They point toward the nearest body of water, hundreds of miles away in the Western Interior.

The vegetated valleys are inhabited by creatures better adapted to land than the amphibians we met in the Mississippian Period. These creatures lay amniote eggs with hard shells and do not depend on the water for reproduction. Their bodies are protected by a scaly skin, and we call them reptiles. At this time they are the most fearsome creatures that walk the earth. Those in the valley below us are different than the reptiles we know today. They are pelycosaurs and look like giant lizards. Especially strange is the fin-backed predator *Dimetrodon*. Several of these display their long dorsal spines in the morning sun as they bask on large rocks. They look like so many ships under full sail. Flying among them are giant dragonfly-like creatures like those of the Mississippian Period. The insects are still the unchallenged masters of the air.

The North American continent looms behind us as we climb. It is a barren desert waste. This setting is a stark contrast to the Pennsylvanian swamps of the previous period. The remains of this period greet us in the tilted sandstones, shales, and coals that cap the higher elevations.

We hope to find some respite from the dry desolation on the other side of the pass. After all, this pass breaches a chain of mountains than runs two thousand miles from the Appalachians of New England to the Ouachitas of Arkansas and Oklahoma. The Appalachian-Ouachita ranges form a long suture that stitches together three continents—North America and the combined continents of Africa and South America, Yucatan included. At the top of the pass, we'll have a good vantage point to see Yucatan and possibly parts of South America.

A strong dry wind greets us at the continental divide. Thankfully, it's dust free and carries only a little gritty sand. Almost constant winds have stripped the soil down to bedrock. Wiping some grit from our eyes, we have our first view of Yucatan. To our disappointment, it is as dry and desolate as the land from whence we came.

Figure 11. A day in the Permian mountains of Mississippi. Vestry 282 million years ago by Katie Lightsey, St. Andrew's Middle School 5th grade.

SITE 5: WINDOW INTO THE TRIASSIC

A Time of Continental Breakup, Rift Valleys, Red Beds, Deserts, and Dinosaurs

Triassic Site

The Triassic Period was a time of uplift and erosion in Mississippi. Sediments from this period are deeply buried in central Mississippi. They are the 220 million-year-old Late Triassic red beds of the Eagle Mills Formation (Scott et al., 1961). Red beds are highly oxidized sediments deposited under desert conditions. These sediments are found along the southeastern wall of the down-faulted Mississippi Salt Basin and roughly parallel the former Ouachita Mountain chain of Pennsylvanian and Permian times (Crosby, 1967).

Most of our subsurface information on the Eagle Mills Formation comes from Newton and Clarke counties (Dinkins et al., 1968; Williams, 1969). Here the Eagle Mills is at depths of 6,000 feet or less and rests on an eroded Paleozoic basement. This basement dips so steeply to the south that no wells have penetrated the Eagle Mills within the Salt Basin's interior.

In the Late Triassic, southern Mississippi, south of the eroded Ouachita-Appalachian mountain trend, resembled the basin and range topography of present-day Nevada and New Mexico. Sediments were eroded from the up-faulted highlands and deposited in the intervening desert basins. The land was pulling apart. A new sea, the Gulf of Mexico, formed between the separating North and South American continents.

Living things in the Triassic were quite different from those of the Permian. A major extinction event at the end of the Permian decimated both the marine and land animals that characterized the late Paleozoic Era. Brachiopods that were once abundant in shallow nearshore waters became rare. In their place, bivalve marine mollusks flourished as they do to this day. Many large reptile species disappeared. In their place came a group that would soon rule the land and characterized life in the Mesozoic Era. We know them as dinosaurs.

Our Triassic site is the State Exploration #1 Flora Johnson near Lake, Mississippi, in Section 21, T. 6 N., R. 10 E., Newton County. Here 330 feet of Eagle Mills sediments rest just one and a half miles southwest of the Phillips Fault System, the northeastern fault bordering the Mississippi Salt Basin. This fault, according to Dinkins et al. (1968, p. 40), cuts beneath Interstate 20 at the town of Lawrence in southwestern Newton County. On the northeast side of this fault, Paleozoic rock once rose 2,800 feet above the basin floor. To the southeast was an arid alluvial apron formed by coalescing alluvial fans. These fans contained fine-grained sediments dumped by intermittent streams that drained the Paleozoic plateau.

A Day in the Triassic Rift Basins of Mississippi:

Lake 220 Million Years Ago

The setting sun illuminates the layered Paleozoic rocks of a fifteen hundred-foot cliff to the northeast. This great wall runs from horizon to horizon and is breached only by the narrow gorges of clear-water, plateau streams. We stand at an oasis along the banks of one such stream as it snakes its way along the alluvial plain. Where the stream has cut its banks, we see the brightly colored red, purple, and green clays of the arid alluvial environment. Interbedded with these are pink and white channel sands. Eroded pillars of sand and clay make a miniature Painted Desert.

A conifer forest borders the stream banks. Large, lizard-like, thecodont reptiles rest along the water's edge. However, unlike lizards, the thecodonts walk with their legs beneath them rather than to the side. They have sharp teeth and are the largest predators around.

A new group of reptiles comes to forage in the afternoon coolness. These reptiles walk on two legs with a gait much like that of an ostrich. They are some of the first predatory dinosaurs. Hunting as a pack, several attack a larger thecodont that has wandered too far from its friends. In the furious battle that follows, we slip into the conifer thicket so as not to attract attention. Unlike the thecodont, we lack sharp teeth and thick scales for defense.

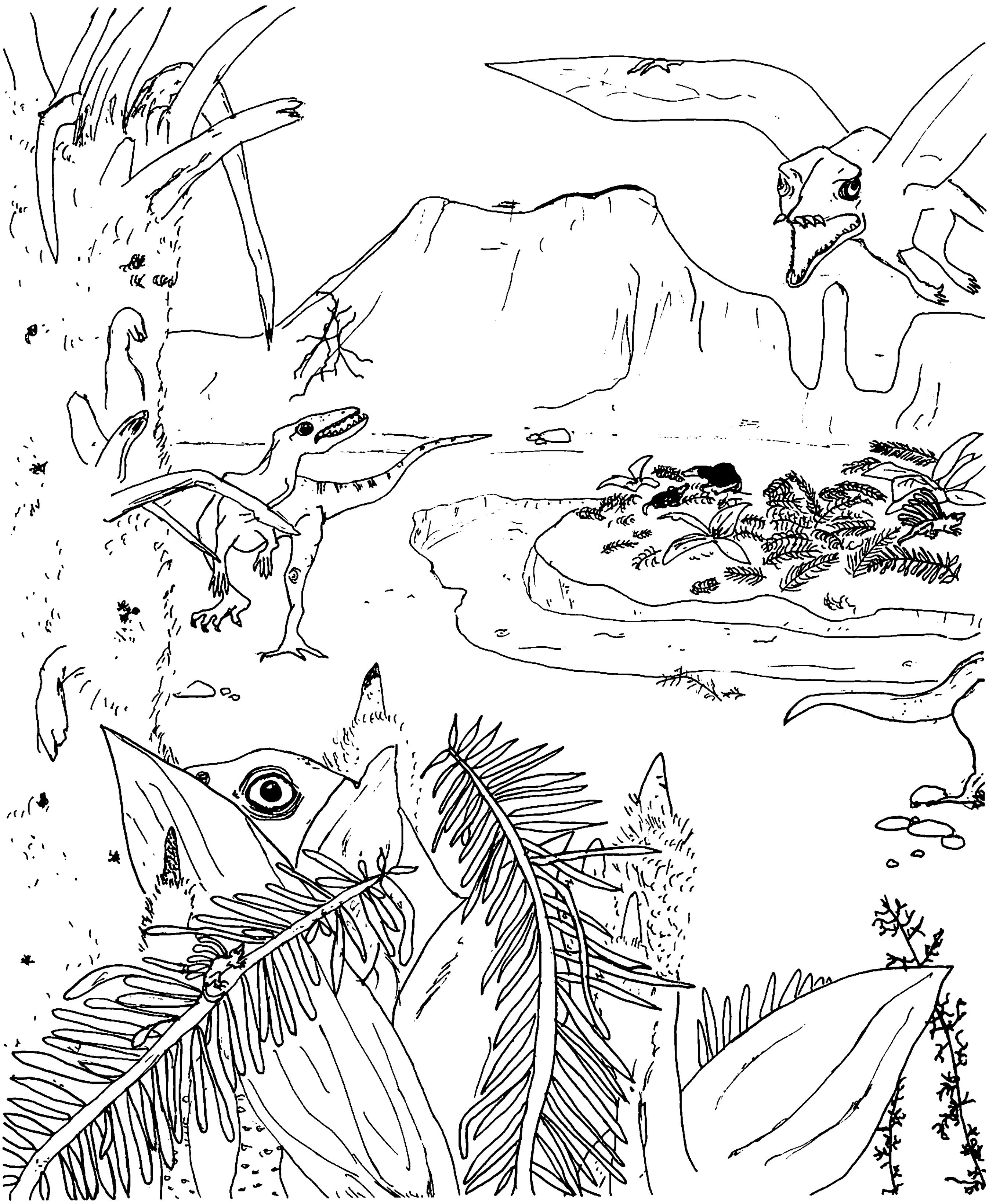


Figure 12. A day in the Triassic rift basins of Mississippi. Lake 220 million years ago by Katie Lightsey, St. Andrew's Middle School 5th grade.

SITE 6: WINDOW INTO THE JURASSIC

The Great Salt Sea

Jurassic Site

Jurassic sediments of Mississippi's Salt Basin consist of evaporites, largely salt, overlain by limestone then sandstones and shales. The volume of salt, called the Louann Salt, buried beneath southern Mississippi is truly impressive. At about five dozen places, it pushes through overlying sediments to form the piercement features we call salt domes. Similar salt deposits underlie the northern Gulf of Mexico and the southern Gulf adjacent to Yucatan. They attest to times when the early Gulf dried up, leaving behind layers of salt and other minerals that were dissolved in the sea water.

Our Jurassic site is a buried Paleozoic knob in northeastern Jasper County between Rose Hill and Pachuta, Mississippi. According to Mississippi Geological Survey cross section CS-4 by Vic Fischer (1976), this knob consists of Cambrian and Ordovician carbonates and stands a thousand feet higher than the Louann Salt. The Pan American Petroleum Corporation #1 Masonite in Section 27, T. 3 N., R. 13 E., Jasper County, drilled into this basement high. For our purposes we will call it the Rose Hill - Pachuta Knoll. This hill is on the southwestern end of a ridge running to the northeast, an extension of the Appalachian Mountains now buried beneath Jasper, Clarke, and Lauderdale counties.

A Day in the Jurassic of Mississippi:

Louann Sea and Rose Hill - Pachuta Knoll

160 Million Years Ago

We sit atop a barren prominence at the southwestern end of a long ridge. No clouds are seen to mar the blue sky, and the air is hot and dry. To the northwest of us is another ridge parallel to ours. The valley between has a flat bottom and is encrusted with salt. To the south of us is the great Louann Sea that extends to the horizon. Its waves gently lap against the foot of our knoll. While mighty dinosaurs roam the continent's western frontier, no life is seen here. Even the great sea before us is barren. It is heavy with salt, one of the greatest dead seas the world has ever known.

Scanning the shoreline, we spot a lone object on the beach. Our binoculars show it to be the remains of a long-necked dinosaur called a sauropod. This plant-eating beast crossed miles of dry valleys only to die at the water's edge. The alluring reflections of water in the salty Louann Sea were a false hope that drew many a Jurassic dinosaur to its death.

Figure 13. A day in the Jurassic of Mississippi. Rose Hill - Pachuta Knoll 160 million years ago by Katie Lightsey, St. Andrew's Middle School 5th grade.

SITE 7: WINDOW INTO THE EARLY CAMPANIAN STAGE OF THE LATE CRETACEOUS

Volcanic Islands Dot a Tropical Sea

Early Campanian Site

Jackson, Mississippi, rests above a geologic structure known as the Jackson Dome. At the center of this structure and at a depth of 2,600 feet is the top of an extinct Cretaceous volcano. This eroded and buried terrain was once an active volcanic island in a tropical sea. The island grew as successive eruptions built up the volcano's flanks with deposits of lava and ash. It also grew as the hot magma below pushed up the sea floor, exposing more land. Between eruptions, floating and airborne seeds rejuvenated the destroyed vegetation. Swimming and debris-rafted animals also colonized the island.

The Jackson volcanic island reached its greatest emergence from the sea possibly in the early Campanian Stage of the Cretaceous Period some 79 million years ago. At this time it may have extended as far west as Clinton, as far east as Brandon's western city limits, as far north as the southern limits of Ridgeland, and as far south as the southern limits of Richland, an area of about 185 square miles. At the core of the island was a volcanic cinder cone centered at what now is the Mississippi Coliseum. A second cone may have been present in west Jackson.

A Day in the Early Campanian Stage of the Late Cretaceous of Mississippi:

Jackson 79 Million Years Ago

We maneuver our boat carefully through a coral reef and into a quiet lagoon. There we anchor it off the sandy north shore of Jackson's volcanic island. In our journey around the island, we noted that the southern shore is arid, with only scrub vegetation. In contrast, the northern side, facing the trade winds, is forested in deep jungles. A river draining the volcano forms a rocky delta along the beach. We plan to follow its course to the volcano's crater. There we will collect specimens of igneous rocks for laboratory analyses. Perhaps this volcano is a carbonatite volcano rich in carbonate minerals like one to the north at Magnet Cove, Arkansas.

Only our academic interest in the nature of the Jackson volcano makes braving the narrow jungle passage worthwhile. We have no idea what might inhabit the dense foliage. Perhaps no large animals have survived the sea to inhabit these shores, or, perhaps they have. Dinosaurs such as the large plant-eating hadrosaurs are most likely. While dangerous for their size, at least they won't eat us. We worry that the jungle may contain a large meat-eating tyrannosaur.

In our journey up the river we encounter only large crocodiles sunning themselves on the sand bars. We carefully avoid them. A gorge cuts the volcano's north slope, providing easy access to the crater. There we hope to find fresh exposures of the crater's igneous rocks.

At the entrance to the crater, our academic interests fade. Before us is a pair of tyrannosaurs guarding their nest. Hadrosaur bones are scattered everywhere. We decide to leave the crater's rocks to them.

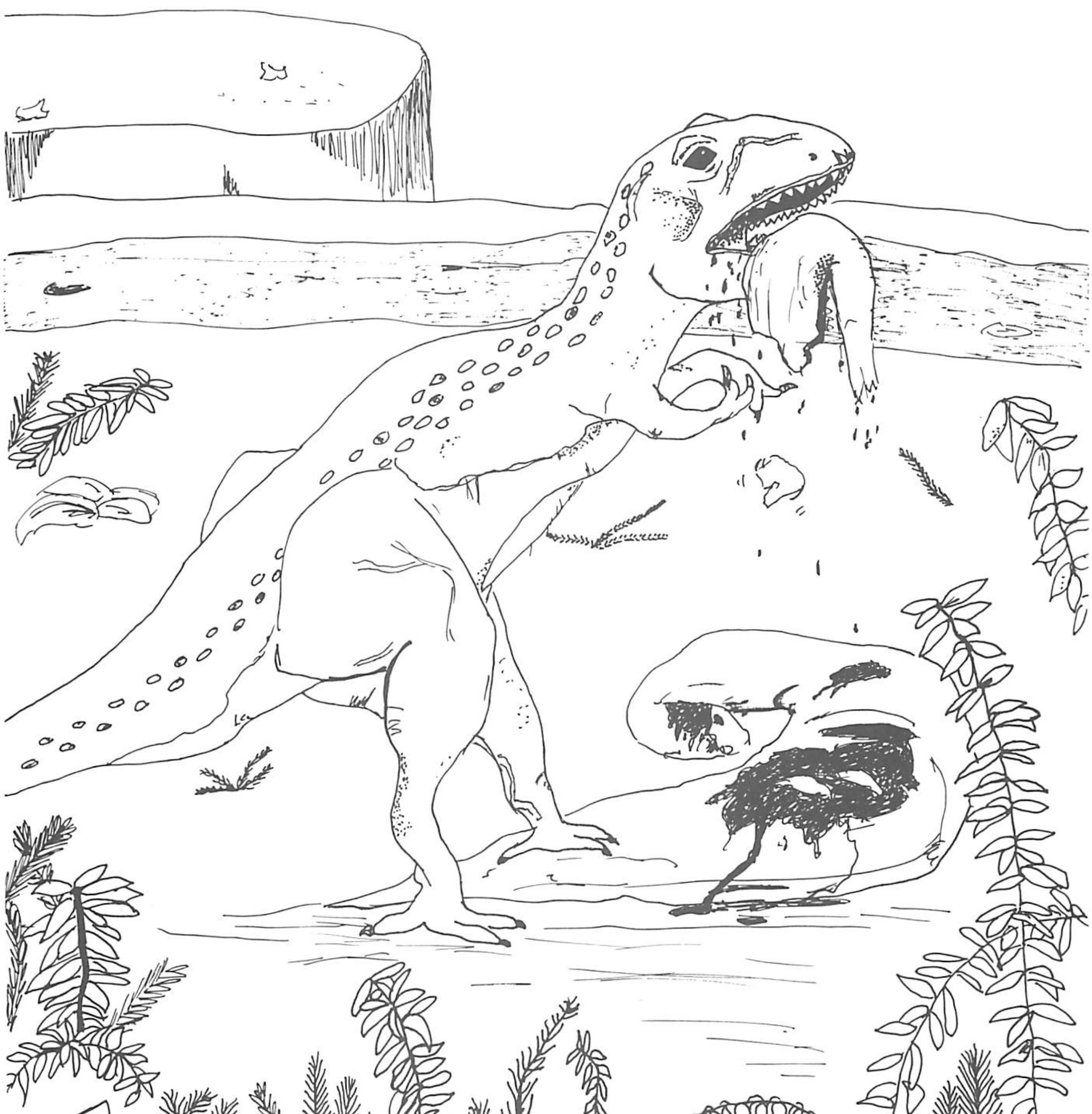


Figure 14. A day in the Early Campanian Stage of the Late Cretaceous of Mississippi. Jackson 79 million years ago by Katie Lightsey, St. Andrew's Middle School 5th grade.

SITE 8: WINDOW INTO THE LATE CAMPANIAN STAGE OF THE LATE CRETACEOUS

Shark-Infested Coastlines and Duckbilled Dinosaurs

Late Campanian Site

A sea-level rise during the late Campanian flooded the ancient beaches and delta plains of northeastern Mississippi. This event is recorded at the unconformable contact of the Coffee Sand and overlying Demopolis Chalk where a basal Demopolis lag deposit of fossil vertebrates and oyster shells rests on the eroded surface of the Coffee Sand. Informally named the Frankstown sand, this one-foot-thick lag deposit can be traced along Highway 45 from Saltillo in Lee County to Corinth in Alcorn County.

The Frankstown sand gained national attention in the summer of 1990 during the construction of the Highway 45 Bypass at Frankstown. A highway cut south of Twenty Mile Creek uncovered the Coffee Sand/Demopolis contact and exposed an abundance of shark teeth and other vertebrate fossils. The news of this fossil bonanza spread, and soon campers with license tags from distant states appeared at the construction site. Fossiliferous sands excavated from the cut were used as roadbed material for a one mile stretch of the highway north of Twenty Mile Creek, allowing plenty of room for collectors to fan out. However, more aggressive collectors went directly to the fossiliferous horizon, digging pits in the roadbed south of the creek, giving the construction site a cratered look.

Booneville High School was awarded a National Science Foundation grant to utilize the Frankstown site as a laboratory for teaching their students about natural history. These students were filmed by an ABC News camera team during a collecting trip on April 26, 1991. The segment was aired nationally on the ABC Sunday evening news (June 16, 1991). Booneville High teacher Patsy Johnson received the "1992 Outstanding Earth Science Teacher for Mississippi" award for her work in this school effort. Another spinoff from this work is Mississippi Office of Geology's Circular 4 (Manning and Dockery, 1992), which illustrates fossils from the site.

On May 6, 1995, a portion of the Frankstown site was dedicated as the W. M. Browning Cretaceous Fossil Park. An eight foot-high granite monolith at the park commemorates the site as follows: *"Excavations at this site in 1990 uncovered abundant shark teeth, some dinosaur teeth, and other fossils of Cretaceous age, a time when dinosaurs roamed the continent and large reptiles swam the ocean. These fossils are evidence that this area was covered by the sea 75 million years ago. Fossils are present in the boulder-sized concretions in Twenty Mile Creek, but the greatest concentration was found below an oyster bed 40 feet higher."*

The park monument is visible from the road and is placed so that the 50-foot-high Cretaceous outcrop in the cut bank of Twenty Mile Creek can be seen behind it. As Mississippi's first roadside park dedicated to paleontology, the W. M. Browning Cretaceous Fossil Park deserves recognition here.

A Day in the Late Campanian Stage of the Late Cretaceous of Mississippi:

Frankstown 75 Million Years Ago

The bellowing cries of hadrosaurs (duckbill dinosaurs) resound from the coastal marshes as the dinosaur herd finds food and water in the shallow ponds behind the beach ridge. Here crocodiles lie in wait for the poor baby hadrosaur who wanders too close. With rising sea level, the beach and dunes move across the coastal meadows like a slow-motion bulldozer, encroaching over the marsh on the landward side, while exposing marsh sediments to the surf on the seaward side. Soon the teeth and bones of dinosaurs, crocodiles, freshwater gars and turtles, and fragments of petrified driftwood are mixed with the remains of sharks and other saltwater fish.

The hadrosaurs characterize this coastal environment and are good swimmers even in the surf, where they often flee to evade predators. Also, the Campanian Stage was the heyday of the hadrosaur, with large herds roaming the North American continent. The sound of the hadrosaur is everywhere as they make trumpeting calls through the air space in their crested skulls. Male hadrosaurs stake out their territories, warning other males to stay away. But soon the sea will reclaim all of this marsh, and the hadrosaur will have to find pasture elsewhere.

During our brief visit to this ancient setting, we choose the safety of the beach and avoid the dinosaurs in the marsh. Here we have a wonderful time collecting seashells along the high tide line. The beach is littered with the exquisitely beautiful shells of marine snails (gastropods) and the occasional giant shell of an ammonite with its flashy mother-of-pearl interior. Among the gastropods are a diversity of aporrhaids with flaring extensions protruding from the shell's

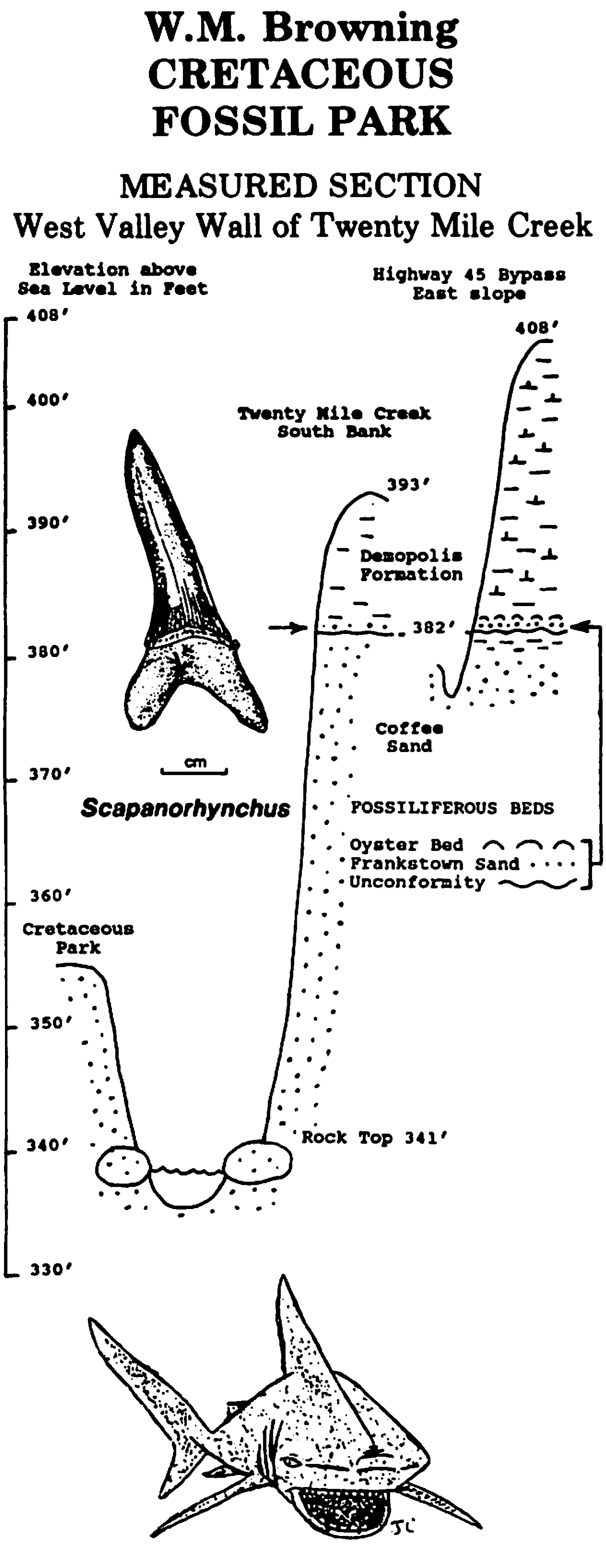


Figure 15. Cover of pamphlet by Booneville High School on the Frankstown fossil locality showing a measured section of the bluffs along Twenty Mile Creek at the Highway 45 Bypass.

mouth (aperture). The largest and most brightly colored shells are those of the spindle-shaped volutes.

Our pursuit of large shells takes us into the surf where we are greeted by a school of fish leaping from the water. In pursuit of them are the large predatory fish *Xiphactinus* and *Enchodus*. These ten-foot-long fish breach the surface with open jaws containing dagger-like teeth. Behind them are the sharks *Scapanorhynchus* and *Squalicorax* looking for leftovers. The commotion attracts the attention of a flock of flying reptiles called pterosaurs. They swoop to grab fish swimming near the surface. Below them, one unfortunate shark is ambushed by a fifteen-foot-long mosasaur, a fierce sea-serpent-like reptile.

The feeding frenzy drives us closer to shore where we see the sawfish *Ischyrhiza* flushing crabs and rays from the sand with its long snout studded with sharply-pointed, lateral teeth. One slash of that snout could inflict a serious wound. Nearby is a cracking sound as the mosasaur *Globidens* munches clams with its blunt conical teeth. We return to the beach, leaving the ocean to the reptiles and fish.

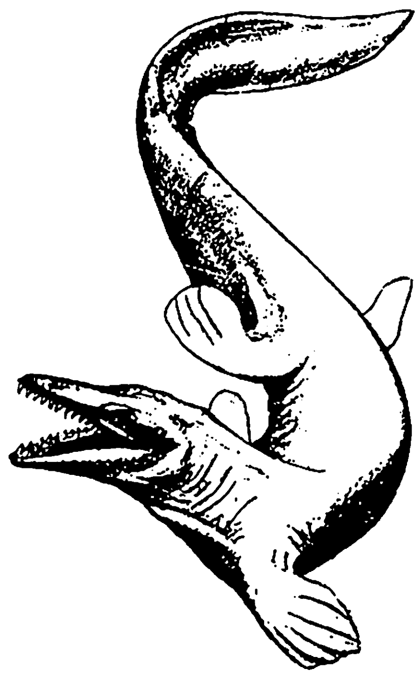


Figure 16. Mosasaur as figured in the Booneville High School Frankstown pamphlet.

SITE 9: WINDOW INTO THE CRETACEOUS/TERTIARY BOUNDARY

The Catastrophe that Killed the Dinosaurs

Cretaceous/Tertiary Boundary Site

The Cretaceous/Tertiary boundary is well exposed in a road cut on the east side of Highway 45, 3.7 miles north of the intersection with Highway 16 in Scooba, Mississippi (SW/4, NE/4, Section 19, T. 12 N., R. 18 E., Kemper County). Here, white chalk of the Cretaceous Prairie Bluff Formation is unconformably overlain by the basal brown sand of the Tertiary Clayton Formation that contains the small, strongly convex oyster *Ostrea pulaskensis* Harris, 1894. Throughout the northern Gulf Coastal Plain, this oyster is a guide fossil to the Midway Group, which includes the Clayton and Porters Creek formations.

What is interesting about this contact is the striking difference in both sediment type and fossils across it. Chalks deposited in the quiet environments of the late Cretaceous ocean are replaced by sands carried seaward by strong currents. This boundary marks one of the five largest extinction events in Earth history (Benton, 1995). Here, the dinosaurs that ruled the land for some 140 million years became extinct, leaving the mammals to flourish.

There have been many theories as to why the dinosaurs became extinct, but the theory most widely accepted at present favors a catastrophic event in which a comet or asteroid crashed into the Yucatan Peninsula, which was covered by the waters of the ancient Gulf of Mexico. During the Late Cretaceous, the Earth was predominantly forested with a variety of conifer and angiosperm plants like those of modern tropical climates (Crane et al., 1995). However, the large animals of these forests were dinosaurs. Mammal fossils of this period are rare and consist largely of the small teeth (multituberculates) of squirrel-like creatures that probably found safety in holes in the ground and in tree tops.

After the impact, when the smoke cleared, the mammals crawled from their holes to find all the dinosaurs dead. There were losses in the air and sea as well. Flying reptiles became extinct, leaving the air to the birds. These were later joined by certain mammals (bats). In the sea, large sea-going reptiles, such as the mosasaurs, became extinct, but turtles and crocodiles survived. A diverse group of nautiloids called ammonites also perished from the sea as did the large carnivorous fish *Xiphactinus* and *Enchodus*; however, the sharks survived.

It should be noted here that though the impact scenario described above has gained momentum not all scientists agree with it. Some point out that extinction of dinosaur species was an ongoing process throughout the Mesozoic Era and that gradual changes in the environment may have killed off the last of them. Naysayers aside, the following story considers the effects of the Yucatan impact event on Scooba, Mississippi, at the end of the Cretaceous Period. Artist conceptions of this catastrophe have appeared in Gould (1989, p. 60-61), Preiss and Silverberg (1992, p. 282-283), and Monastersky (1994, p. 156-157).

The Day of the Terminal Cretaceous Disaster:

Scooba, Mississippi, 65 Million Years Ago

A group of mosasaurs sports amongst the gentle waves of a late Cretaceous sea. As reptiles, they must surface regularly for air. The early morning surface waters are warm and tinted green with microscopic algae called calcareous nannoplankton. All of Mississippi is below sea level with the shore line in Alabama and Tennessee. The mosasaurs are migrating to the site of their birth where they will mate and have their young. In daylight hours they navigate using the sun as a compass. However, today is different – there are two bright bodies in the sky, the rising sun and a fuzzy object directly overhead. This object, a comet, has a milky shroud that sweeps the sky and hides its solid core.

The mosasaurs are confused in their migration and circle, watching both the rising sun and the coma of an approaching comet with interest. Soon contrails appear overhead as rocky particles in the coma's outer edge enter the atmosphere. Loud sonic booms follow. Contrails become increasingly numerous so as to fill the sky, and the loud booms are continuous. The sea surface is dotted with splashing fragments. The mosasaurs dive momentarily to escape the commotion, but resurface for another look. As they do, the sky is split by a blinding light as the comet's ten-kilometer diameter nucleus races from north to south across the sky. The blast that follows dampens the waves as it rebounds from the ocean surface. In the south the light brightens to a crescendo with the appearance of a red-hot, mushroom-shaped cloud rising above the Earth's atmosphere and turning the sky into an oven.

Again the mosasaurs dive to escape the heat. Above, pterosaurs drop dead from the sky, their wings withered and useless. The ocean surface sizzles until the cloud cools as it expands into space. New contrails appear as red-hot debris blasted into low Earth orbit re-enters the atmosphere, and the sky glows red in the onslaught. The mosasaurs quickly swim through the hot surface waters for another breath. As they dive again to the depths, they hear a rumbling in the ocean—a giant tsunami or tidal wave is approaching.

The wave lifts the animals a thousand feet into the air as they attempt to surf below its crest. Some survive to ride the wave. Others are ground into the ocean floor a thousand feet below. Those that successfully ride the wave are carried a hundred miles inland and stranded in the darkness of a scorched forest. For three years the sky is black with ash, and the climate turns cold. Before the sky clears, more than half of all living things cease to exist.

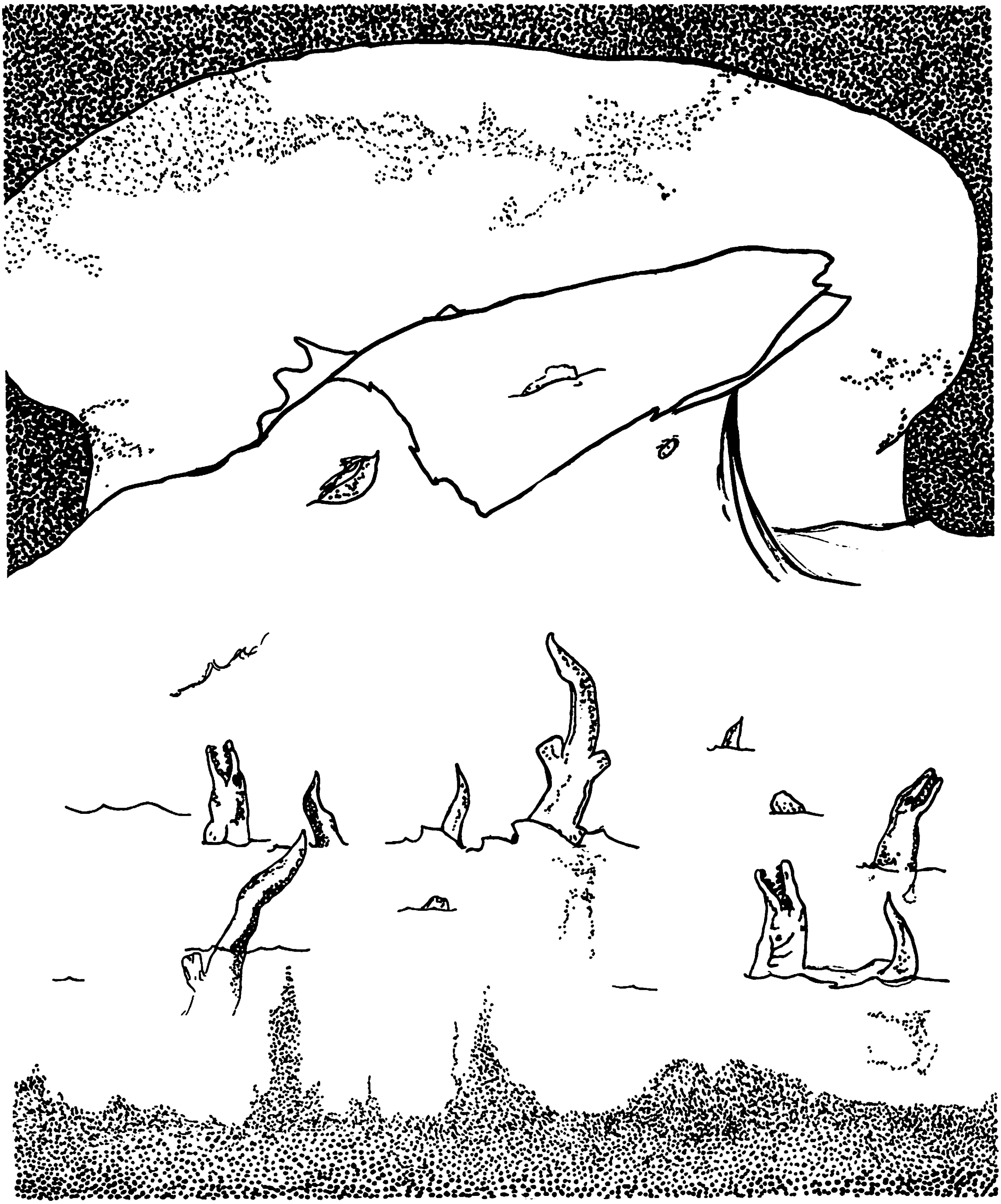


Figure 17. The terminal Cretaceous impact. Scooba 65 million years ago by Katie Lightsey, St. Andrew's Middle School 6th grade. A fireball rises on the southern horizon as mosasaurs breach sizzling surface waters for a gasp of air. Bearing down on them is the first cresting swell of several thousand-foot-high tidal waves to come.

SITE 10: WINDOW INTO THE MIDDLE PALEOCENE

Tropical Jungles Flourish as Sea Level Falls

Middle Paleocene Site

In the late Cretaceous and early Tertiary (Paleocene Epoch), the Rocky Mountains rose up from what had been a seaway across North America's Western Interior. During this time, a trough formed along the course of the present Mississippi River. This trough, called the Mississippi Embayment, received large quantities of sediments shed from the young Rockies. John McPhee (1986, p. 49) described the erosion of the Rockies as follows: "Twenty thousand feet of rock was deroofed from the rising mountains. The entire stratigraphy from the Cretaceous down to the Precambrian was broken to bits and sent off to Natchez, as the mountains were denuded to their crystalline and metamorphic cores." Natchez, Mississippi, today is the site of a significant oil industry that produces oil largely from early Tertiary rocks.

A drop in sea level within the Mississippi Embayment during the middle Paleocene is responsible for some of the highest quality kaolinitic clay and the only bauxite in Mississippi. These deposits occur in the Naheola Formation (Thompson, 1995, p. 54) and indicate times of intense erosion and weathering in a humid, tropical climate. Such conditions stripped minerals from the soil, leaving behind only silica and aluminum oxide of low solubility. In some places, even the silica was leached to form an aluminum oxide rock called bauxite, an ore of aluminum. Soils of this type form in tropical jungle environments today and are called laterites.

Paleocene lateritic deposits of northern Mississippi developed on an ancient jungle topography. When sea level rose, these surfaces were buried under sediments and preserved. On hill tops where intense weathering produced resistant bauxitic soils, this Paleocene surface was especially hard. As a result, some of these ancient hills (about 60 million years old) have been exhumed by Recent erosion. One such hill is Smoky Top in the SE/4 of Section 20 and NE/4 of Section 29, T. 8 S., R. 1 E., Pontotoc County. The 263-acre bauxite deposit along the crest of Smoky Top constitutes the largest and best-grade ore body in Mississippi, totaling between 350,000 and 400,000 tons (Morse, 1923, p. 90).

A Day in the Middle Paleocene Jungles of Mississippi:

Smoky Top 60 Million Years Ago

To climb Smoky Top, we must chop our way through thick underbrush as mosquitoes and flies buzz our face. Crocodiles and large snakes related to the modern boas are a constant concern, but at least we needn't worry about lions, and tigers, and bears — there are none. We're in the Tiffanian Land Mammal Age in a Mississippi jungle. The mammals are all smaller than us, except for the sheep-size pantodonts, but these are shy plant eaters who run away when we approach. Birds fly about the jungle's upper canopy, sharing the trees with lizards, frogs, and small rodent-like mammals.

This jungle is sadly quiet. The small arboreal birds we see hovering and plunging amongst the tree tops belong to Order Coraciiformes and are related to modern kingfishers. They make rattling noises as they hunt lizards and insects hidden in the foliage. There are no songbirds of the Order Passeriformes. Though these comprise 60% of modern birds, they do not appear for another 35 million years in the Late Oligocene (Boles, 1995). Neither are there monkeys screaming in the trees. The first primates appear in the Wasatchian Land Mammal Age.

The sky darkens as an afternoon thunderstorm approaches. Soon we are drenched in a tropical downpour. Retreating to the slight cover afforded near the base of a large tree, we encounter the upland king of this jungle, a large boid snake. The snake seems perplexed at seeing mammals so large and, after a tense standoff, slithers into the brush. As it goes, we see a surprising feature of this creature—tiny hind legs.

Figure 18. A day in the Middle Paleocene of Mississippi. Composite scene including Mississippi's tropical setting as viewed to the west of Smoky Top 60 million years ago, but with volcanoes of the rising Rocky Mountains in the distance, by Katie Lightsey, St. Andrew's Middle School 6th grade. Can you find all the reptiles in this picture? A pantodont, the largest mammal of the time, walks the river's opposite shore.

SITE 11: WINDOW INTO THE LATE PALEOCENE

Horses and Primates Appear in a World Dominated by Mammals

Late Paleocene Site

A creek diversion behind the Red Hot Truck Stop in Meridian, Mississippi, in 1955 exposed shark teeth amongst the boulder-sized concretions of the Bashi Formation in the graded bluffs behind the diner's spacious parking lot. Since then, this early Eocene site has been a favorite for geological field trips, college classes, hobbyists, and gem and mineral clubs. Collectors tunneling under the giant Bashi concretions for shark teeth have completely excavated parts of the formation, leaving only the boulders behind.

Fossil shark specialist Gerard Case visited the site in 1979 without the assistance of a local guide and began digging at the first level in the bluffs where he noted shark teeth. This led to the discovery of a Paleocene vertebrate lag deposit in the upper Tuscahoma Formation, one that collectors had walked over for forty years as they climbed to the concretion bed of the Bashi Formation above. What turned out to be so special about the Tuscahoma horizon, called the "T4 sand" (Ingram, 1991), was not the shark teeth but those of land mammals.

Recognition of land mammal teeth in both the T4 sand and Bashi Formation was the result of paleontological sleuthing by Chris Beard of the Carnegie Museum of Natural History, who noted the tiny teeth in Case's collection at the Yale Peabody Museum. Among them was the first Eocene primate jaw and tooth found east of the Mississippi River (Beard and Tabrum, 1991). Beard and Tabrum, with help from Case, excavated the T4 sand at the Meridian site in April and again in November of 1990, resulting in additional mammal finds. Three other excavations followed in April of 1991, March of 1992, and September of 1994; the latter excavation was assisted by teachers of Northeast Lauderdale Middle School. A summary of the mammal finds, including some 25 species, was published by Beard et al. (1995). Other fossils from the site include shark teeth (Case, 1994a), teeth of bony fish (Case, 1986, 1994b), snake vertebrae (Holman et al., 1991), and plants (Call et al., 1993).

A Day in the Late Paleocene of Meridian Bay:

Meridian 54.6 Million Years Ago

We travel by boat in a protected bay with thick jungles along its shores. Waters of this estuary are filled with a strange mix of sharks, rays, sawfish, and freshwater gars. Marine snakes, relatives of modern boas, swim alongside our boat until chased away by a pair of crocodiles. As we approach the shore, a herd of antelope-like artiodactyls, no larger than terrier dogs, flee the water's edge and gracefully bound into the jungle. Unalarmed by our presence is the largest land mammal of this time, a hippopotamus-sized pantodont named *Coryphodon*, wading in the shallows. This animal's size and its formidable, tusk-like, canine teeth protect it from hungry sharks. The *Coryphodon* need only worry about the larger crocodiles.

The sharks ignore the *Coryphodon* and cruise under overhanging branches of the *Wetherellia* trees waiting for one of the forest's arboreal animals to make a slip. Several species of squirrel-like rodents, ranging in size from chipmunks to large squirrels, play among the branches, oblivious to the danger below. One rodent nips a *Wetherellia* nut that misses the land and falls into the bay waters. The nut is struck by a hungry shark thinking it to be a fallen mammal. When found to be tasteless and hard as a rock, the nut is immediately spit out and floats to the surface where it rides currents bound for some distant shore. There it may germinate and add to the coastal *Wetherellia* flora.

The sharks soon find something more palatable as a young, lemur-like, omomyid primate loses its grip and falls into the water. It is quickly devoured as its companions above shake the foliage and screech in protest. After digestion, only the omomyid's teeth will pass the shark's gut. These teeth will mix with the remains of marine animals in the estuarine sediments of the bay's bottom. Such becomes the fate of many small mammals that venture near the water's edge.

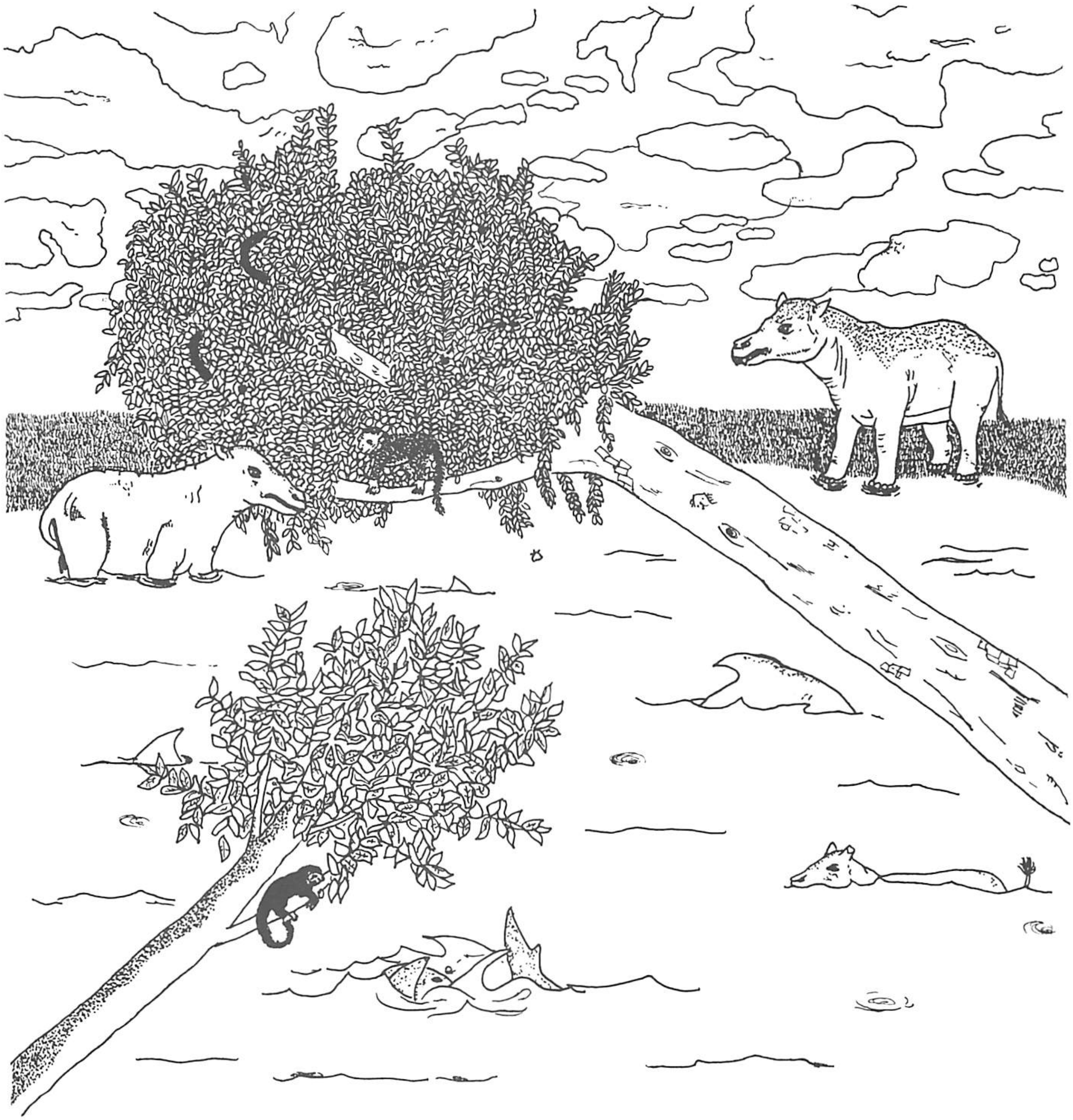


Figure 19. A day in the Late Paleocene of Meridian Bay. Meridian 54.6 million years ago by Katie Lightsey, St. Andrew's Middle School 6th grade. *Coryphodons* wade in the shallows as omomyid primates play in the trees leaning precariously over shark-infested waters.

SITE 12: WINDOW INTO THE EARLY EOCENE

The Ocean Reclaims Meridian Bay

Early Eocene Site

Perhaps a mere 200,000 years separate the ages of the late Paleocene T4 sand and the overlying early Eocene marine sediments of the Bashi Formation at Meridian, Mississippi. Concretionary beds of the Bashi Formation contain an abundance of marine mollusks (see Dockery, 1980), shark, ray, and bony-fish teeth (Case, 1986, 1994a & b), occasional snake vertebrae (Holman et al., 1991), occasional crocodile vertebrae and teeth, and rare land mammal fossils. Three land mammals have been identified from the Bashi Formation, an omomyid primate jaw fragment and tooth (Beard and Tabrum, 1991), specimens of a jaw fragment and molar of the small horse *Hyracotherium* (a species one and a half times larger than those of the T4 sand below), and a jaw fragment with molar and premolar of the creodont *Prototomus deimos* Gingerich and Deutsch, 1989. Unfortunately, the latter two specimens, which were found at a construction site along Gallagher Creek, were lost in the return shipment after their identification.

A Day in the Early Eocene along Meridian's Beach:

Meridian 54.4 Million Years Ago

The ocean has encroached into the Meridian bay, and now we walk in shallow surf looking for clams. Our netted bags are full of the large species *Venericardia bashiplata* with its prominent radial ribs. Small, fresh mounds of sand indicate the presence of a clam below, and we dig them up with a forked tool. The venericards are feisty clams that squirt us with a jet of sea water when collected. We are especially careful not to get our fingers caught between their massive shells. On shore are the fire and burlap bags for our clam bake. An omomyid primate twice the size of those we saw in Tuscahoma times finds one of our bags interesting and absconds with it.

As we walk, we carefully poke the sand ahead of us. We want to make sure not to step on one of the many large stingrays common to this area. Sharks are common in the deeper water but leave us alone. Our biggest concern has been a large crocodile we've seen sunning on a distant shoreline. But he seems to be content with the small horse *Hyracotherium* that he ambushed on the beach. Several carnivorous creodont mammals of the genus *Prototomus* try to steal the crocodile's catch. The croc will have none of it, dispersing the small hyena-like creatures with his swinging tail and snapping jaws.

The action on shore has distracted us from an approaching sea serpent. We see it just in time to run to the beach with the curious 18-foot snake swimming close behind. From the safety of the beach, we admire the fearsome predator; it is a giant specimen of the marine snake *Palaeophis virginianus.*

SITE 13: WINDOW INTO THE MIDDLE EOCENE

Titanothere Land Mammals and Saddle-Shaped Oysters in Clear Seas

Middle Eocene Site

Dobys Bluff on the Chickasawhay River just south of Quitman, Mississippi, is a white limestone cliff that exposes some fifty feet of the Archusa Marl Member of the Cook Mountain Formation, also known as the Cook Mountain Limestone. This limestone is in sharp contact with shales of the underlying Kosciusko Formation. It was deposited at a time when the clear, tropical waters of the Gulf of Mexico covered the area some 41 million years ago.

Within the Archusa Marl are a great variety of marine molluscan shells, including the large saddle-shaped oyster *Cubitostrea sellaeformis* (Conrad, 1832). This oyster is found in the Cook Mountain Formation and its equivalents from Texas to Virginia and is about the same age as Lutetian limestones in Europe, indicating a worldwide rise in sea level at this time. At a locality not far from Dobys Bluff, the Archusa Marl contained a particularly interesting find, the skull and jaw of a new species of titanothere, *Notiotitanops mississippiensis* Gazin and Sullivan (1942).

A Day in the Middle Eocene of Mississippi:

Quitman 41 Million Years Ago

We arrive in Quitman on the heels of a devastating hurricane. Trees are down everywhere and the limy beach is piled with shells, especially those of the large oyster *Cubitostrea sellaeformis.* Washing up on the beach among the uprooted palm trees are a variety of dead mammals that once inhabited the coastal forests and meadows. The largest of these is the titanothere, *Notiotitanops mississippiensis.*

Vultures and birds of prey circle overhead as additional corpses wash ashore; yet, we see many bodies floating far out in the clear, blue Gulf waters. One especially large corpse of a *Notiotitanops* has attracted sharks. They quickly decapitate the animal in a feeding frenzy. Remains of the head fall to the sea floor as the bloated body continues to drift to shore.

SITE 14: WINDOW INTO THE EARLY LATE EOCENE

Jackson, the "Sanibel Island" of the Late Eocene Gulf

Early Late Eocene Site

Jackson, Mississippi, is the type locality for both the Jackson Group and its lower unit, the Moodys Branch Formation. The transgressive marine sands of the Moodys Branch Formation contain the remains of beautifully preserved sea shells. These shells attracted the attention of naturalists in the early 1800s, including the famous English geologist and writer of the earliest credible geologic textbooks, Charles Lyell, who collected fossils at Jackson on the 19th and 20th of March 1846 during his second visit to North America. Fossils from Jackson were later illustrated by T. A. Conrad, a pioneer in Gulf Coast paleontology, and published in the first book on Mississippi's geology (Wailes, 1854). More recent texts on Jackson's Late Eocene mollusks include those of Harris and Palmer (1946, 1947) and Dockery (1977).

Two other interesting aspects of the Moodys Branch Formation concern discoveries at Tinsley northeast of Jackson. In 1939, Fred Mellen, a past director of the Mississippi Geological Survey, noted that the Moodys Branch Formation was structurally high along Perry Creek at Tinsley; this led to the discovery of the giant Tinsley Oil Field. This was the state's first productive oil field and is still producing today. In 1971, members of the Mississippi Gem and Mineral Society discovered a fossil archaeocete whale, *Zygorhiza kochi*, in neighboring Thompson Creek. This 16-foot specimen was excavated from the upper part of the Moodys Branch Formation (Dockery, 1974) and now hangs from the ceiling of the Mississippi Museum of Natural Science. In commemoration of the find, the state legislature passed Senate Concurrent Resolution No. 557 on March 12, 1981, designating the "prehistoric whale as the official fossil of the State of Mississippi" (*Mississippi Geology*, March 1983). Other partial skeletons of *Zygorhiza kochi* have been found in the Moodys Branch Formation at Jackson.

The speculation that Jackson may have been an island during the early transgressive phase of the Moodys Branch Formation assumes that the Jackson Dome was a positive topographic feature at the time. As sea level rose, Jackson was isolated from the mainland as an island until the time it was covered by waters of the Jackson Sea, which extended as far north as Memphis, Tennessee. Fossiliferous marine sands of the Moodys Branch Formation in Jackson are exposed at Fossil Gulch along the nature trail in LeFleur's Bluff State Park. In the narrative that follows, the reader will note that the author's name and date of publication for certain species are in parentheses while others are not. The parentheses indicate that the generic placement of the species is different than that originally published.

A Day in the Early Late Eocene of Jackson Island:

Jackson 40 Million Years Ago

We comb the Jackson sand beaches at low tide under a tropical sun much as shell collectors do today on Sanibel Island off Florida's Gulf Coast. Active mollusks with their colorful shells crawl about in the tidal pools. Probably the strangest looking snail is the hand-sized, rotund, opisthobranch *Umbraculum* that is only partly covered by a plate-like shell. Some of the most colorful shells are the volutes *Athleta*, *Lapparia*, and *Caricella*. The shell of the latter has a shape and color pattern similar to that of Sanibel's prized *Scaphella junonia* (Lamarck, 1804). Crawling just below the wet sand surface are the common moon snails *Natica* and *Polinices*, looking for clams or other unfortunate prey, which they eat out of house and home by boring through their shells.

A very popular group among collectors of this ancient beach are the cypraeids or cowrie shells. Here eight different species are present. The large cone shell *Conus tortilis* Conrad *in* Wailes, 1854, is also a popular find, but the collector must beware; this snail can fire a poisonous dart. One of the most exquisite finds is a strombid with a broad flaring lip, *Platyoptera extenta* (Conrad *in* Wailes, 1854). Favorites of my wife are the muricid *Hexaplex marksi* (Harris, 1894) and the wentletrap *Cirsotrema nassulum creolum* Palmer, 1947.

About 270 different species of molluscan shells are known from this beach, but many of these are small and require stooping and close observation to be found. One small prize is thus discovered, the carinate turrid *Cochlespira columbaria* (Aldrich, 1886). It was hidden among colorfully rayed shells of the clam *Callista annexa* (Conrad, 1865). Nearby is the carrier snail *Xenophora reclusa* (Conrad *in* Wailes, 1854) with a cluster of other shells cemented to the spire of its own shell. At rest, it is perfectly camouflaged as a pile of dead shells.

We now must pick through our overloaded bags and decide which shells to save and which to discard. As we do, we're entertained by a group of *Zygorhiza* and basilosaurs feeding in the deeper waters offshore. However, lying on the beach before us is evidence that they don't rule the waves alone. We see a three inch-long, serrated tooth of their foe, the giant shark *Carcharocles*.

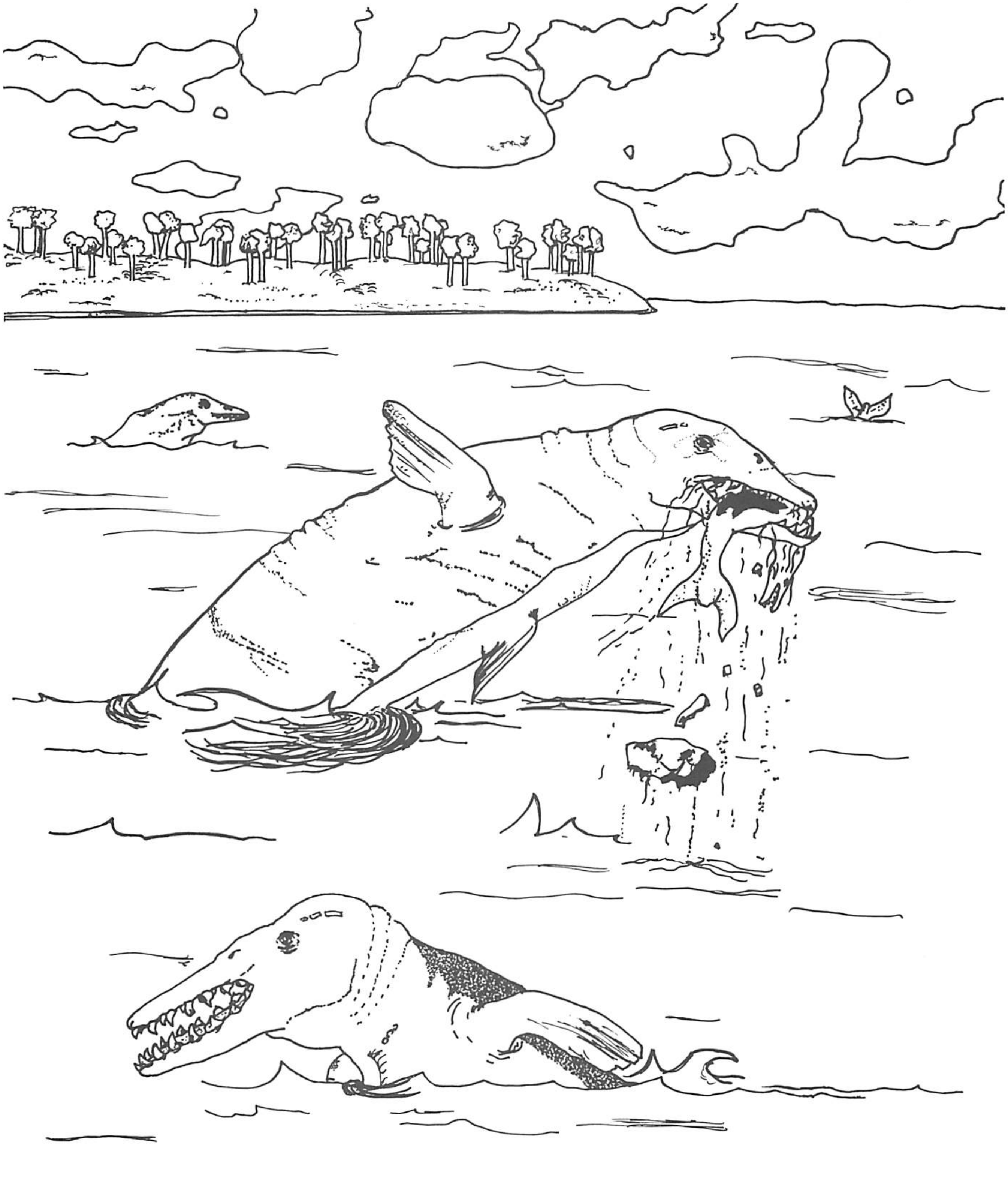


Figure 20. A day in the Early Late Eocene off Jackson Island. Jackson 40 million years ago by Katie Lightsey, St. Andrew's Middle School 6th grade. A hungry basilosaur finds a meal.

SITE 15: WINDOW INTO THE LATE LATE EOCENE

Tropical Seas with Archaeocete Whales and Giant Sharks

Late Late Eocene Site

The upper clays of the Yazoo Formation were once best exposed in the Jackson Ready Mix Miss-Lite clay pit at Cynthia, Mississippi, just north of Jackson. This mine was abandoned in 1992 and is now overgrown. During its operation, the mine was featured in both the Madison and Hinds county geology bulletins, in eight articles published in *Mississippi Geology*, and as a field-trip stop for the 28th International Geological Congress (see Priddy, 1960, p. 40; Moore et al., p. 236-238; Dockery and Siesser, 1984; Dockery, 1985, 1989, 1992; Dockery and Zumwalt, 1986; Smith and Zumwalt, 1987; Byerly et al., 1988; Reeves and Kopp, 1989; Dockery et al., 1991, p. 22-23).

Archaeocete whale bones were encountered on numerous occasions in the excavation of the Cynthia pit, but only three specimens can be accounted for today. The anterior third of a basilosaur was excavated from the pit's south wall by Eleanor Daly of the Mississippi Museum of Natural Science in May of 1988. Remains of this specimen are in the museum's drawers with the exception of the skull, which is in Daly's office in a plaster cast.

In June of 1989, several basilosaur vertebrae were collected from the pit's west wall by Ole Miss students on a field trip with William R. Reynolds' class for science teachers. Miss-Lite Plant Superintendent, Tollie Waldrup, kept an eye on the site and, in July of 1990, with the help of his wife Jenny, excavated the skull, jaws, and other anterior bones of a *Basilosaurus cetoides* (Owen, 1839). These bones remained under cover in the Waldrup yard until March of 1991 when they were given to the writer. After tedious reconstruction, the skull and right jaw are now mounted and displayed in a plexiglass case in the writer's office, and represent one of a few largely complete basilosaur skulls anywhere.

The partial anterior part of a *Zygorhiza kochi* (Reichenback, 1847) was excavated from the upper part of the pit's northeast wall in the summer of 1992 by Carson B. Montgomery, an eighth grade student and the grandson of retired U.S. Geological Survey geologist, Ernie Boswell. This specimen is at Montgomery's home.

Two other interesting aspects of the upper Yazoo Clay in the Cynthia area are the occurrence of the teeth of the giant shark *Carcharocles* and thin beds of bentonite, the alteration product of volcanic ash. Radiometric ages obtained from these bentonites vary from 34.4 million years old (Obradovich et al., 1993) in the middle part of the Yazoo Clay to as young as 33.6 million years old (Obradovich and Dockery, 1996) in the upper part. The latter bentonite is close to the same age as one occurring at 87.4´-88.2´ in the Mossy Grove core hole (Dockery et al., 1991) about 5 miles west of Cynthia. The Mossy Grove bentonite is some 80 feet above a limy bed at 168´-170´ that is believed to be the same bed lying 10 feet above the basilosaur specimen collected by the Waldrups in the Cynthia pit. Together this information gives us all we need to propose a battle of the titans in the late late Eocene sea over Cynthia some 34 million years ago.

A Day on the Late Late Eocene Ocean of Mississippi:

Cynthia 34 Million Years Ago

To visit Cynthia in the late late Eocene we must do so by boat as the location is 200 miles offshore and covered by several hundred feet of water. Among our passengers are several whale watchers, who plan to film a group of 16-foot-long *Zygorhiza* sporting in the aqua-blue waters ahead of us. The captain carefully lowers their 18-foot wooden vessel to sea over the ship's side. As the skiff quietly motors ahead, the whales show no alarm. They have not learned to fear humans and find the small boat interesting. Some come close and nudge the sides with their long snouts. The whale watchers are delighted at such a sight and pat the animals on the head as they pass by.

Suddenly the *Zygorhizas* flee the vessel in all directions, leaving the whale watchers to wonder why the animals were frightened. Those aboard our ship watch in stunned silence as the sea explodes under the small craft. Believing it to be a *Zygorhiza*, a 40-foot-long *Carcharocles* shark has the side of the boat in its jaws. Passengers are flung from the craft as the shark shakes it from side to side and then dives below the surface.

The shark resurfaces, attacking the empty boat again and cutting it in half. This disturbance attracts the attention of a second giant, whose wake cuts across the ship's bow like a torpedo before diving in front of the wrecked boat and floating passengers. In the most explosive encounter yet, the water turns red with blood. The captain hides his eyes for a moment and then begins counting his passengers; they are swimming frantically for the ship. Behind them the ocean parts in a fountain of red, as a 60-foot-long *Basilosaurus cetoides* breaches the surface with the shark's head in its mouth.

The captain is relieved to pull all his passengers aboard, determining there will be no more whale-watching excursions this day. When a calf surfaces beside the basilosaur, we realize why she was so aggressive. She was in no mood to share her space with predators, especially a giant *Carcharocles*.

Figure 21. A day in the Late Late Eocene ocean of Mississippi. Cynthia 34 million years ago by Katie Lightsey, St. Andrew's Middle School 5th grade. A basilosaur attacks a *Zyghoriza.*

SITE 16: WINDOW INTO THE EARLY EARLY OLIGOCENE

Large Rivers and Forested Flood Plains

Early Early Oligocene Site

A fall in sea level at the end of the Eocene brought large rivers and swamps across central Mississippi. Occasionally, these rivers cut their banks, choking their channels with fallen trees. In time, the rivers abandoned the clogged channels for new ones. The old channels gradually filled with sand, and mineral-rich ground waters replaced woody tissue in the logs with silica, turning them to stone. One such ancient logjam is present at the Mississippi Petrified Forest near Flora, Mississippi, a site so interesting that it made the September 1937 issue of the *National Geographic* magazine (Hildebrand, 1937).

Richard Priddy (1960), in his bulletin on Madison County Geology, illustrated petrified logs protruding from gullies in badlands developed within the Forest Hill Formation. These badlands were at the northern end of a north-south extension of the Vicksburg Hills running from western Clinton to just south of Flora. Priddy (1960, p. 90) noted an effort had been made to develop a "petrified forest" and that the site was so designated on some highway maps. These plans were realized on October 22, 1962, when the site was purchased from Judge J. S. Black by Bob Schabilion; it opened to the public on April 1, 1963, as the Mississippi Petrified Forest. On June 4, 1966, the Secretary of the Interior declared the Mississippi Petrified Forest a Registered National Natural Landmark.

A Day in the Early Early Oligocene Flood Plains of Mississippi:

The Mississippi Petrified Forest 33 Million Years Ago

The late Eocene Gulf that once extended north of Memphis, Tennessee, has disappeared with falling sea level, exposing the ancient sea floor to erosion. We now stand on the bluffs of a large river that drains the mid-continent of North America. This early Oligocene river snakes its way along the approximate course of the modern Mississippi River. At Flora, Mississippi, where we stand, flood waters are cutting the bank before us along the outside curve of a large loop called a meander. Below is a deep hole in the river bed called a scour pool. Such pools are separated at low water by shoals known as riffles. Logs carried by the flood have collected in a jam downstream that constricts the river flow.

We feel the ground tremble under our feet and step back just in time before the bluff caves into the flood waters. It makes a thundering splash as it carries a forest of full-grown trees into the scour pool. Some trees sink to the bottom, while others collect in the logjam downstream. Soon dirt and sand add to the trees of the jam to form a dam. For a while the flood waters back up, and then they break through the neck of the meander and cut a new course. River sands now begin filling the old scour pool and entomb the sunken logs.

Logs preserved in this hole include hardwoods such as maple (Dukes in Priddy, 1960) and the conifer *Cupressinoxylon* (Blackwell et al., 1981). These woods lack the well-defined growth rings indicative of seasonal growth such as are found in later Pliocene-Pleistocene woods. Thus they show the Oligocene climate to be warmer and without severe winters.

As we travel back to present day, we find that the genus *Cupressinoxylon* is extinct. The only conifer families comparable to it are the Podocarpaceae and Cupressaceae, which live predominantly in the Southern Hemisphere (Blackwell, 1983). Minerals in the ground water moving through sands of the ancient scour pool at Flora have turned the buried logs to stone. They may be seen today at the Mississippi Petrified Forest, where they bear record of the ancient flora at Flora.

SITE 17: WINDOW INTO THE LATE EARLY OLIGOCENE

Coastal Forests, Rhinoceroses, and Clear-Water Tropical Seas

Late Early Oligocene Site

The Early Oligocene marine section overlying the Forest Hill Formation is well exposed along the Mississippi River banks at Vicksburg. This section attracted the attention of naturalist Charles A. Lesueur in 1828, who was en route to New Orleans on a flatboat. He collected shells and vertebrate fossils at Walnut Hills, which he illustrated in a series of twelve plates (Dockery 1982a, b). The Vicksburg Oligocene section later became known as the Vicksburg Group (Conrad, 1856). Near the top of this sequence are the fossiliferous sands of the Byram Formation, named for exposures along the Pearl River at Byram, Mississippi.

The writer was taking French paleontologists to collect fossil sea shells from the Byram Formation exposed in the bluffs of the Big Black River near Edwards, Mississippi, when he discovered bone material encrusted with corals and oysters. A fossil whale seemed the most plausible explanation for a large vertebrate animal in a marine setting. However, when the excavation began, it was apparent that the large skull was not that of a marine mammal. It was that of an ancient land mammal named *Metamynodon planifrons,* a relative of the modern rhinoceros (see Manning et al., 1985). Later another rhinoceros fossil was found at this locality. This find was published in the *Journal of the Mississippi Academy of Sciences* (Dockery and Manning, 1990) as the jaws of a *Subhyracodon.*

The skull and jaws of two different land mammals in the Byram Formation indicate that the shoreline was nearby. As in the case of the titanothere found in the Cook Mountain Formation, these animals were probably washed out to sea in a storm. After the carcasses bloated and began to rot, the heads and jaws separated and fell to the sea floor.

A Day along the Late Early Oligocene Coastline of Mississippi:

Edwards 30 Million Years Ago

The mother *Metamynodon* frantically fought the swollen river currents to reach her calf. She could barely see her young by the frequent flashes of lightning. All else was darkness, wind, and rain. Her struggle lasted through the night. In the early morning's light, she found herself surrounded by water. The fast currents had carried her beyond the river's mouth into the open ocean. Her baby was gone. Now weakened by her struggle, the mother lacked the energy to grieve. She could barely keep her head above the water. Her gasps for air revealed her moderate-sized canine teeth, indicative of her gender. Males had larger canines for fighting. Soon she slipped below the surface to join her baby in the vast Gulf waters.

The mother *Metamynodon* floated for days in the warm, blue waters of the Gulf before her rotted head separated and fell to the sea floor at a spot near the present-day town of Edwards, Mississippi. The fate of the rest of her body is unknown. Once on the ocean's floor, the skull provided a hard surface for oyster spats and coral larvae to settle and grow. After several months it harbored a small colony of sea life. However, before the oysters grew to be a year old, another storm buried the skull in sand, thus preserving it for us to find.

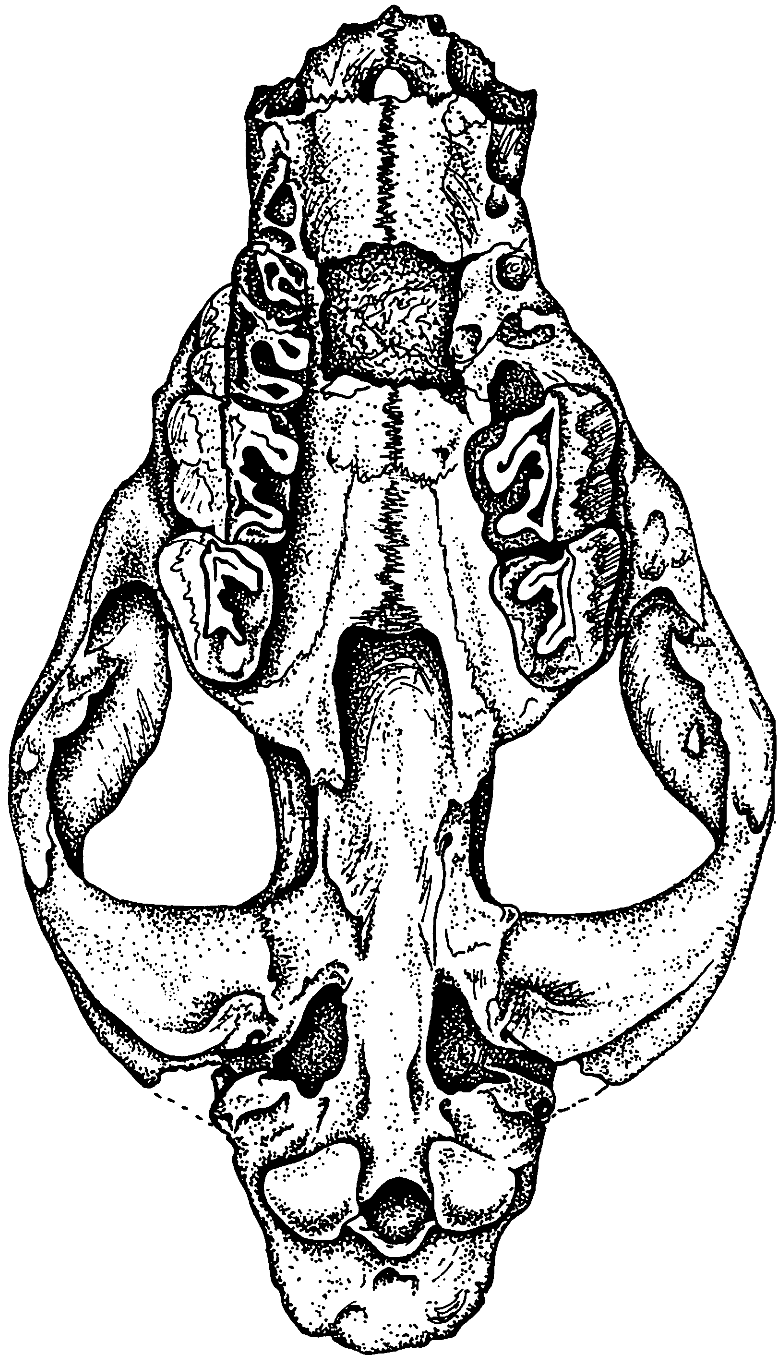


Figure 22. Late Early Oligocene *Metamynodon* skull from the Byram Formation at Edwards, Mississippi, as viewed from the ventral side, showing palate and teeth. Drawing by Kevin D. Moody at about 1/3 the actual size. The skull is 60 centimeters or 2 feet long by 34 centimeters or 1.1 feet wide.

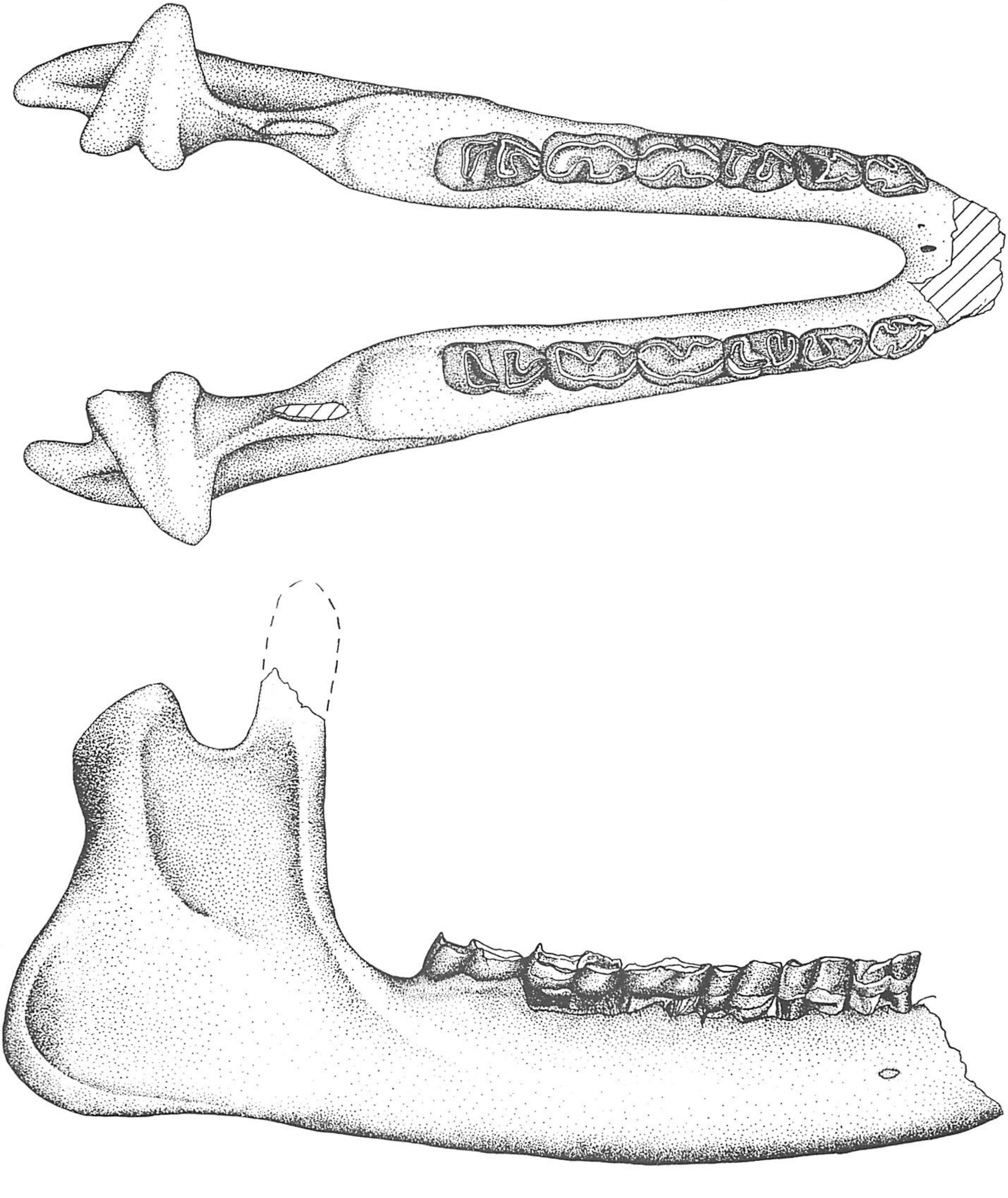


Figure 23. Late Early Oligocene *Subhyracodon* jaw from the Byram Formation at Edwards, Mississippi, drawn by David B. White at about 1/2 the actual size. The jaw is 33 centimeters or 13 inches long and 19 centimeters or 7 1/2 inches wide.

SITE 18: WINDOW INTO THE LATE OLIGOCENE

Manatees Inhabit Clear-Water Streams and Blue Subtropical Seas

Late Oligocene Site

Late Oligocene limestones and interbedded sands and clay of the Chickasawhay Limestone and overlying Paynes Hammock Formation are well exposed along the Chickasawhay River in Wayne County. Both units are characterized by finger-sized calcite tubes of the clam *Kuphus incrassatus* and by the scallop *Pecten howei*. Less common, but frequently found, are the black, dense rib fragments of manatees. These rib fragments are all that's left of some ancient creature's dinner, perhaps that of the large shark *Carcharocles*.

Manatee remains mixed with marine fossils indicate shallow seas with nearby clear-water rivers full of aquatic plants. The scallops themselves may indicate the presence of sea grass. On the right bank of the Chickasawhay River just downstream from the Highway 63 bridge south of Waynesboro, a partial manatee skeleton was excavated from the Paynes Hammock Formation. All that remained of this manatee were the vertebrae and ribs, and it is the fate of this gentle creature we will consider in our visit to the late Oligocene.

A Day in the Late Oligocene of Mississippi:

Waynesboro 28 Million Years Ago

A large, well-fed, male manatee makes its way out to sea to find a river of its own. This is not a trip of his choosing. Other adult males have encouraged him on his way to prevent overcrowding of their home territory. The young male has enough body fat to last for a journey of several days. Others of his kin have made this journey never to return. Such travels are responsible for the manatees' worldwide distribution.

Manatees enjoy a degree of protection in their fresh-water habitats because of their large size. Here the only danger would be from a very large crocodile. In the Oligocene ocean, manatees had the added danger of the large *Carcharocles* sharks and perhaps whales.

Our wandering manatee is making his journey in the spring, the usual time of year young males set out on their own. This migration is well known to a dangerous predator, a fifty-year-old, thirty-foot-long, female *Carcharocles* shark. Many seasons of feeding on manatees have put southern Mississippi on the shark's spring agenda. Unwary new travelers make an especially easy target.

The shark watches the manatee's silhouette overhead. From its shape and the sound of its swimming, the shark has positively identified it as a marine mammal, her favorite food group. The shark accelerates from below and, with open jaws, tears into the side of the manatee, leaving it stunned and bleeding.

Other sharks are attracted by the blood but dare not venture too close. They wait for the thirty-footer to finish her meal. There's usually plenty of scraps to go around. However, this time the large *Carcharocles* is greedy, leaving only a section of the back and ribs. The leftovers fall into the sea grass and are lost in the shifting sands. Ironically, the poor manatee's remains will find a river of their own some 28 million years later along the banks of the Chickasawhay.

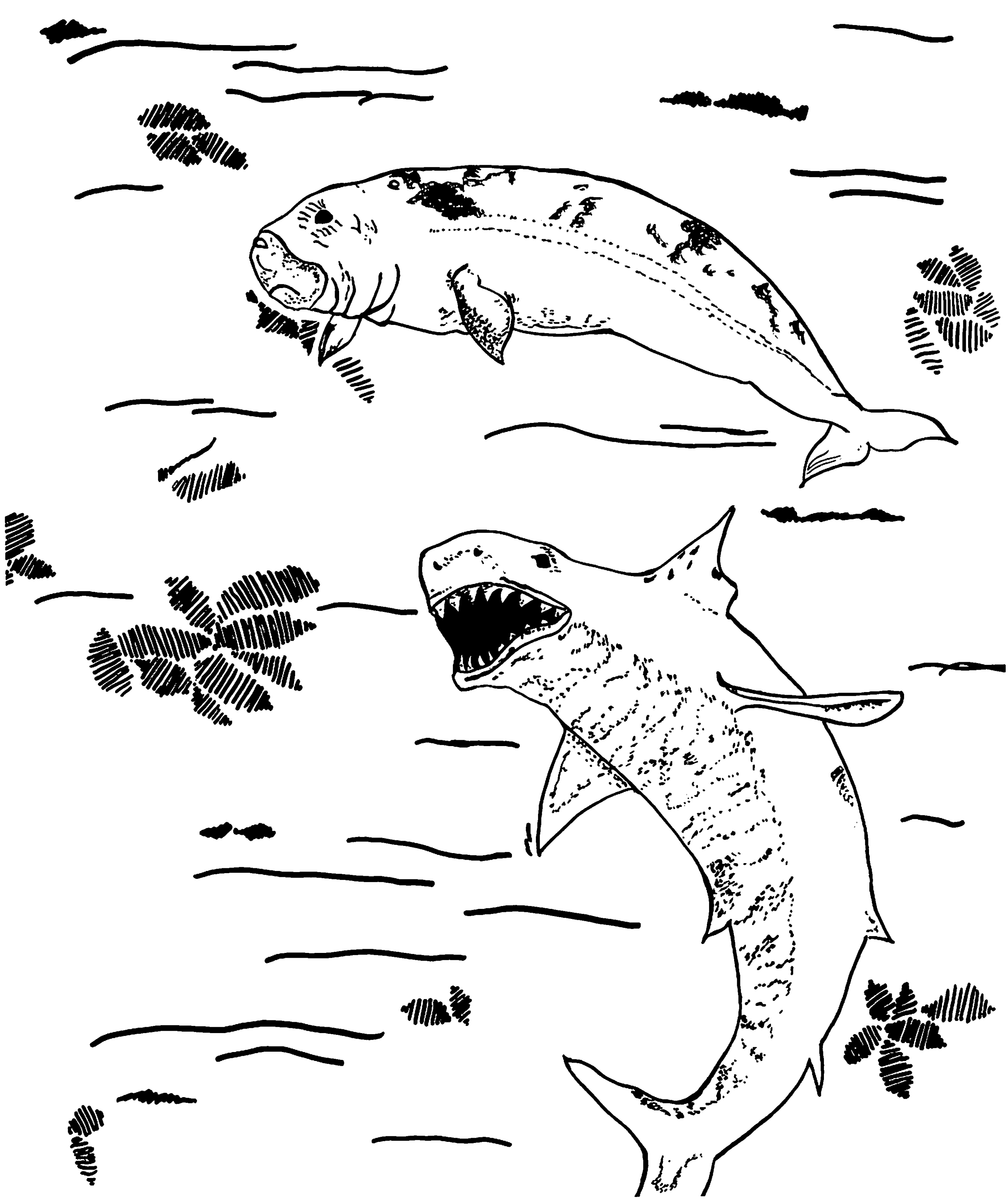


Figure 24. A day in the Late Oligocene of Mississippi. Waynesboro 28 million years ago by Katie Lightsey, St. Andrew's Middle School 6th grade. A *Carcharocles* shark stalks a dugong, a sea cow related to the manatee and closely related to fossil sea cow remains found in the Chickasawhay and Paynes Hammock formations.

SITE 19: WINDOW INTO THE EARLY MIOCENE

Deltas, Shallow Seas, and Volcanic Ash

Early Miocene Site

The Rocky Mountains in the Western Interior, which had been flattened by erosion in the early Tertiary, were exhumed by uplift in the Miocene. Miocene fill was shed from these mountains across the Great Plains and carried by river down the ancestral Mississippi Valley. So great was the load carried by the ancient Mississippi that the Miocene sediments beneath New Orleans extend to a depth of 12,000 feet. These sediments are a major source of oil and natural gas in southern Louisiana and of gas in Mobile Bay, Alabama. Associated with the rising of the Rockies and Great Plains was widespread volcanic activity. Westerly winds carried volcanic ash as far as Mississippi.

Microscopic glass beads from volcanic ash are common in Mississippi's lower Miocene deltaic sediments of the Catahoula Formation. When exposed above the water table, this glass dissolves, producing sandstones with a siliceous cement. These sandstones were used in the construction of Mississippi's Old Capitol Building (Moore et al., 1965, p. 108) and in the beautiful stonework at Piney Woods School. They are also responsible for the rapids along the popular canoe routes of the Strong and Okatoma rivers.

The roadside park at Merit where Highway 43 crosses Rials Creek in Simpson County southwest of Mendenhall is typical of a rocky Catahoula stream exposure. Just below the Highway 43 bridge, Rials Creek cuts though and flows over a sandstone ledge that forms a bench along the stream's right side. The writer remembers this park from his childhood almost 40 years ago, when his parents cut watermelons on the picnic tables, while he and his friends played below the falls. A recent visit to this site found it the same today as it was then—the same smell of white water along a clear creek and the same sight of water-swept sandstone infested with potholes. The enduring falls of the Merit Roadside Park is a testimony to the resistance of sandstone layers in the Catahoula Formation.

A Day in the Early Miocene of Mississippi:

Merit 20 Million Years Ago

Palm trees inhabit the sandy shoreline of a foundering river delta. Compaction of deltaic clays below is causing a drop in land elevation and a rise in sea level. In front of the sand beach is a shallow muddy sea floor with sandy shoals. A diverse group of mammals inhabits the delta plain, and a modern assemblage of marine organisms inhabits the ocean. So modern is the plant and animal life that the Miocene and following Pliocene epochs are placed together in the latter half of Tertiary time within a system called the Neogene. *Neos* is a Greek word meaning new, young, or recent. Unfortunately, the acidic ground water of Mississippi's Miocene delta eats away at bones and shells, leaving no trace of its early Neogene inhabitants.

Glassy volcanic ash is blowing in from the west. It clogs the streams with silt and lays down a fresh layer of sediment on the sea floor. Burrowing organisms soon break through this layer and thoroughly mix it with the sands and clays below, adding to the acidic nature of the substrate. Buried shells are leached and removed by solution, leaving no evidence of the formation's marine nature. However, while marine organisms leave no trace, palm trunks that float to sea are beautifully replaced by silica from weathered ash, turning to petrified logs. These logs are rare, and today are only found in stream gravels where the stream crosses the Catahoula outcrop belt.

SITE 20: WINDOW INTO THE PLIOCENE

Gravel-laden, Braided Streams Cross a Broad Alluvial Plain

Pliocene Site

In the Pliocene Epoch, the southern half of Mississippi was a broad alluvial plain with braided steams loaded with gravel. Much of the gravel came from Tennessee where the Nashville Dome was arching its back (Self, 1993). Here eroding Paleozoic limestones released large quantities of hard chert inclusions. Another source of gravel was the Appalachian Mountains in Alabama, which contributed quartzite pebbles as well as chert. Rivers draining these high points brought loads of gravel to Mississippi.

Some of the thickest Pliocene gravel deposits in Mississippi are in the Citronelle Formation at Crystal Springs. Here the gravel is mined and washed from numerous pits and sent to Jackson and surrounding areas by truck. These gravels contain semiprecious stones such as agates, carnelian, quartz crystal, jasper, and petrified wood. They also contain fossils of late Paleozoic age. A guidebook to rocks and fossils in these gravels is found in the June 1995 issue of *Mississippi Geology* (Dockery, 1995).

The former river-bottom gravels of the Citronelle Formation now cap the highest hills in southern Mississippi. Sands and gravels of this formation resist erosion. When the land rose in the late Pliocene, stream divides eroded more quickly than the bottoms, leaving the bottoms to stand in relief. Standing atop a Citronelle hill in the state's Piney Woods Physiographic Province, one realizes just how much land has eroded and washed out to sea since that time. The uplift of southern Mississippi was accompanied by a drop in the water table and intense weathering. This weathering gave the Citronelle its characteristic reddish brown color and produced ironstone conglomerates at its lower contact.

North and South America, which were separated in the Triassic, were reconnected by the closing of the Panama Isthmus in the Pliocene. At this time, North American mammals such as rabbits, mastodons, deer, camels, bears, dogs and cats migrated to South America, while the armadillos, sloths, porcupines, and opossums of South America migrated north (Stanley, 1986, p. 605). Before the appearance of North American carnivores in the Pliocene, South America's dominant terrestrial predators were giant flightless birds called phorusrhacoids (Marshall, 1994). These birds were as tall as a human and had powerful beaks and talons. However, they disappeared 2 million years ago, suggesting they were no match for North America's big cats.

A Day in the Pliocene of Mississippi:

Crystal Springs 3.5 Million Years Ago

A braided river flows through what is now Crystal Springs with many shifting bars of sand and gravel. Along the edges are scrub brush and willows. While thick forests occupy parts of northern Mississippi, the wandering stream channels in the south destroy the trees after only a few years of growth. Only those trees that grow quickly have a chance to reproduce here.

A great variety of mammals inhabits the southern Mississippi alluvial plain, but their bones are not preserved in the acidic soil. However, from Pliocene fossils found at two localities in Florida (Santa Fe River 1B in Gilchrist County and Haile 15A in Alachua County; Kurtén and Anderson, 1980), we know they included sloths, horses, llamas, tapirs, white-tail deer, mastodons, sabre-tooth tigers, raccoons, coyotes, dogs, rabbits, beavers, and armadillos (Webb, 1974).

In the Citronelle Formation, only the gravels, sands, and clays remain to tell of ages past. They indicate a time of uplift and fast, anastomosing streams. Not since Tuscaloosa time some 90 million years ago have rivers carried so much gravel into Mississippi.

SITE 21: WINDOW INTO THE LATE PLEISTOCENE

A Cold Climate with Spruce Forests and Giant Land Mammals

Pleistocene Site

The Pleistocene was a time of climatic cooling that produced at least four cycles of glaciation in North America with intervening warm periods. Some have suggested that the Holocene Period in which we live is only a brief interlude before the next glacial cycle. That's a scary thought. Another ice age would force the populations of Canada and the northern Midwest and Great Plains of the U.S. to move south or be buried in ice. Where would these people live? One possibility is that they could move to lands reclaimed from the sea. Accumulation of ice on the continents is accompanied by a corresponding drop in sea level. The downside of falling sea level is that all our port cities would become useless.

Problems of shifting habitats such as mentioned above plagued life in the Pleistocene. According to studies of ice cores from Greenland and Antarctica (Mayewski et al., 1996), climatic changes in the ice age were sudden and dramatic. Perhaps these changes were too dramatic for many of North America's large mammals, causing the extinction of the sabre-tooth tigers, giant bison, musk ox, horses, mastodons, mammoths, and giant ground sloths. Some of these extinctions have been attributed to the arrival of man in North America between 12,000 and 11,000 years ago (Kunz and Reanier, 1994) near the end of the Pleistocene. Fortunately, our ancestors survived the Pleistocene, but our less sophisticated cousins, the neanderthals of Europe, did not.

Unlike Mississippi's weathered Pliocene sediments, the state's Pleistocene deposits contain the bones of ancient mammals. These may be found in alluvial sediments across the state from the sand bars of the Mississippi River at Rosedale in Bolivar County to Tibbee Creek in Clay County. However, Pleistocene bones are found most frequently in the streams that cut the Loess Belt of western Mississippi. Here, bones preserved in the wind-blown dust we call loess are concentrated as lag deposits in the stream bed.

Daly (1992) lists 56 different Pleistocene mammals known from Mississippi. These include large animals such as lions, wolves, bears, giant beavers, pigs, llamas, deer, giant bison, musk ox, horses, zebras, tapirs, mastodons, mammoths, and giant ground sloths. Of these, the most commonly found, and perhaps the most spectacular, are the teeth and bones of mastodons. Unlike their elephant relatives, the savanna-loving woolly mammoths, mastodons were browsers of the spruce forests that covered Mississippi in the ice age. Such remains give their name to Mammoth Bayou at Natchez, a site noted by naturalists in the early 1800s and visited in 1846 by the famous English geologist Charles Lyell.

The age of mammal bones found in Mississippi's loess is late Pleistocene. In the early 1800s, a human pelvis was found in Mammoth Bayou along with the bones of extinct mammals. This find became known as Natchez Man and began a debate that lasted over a hundred years as to when the first humans arrived in Mississippi. Charles Lyell thought the pelvis had eroded from an Indian grave and mixed with older bones in the creek. Others argued that the pelvis was as strongly mineralized as the bones found with it. This debate was only recently put to rest when the radiocarbon age of Natchez Man and a ground-sloth bone found with it were determined using the University of Arizona's accelerator mass spectrometer. The results were: ground sloth 17,840 ± 125 years old and Natchez Man 5,580 ± 80 years old (Hamilton, 1990). Lyell was right; Natchez Man was Archaic but not a Paleo-Indian.

A Day in the Late Pleistocene of Mississippi:

Mammoth Bayou 17,800 Years Ago

An aging mastodon munches shrubbery in the cold fall air. His thick furry coat keeps him warm. Grazing on the Mississippi River flood plain below the high bluffs overlooking Mammoth Bayou, he surveys the mud-cracked, alluvial sediments along the western horizon. Other animals detect the wind shift and a blast from a westerly breeze. They flee the flood plain and seek shelter in forests to the east along the bluff line. A cold front is racing unabated across the flood plain's dry expanse. Bearing down on the scene is a five-hundred-foot wall of thick, suffocating dust.

Frequent flooding and shifting sands inhibit tree growth on the alluvial plain, making room for a variety of low shrubs. These shrubs provide wonderful grazing grounds for large hungry mammals, which forage while keeping a wary eye for rising dust storms from the west. At last the old mastodon spots the rising cloud, but all too late. Frogmore, Louisiana, is now covered beneath its veil.

The mastodon hurries eastward up Mammoth Bayou as the wind ruffles his fur. Dust clouds block the afternoon sun, spreading their dark shadows before him. Soon the dust overtakes him. Running is not possible in its smothering grasp. The large animal kneels down with its back to the wind, never to rise again. Dust piles up around its sides. When the storm is over only a dusty mound remains.

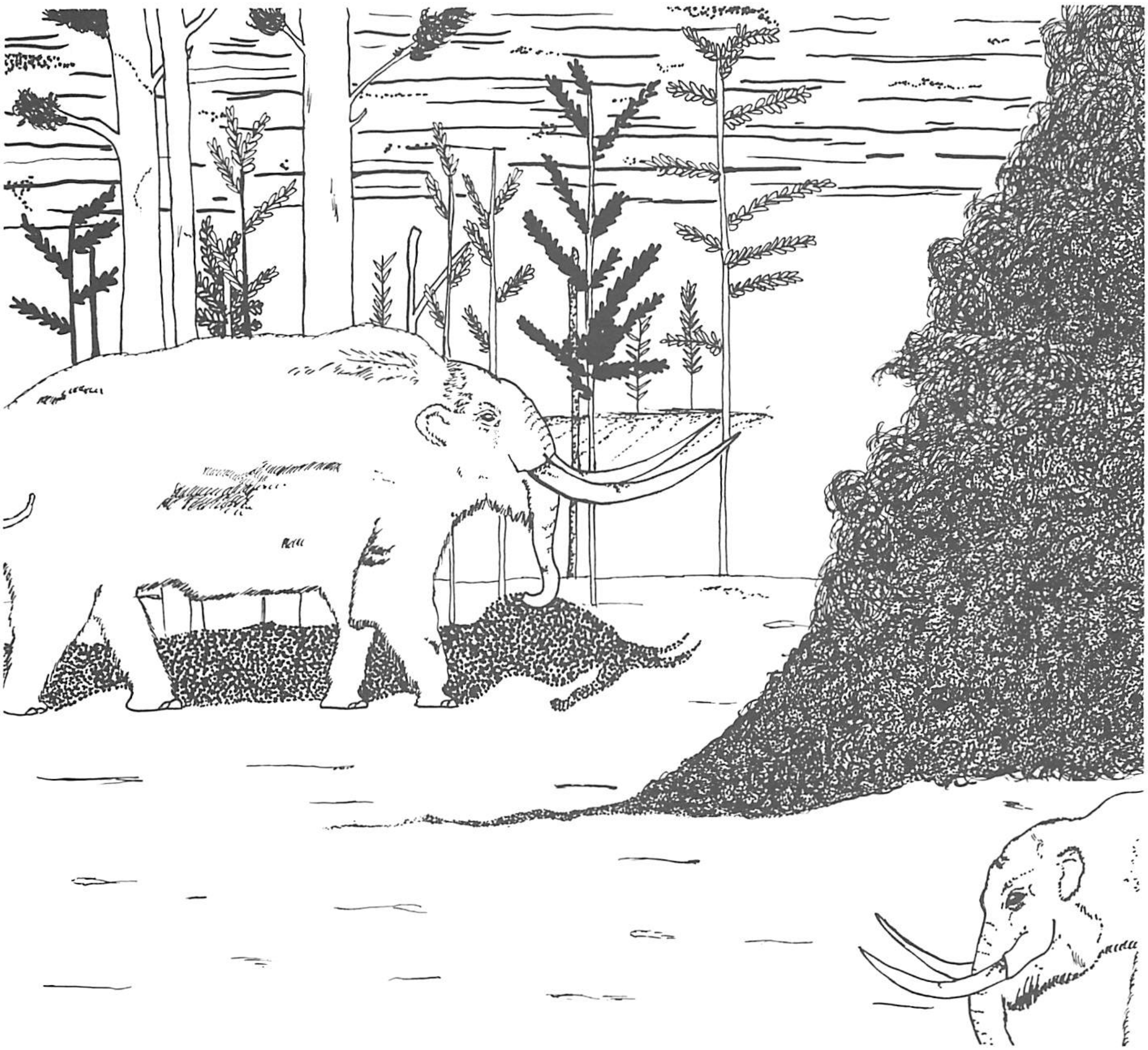


Figure 25. A day in the Late Pleistocene of Mississippi. Natchez 17,800 years ago by Katie Lightsey, St. Andrew's Middle School 6th grade. A mastodon watches an approaching dust storm.

SITE 22: WINDOW INTO THE LATE LATE PLEISTOCENE

Melting of the Laurentide Ice Sheet

Late Late Pleistocene Site

The Laurentide Ice Sheet was the last of at least four ice sheets to form over southeastern Canada and the Great Lakes region during the Pleistocene Epoch. This ice sheet contributed to the excavation of the Great Lakes and may have been 5,000 feet thick. So much frozen water was tied up in this and other Late Late Pleistocene ice sheets that sea level was some 400 feet lower than today. It was at this time, about 11,000 years ago, that people from Asia traveled a land bridge across the Bering Straits to be the first human inhabitants of North America.

Meltwater from Pleistocene ice sheets periodically flooded the Mississippi and Ohio river valleys. These floods carried large quantities of sand and gravel, forming valley train deposits in their wake. Much of the gravel consisted of chert stones derived from sedimentary rock, but igneous rocks were also common. The latter rocks were cut from bedrock as far north as Canada by the massive ice sheets and then carried south by the rivers.

Braided streams existed on the Mississippi and Ohio River flood plains for much of the Pleistocene Epoch. These streams had many small interconnecting channels rather than a single large one. Grass and brush lands developed between the channels and supported herds of buffalo and horses.

Today, the bones of Pleistocene mammals wash up on sand bars along the Mississippi River, being most common between Helena, Arkansas, and Greenville, Mississippi. One collection of over 1,300 bones, assembled by archaeologist John Connaway from Clarksdale, Mississippi, was recently donated to the Memphis Museum System. This collection contains specimens of many large ice-age mammals, including the skulls of big-horned buffalo and musk ox.

It is interesting to note here that for most of Pleistocene time the Mississippi River flowed west of Crowley's Ridge, a 250 mile-long ridge running north-south through Arkansas and Missouri. The Ohio River flowed east of this ridge, joining the Mississippi River somewhere south of Helena, Arkansas. Thus the Ohio River once flowed though northwestern Mississippi. However, this drainage pattern changed about 14,500 years ago when a catastrophic flood cut through Crowley's Ridge at Bell City - Oran Gap in Missouri, diverting flood waters to the St. Francis Basin on the eastern side (Saucier, 1994). So today the Mississippi River, not the Ohio River, forms Mississippi's northwestern border with Arkansas.

In the Late Late Pleistocene, meltwaters from the retreating Laurentide Ice Sheet accumulated behind a natural dam made of debris that had piled up in front of the ice sheet's earlier advance. A proglacial lake, Lake Agassiz (Teller, 1987), formed between the ice sheet and the dam. About 10,000 years ago, the dam of this huge lake burst, flooding the upper Mississippi River Basin and cutting a breach in Crowley's Ridge at Thebes Gap along the Illinois-Missouri state border. As torrents from the Mississippi River spilled onto the Ohio River flood plain, numerous Paleo-Indian sites of the Dalton period (which extended from about 10,500 to 9,500 years ago) were flooded. The change in the course of the Mississippi River was permanent, and it flows through Thebes Gap to this day.

The Great River Road State Park at Rosedale, Mississippi, is a place where visitors can see natural environments along the Mississippi River today. Before the rupture of Lake Agassiz 10,000 years ago, this park was most likely on the Arkansas side of the river. The Mississippi River has changed its course many times since then, laying down thick layers of sand and silt and forming the rich Delta soils. Underlying these sediments are the ancient, gravelly, braided-stream terrains on which Mississippi's first human inhabitants lived. Gravels from these terrains have been scoured from the river bottom and redeposited in a sandbar not far north of The Great River Road State Park. This sandbar is now the site of a county gravel-mining operation.

A Day in the Late Late Pleistocene of Mississippi when waters topped and breached Lake Agassiz's Dam:

The Great River Road State Park 10,000 Years Ago

Paleo-Indians of the Dalton Culture hide in the brush, waiting for passing white-tail deer. These graceful animals frequently come to drink from a nearby lake. Each Indian carries a long dart tipped with a serrated stone point, characteristic of this period. These points are tightly fastened to their shafts and, with the aid of a throwing stick to increase power, will easily penetrate the deer's hide.

It is the dry season, a warm late summer's day with puffy clouds against a blue sky. But, to the north, the warm weather has added more meltwater to Lake Agassiz than it can hold. Just days before, these waters topped Lake Agassiz's dam, sending an unseasonal flood through Thebes Gap and down the lower Mississippi River Valley.

The Indians note unusual anxiety in a herd of buffalo seeking high ground. Soon they see the glistening of water moving into the mud-cracked river bottoms around them. The Indians make a hasty retreat along the pathway toward home. Their camp site is many miles to the west on high ground near Crowley's Ridge.

Along their path, the Indians find that a stream they forded the previous day is now dangerously swollen. They must make a choice, a risky crossing or wait out the flood on the high ground of an old natural levee. Knowing it is the dry season, they make a decision that will cost them their lives. The Indians choose to wait, unaware of the large volume of water pouring through Thebes Gap hundreds of miles to the north.

In the days that follow, the surrounding high grounds will be flooded, forcing the Indians into the tree tops. There they will sit until one by one, exhausted and starved, they drop from their perches into the flood waters below.

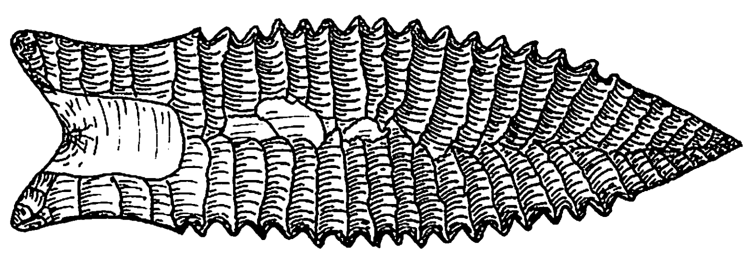


Figure 26. Paleo-Indian projectile point of the Dalton Culture drawn at actual size by Sam McGahey, archaeologist with the Mississippi Department of Archives and History.

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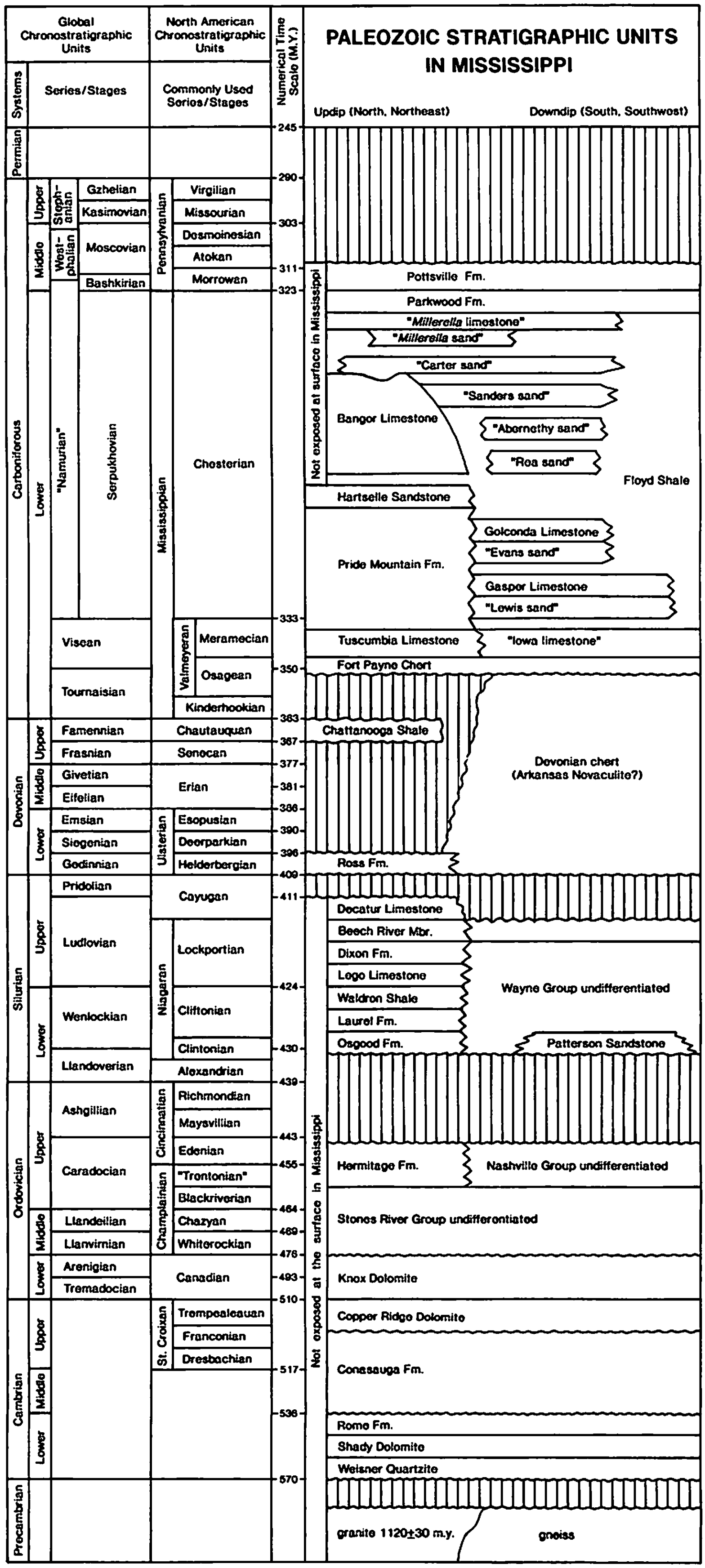
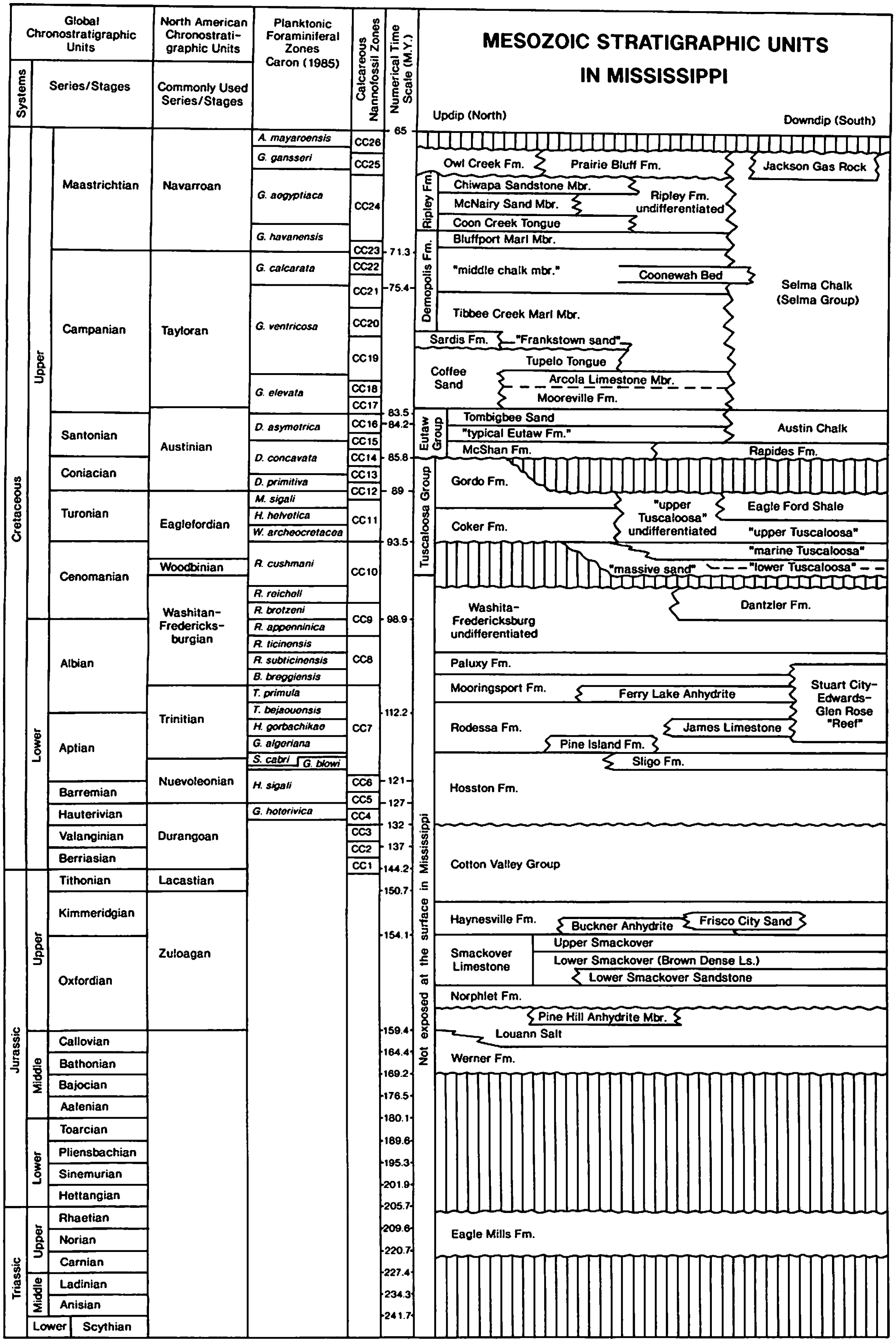
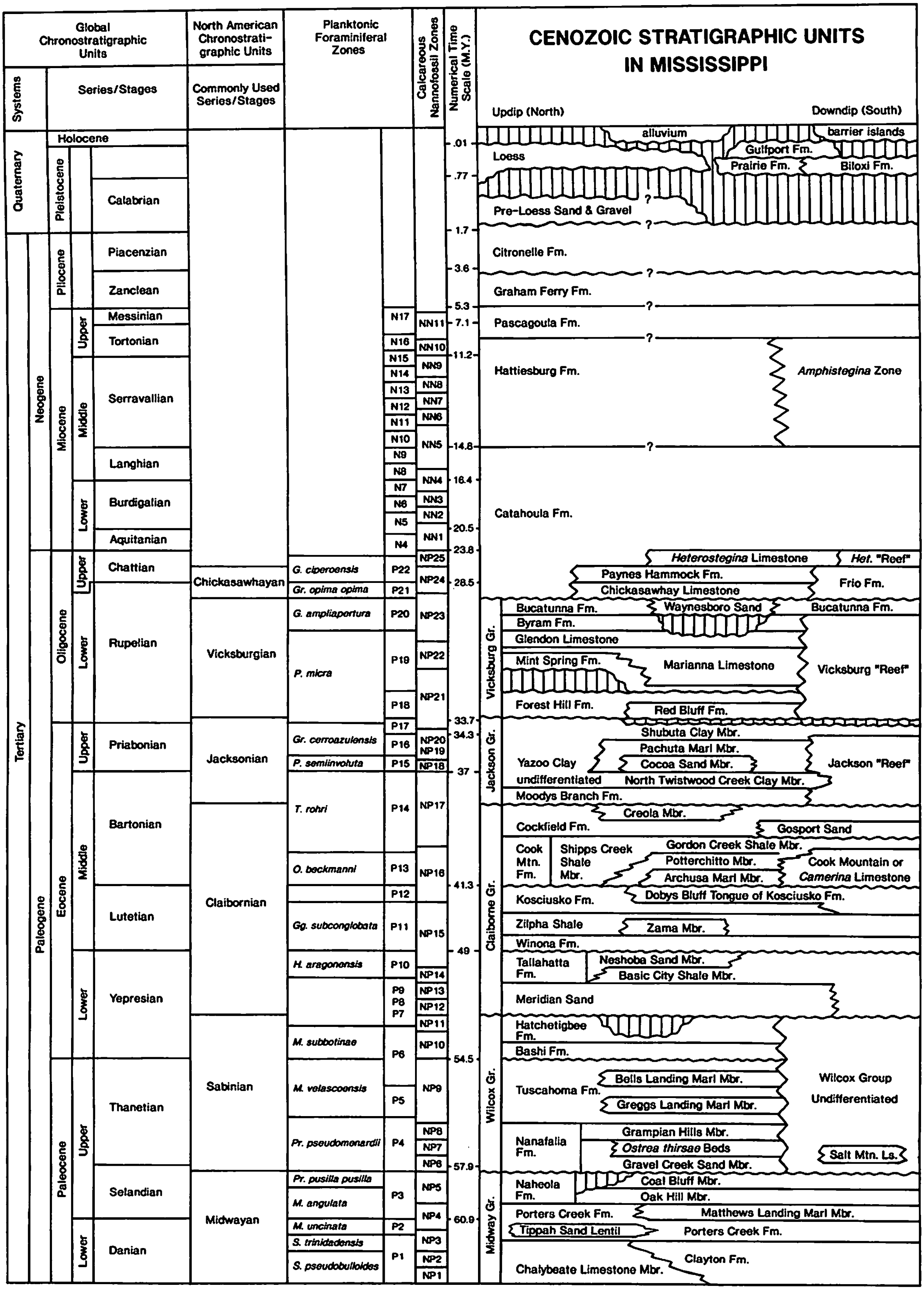
APPENDIX 1

The following Paleozoic, Mesozoic, and Cenozoic stratigraphic columns (from Dockery, 1996) show geologic formations and groups (including two or more formations) in the same sequence they would be found by drilling a deep well. They are given in ascending order from the oldest formation on bottom to the youngest at the top. These charts also show that a formation of one rock type (e.g., limestone) may grade laterally into another formation of the same age but of a different rock type (e.g., shale). Find the geologic formations given for sites 1-22, then highlight and number them for easy reference. To find the correct formation, use the geologic periods in the left-hand column and the numerical time scale in the center column as guides.


PALEOZOIC STRATIGRAPHIC UNITS IN MISSISSIPPI
Global Chronostratigraphic Units
North American Chronostratigraphic Units
Numerical Time Scale (M.Y.)
Systems
Series/Stages
Commonly Used Series/Stages
Updip (North, Northeast)
Downdip (South, Southwest)
Permian
Carboniferous
Upper
Middle
Lower
Steph-anian
West-phalian
"Namurian"
Gzhelian
Kasimovian
Moscovian
Bashkirian
Serpukhovian
Visean
Tournaisian
Pennsylvanian
Mississippian
Virgilian
Missourian
Desmoinesian
Atokan
Morrowan
Chesterian
Valmeyeran
Meramecian
Osagean
Kinderhookian
245
290
303
311
323
333
350
363
367
377
381
386
390
396
409
411
424
430
439
443
455
464
469
476
493
510
517
536
570
Not exposed at surface in Mississippi
Pottsville Fm.
Parkwood Fm.
"Millerella limestone"
"Millerella sand"
"Carter sand"
"Sanders sand"
Bangor Limestone
"Abernethy sand"
"Roa sand"
Floyd Shale
Hartselle Sandstone
Golconda Limestone
"Evans sand"
Pride Mountain Fm.
Gasper Limestone
"Lewis sand"
Tuscumbia Limestone
"Iowa limestone"
Fort Payne Chert
Devonian
Famennian
Frasnian
Givetian
Eifelian
Emsian
Siegenian
Gedinnian
Chautauquan
Senecan
Erian
Ulsterian
Esopusian
Deerparkian
Helderbergian
Chattanooga Shale
Devonian chert (Arkansas Novaculite?)
Ross Fm.
Silurian
Pridolian
Ludlovian
Wenlockian
Llandoverian
Cayugan
Niagaran
Lockportian
Cliftonian
Clintonian
Alexandrian
Decatur Limestone
Beech River Mbr.
Dixon Fm.
Lego Limestone
Waldron Shale
Laurel Fm.
Osgood Fm.
Wayne Group undifferentiated
Patterson Sandstone
Ordovician
Ashgillian
Caradocian
Llandeilian
Llanvirnian
Arenigian
Tremadocian
Cincinnatian
Champlainian
Richmondian
Maysvillian
Edenian
"Trentonian"
Blackriverian
Chazyan
Whiterockian
Canadian
Not exposed at the surface in Mississippi
Hermitage Fm.
Nashville Group undifferentiated
Stones River Group undifferentiated
Knox Dolomite
Cambrian
St. Croixan
Trempealeauan
Franconian
Dresbachian
Copper Ridge Dolomite
Conasauga Fm.
Rome Fm.
Shady Dolomite
Weisner Quartzite
Precambrian
granite 1120±30 m.y.
gneiss


MESOZOIC STRATIGRAPHIC UNITS IN MISSISSIPPI
Global Chronostratigraphic Units
Systems
Series/Stages
North American Chronostrati-graphic Units
Commonly Used Series/Stages
Planktonic Foraminiferal Zones Caron (1985)
Calcareous Nannofossil Zones
Numerical Time Scale (M.Y.)
Updip (North)
Downdip (South)
Cretaceous
Upper
Lower
Maastrichtian
Campanian
Santonian
Coniacian
Turonian
Cenomanian
Albian
Aptian
Barremian
Hauterivian
Valanginian
Berriasian
Jurassic
Tithonian
Kimmeridgian
Oxfordian
Middle
Callovian
Bathonian
Bajocian
Aalenian
Toarcian
Pliensbachian
Sinemurian
Hettangian
Triassic
Rhaetian
Norian
Carnian
Ladinian
Anisian
Scythian
Navarroan
Tayloran
Austinian
Eaglefordian
Woodbinian
Washitan-Fredericks-burgian
Trinitian
Nuevoleonian
Durangoan
Lacastian
Zuloagan
A. mayaroensis
G. gansseri
G. aegyptiaca
G. havanensis
G. calcarata
G. ventricosa
G. elevata
D. asymetrica
D. concavata
D. primitiva
M. sigali
H. helvetica
W. archeocretacea
R. cushmani
R. reicheli
R. brotzeni
R. appenninica
R. ticinensis
R. subticinensis
B. breggiensis
T. primula
T. bejaouensis
H. gorbachikae
G. algeriana
S. cabri
G. blowi
H. sigali
G. hoterivica
CC26
CC25
CC24
CC23
CC22
CC21
CC20
CC19
CC18
CC17
CC16
CC15
CC14
CC13
CC12
CC11
CC10
CC9
CC8
CC7
CC6
CC5
CC4
CC3
CC2
CC1
65
71.3
75.4
83.5
84.2
85.8
89
93.5
98.9
112.2
121
127
132
137
144.2
150.7
154.1
159.4
164.4
169.2
176.5
180.1
189.6
195.3
201.9
205.7
209.6
220.7
227.4
234.3
241.7
Owl Creek Fm.
Prairie Bluff Fm.
Jackson Gas Rock
Ripley Fm.
Chiwapa Sandstone Mbr.
McNairy Sand Mbr.
Ripley Fm. undifferentiated
Coon Creek Tongue
Bluffport Marl Mbr.
Demopolis Fm.
"middle chalk mbr."
Coonewah Bed
Selma Chalk (Selma Group)
Tibbee Creek Marl Mbr.
Sardis Fm.
"Frankstown sand"
Tupelo Tongue
Coffee Sand
Arcola Limestone Mbr.
Mooreville Fm.
Eutaw Group
Tombigbee Sand
"typical Eutaw Fm."
Austin Chalk
McShan Fm.
Rapides Fm.
Tuscaloosa Group
Gordo Fm.
"upper Tuscaloosa" undifferentiated
Eagle Ford Shale
Coker Fm.
"upper Tuscaloosa"
"marine Tuscaloosa"
"massive sand"
"lower Tuscaloosa"
Washita-Fredericksburg undifferentiated
Dantzler Fm.
Paluxy Fm.
Mooringsport Fm.
Ferry Lake Anhydrite
Stuart City-Edwards-Glen Rose "Reef"
Rodessa Fm.
James Limestone
Pine Island Fm.
Sligo Fm.
Hosston Fm.
Not exposed at the surface in Mississippi
Cotton Valley Group
Haynesville Fm.
Buckner Anhydrite
Frisco City Sand
Smackover Limestone
Upper Smackover
Lower Smackover (Brown Dense Ls.)
Lower Smackover Sandstone
Norphlet Fm.
Pine Hill Anhydrite Mbr.
Louann Salt
Werner Fm.
Eagle Mills Fm.


CENOZOIC STRATIGRAPHIC UNITS IN MISSISSIPPI
Global Chronostratigraphic Units
Systems
Series/Stages
North American Chronostratigraphic Units
Commonly Used Series/Stages
Planktonic Foraminiferal Zones
Calcareous Nannofossil Zones
Numerical Time Scale (M.Y.)
Updip (North)
Downdip (South)
Quaternary
Tertiary
Neogene
Paleogene
Holocene
Pleistocene
Pliocene
Miocene
Oligocene
Eocene
Paleocene
Upper
Middle
Lower
Calabrian
Piacenzian
Zanclean
Messinian
Tortonian
Serravallian
Langhian
Burdigalian
Aquitanian
Chattian
Rupelian
Priabonian
Bartonian
Lutetian
Ypresian
Thanetian
Selandian
Danian
Chickasawhayan
Vicksburgian
Jacksonian
Claibornian
Sabinian
Midwayan
G. ciperoensis
Gr. opima opima
G. ampliapertura
P. micra
Gr. cerroazulensis
P. semiinvoluta
T. rohri
O. beckmanni
Gg. subconglobata
H. aragonensis
M. subbotinae
M. velascoensis
Pr. pseudomenardii
Pr. pusilla pusilla
M. angulata
M. uncinata
S. trinidadensis
S. pseudobulloides
N17
N16
N15
N14
N13
N12
N11
N10
N9
N8
N7
N6
N5
N4
P22
P21
P20
P19
P18
P17
P16
P15
P14
P13
P12
P11
P10
P9
P8
P7
P6
P5
P4
P3
P2
P1
NN11
NN10
NN9
NN8
NN7
NN6
NN5
NN4
NN3
NN2
NN1
NP25
NP24
NP23
NP22
NP21
NP20
NP19
NP18
NP17
NP16
NP15
NP14
NP13
NP12
NP11
NP10
NP9
NP8
NP7
NP6
NP5
NP4
NP3
NP2
NP1
.01
.77
1.7
3.6
5.3
7.1
11.2
14.8
16.4
20.5
23.8
28.5
33.7
34.3
37
41.3
49
54.5
57.9
60.9
alluvium
barrier islands
Loess
Gulfport Fm.
Prairie Fm.
Biloxi Fm.
Pre-Loess Sand & Gravel
?
Citronelle Fm.
Graham Ferry Fm.
Pascagoula Fm.
Hattiesburg Fm.
Amphistegina Zone
Catahoula Fm.
Heterostegina Limestone
Het. "Reef"
Paynes Hammock Fm.
Chickasawhay Limestone
Frio Fm.
Vicksburg Gr.
Bucatunna Fm.
Waynesboro Sand
Bucatunna Fm.
Byram Fm.
Glendon Limestone
Mint Spring Fm.
Marianna Limestone
Vicksburg "Reef"
Forest Hill Fm.
Red Bluff Fm.
Jackson Gr.
Shubuta Clay Mbr.
Pachuta Marl Mbr.
Yazoo Clay undifferentiated
Cocoa Sand Mbr.
Jackson "Reef"
North Twistwood Creek Clay Mbr.
Moodys Branch Fm.
Claiborne Gr.
Creola Mbr.
Cockfield Fm.
Gosport Sand
Cook Mtn. Fm.
Shipps Creek Shale Mbr.
Gordon Creek Shale Mbr.
Potterchitto Mbr.
Archusa Marl Mbr.
Cook Mountain or Camerina Limestone
Kosciusko Fm.
Dobys Bluff Tongue of Kosciusko Fm.
Zilpha Shale
Zama Mbr.
Winona Fm.
Tallahatta Fm.
Neshoba Sand Mbr.
Basic City Shale Mbr.
Meridian Sand
Wilcox Gr.
Hatchetigbee Fm.
Bashi Fm.
Tuscahoma Fm.
Bells Landing Marl Mbr.
Greggs Landing Marl Mbr.
Wilcox Group Undifferentiated
Nanafalia Fm.
Grampian Hills Mbr.
Ostrea thirsae Beds
Gravel Creek Sand Mbr.
Salt Mtn. Ls.
Midway Gr.
Naheola Fm.
Coal Bluff Mbr.
Oak Hill Mbr.
Porters Creek Fm.
Matthews Landing Marl Mbr.
Tippah Sand Lentil
Porters Creek Fm.
Clayton Fm.
Chalybeate Limestone Mbr.

CIRCULAR 6. WINDOWS INTO MISSISSIPPI'S GEOLOGIC PAST: DOCKERY. Miss. Office of Geology, 1997