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FORENSIC GEOLOGY: GEOLOGIC INVESTIGATION AS A TOOL FOR ENFORCEMENT OF ENVIRONMENTAL REGULATIONS

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INTRODUCTION

As profit becomes the driving influence on business practices, and population increases swell the demand for housing, government is often forced to impose regulations to insure that the well-being of society and the rights of individuals and other competing interests do not get violated by the quest for more efficient and profitable production. Such has been the case with regulations governing the control of storm water runoff from large construction sites. When large areas of soil are denuded of vegetation during a construction project, rain water runoff often erodes large quantities of soil and mud, which are carried into adjoining streams, creating an unsightly pollution hazard for fish and wildlife, and on occasion even filling the streams with sediment to the point of creating a flash-flood hazard for nearby residents. Control of this runoff is accomplished with the installation of vegetative cover and sediment traps in the drainage system upstream of the discharge point at the construction site. Storm water discharge permits are required for large sites to insure that pollution control standards are met.

Usually the sediment-laden runoff can be easily traced upstream to its source, and that source can be remediated with erosion-control measures to halt the pollution. When there is uncertainty as to the source of sediment pollution in a stream, the geologic character of the offending sediment, the possible source areas, and the hydrodynamics of the stream system can be investigated to pinpoint the problem and correct it through enforcement of storm water control regulations.

The focus of this article concerns such an investigation conducted by the Office of Geology at the request of the Storm Water Section of the Office of Pollution Control to identify the source of pollution of a small subdivision lake in Mississippi.

SITE DESCRIPTION AND PROBLEM DEFINITION

The focus of this study is a small, dammed, urban subdivision lake built in the late 1950s and fed by a local stream with a

Figure 1. Sediment delta formed at the head of the subdivision lake.

limited watershed of approximately 450 acres. The stream historically drained an agricultural habitat with seasonally cultivated row crops. Historical aerial photographs showed the lake to have a muddy appearance, probably due to rain runoff from the freshly-plowed row crops. The lake had supported a prolific and varied aquatic fauna in the past, with no reported problems by surrounding residents since its construction.

In 1991 construction began on an extensive residential subdivision upstream from the lake within the drainage basin for the local stream. After construction began, residents around the lake noticed an increase in the sediment content of the lake water and rapid deposition of a sediment delta at the head of the lake where the stream entered (see Figure 1). According to local residents, the fish population of the lake greatly diminished with the increased pollution, and only bottom-feeding species survived. Complaints were filed, and the developer was issued a storm water discharge permit and instructed to install erosion controls to halt further runoff pollution of the stream. Some minor controls were installed by the developer, but the pollution continued, and even increased as more land was cleared for the subdivision development (see Figure 2).

Because there was some uncertainty about the amount of sediment introduced into the lake from each of the possible sources, the Office of Geology was asked to identify the source or sources of the sediment pollution, if possible, and to quantify the amount of sediment pollution contributed to the lake from each source. In order to do this, the sediment column in the lake bed had to be sampled, and strata within the column had to be correlated with specific localities within the drainage basin as well as specific ages corresponding to known historical events since the lake was constructed.

METHOD OF INVESTIGATION

Office of Geology personnel visited the site in late 1993 after a heavy rain event and photographed the area with video and 35 mm camera equipment. Because there were no discernible mineralogical differences between soils in the construction area and the agricultural areas, it was decided to investigate grain size differences in sediment derived from the different areas as a means of correlating source areas with the fill in the lake.

Sediment samples were collected from ditches within the construction site and from the stream bed directly downstream from the site. Samples were also collected from the stream bed of tributaries which drained only the agricultural row crop areas, as well as from the surface of the lake bottom. The wet samples were processed for grain size analysis using the pipette method described by Folk (1968) to separate silt and clay size particles. Four vibracores were collected from the delta built in the lake and from the lake bottom to determine the thickness of the lake fill and any indication of stratification in the sediment column which might be used to identify the sediment sources.

The vibracores were collected using the Office of Geology vibracore rig, which consists of a portable gasolinepowered concrete vibrator with the vibrating head clamped to a 3-inch diameter aluminum pipe. With the tubing upright on the lake bottom, the action of the vibrator liquefies wet sediment in and around the pipe, allowing the pipe to descend through the sediment and collect an undisturbed column of sediment inside the pipe. The open top end of the pipe is plugged to retain the sediment column as the pipe is pulled from the bottom with a winch cable. The sediment-filled pipe is later cut lengthwise and laid open to allow examination and analysis of the enclosed sediment column.

During another visit to the lake in the spring of 1994 ten more vibracores were collected to effectively sample the entire lake bottom, and the lake bottom was surveyed with a total station to record an accurate bathymetric map of the lake (Figure 3). The lake depths were surveyed from the top of the dam using a prism rod placed on the lake bottom, and the survey was tied to the elevation of the dam spillway.

All of the sample and core locations were verified using Global Positioning System (GPS) survey equipment for horizontal position placement within 1 meter. A U.S. Geological Survey 1:24,000 scale topographic map of the area was digitized in AutoCAD and used for sample placement outside of the immediate lake area. The lake perimeter was mapped with GPS equipment to calculate the area of the lake (14.6 acres). All data were transferred into ARC/INFO for spatial inquiry and volumetric calculations.

SAMPLE ANALYSIS RESULTS

Samples collected from the construction site and from the stream bed immediately below the site show a marked difference in grain size from samples collected in the stream bed currently draining only agricultural land. Samples collected from the surface of the lake bed show grain size distribution matching that of the construction site samples. The grain size of sediment from the agricultural source areas is significantly finer than that from the construction site and from the lake bottom surface (see Figure 4). This can be explained by the greater stream transport distance of the agricultural source material as well as the relatively fresh exposure of the construction site material and reduced weathering of that material. The results of the analysis clearly show that the bulk of the material near the surface of the lake bottom and in the stream bed came from the construction site, not from the agricultural areas.

CORE DESCRIPTIONS AND ANALYSIS

All of the vibracores were split and described within three days of collection. The length of the cores varied from 8.2 feet to 34 inches depending on the depth reached prior to the end of penetration by the vibrating pipe. Descriptions were done at the Office of Geology core and sample facility in

Figure 2. Construction site showing extensive soil erosion due to rain runoff.

Jackson, and the split cores were photographed immediately after opening.

The cored material consists of dark gray muddy silt and gray clay with several stratified layers of concentrated organic material ranging from 1/2 inch to 7 inches in thickness consisting of blackened leaf material and twigs. Some cores contain layers of coarser sand and gravel, and several cores contain preserved root zones. There is a slight decrease in grain size of the silt and clay material with depth in most of the cores, but this trend is not definitive. Most of the cores contain at least two distinct layers of concentrated organic material located near the top of the sediment column.

The fauna of the lake includes numerous bottom-feeding species, including mussels, which would likely rework the top layer of sediment on a regular basis and thus would disseminate any accumulated organic material in the sediment column, as well as digest it through normal feeding habits. The presence of two distinct organic accumulations in the top half of the sediment column is, therefore, unusual when compared with the

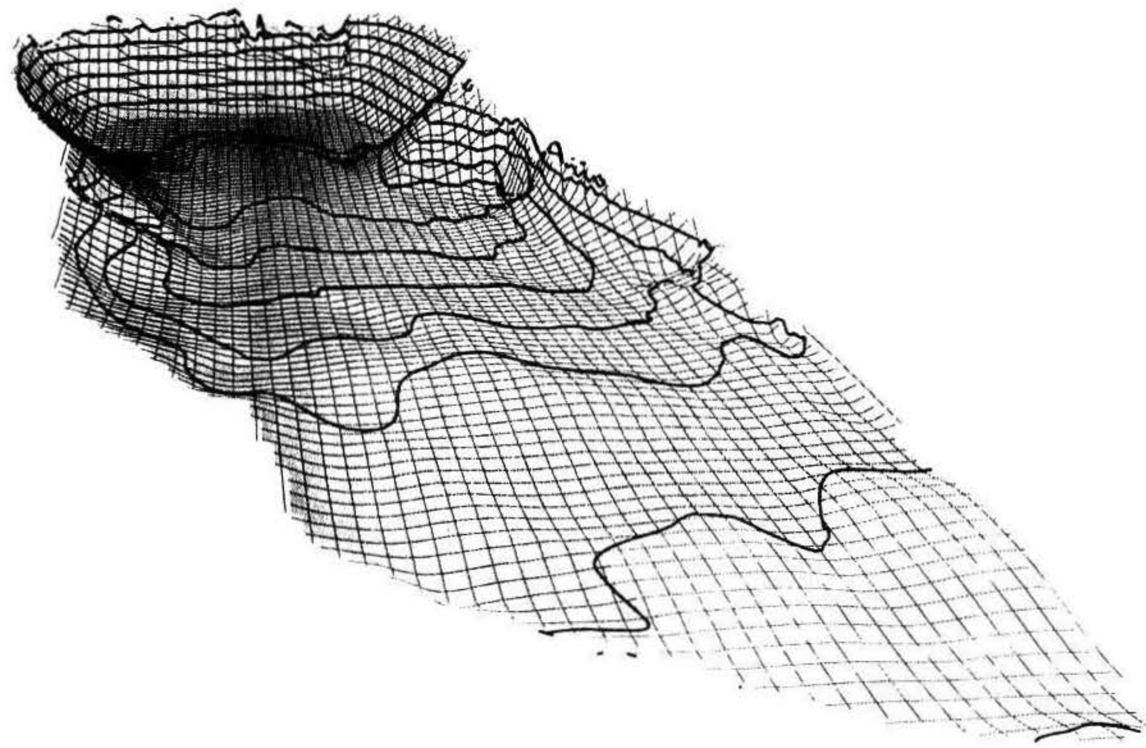

Figure 3. Perspective view of the present lake bathymetry. View is looking toward the dam from the head of the lake. Shaded area is below the water surface, and the contour interval is one foot.

lack of any noticeable organic material in the rest of the column.

The stream drainage area above the lake is dominated by a deciduous hardwood flora which contributes considerable leaf material to the stream during the fall defoliation. This material is carried downstream and accumulates in the lake each winter. Normally this leafy material would decompose naturally over the course of a year and be dispersed by bottom feeders in the lake. Preservation of concentrated organic layers such as those found in the cores could only be accomplished by rapid burial of the material under sediment in an anoxic environment.

Construction of the development upstream began in 1991, so there would have been at least two and possibly three annual defoliation events prior to collection of the cores in 1993 and 1994. Increased sediment deposition in the lake as a result of construction activities could easily have buried those leaves to produce the layers found in the cores. The lack of deeper organic layers in the cores indicates a much reduced sediment accumulation rate prior to the construction activity. Thus the two organic layers observed correspond to the fall defoliation events in 1992 and 1993.

Assuming that the lower organic layer in each core corresponds to the annual defoliation event in 1992, the thickness of sediment above that layer would equal the amount of sediment deposited in the lake due to construction activity since that time. The depth to the 1992 organic layer was measured in each core and subtracted from the depth of the lake to produce a map of the lake bathymetry prior to the construction activities upstream (Figure 5).

Most of the cores bottomed in a hard clay or sandy clay with gravel which showed a mottled, oxidized, orange appearance similar to a soil exposure surface. This zone corresponds to the surface of the ground prior to construction of the dam and filling of the lake with water. Depths to this surface were subtracted from the present lake depth to produce a bathymetric map of the lake before any sediment filling took place (Figure 6). Volumetric differences between each of these surfaces were calculated in ARC/INFO to derive the volume of sediment fill in the lake from its construction to 1992 and from 1992 to the present. Total sediment fill in the lake since the 1950s is approximately 71,000 cubic yards, and of that total approximately 29,000 cubic yards were added since the 1992 annual defoliation event due to construction activities upstream. This represents a twelve-fold increase in sediment pollution of the lake due to lack of erosion controls in the new subdivision development.

SUMMARY

A 14.6-acre urban lake in Mississippi at the terminus of a 450-acre drainage basin has been adversely affected by lack of erosion controls in a new subdivision development upstream. Investigation by the Office of Geology revealed a difference in grain size between sediment derived from the subdivision development and sediment from normal row crop activities in the drainage basin. Increased sediment deposition in the lake due to the construction activities preserved annual leaf defoliation accumulations in the lake which were previously disseminated by bottom-feeding organisms. Two annual leaf fall events were documented, corresponding to the approximate length of time since the construction activities started upstream.

Annual sediment fill in the lake since its construction in the late 1950s was approximately 1200 cubic yards per year prior to construction activity upstream. This increased twelve-fold to 14,500 cubic yards per year due to erosion at the construction site. Total pollution of the lake due to the construction amounts to approximately 29,000 cubic yards of silt and mud.

The developer agreed to implement a remediation plan for the lake and install additional erosion control measures at the

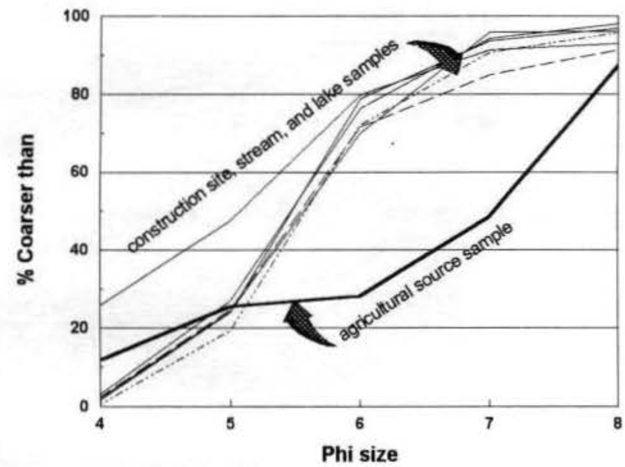

Figure 4. Grain size analysis data for samples from the construction site, the stream bed, the lake bed, and a stream tributary sourced from agricultural areas.

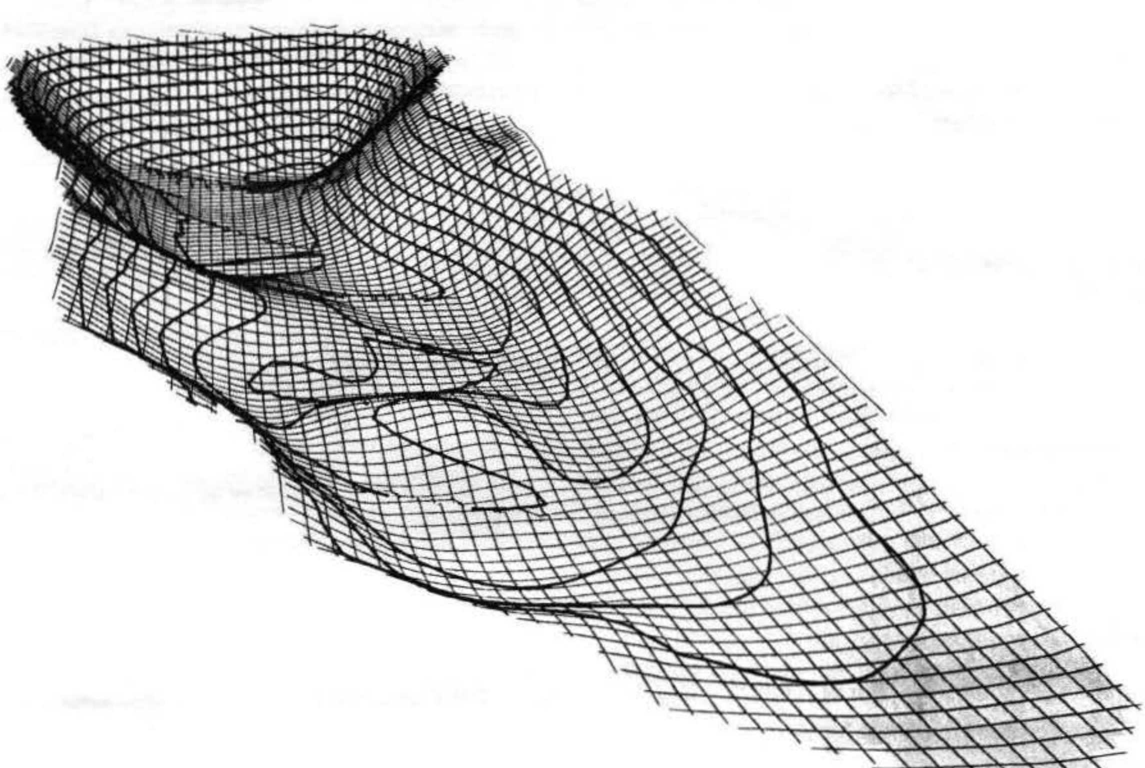

Figure 5. Perspective view of the lake bathymetry prior to the 1992 annual leaf fall event (calculated from core data). Contour interval is one foot.

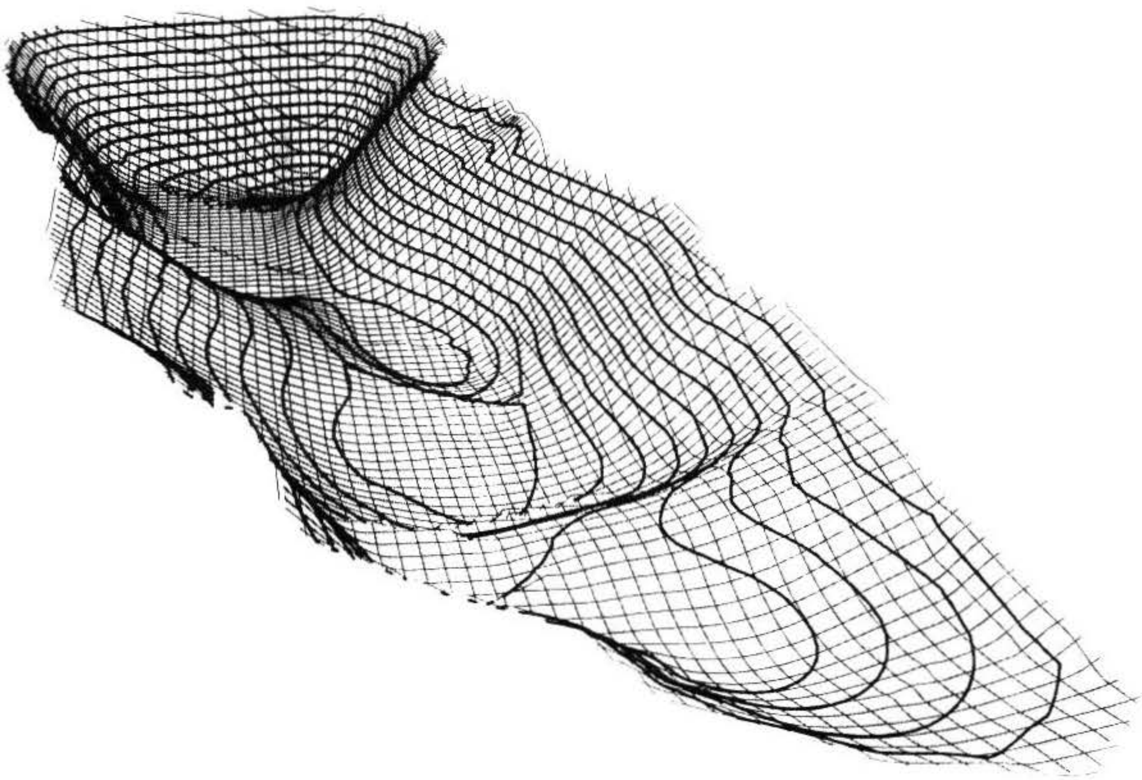

Figure 6. Perspective view of the original lake bathymetry in the 1950s prior to any sediment fill (calculated from core data). Contour interval is one foot.

construction site upstream as required by the storm water discharge regulations.

ACKNOWLEDGMENTS

Field work during this investigation, including surveying and the collection of samples and vibracores, was accomplished with the assistance of Peter Hutchins, Kenneth LaFleur, Milton Brumfield, Lynn Burrell, and Harry Wilson. Laboratory grain size analysis of the samples was done by Philip White. Barbara Yassin analyzed the data in ARC/INFO, and produced the bathymetric maps shown in figures 3, 5, and 6.

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CHARLES LYELL'S VISIT TO MISSISSIPPI IN 1846

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INTRODUCTION

In the years 1845 and 1846, the great British geologist Charles Lyell (1797-1875) made the second of his four visits to North America. He traveled widely in the eastern United States and Canada, studying the geology and natural history, visiting men of science, and giving lectures. This article marks the sesquicentennial of his visit to the State of Mississippi.

Charles Lyell was born November 14, 1797, on the family estate of Kinnordy, Forfarshire, Scotland (though he was raised in England). He became one of the most important men in the history of our science. His *Principles of Geology* (3 volumes, 1830-33), has been called "perhaps the most influential book in the history of geology" (Hallam, 1983). He is also known for his *Elements of Geology*, 1838, and *The Antiquity of Man*, 1863. He was knighted in 1848, so at the time of his visit to Mississippi it was Mister, not Sir, Charles Lyell.

Lyell, foremost proponent of uniformitarianism, was already a famous and respected geologist by the time of his tours of North America. He was well known in the United States. Many of his writings were reprinted in the *American Journal of Science* and other publications. His "Glossary of geological and other scientific terms" was printed in reports of the New Jersey Geological Survey in 1836, and also in the Fifth Pennsylvania Report. An American edition of his *Principles of Geology* was published in 1837, and his *Elements of Geology* in 1839, though both without compensation to the author (Silliman, 1995). The account of his travels on his first tour of North America in 1841-1842 was published in 1845 (Lyell, 1845). C. F. Berkstresser (1994), in a study of the development of the stratigraphic column in Kansas, mentioned that "Stratigraphy was not seriously considered by geologists traveling with the western explorers until 1845, when Lyell produced his first geologic map of the U.S." The Lyells were treated with great respect wherever they visited, and the local geologists were eager to serve as field guides (Arden, 1982).

LYELL'S SECOND VISIT TO THE UNITED STATES

The spring of 1996 marked the sesquicentennial of the visit of Charles Lyell to the deep South. He visited the coal fields and Tertiary deposits of Alabama and the Mississippi River and its delta in Louisiana. In Mississippi, Lyell made significant geological observations at Natchez, Vicksburg, and Jackson. Lyell's geological observations in Mississippi and Louisiana reinforced his uniformitarian views as expounded in the *Principles* (Brown, 1975a and b). He then traveled farther up the Mississippi River and toured the New Madrid, Missouri, area some 34 years after the series of great earthquakes in that region. Much of the traveling was done by steamboat, but Lyell used every available mode of transportation. Lyell's wife traveled with him, though she would stay in town during some of his geological excursions.

Most of the information for this article comes from Lyell's account of his travels during 1845 and 1846, published in New York in 1849 as *A Second Visit to the United States of North America*, in two volumes. In this book he notes his observations on geology and other aspects of natural history, and also reports his observations on education, religion, plantation life, and government. Lyell's book provides an interesting insight into life in this region 150 years ago. Unattributed quotations in this article are from this book. Some of the dates are given exactly in the book and are cited here with confidence. Other dates are not given exactly and are estimated here to within a day or two.

The first part of Lyell's second journey to North America is outlined here to put the trip in perspective. The journey began on September 4, 1845, when Charles Lyell and his wife left Liverpool, England, bound for Halifax and Boston. On September 13, 1845, aboard the steamship *Britannia*, Lyell observed a large iceberg for the first time in his life. This was very important to him because one of the major geological questions of the day was an explanation of drift, striations, and erratic boulders. Lyell believed that drifting ice was responsible for these features. The Lyells landed at Halifax and then Boston; they toured Maine and other parts of New England. On October 7, 1845, Lyell and his wife climbed a snow-free Mt. Washington, New Hampshire. Later in October, 1845, they returned to Boston and saw the streets covered with placards proclaiming the "SEA SERPENT ALIVE" to be exhibited by Mr. Koch. This hydrarchos, or water king, was the leviathan of the Book of Job (chapter 41). Lyell determined it to be the zeuglodon, an Eocene whale, with the vertebrae of several specimens joined together and arranged in a serpentine manner. Lyell later visited the site in Alabama where Koch had excavated the remains.

On December 4, 1845, Lyell was entertained by Professor Benjamin Silliman and his son in New Haven, as he was traveling from Boston to New York on his journey to the southern United States. Next Lyell studied the geology and visited local naturalists through Washington, D. C., Virginia, North Carolina, South Carolina, and Georgia. Lyell spent some time in Alabama, studying the coal beds and the Cretaceous and Tertiary rocks and fossils.

Charles Lyell first entered Mississippi on February 23, 1846, when he passed between the mainland and offshore islands at night en route by steamer from Mobile to New Orleans. He made no geological observations on this leg of the journey because it was at night. The Lyells stayed a couple of weeks in New Orleans, enjoying the cosmopolitan city. Lyell made some geological excursions from New Orleans. He visited the mouth of the Mississippi River and attempted a calculation of the amount of time required to build the delta, considering changes since the earliest French maps were made and the amount of sediment carried in the water (Lyell, 1847a). Lyell's visit to Louisiana and his influence on later writers on Louisiana geology was described by Skinner (1976). On March 10, 1846, Lyell left New Orleans, traveling up the Mississippi River by steamboat; his travel book contains several observations of oxbow lakes.

Lyell next saw the State of Mississippi at the bluffs at Fort Adams ("a very picturesque line of precipices") and Ellis's Cliffs, observing white sand at both. These bluffs are on the east side of the river in southwestern Mississippi.

NATCHEZ

Some of Lyell's most important scientific observations during his visit to Mississippi were made in the vicinity of Natchez, which town he reached on or about March 13, 1846. For this reason, and to illustrate Lyell's style of writing, the following lengthy quotation is made from his *Second Visit*.

"At Natchez (where I rejoined my wife), there is a fine range of bluffs, several miles long, and more than 200 feet in perpendicular height, the base of which is washed by the river. The lower strata, laid open to view, consist of gravel and sand, destitute of organic remains, except some wood and silicified corals, and other fossils, which have been derived from older rocks; while the upper sixty feet are composed of yellow loam, presenting, as it wastes away, a vertical face toward the river. From the surface of this clayey precipice are seen, projecting in relief, the whitened and perfect shells of land-snails, of the genera *Helix*, *Helicina*, *Pupa*, *Cyclostoma*, *Achatina*, and *Succinea*. These shells, of which we collected twenty species, are all specifically identical with those now inhabiting the valley of the Mississippi.

"The resemblance of this loam to that fluviatile silt of the valley of the Rhine, between Cologne and Basle, which is generally called 'loess' and 'lehm' in Alsace, is most perfect. In both countries the genera of shells are the same, and as, in the ancient alluvium of the Rhine, the loam sometimes passes into a lacustrine deposit containing shells of the genera *Lymnea*, *Planorbis*, and *Cyclas*, so I found at Washington, about seven miles inland, or eastward from Natchez, a similar passage of the American loam into a deposit evidently formed in a pond or lake. It consisted of marl containing shells of *Lymnea*, *Planorbis*, *Paludina*, *Physa*, and *Cyclas*, specifically agreeing with testacea now inhabiting the United States. With the land-shells before mentioned are found, at different depths in the loam, the remains of the mastodon; and in clay, immediately under the loam, and above the sand and gravel, entire skeletons have been met with the megalonyx, associated with the bones of the horse, bear, stag, ox, and other quadrupeds, for the most part, if not all, of extinct species. This great loamy formation, with terrestrial and fresh-water shells, extends horizontally for about twelve miles inland, or eastward from the river, forming a platform about 200 feet high above the great plain of the Mississippi. In consequence, however, of the incoherent and destructible nature of the sandy clay, every streamlet flowing over what must originally have been a level table-land, has cut out for itself, in its way to the Mississippi, a deep gully or ravine. This excavating process has, of late years, proceeded with accelerated speed, especially in the course of the last thirty or thirty-five years. Some attribute the increased erosive action to partial clearings of the native forest, a cause of which the power has been remarkably displayed, as before stated, within the last twenty years, in Georgia. Others refer the change mainly to the effects of the great earthquake of New Madrid, in 1811-12 by which this region was much fissured, ponds being dried up and many landslips caused.

"In company with Dr. Dickeson and Colonel Wales, I visited a narrow valley, hollowed out through the shelly loam recently named 'the Mammoth ravine,' from the fossils found there. Colonel Wiley, a proprietor of that part of the State of Mississippi, who knew the country well before the year 1812, assured me that this ravine, although now seven miles long, and in some parts sixty feet deep, with its numerous ramifications, has been entirely formed since the earthquake. He himself had plowed some of the land exactly over one spot which the gully now traverses.

"A considerable sensation was recently caused in the public mind, both in America and Europe, by the announcement of the discovery of a fossil human bone, so associated with the remains of extinct quadrupeds, in 'the Mammoth ravine,' as to prove that man must have co-existed with the megalonyx and its contemporaries. Dr. Dickeson showed me the bone in question, admitted by all anatomists to be part of a human pelvis, and being a fragment of the *os innominatum*. He felt persuaded that it had been taken out of the clay underlying the loam, in the ravine above alluded to, about six miles from Natchez. I examined the perpendicular cliffs, which bound a part of this water-course, where the loam, unsolidified as it is, retains its verticality, and found land-shells in great numbers at the depth of about thirty feet from the top. I was informed that the fossil remains of the mammoth (a name commonly applied in the United States to the mastodon) had been obtained, together with the bones of some other extinct mammalia, from below these shells in the undermined cliff. I could not ascertain, however, that the human pelvis had been actually dug out in the presence of a geologist, or any practiced observer, and its position unequivocally ascertained. Like most of the other fossils, it was, I believe, picked up in the bed of the stream, which would simply imply that it had been washed out of the cliffs. But the evidence of the antiquity of the bone depends entirely on the part of the precipice from which it was derived. It was stained black, as if buried in a peaty or vegetable soil, and may have been dislodged from some old Indian grave near the top, in which case it may only have been five, ten, or twenty centuries old; whereas, if it was really found in situ at the base of the precipice, its age would more probably exceed 100,000 years, as I shall endeavor to show in a subsequent chapter. Such a position, in fact, if well authenticated, would prove that man had lived in North America before the last great revolution in the physical geography of this continent had been accomplished; in other words, that our race was more ancient than the modern valley, alluvial plain, and delta of the Mississippi—nay, what is more, was antecedent to the bluffs of Port Hudson and Natchez, already described. Now that elevated freshwater formation, as I shall by and by endeavor to show, is the remnant of a river-plain and delta of extremely high antiquity; and it would follow, if the human race was equally ancient, that it co-existed with one group of terrestrial mammalia, and, having survived its extinction, had seen another group of quadrupeds succeed and replace it."

Lyell's comparison of the loess of Mississippi with that of the Rhine valley was a significant observation. His belief in the fluvial and lacustrine origin of the loess, however, backed by the weight of his reputation, may have retarded later geologists' acceptance of the eolian theory of loess origin.

The story of Natchez Man was a fascinating scientific mystery for 145 years. In 1845 Montroville W. Dickeson, M.D., found the pelvis of a 16-year-old human male at Mammoth Bayou, near Natchez, associated with bones of such extinct Pleistocene mammals as ground sloths, mastodons, horses, and bison. The find created a sensation, as alluded to above. He showed the bone to Charles Lyell when he visited Natchez the next year, and he and B. L. C. Wailes accompanied Lyell to the "Mammoth ravine," called Mammoth Bayou on the current topographic maps. Calvin S. Brown has warned us about Dr. Dickeson, whom he described (1926) as "a Philadelphia showman and archeologist, whose methods and conclusions were perhaps not always strictly scientific." Benjamin Leonard Covington Wailes (1797-1862) was a Natchez-area planter, naturalist, historian, and founder of Jefferson College. He would be one of the first geologists of the Mississippi Geological Survey and the author of the first book on the geology of Mississippi, published in 1854. Lyell was Wailes' house guest in 1846 (Sydnor, 1938).

Lyell saw the bone and visited the bayou on March 14, 1846. Although the quotation above from the 1849 travel book sounds ambiguous, in a scientific article Lyell (1847b) more clearly concluded that the pelvis probably came from an old but not ancient Indian burial and that it had washed into the stream bed with the Pleistocene mammal bones.

In spite of the doubts of Lyell, Wailes, and other scientists (Lyell, 1847b; Sydnor, 1938), there was continued sporadic discussion in the literature through the years of the age of Natchez Man and what it might tell us about the antiquity of man in the New World. Tests of fluorine content of the pelvis and a sloth bone in 1895 confirmed that both were mineralized and presumably Pleistocene. Debate by the experts continued on and off. In 1990 the pelvis and ground sloth bones were sent to the University of Arizona Accelerator Mass Spectrometer for radiocarbon dating (Hamilton, 1990). The results: ground sloth 17,840 ±125 years old; Natchez Man 5580 ±80 years old. Lyell was correct.

On March 15, Lyell went on an excursion by ferry across the Mississippi River to Vidalia, Louisiana, with a Mr. Davis, who showed him his plantation. They were joined by the engineer Mr. Forshey and looked at the recently cut off oxbow Lake Concordia.

The Lyells left Natchez by steamboat on March 17, 1846. On March 18, 1846, Lyell arrived at Grand Gulf and examined the bluff. He described it as "about 180 feet high, the uppermost 60 feet, composed, as at Natchez, of yellow loam or loess, beneath which was white quartzose sand, partially concreted into solid sandstone, which is quarried here for building. From the summit, the river-plain to the westward seemed as level, blue, and boundless as the ocean." Along the way upriver, Lyell remarked on the magnitude of the Mississippi River. "Yet, in spite of the occasional undermining of forests on its banks, it may be truly characterized as 'strong, without rage;' absorbing, as it does, in its course, one great tributary after another, several of them scarcely inferior in width to itself, without widening its channel, and in this manner carrying down noiselessly to the sea its vast column of water and solid matter, while the greater part of its alluvial plain is left undisturbed."

VICKSBURG AND JACKSON

On March 19, 1846, Lyell arrived at Vicksburg, where he found the upper part of the bluff composed of loess as at Natchez, and the lower part of "Eocene" marine deposits, from which he collected many shells and corals. These rocks are today mapped as the Oligocene Vicksburg Group.

On March 19-20, 1846, Lyell went by railroad to Jackson, the state capital, to collect marine fossils. Along the way, he noted that "For the first ten miles, the cars traversed a table-land, corresponding in height with the summit of the bluff at Vicksburg, and preserving an even surface, except where gullies had been hollowed out in the soft shelly loam and loess." This observation was in keeping with his ideas about the mode of origin of the loess, as described at

Natchez. He also remarked about the perpendicularity of the loess in natural bluffs and cuts, "although composed of materials wholly unconsolidated." Lyell arrived in Jackson on the 19th with no contacts or letters of introduction. As was his custom in such a situation while traveling, he asked at a pharmacy for anyone interested in geology. He was in luck this day, as he was directed to Dr. Gist, a physician on the floor above, who had read his work on geology. Lyell reports that "... within ten minutes of my 'landing' from the cars, we were on our way together to explore the dried-up channel of a small tributary of the Pearl River, where I found a rich harvest of fossil marine shells and zoophytes." David Dockery has suggested to me that the locality was probably Town Creek, with exposures of the Eocene Moodys Branch Formation.

On the 20th Lyell made a geological excursion (not described in the travelogue) and visited the State House and Governor's Mansion, then returned to Vicksburg by train.

The remainder of Lyell's visit to Mississippi consisted of a continuation of his travel up the river from Vicksburg to Memphis, Tennessee, which he reached March 24, 1846. He described this leg of the journey as monotonous and wearisome. "The aspect of things, day after day, is so exactly similar, that it might seem as necessary to take astronomical observations, in order to discover what progress one has made, as if the voyage were in mid-Atlantic." On March 23 "some variety was afforded by a squall of wind, accompanied by lightning. I never expected to see waves of such magnitude...."

Lyell continued up the river, arriving March 25, 1846, at New Madrid, where the great earthquakes had occurred 34 years before. There he searched for evidence remaining from the earthquakes and observed sand-blows, fissures, a lake that had been drained by the earthquake, and an area of "sunk country" where "all the trees of a date prior to 1811, although standing erect and entire, are dead and leafless."

After New Madrid, the Lyells continued upstream and entered the Ohio River. In his travelogue, for the date March 29, Lyell recorded an observation on a recurring theme, but which in this instance may be of interest to readers of this journal. "On reaching the mouth of the Wabash River, which divides Illinois from Indiana, I learnt that when the ice breaks up there in the spring, it is often packed into such masses that, before melting, they float down with gravel frozen on to them as far as New Madrid. This fact may explain the coarseness of the materials observable in the shoals of the Mississippi, at low water, near Natchez, and still farther down; and may perhaps throw light on some large boulders, of a former period, in the ancient gravel below the shelly loam of Natchez."

On March 29, 1846, the Lyells stopped at New Harmony, Indiana, and were entertained by State Geologist Dr. and Mrs. David Dale Owen. Templeton (1895) gave an account of the unscientific excavation of an Indian burial during this visit that Lyell was not in charge of and does not relate in his travelogue. On April 5, 1846, Lyell studied a Devonian coral reef with many species of corals and crinoids on the Ohio River at New Albany, Indiana, opposite Louisville. Their journey continued through Cincinnati, Pittsburgh, Philadelphia, to New York, where he visited his publisher, and back to Boston. On June 1, 1846, the Lyells sailed from Boston, again in the *Britannia*, to Halifax, and thence across the Atlantic. On June 7, 1846, Lyell again observed icebergs, looking for rocks or soil being transported, since this would be evidence for his idea that erratics and other glacial deposits and features were thus formed. On June 13, 1846, Lyell and his wife arrived at Liverpool, nine months and nine days after leaving that port.

SIGNIFICANCE OF LYELL'S OBSERVATIONS

While he was in Mississippi, Lyell made important observations in support of the uniformitarian ideas described in his *Principles of Geology*. This was one of the goals of his tour (Silliman, 1996). He collected statistical data about rates of growth of the delta of the Mississippi River. He sought information about the antiquity of man. More generally, Lyell was looking for evidence with which scientists could convince the population at large about the "earth's antiquity, together with the history of successive races of organic beings" (Lyell, 1847a).

Lyell was the first, I believe, to identify the loess of Mississippi and compare it with that of the Rhine valley.

Some of Lyell's more significant observations were made when he was in the company of local naturalists. This is to be expected because it was his habit to seek out knowledgeable people in each area, pump them for information, and have them direct him to significant collections and geological features. Silliman (1995) has described the difficulties that arose after charges of intellectual piracy were made during Lyell's first visit to the U. S. I have not located any evidence of what Mississippi's scientists thought of Lyell during his visit here, other than an apparent eagerness to help.

It is interesting to speculate that perhaps Lyell's 1846 visit to Mississippi had some impact on the work toward organization of our first geological survey, which was attempted in the 1848 session of the legislature and accomplished in 1850. He did visit the State House and the Governor's Mansion while in Jackson March 20. Brown (1975b) reported that in 1847 M. W. Philips of Mississippi wrote to the prominent New York State Geologist James Hall for help in finding a geologist for a survey. Brown (1975b) further speculated that Lyell may have suggested the Englishman John Millington (1779-1868) for that job when he was the house guest of B. L. C. Wailes. Millington was elected to the chair of Natural Science at the newly organized University of Mississippi in 1848 (and was the first faculty member to report to duty) and became the first State Geologist of Mississippi in 1850 (Holmes, 1923; Gladden, 1933).

Basically, it is interesting to learn something about the visit of the great geologist to Mississippi, so that we can celebrate the sesquicentennial of that visit.

FINAL NOTE

Please note that it is not too soon to begin your preparations for the celebration of the bicentennial of the birth of Charles Lyell, November 14, 1797, on the family estate of Kinnordy, Forfarshire, Scotland. (The year 1997 is also the bicentennial of the death of another great British geologist important to the development of our science, James Hutton, and of the birth of our B. L. C. Wailes, on August 1.) Lyell died in London on February 22, 1875, and was buried in Westminster Abbey.

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BROODING IN THE LATE CRETACEOUS GASTROPOD *GYRODES*?

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INTRODUCTION

A steinkern of *Gyrodes abyssinus* (Morton, 1834) collected from a phosphatic bed in the Prairie Bluff Formation (Cretaceous, Maastrichtian) at Moscow Landing on the Tombigbee River in Sumter County, Alabama, has a cluster of 24 pits on the body whorl with two stray pits closer to the aperture. Upon examination by the collector Earl Manning, these pits were found to be the well-preserved, external molds of juvenile *Gyrodes* shells with their apertures against the peripheral surface of the parent(?) steinkern. This find was reported by Dockery and Manning (1995) but never illustrated.

The phosphatic bed from which the *Gyrodes* steinkern was collected is one meter below the top of the Prairie Bluff Formation and is locally cut by channel sands at the base of the Clayton Formation. This bed is indicated by "paisley" symbols in the measured section of Smith (1989, fig. 2.3.6, p. 69). A photograph of the outcrop labelling the phosphatic bed is given in Mancini et al. (1989, fig. 4B, p. 97); the bed is shown as sample 2 in section 2a of fig. 2 (p. 95) of that same paper. Measured sections of Moscow Landing are also given in Mancini and Tew (1991, p. 24; 1992, p. 30).

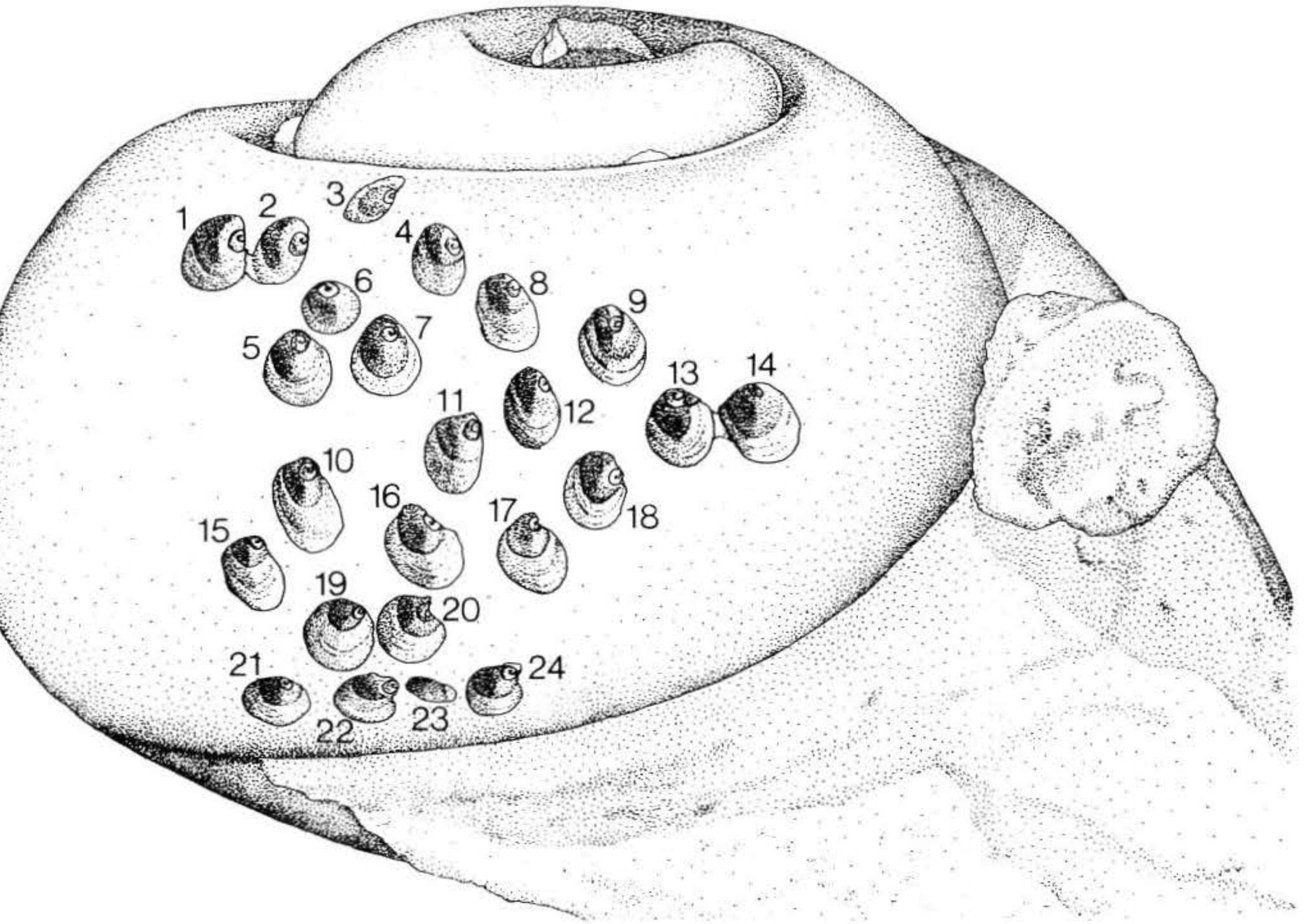
DISCUSSION

The drawing is from a photo-enlargement of the steinkern, showing the alignment of the young *Gyrodes*. This "motherhood steinkern," as coined by Earl Manning on the label, is 31.5 mm in width and 27.5 mm in height (full dimensions are not shown in the figure). The juveniles range from 1.5 mm to 2.0 mm in width and are clustered on the body whorl at 20° to 100° with strays at 165°. Three aspects of the clustering indicate that the juveniles were alive when buried in the "mother" shell. First, the individuals are regularly spaced along a curved surface rather than randomly gathered in a low spot and are grouped in a V-shaped pattern that points toward the shell's interior. Secondly, all but the juvenile labeled as no. 23 have their apertures pressed against the exterior of the steinkern, which was once the interior shell surface. Thirdly, and most interesting, all are in close alignment with their apices pointing to that of the "parent" shell.

It is possible that a parent *Gyrodes* laid its eggs in a vacant shell of the same species and that the hatchlings took refuge inside, or perhaps that the eggs washed into the shell by chance. However, it seems more probable that this population of young was a brood that survived the death of the mother only to be buried alive within her shell. The mother could have become the meal of a crab, leaving the brood to cling for dear life against the interior of her empty shell. Fossil crabs are often found in association with mollusks in Gulf Coast Cretaceous sediments. If the latter is true, this is the first evidence that *Gyrodes* is an ovoviviparous gastropod and the first report of ovoviviparousness in any naticid. The rapidly expanding body whorl of *Gyrodes* is larger than that of most naticids and may represent a special accommodation for brooding.

Evidence of brooding in *Gyrodes* may support the argument of some against the placement of this genus in the Family Naticidae. However, *Gyrodes* is the largest naticiform shell known from the Late Cretaceous of the Gulf Coast and is the only one capable of drilling a 6-mm-diameter, naticid-like, bore hole such as noted in a large *Cyprimeria* (bivalve) shell from the Coffee Sand of Mississippi.

Though brooding has not previously been reported within the Naticidae, it is present in other gastropod taxa and has been noted in Gulf Coast and New Zealand fossil turritellids. Some of these occurrences as recorded by Marwick (1971) include: *Turritella cumberlandica* Conrad and *Turritella indenta* Conrad of the Miocene of Maryland (Burns, 1899); *Turritella alumensis* Mansfield of the Miocene of Florida (Sutton, 1935); *Turritella pilsbryi* Gardner of the Miocene of Virginia (Gardner, 1948; Palmer, 1958); and *Zeacolpus taranakiensis* Marwick of the Miocene of New Zealand (Marwick, 1971). In these reports, randomly-oriented, juvenile shells were noted within the matrix of the body whorl of the adult. The fact that certain living turritellids, such as *Turritella gunni* Reeve of New South Wales (Peile, 1922), are ovoviviparous strongly supports the view that



Steinkern of *Gyrodes abyssinus* (Morton, 1834) with brood(?). Drawing by David White from photo-enlargement (x5.7) and with specimen at hand. Figured specimen number 1793 MGS (Mississippi Geological Survey).

such associations of juveniles and adults as fossils are indicative of broods and not just small shells washed into an empty adult shell of the same species.

ACKNOWLEDGMENTS

The writer greatly appreciates the contributions of Earl Manning who collected the *Gyrodes* steinkern and recognized its importance. Also, helpful comments concerning the first report of this specimen (Dockery and Manning, 1995) were received from Warren Allmon of the Paleontological Research Institution, Ithaca, New York, Klaus Bandel of the University of Hamburg, Hamburg, Germany, Alan Beu of the Institute of Geological and Nuclear Sciences Ltd., Lower Hutt, New Zealand, LouElla Saul of the Natural History Museum of Los Angeles County, California, Richard Squires of California State University, Northridge, California, Anders Warén of the Swedish Museum of Natural History, Stockholm, Sweden, and Ellis Yochelson of the U. S. Museum of Natural History, Washington, D. C. (retired). Berry Tew and Charles Smith helped with references concerning Moscow Landing.

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OSTREA ARROSIS FROM THE NANAFALIA FORMATION OF MISSISSIPPI

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Mississippi Office of Geology

INTRODUCTION

The absence of age-diagnostic guide fossils in the lower Wilcox Group of Mississippi makes surface mapping difficult if not problematic. Hughes (1958, p. 157-160) was the only one to recognize fossiliferous lower Wilcox marine deposits within the state. He correlated fossiliferous marine sands along Highway 39 north of DeKalb, Mississippi, with the *Ostrea thirsae* beds of the Nanafalia Formation of Alabama. However, the Highway 39 locality lacked the guide fossil *Ostrea* (=*Odontogryphaea*) *thirsae* and consisted largely of planicostate venericard casts in friable sand. More recently this outcrop was mapped by David Thompson as the Tuscahoma Formation.

Mississippi Office of Geology test hole PT3 in eastern Lauderdale County and test hole PT5 in southern Kemper County encountered oyster-bearing fossiliferous sands in the Grampian Hills Member of the Nanafalia Formation. Rather than *Odontogryphaea thirsae* (Gabb, 1862) these sands contained *Ostrea arrosis* Aldrich, 1904, an oyster common only in the Nanafalia of eastern Alabama on the Pea River. Also present below the oyster-bearing sand in PT3 were planicostate venericards believed to be *Venericardia* (*Venericor*) *nanaplata* Gardner and Bowles, 1939, which, according to Toulmin (1977, Table 2), are most common in association with *Ostrea arrosis* at the Pea River locality ADa-2.

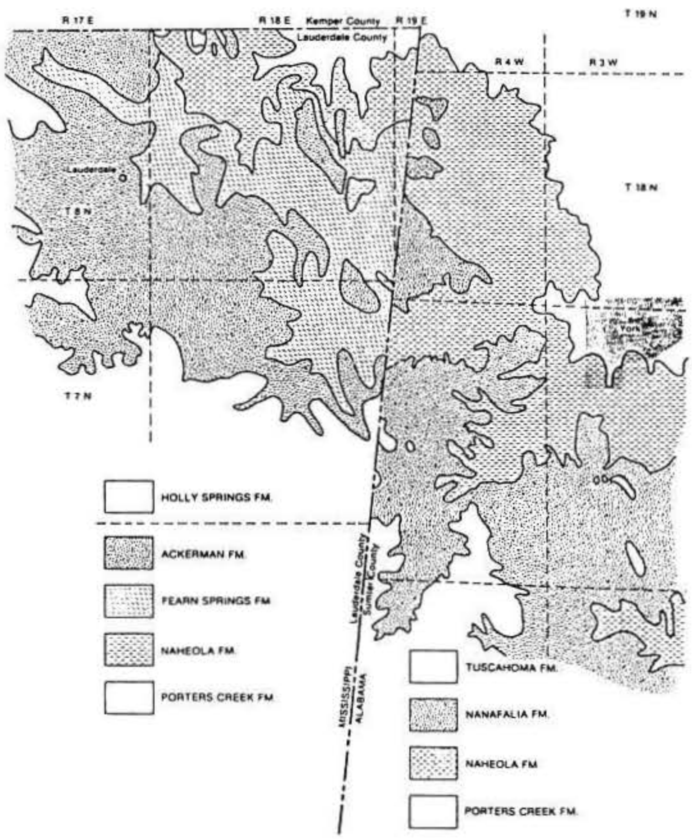

Figure 1. Composite of Foster's 1940 geologic map of Lauderdale County, Mississippi, and Sanford and Ellard's 1978 geologic map of Sumter County, Alabama.

MIDWAY-WILCOX STRATIGRAPHY

The Paleocene-Eocene stratigraphy of the Midway and Wilcox groups is well understood in its type area of southern Alabama where marine beds contain diagnostic fossils and can be easily mapped. Unfortunately, many of these beds lose their marine character near the Mississippi-Alabama state line as the outcrop belt turns toward the north. The lack of diagnostic marine fossils in Mississippi's upper Midway and Wilcox section led early workers to construct their own stratigraphy for the state. Lowe (1913) subdivided the Wilcox into three formations, the "Ackerman beds," consisting of clays, sands, and lignites in the lower Wilcox, the middle "Holly Springs Sands," and the "Grenada Beds," consisting of upper Wilcox clays and lignites. Mellen (1939) recognized an additional unit in the Wilcox Group, the Fearn Springs Formation. This formation contained clays, sands, and lignites that rested disconformably above the kaolinitic clays of the Betheden Formation and below the more sandy sediments of the Ackerman Formation. Mellen's (1939) Betheden Formation was supposedly a Paleocene lateritic soil developed on the Porters Creek Formation of the upper Midway Group. Correlations of these units with those in Alabama were problematic, and later controversy

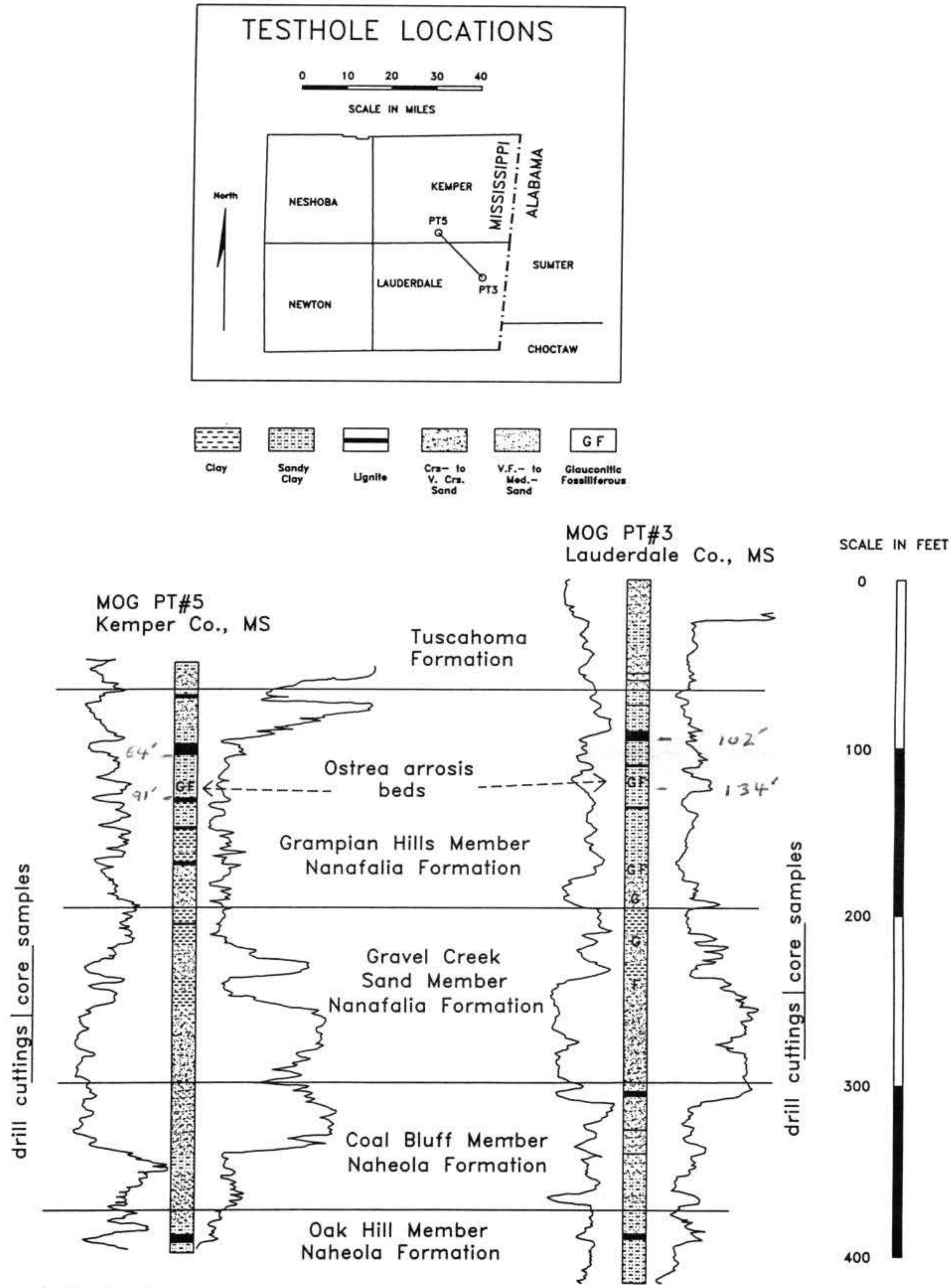

Figure 2. Stratigraphy of test holes PT3 and PT5.

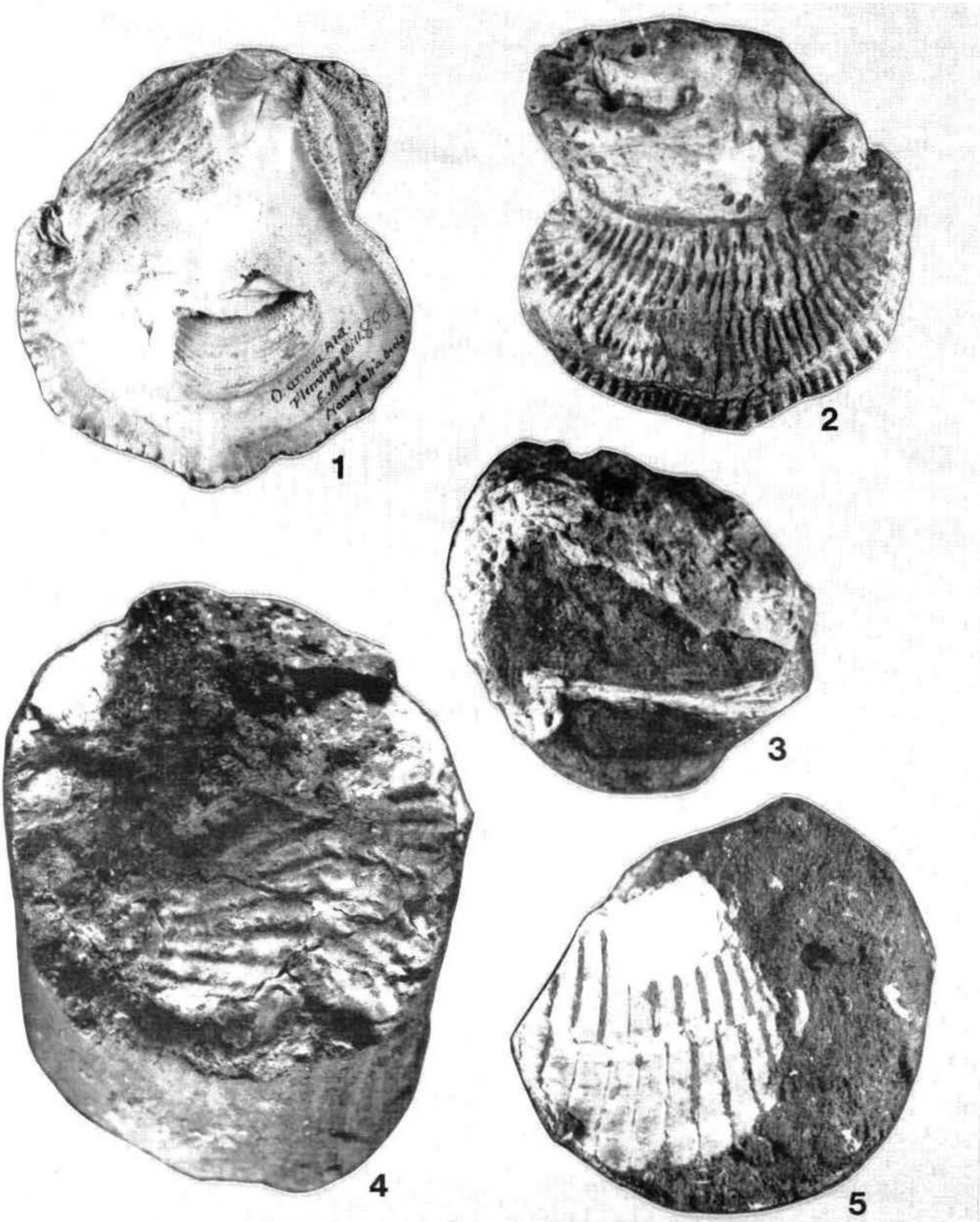

Plate 1. Figures 1-2, *Ostrea arrosis* Aldrich, 1904, left valve, GSA 186-1 (=Aldrich Collection no. 850), locality ADa-2, height 111 mm, width 103 mm. Figure 3, *Ostrea arrosis* with left valve at top and right valve below as cut in core of PT3. Figure 4, *Ostrea arrosis* ribbed left valve in core of PT3 between 123 and 133 feet below surface. Figure 5, *Venericardia* (*Venericor*) *nanaplata* Gardner and Bowles, 1939, in core of PT3 between 176 and 178 feet below surface.

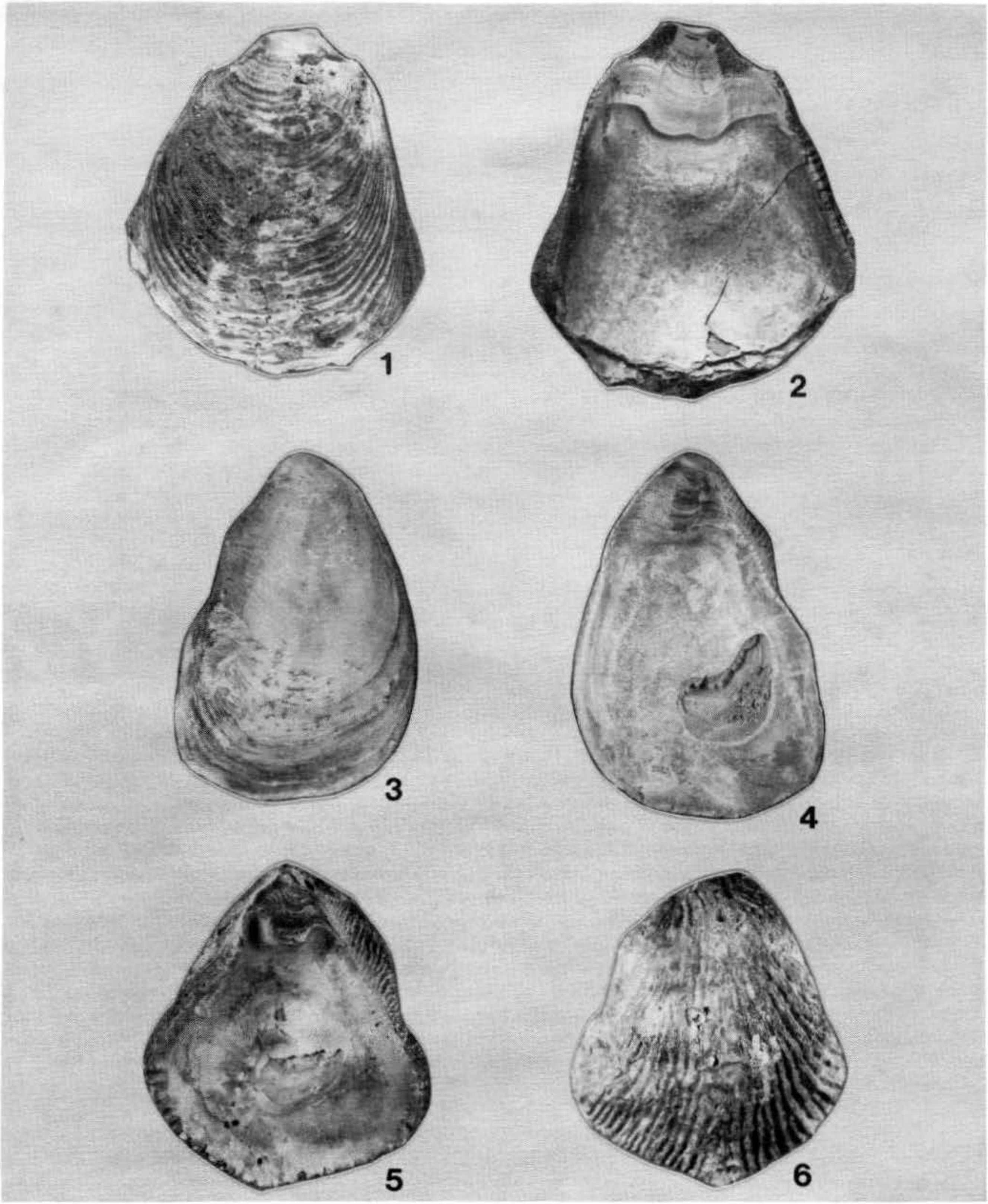

Plate 2. Figures 1-2, *Ostrea arrosis* Aldrich, 1904, incomplete right valve from core of PT3 between 123 and 133 feet below surface, height (incomplete) 57 mm, width 50 mm. Figures 3-4, *Ostrea arrosis*, right valve, GSA 186-2, locality ADa-2, height 72 mm, width 50 mm. Figures 5-6, *Ostrea arrosis*, left valve, GSA 186-3, locality ADa-2, height 87 mm, width 77 mm.

concerning the stratigraphic placement of the Fearn Springs Formation prompted Mellen (1950) to write a bulletin on the subject entitled "Status of Fearn Springs Formation."

Mississippi's local Midway-Wilcox stratigraphy as described above was utilized by Foster (1940) in his geologic report of Lauderdale County. As illustrated in Figure 1, Foster's geologic map of Lauderdale County shows a profound "state-line fault" when joined with the adjacent Sumter County, Alabama, map of Sanford and Ellard (1978). From this figure, it is clear that Mellen's Fearn Springs Formation is equivalent to the upper Naheola Formation of the Midway Group in Alabama while the Ackerman Formation is equivalent to the Nanafalia Formation of the Wilcox Group. The upper Midway and lower Wilcox stratigraphy of Lauderdale County was recently re-mapped on 7.5-minute quadrangle sheets by David Thompson (in press). These maps recognize the classical Midway and Wilcox units of the Alabama type area as shown in the stratigraphic correlation of test holes PT3 and PT5 in Figure 2.

In a section largely devoid of fossils and where thick sands may appear in units of different ages, lignite seams and clay-rich intervals provide useful marker beds in mapping the Midway and Wilcox of Mississippi. When rare fossils are present, they can provide confirmation to the mapper's work. Such was the case in cored intervals of test holes PT3 and PT5 in Lauderdale and Kemper counties. Occurring in a clay-rich zone mapped as the Grampian Hills Member of the Nanafalia Formation were fossiliferous marine beds containing oysters. These oysters were determined to be new occurrences of *Ostrea arrosis* Aldrich, 1904. Previously, this oyster was only known from the Nanafalia Formation of Alabama where it is common at Toulmin's (1977) locality ADa-2 on the Pea River (Becks Mill) in Dale County, Alabama. Another marine sand in PT3 43 feet below the oyster-bearing zone contained planicostate venericards. Based on their size, these were determined to be *Venericardia (Venericor) nanaplata* Gardner and Bowles, 1939, which are also common in the Nanafalia Formation at locality ADa-2.

OSTREA ARROSIS ALDRICH, 1904

Aldrich (1904) described *Ostrea arrosis* as having an oval, thick, lower (left) valve with close-set ribs on the surface (exterior) and a smaller and thinner upper (right) valve with fine, raised, growth lines on the exterior. The interior margins of both valves had crenulations near the beaks, and the right valve fit inside the left upon the crenulations. He also noted that in some specimens the beaks were bent strongly to one side.

Plate 1, figures 1 and 2 show a ribbed left valve of *Ostrea arrosis* from the Aldrich collection at the Geological Survey of Alabama. The middle of a left valve was cored in test hole PT3 as shown in figure 4. A cross section of both left and right valves encountered in PT3 is shown in figure 3. Figure 5 of Plate 1 shows the posterior portion of the right valve of *Venericardia (Venericor) nanaplata* Gardner and Bowles, 1939.

Plate 2 shows the concentric growth lines and crenulate anterior margins of a right valve from PT3 in figures 1 and 2 and of a right valve from Toulmin's locality ADa-2 in figures 3 and 4. Figures 5 and 6 are of a moderate-sized left valve from ADa-2. The only difference noted between specimens from PT3 and ADa-2 is that those from ADa-2 often have the beaks bent strongly to one side.

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The writers wish to acknowledge Andrew K. Rindsberg and the Geological Survey of Alabama for the loan of certain specimens figured here.

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