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NORM STUDY COMPLETES FIRST PROJECT YEAR IN MISSISSIPPI

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INTRODUCTION

There is a lack of scientific data with respect to the concentrations and isotopic compositions of uranium, thorium, and radium in the produced formation fluids (brines), precipitates, and sludges generated with the operation of oil and gas wells in Mississippi. These radioactive elements when contained in the formation fluids are referred to as NORM, which is an acronym for naturally occurring radioactive materials. When they are technologically enhanced during oil and gas production activities resulting in the formation of scale (precipitates) and sludges they are termed TENORM (technologically enhanced naturally occurring radioactive materials). As a result of this lack of data no scientifically sound theses may be developed concerning the presence of these radionuclides in the fluid (brine), precipitate (scale), or sludge phases. Also, there is little or no published information on the relative amounts or isotopic compositions of NORM in Mississippi, even though Mississippi oil and gas production produces vast amounts of formation water. Over the period of just one year, 1997 for example, Mississippi produced over 39,372,963,584 liters (10,402,368,186 gallons or 247,675,433 barrels) of formation water associated with hydrocarbon production from 41 oil and gas producing counties across the state.

Figure 1 is a pie chart of the generalized sources and amounts of radiation we are exposed to in our environment. The illustration is to acquaint the reader with the many and varied radiation scenarios. The amount of NORM contained in brines is extremely low. To add perspective to the issue of NORM please refer to Figure 2.

Initial published studies have indicated that the main contributor to NORM in oil and gas production is radium. Further, assumptions have been made concerning this issue especially with respect to the isotopic composition of the radium, i.e. ^{228}Ra versus ^{226}Ra, found in NORM. ^{228}Ra is a product in the decay chain of thorium-232 and ^{226}Ra is the daughter product of the naturally occurring uranium-238 decay series. Few studies have been made concerning the isotopic composition of naturally occurring radium. It has been assumed that ^{228}Ra and ^{226}Ra are present in equal amounts. This assumption has not been supported or refuted in the literature. The underlying significance is that ^{226}Ra, which has a half-life of approximately 1,620 years, undergoes radioactive decay by emitting an alpha particle and a gamma ray; and ^{228}Ra, which has

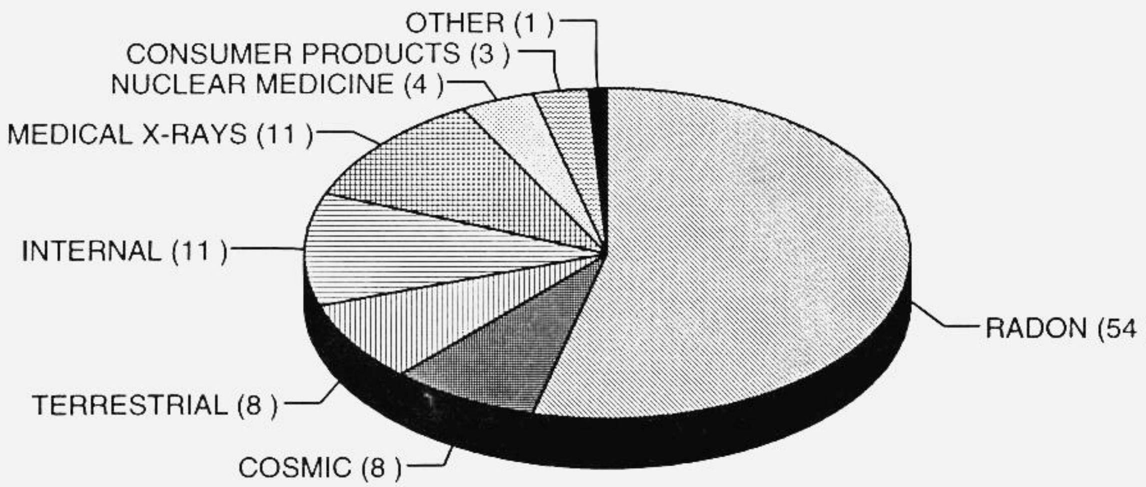

Figure 1. Typical radiation sources and amounts, all values in percent.

a half-life of approximately 5.76 years, undergoes radioactive decay by beta particle emission (Figure 3). Of these three radiation emissions, gamma emissions have been documented to be the most worrisome because of their capability to travel through steel, iron, etc.; they have a "whole body" penetrating ability because they can travel a considerable distance in body tissue. However, based on the destructive capabilities of these emissions, the radiation which has the greatest potential of causing biologic damage is alpha radiation but only under certain conditions. An alpha particle is comprised of two protons and two neutrons and is basically a helium atom without its orbital electrons. Because of its high mass and net electrical charge of +2e, an alpha particle may be stopped effectively by a single sheet of paper or a few centimeters in air. Alpha radiation only poses a significant health hazard if ingested, whereas gamma radiation and to a lesser degree beta radiation do not have to be ingested and may cause biologic damage at a distance. In the case of gamma radiation, as previously discussed, it can penetrate and exit materials such as steel, wood, glass, etc. and therefore it is more invasive and pervasive than alpha radiation. The following figure (Figure 4) illustrates the overall penetrating capacity of several different forms of radiation.

The intent of this study however is not to assess radiation risk associated with NORM or TENORM nor to assess its effects on biologic tissue. The purpose of the study is to contribute primary, unbiased data which will provide the knowledge base from which rational, informed, social, economic, and environmentally sound decisions may be made. The NORM/TENORM database that will be developed during the course of this study may be extremely useful in any epidemiological studies and inferences concerning the issue.

It is anticipated that this database development will include identification of relevant references in the geological literature, acquisition of necessary petrophysical well logs, identification of oil and gas pools from these logs, and provision of guidance as to implications of rock type and petrogenesis as to the occurrence of NORM in Mississippi. This information and the database that will be developed may also be usefully applied to other areas of the United States as well as worldwide where NORM is an issue of consideration and importance.

SUMMARY OF PROJECT

During the initial "start-up" period of this project, the background infrastructure was developed for the major work required in the later phases of the investigation. A significant portion of the work involved consultations among the Mississippi Office of Geology, the Mississippi Mineral Resources Institute (MMRI) and the Research Institute of Pharmaceutical Science (RIPS). As a result of these discussions there was a standard procedure developed for sample collection, labeling, and handling of samples that is both unambiguous and straightforward. An equally important aspect of the sample collection procedure is the maintenance of custody records which can accurately document the handling of the

Bioeffects - Relative Risk

Action	Minutes of Life Expectancy Lost
Buying a small car	7,000
Coast to coast drive	1,000
Smoking a cigarette	10
1 mrem of radiation	1

Figure 2. Examples of relative risk.

sample(s) from the field collection site(s) to the final laboratory analysis(es). The important aspect of this task was not only to create a workable system, but to assure that all three organizations intimately understand how it will work so as to minimize the potential for errors during sample handling.

To date approximately 1,500 liters of oil field brines has been collected from 180 wells from several different producing horizons and fields in Mississippi. Approximately 150 liters of oil field brines were initially collected from 16 wells completed in several different producing horizons in Baxterville Field, located in Lamar County, Mississippi. Baxterville Field ranks as the most prolific oil producing field in the state and is ranked as the third largest field in cumulative gas production. Baxterville has been continuously producing hydrocarbons since its discovery in November, 1944. Along with the brines which were collected from the operational oil wells completed in the Lower Tuscaloosa "stringer" sands and the Lower Tuscaloosa Massive Sand, produced formation brine was also obtained from an Eagleford gas pool at Baxterville. During the pilot phase, prior to the commencement of this study, formation brine samples were collected from a Sparta gas field at South Smithdale Field, located in Amite County, Mississippi, from a Rodessa oil pool at Traxler Field, located in Smith County, and at several Wilcox fields located in the southwestern portion of the state.

After the pilot phase sampling has recovered brines from producing horizons ranging in age from the Upper Jurassic through the Upper Cretaceous at the following 32 fields located in the Mississippi Interior Salt Basin: Quitman, Davis, and Frances Creek (Clarke County); Brownsville Dome, Bolton, and Edwards (Hinds County); West Paulding, Verba, East Heidelberg, and West Heidelberg (all located in Jasper County); Pool Creek, Reedy Creek, Sandersville, Summerland, and Laurel (Jones County); Baxterville (Lamar County); East Flora and Flora (Madison County); East Apollo (Perry County); Puckett (Rankin County); Boykin Church and Mize (Smith County); North Clara, West Yellow Creek, Cypress Creek, Diamond, Eucutta, East Eucutta, and South Thompson Creek (Wayne County); Satartia and Tinsley (Yazoo County); and SoSo (Jasper, Smith, and Jones counties).

In addition to these samples, brine samples have also been collected at the following four fields: Buttahatchie, Maple

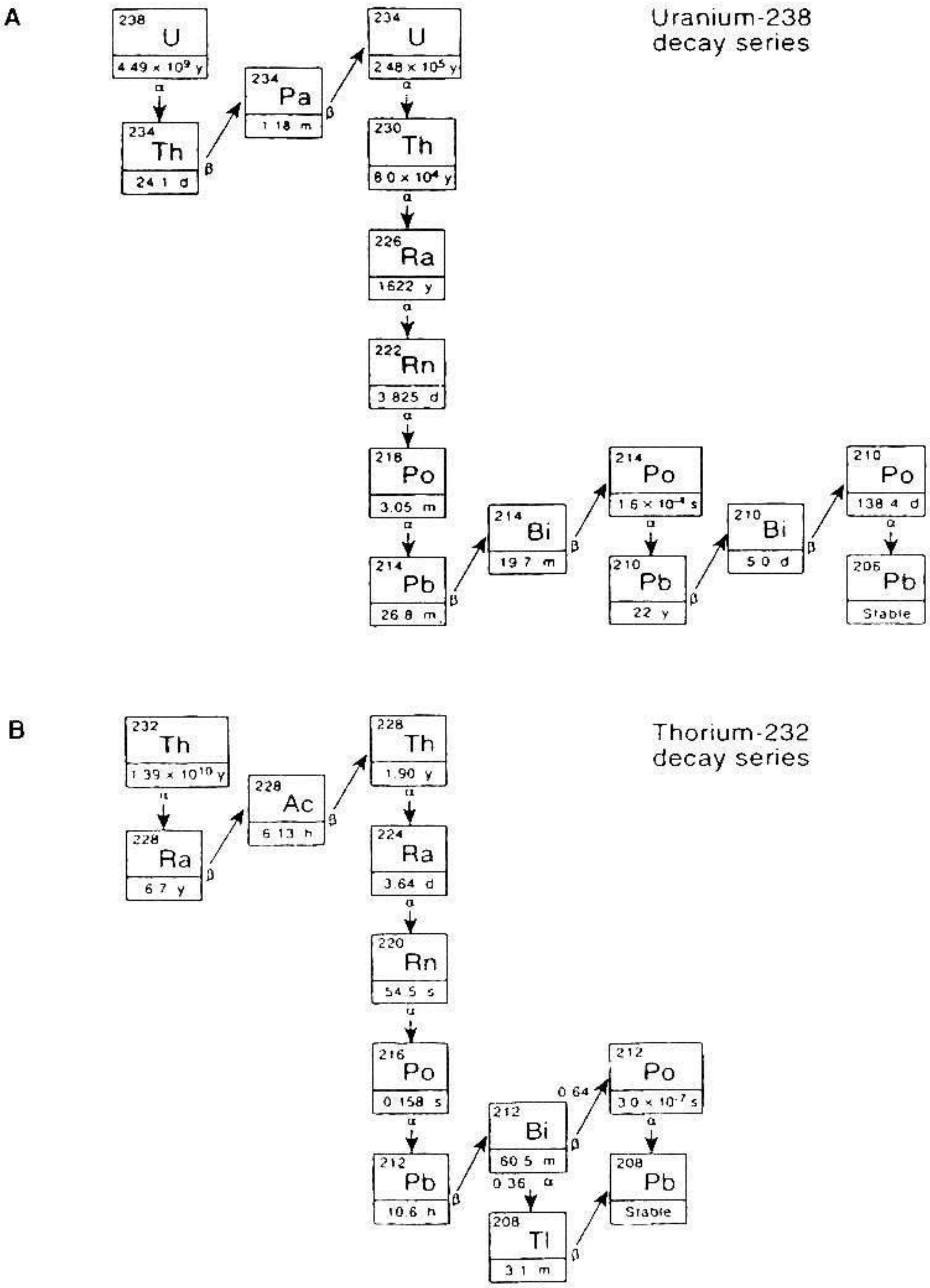

Figure 3. (A) Uranium-238, (B) Thorium-232, decay series and half-lives of isotopes (adapted from Fisher, 1998). α = alpha decay; β = beta decay; y = years; d = days; h = hours; m = minutes; s = seconds.

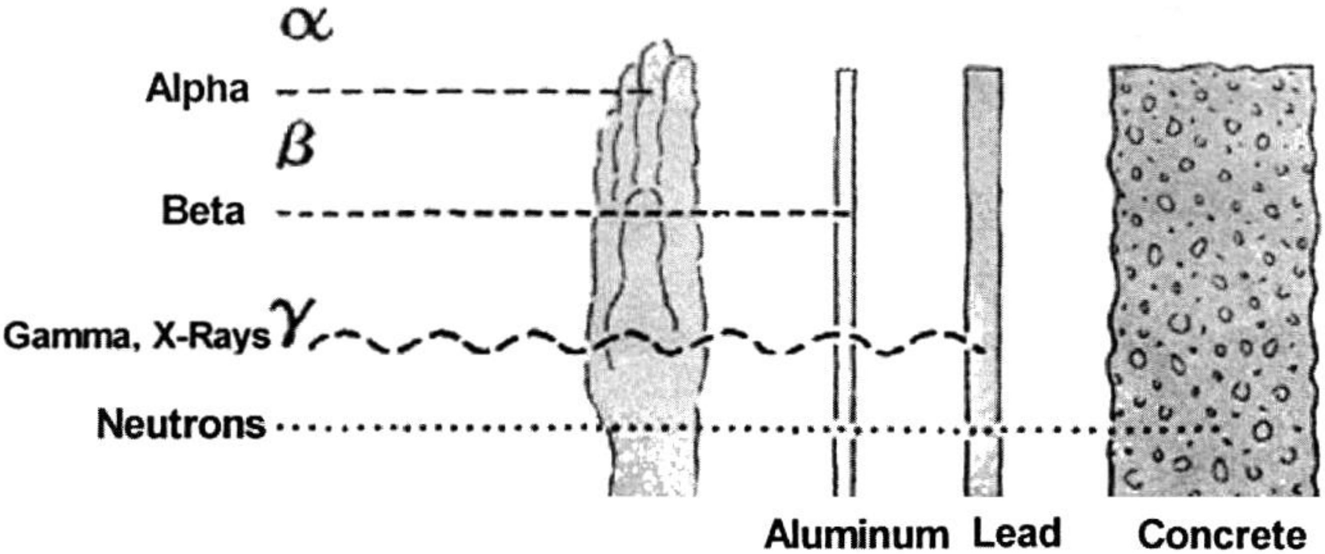

Figure 4. Examples of the penetrating capabilities of different forms of radiation.

Branch, and McKinley Creek fields (Monroe County), and Corinne Field (Monroe, Clay, and Lowndes counties), all of which are located and productive from the Paleozoic-age Black Warrior Basin (Mississippian System, Chesterian Series). Figure 5 depicts all the areas within the state, on a county basis, where brine samples have been collected.

FIELD COLLECTION PROCEDURES

On-site sampling procedures had to be devised to help minimize the amount of oil included in the collected, produced fluids. To help minimize the amount of oil contained in the samples, the fluid being produced at the wellhead was first collected in a 20 liter (5 gallon) sampling container equipped with an on/off valve located at its base. After the container was filled approximately two-thirds to three-quarters full, the collected fluid was allowed to sit briefly, which allowed a preliminary separation of the produced oil and water. The oil and water separated, leaving a fairly distinct two-phase fluid; oil, because of its lesser density than the brine, was the upper layer and the brine, being more dense than the oil, the lower layer. The produced brine was then transferred to a 4 liter sample container by simply opening the valve at the base of the collection container, which allowed for the water phase to be removed without introduction of large amounts of oil with the brine. Figures 6 and 7 illustrate this sample collection process. During the course of sampling, the preferred source was at the wellhead. However, this was not always possible as a result of emulsions which would not break into water/oil phases, or because there were no valves to remove fluid at the wellhead, or because the gravity of the oil was so low it could not physically be poured into the sample containers. When a sample could not be collected at the wellhead other sample collection sources were in order of preference: 1) flow lines to separators, heater treaters, or salt water storage tanks, 2) separators, 3) heater treaters, and 4) salt water storage tanks.

DISPOSITION OF SAMPLES

At each sample collection point approximately 8 liters of produced formation fluid is being collected. During the current chemical analysis procedure, approximately 4 liters of each sample is utilized; a portion of this (500 ml) is being acidified and stored for potential future reference. The remaining 4 liters of fluid is being stored for any additional chemical analyses which may be required or desired.

SUMMARY OF PRELIMINARY CHEMICAL AND ISOTOPIC DATA

To date the complete analysis of 89 brine samples from 20 fields has been done and partial analyses have been performed on 39 additional samples and 9 additional fields. Brine pH values have ranged from 3.66 to 7.74 with an average of 5.69. It has been observed that the pH values can change by as much as 0.5 pH units upon storage. This is most probably due to uptake of CO_2 from the atmosphere. Dissolved solutes have ranged from 0.2 g/l to 315.8 g/l with an average of 155.44 g/l. The

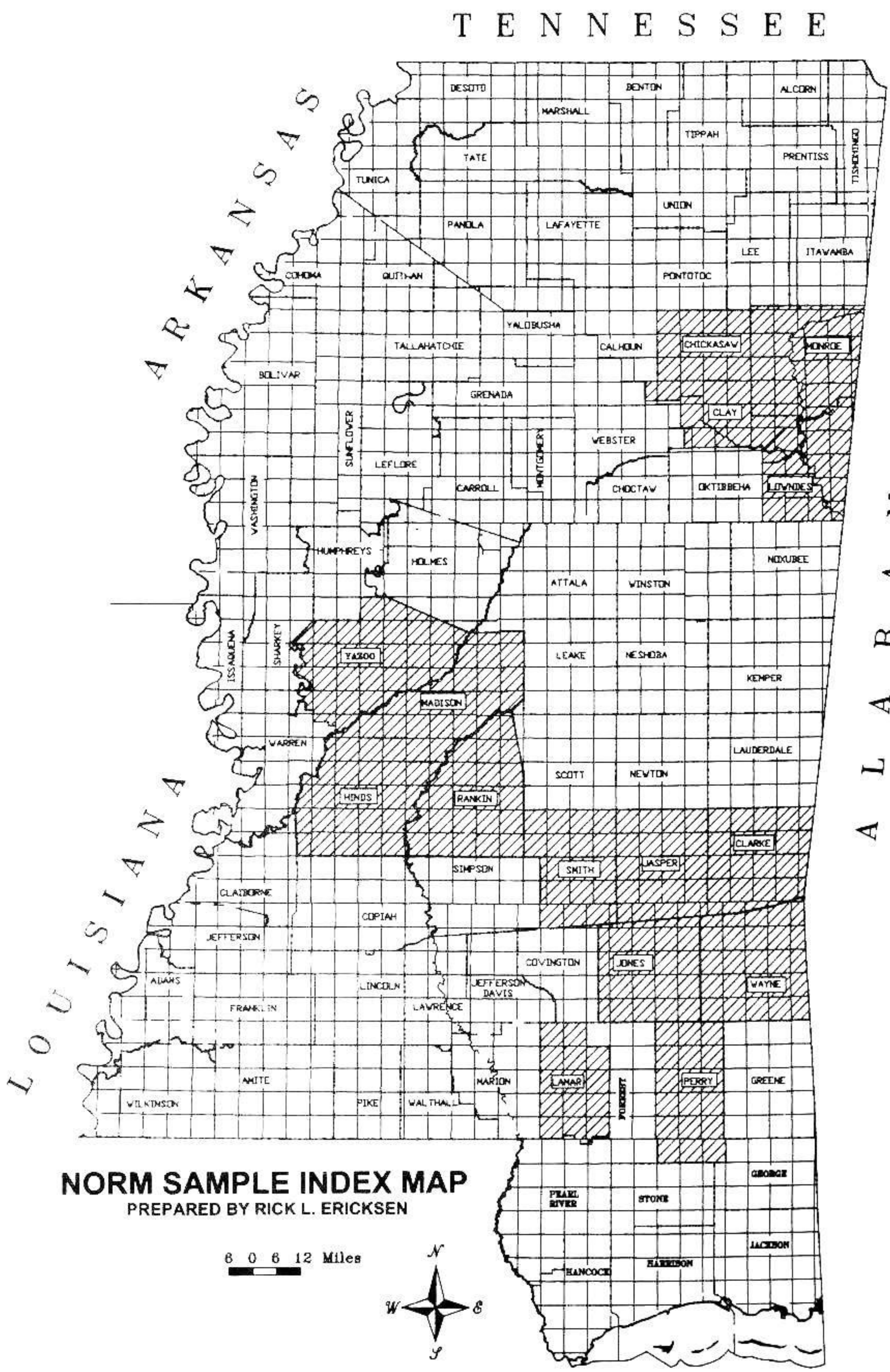

Figure 5. NORM sample collection areas, county-wide basis.

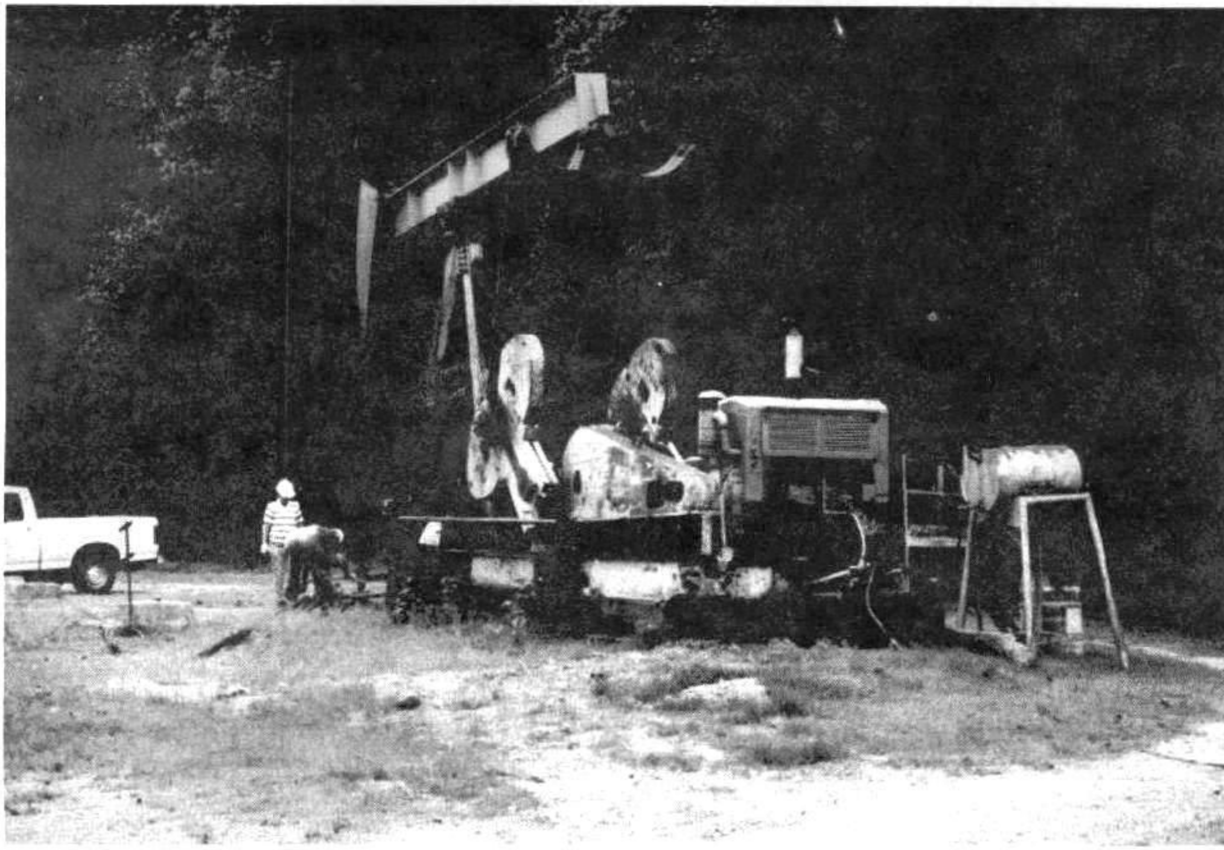

Figure 6. Collection of brine sample at wellhead.

low dissolved solute of 0.2 g/l came from a sample collected at Maple Branch Field in the Black Warrior Basin. This sample and others collected from Black Warrior Basin wells had low solute concentrations. This may be the result of maintenance work which had been performed at these facilities which involved the introduction of fresh water into the salt water storage tanks. If one does not consider the values of the Black Warrior samples or other anomalous samples, the range of dissolved solute is from 114.4 g/l to 315.8 g/l. ^{226}Ra concentration levels range from 0.142 to 22.66 pM/l with an average of 7.14 pM/l. ^{228}Ra levels have ranged from 0 to 3.41 fM/l with an average of 0.66 fM/l. The molar concentration ratios of ^{226}Ra to ^{228}Ra range from 1,106 to 67,660 and average 11,125.

Recent studies have indicated a correlation between total chlorinity and radium content (e.g. Fisher, 1998). This current study has been modified to analyze samples for total chlorinity to evaluate the reported correlation. Preliminary data neither confirm nor deny the correlation which has been noted. Figure 8 is a photograph of the laboratory where the chemical and isotope geochemistry is being performed.

CONCLUSION

As noted, the data ranges presented are preliminary. The complete isotopic and concentration analyses for radium, thorium, and uranium will be presented with the final report of this study. It is anticipated that updates on this study will be provided as the data are accumulated along with correlations and/or trends which may be developed concerning the occurrence of NORM.

In addition, we have begun to collect soil samples from areas of oil and gas operations and other areas which have had none but have elevated NORM readings. These samples are currently in the process of being analyzed to determine the mobility of NORM contained therein and the concentrations of uranium, thorium, and radium and the isotopic composition of radium. These samples are currently being exposed to laboratory simulated acid rain conditions to better ascertain the mobility of the radium which may be present. From the data which are being acquired a better understanding of radium and its potential pathways of movement in the environment may be developed.

Figure 7. Transfer of brine sample into sample collection bottle.

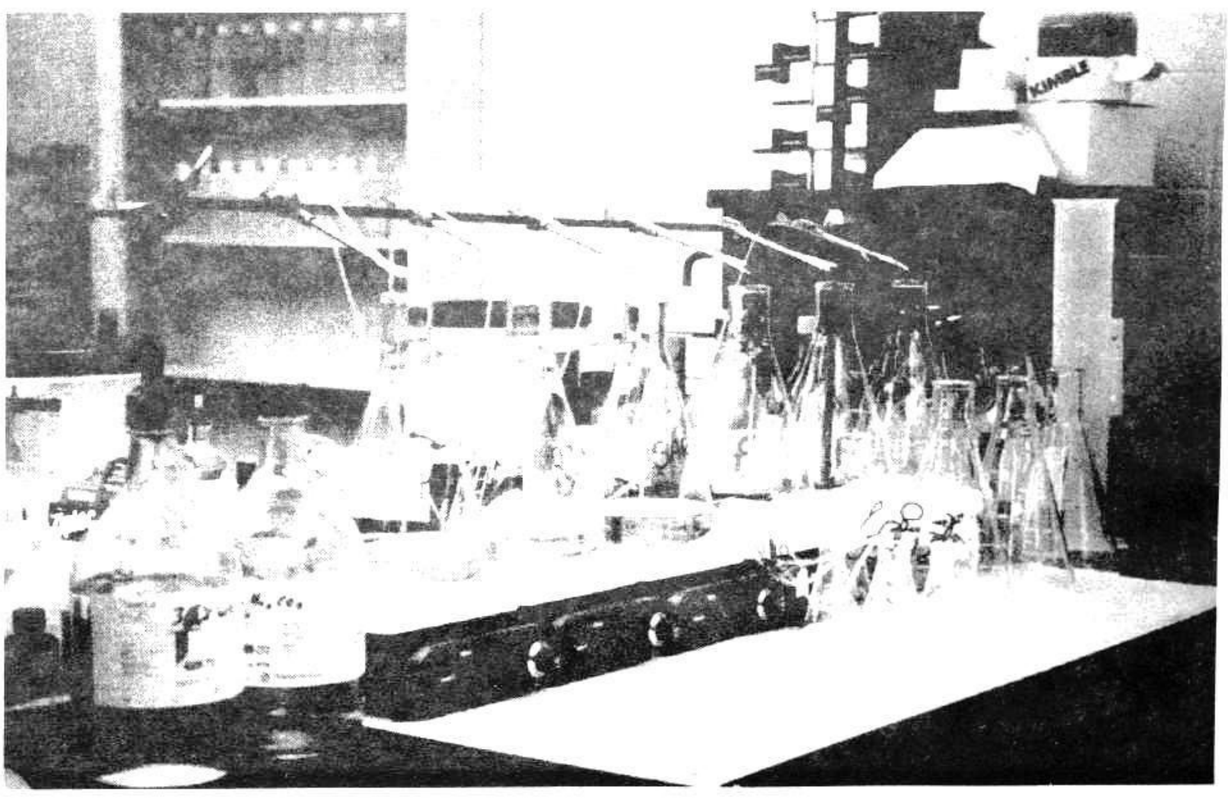

Figure 8. Laboratory at the Research Institute of Pharmaceutical Science, University, Mississippi.

List of Acronyms, Abbreviations, and Definitions

barrel(s) .... 42 gallons = 168 quarts = 158.97 liters = bbl(s)
bbl(s) .... barrel(s)
Ci .... curie = $3.7 X 10^{10}$ disintegrations per second (dps) = $2.22 X 10^{12}$ disintegrations per minute (dpm)
curie .... Ci = $3.7 X 10^{10}$ disintegrations per second (dps) = $2.22 X 10^{12}$ disintegrations per minute (dpm)
dyne .... a centimeter-gram-second unit of force, equal to the force required to impart an acceleration of one centimeter per second per second to a mass of one gram
erg .... a centimeter-gram-second unit of energy or work equal to the work done by a force of one dyne acting over a distance of one centimeter
fM .... femtomole = $1 X 10^{-15}$ mole
femtomole(s) .... fM = $1 X 10^{-15}$ mole(s)
g .... gram
gram .... g
L or l .... liter
liter l
M .... molar
milliliter .... ml
millirem .... mrem
mrem .... millirem = a unit of radiation exposure equal to one-thousandth of a rem
Mississippi Mineral Resources Institute .... MMRI
ml .... milliliter
MMRI .... Mississippi Mineral Resources Institute
nanocurie(s) .... nCi = $1 X 10^{-9}$ curie(s)
Naturally Occurring Radioactive Materials .... NORM
NORM .... Naturally Occurring Radioactive Materials
Normal .... N
picomole(s) .... pM = $1 X 10^{-12}$ mole(s)
pM .... picomole = $1 X 10^{-12}$ mole
rem .... radiation equivalent man = unit of dose equivalent = the amount of any type of radiation that will cause damage to body tissue equivalent to that which would be caused by absorbing 100 ergs of gamma ray energy per gram of body tissue
Research Institute of Pharmaceutical Science .... RIPS
RIPS .... Research Institute of Pharmaceutical Science
Technologically Enhanced Naturally Occurring Radioactive Materials .... TENORM
TENORM .... Technologically Enhanced Naturally Occurring Radioactive Materials

Oil and gas operators in Mississippi continue to provide us with virtually unlimited access to producing properties and it appears that the goals of the brine sampling phase of this investigation will be accomplished. It is anticipated that additional Black Warrior Basin and Mississippi Interior Salt Basin fields, as well as producing areas in the Wilcox Trend in the southwestern portion of the state, will be sampled during the next year.

ACKNOWLEDGMENTS

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AQUEOUS FAUNA DISCOVERED IN THE LATE PLEISTOCENE (PEORIAN) LOESS OF VICKSBURG, MISSISSIPPI

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INTRODUCTION

One of the world's largest blankets of Late Pleistocene (Peorian) loess lies in the central United States along the Missouri, Mississippi and Ohio river drainage basins. In Mississippi, loess deposits form the rugged topography along the eastern valley wall of the Mississippi River Alluvial Plain. These deposits are believed to be eolian in origin due to their texture, stratigraphy, mineralogy and field relationships (Snowden and Priddy, 1968), though this has been a matter of historical debate. Some fossils in the loess, such as freshwater clam shells, indicate an aqueous mode of deposition. Such fossils were noted in the early 1800s by renowned geologists such as Charles Lyell, who observed them on his trip to Natchez in 1846.

Early this century, Shimek (1902 and 1930) studied the molluscan fauna of the loess at Natchez where he collected a diverse land-snail fauna often in association with the bones of Pleistocene land mammals. Shimek concluded that the snail fauna suggested an eolian origin for the loess. In his study, Shimek (1902, pl. 14) identified 21 species of land snails. In a revision some 28 years later (Shimek, 1930, pl. 19-20), he added 28 species to his faunal list, for a total of 49 species. In this revision, Shimek (1930, p. 681) mentioned his finding of land snails in extremely rare associations with freshwater pulmonates and the rare shells of the clam *Pisidium*, which suggested a small lake or pond that once existed in the ancient Mississippi forests and plains. The occurrence of rare aqueous faunas in the loess of Mississippi indicates a more complicated depositional history for this sediment than one of solely eolian origin.

Several fossil hunting trips by the writer to Ballground Creek in Vicksburg have turned up previously undocumented forms in the loess. Here land snails have been discovered in close association with extremely rare aqueous forms including a nearly complete left valve of the freshwater washboard mussel *Megalonaias nervosa*, the rare shells of the thumbnail-size clam *Pisidium*, the extremely rare shells of the freshwater river gastropod *Pleurocera*, a rare occurrence of the freshwater viviparid gastropod *Campeloma decisum*, and the fossilized gastroliths of a Pleistocene six-inch crayfish, tentatively identified as *Cambarus*. While the shells of *Pisidium* were previously documented by Shimek (1930) in Natchez, he made no mention of the species occurring as far north as Vicksburg.

THE BALLGROUND CREEK LOCALITY

The discovery of aqueous fossils in the loess along Ballground Creek, north of Redwood in Warren County, Mississippi, was a serendipitous find as the writer was collecting petrified wood and Pleistocene mammal bones in the creek gravel. This locality is near the terminus of Dan Hall Road, where it reaches the creek as a trail (permission to visit the site must be obtained from the land owner). Upstream from the trail on the right bank is a high vertical bluff with a land-snail fauna throughout and unweathered gray loess in the lower section. The next bluff upstream on the right bank is lower, partly vegetated, and contains a mixed aqueous and land-snail fauna, with a concentration of the clam *Pisidium in situ* within the loess at about ten feet above the creek's low-water level. These clams are fragile and some are complete with both valves closed, an indication that they were buried where they lived (a biocoenosis) rather than transported to the site by sedimentary processes (a thanatocoenosis). The creek below the bluff flows over a bed load of sand, gravel, and reworked loess, resting on bedrock of the lower Oligocene Byram Formation, which appears as rip-up clasts in the creek gravel.

At the second bluff, the nature of the surfaces bounding the aqueous fauna with surrounding deposits of eolian loess are not evident due to vegetation cover, but a channel contact is evident at the third bluff on the creek's right bank. Here the irregular scour surface of a channel separates two loess deposits, the lower deposit comprising the bedrock and the upper one comprising the channel fill. Above the scour surface is a thin channel-lag deposit composed of woody material on one side, including an unaltered log, and sand and gravel on the other. Such lag deposits might readily provide lateral conduits for ground water in the loess.

An explanation for the mix of fossil land snails and aqueous mollusks at the second bluff is provided by the recent sediments of Ballground Creek. Here, land snails eroded from loess deposits upstream are common and are mixed with freshwater

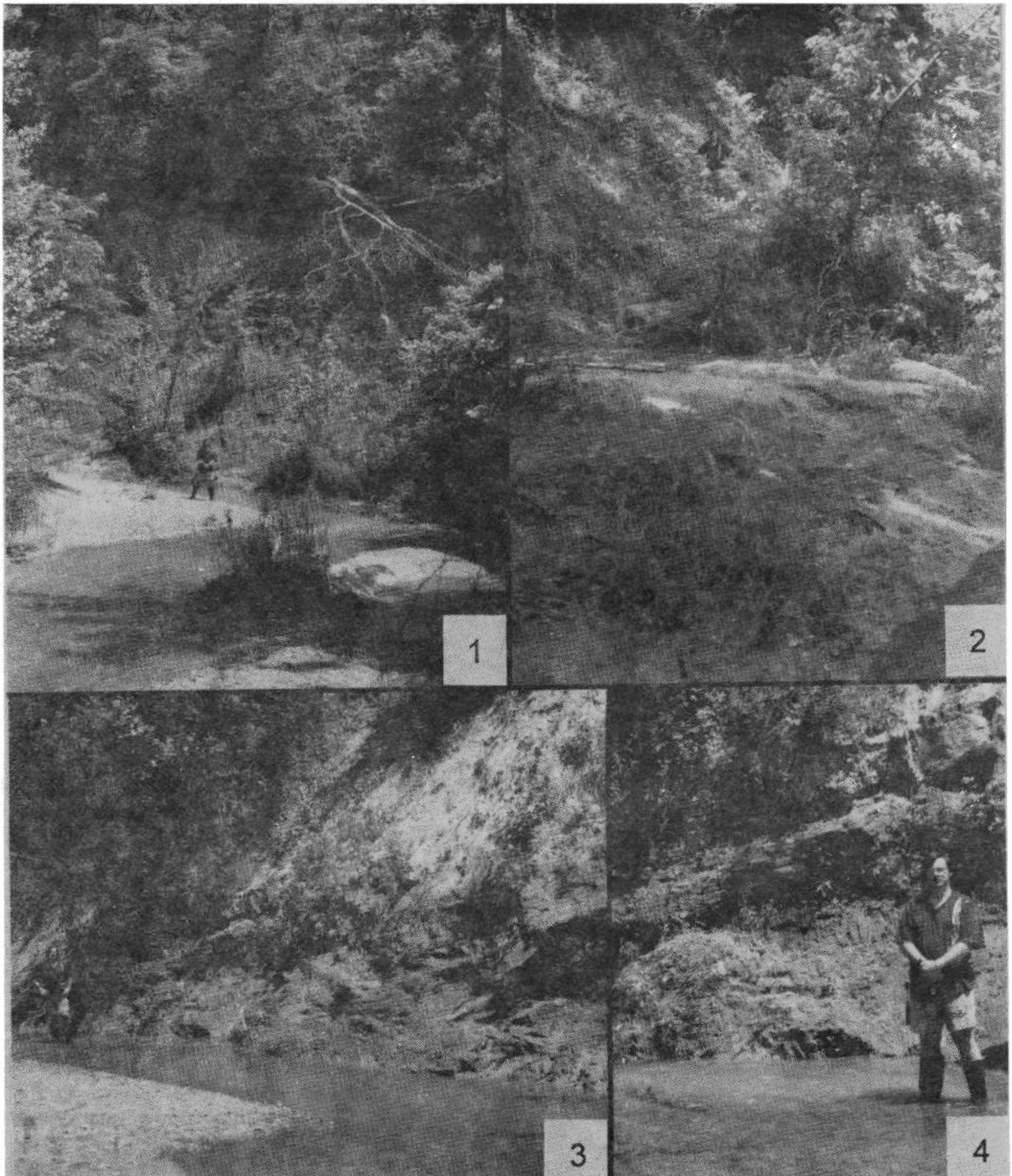

Plate 1. Figure 1: First Bluff upstream from the Dan Hall Road trail with land snail fauna throughout the section and unweathered gray loess at base. Figure 2: Second Bluff with mixed aqueous and terrestrial faunas; writer is pointing to a concentration of clam shells of the species *Pisidium supinum* at his shoulder level. Figure 3: Third Bluff with the irregular base of a channel within the loess. Figure 4: Close view of channel contact containing woody debris and an unaltered log.

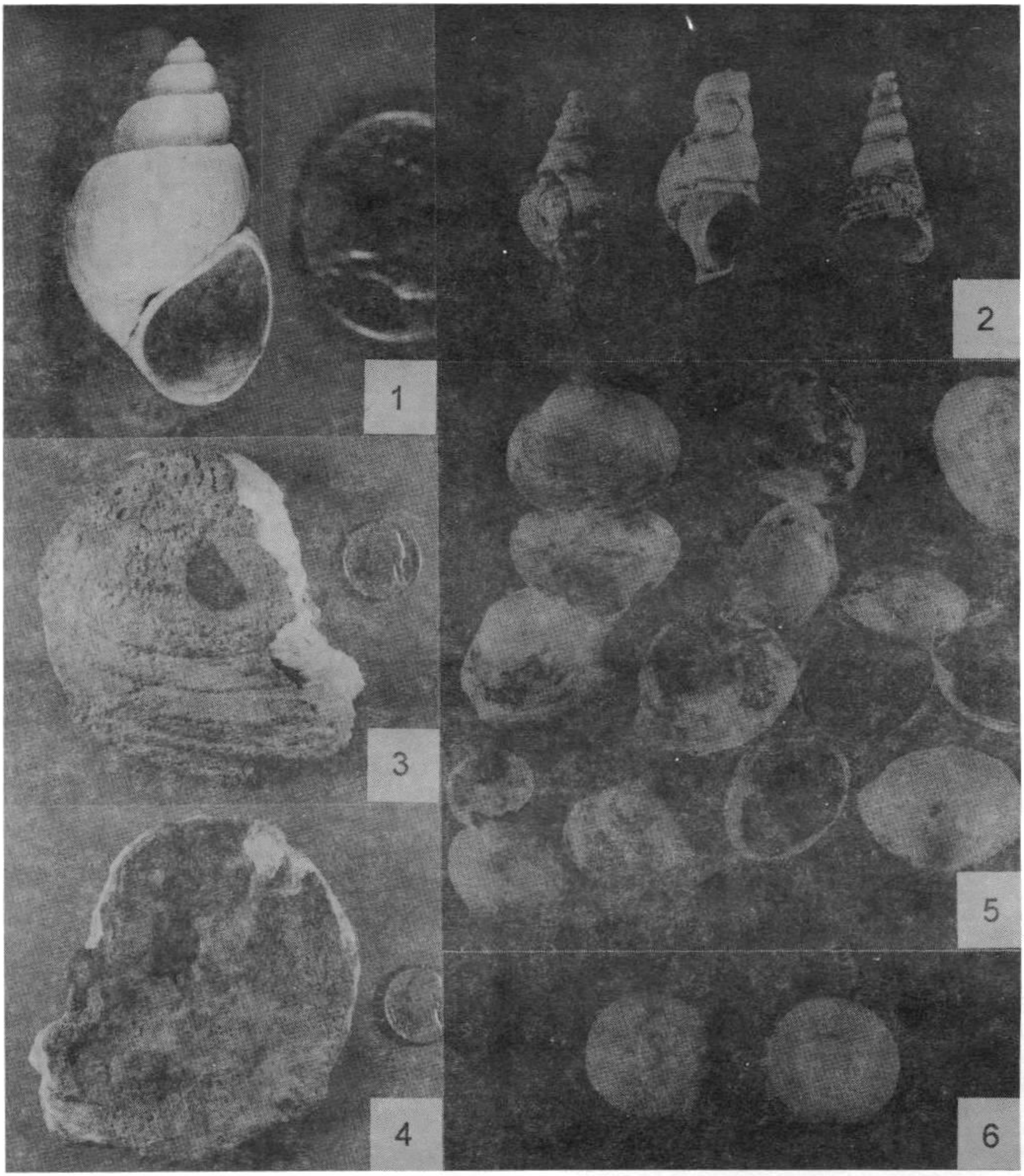

Plate 2. Figure 1: Well preserved specimen of freshwater snail *Campeloma decisum*. Figure 2: Eroded specimens of the freshwater snail *Pleurocera acuta* Rafinesque, 1831. Figures 3-4: Exterior and interior views of a partial and mineral-encrusted specimen of the freshwater clam *Megalonaias nervosa* (Rafinesque, 1820). Figure 5: Specimens of the freshwater clam *Pisidium supinum* Schmidt, 1851. Figure 6: Crayfish gastrolith specimens presumably of the Genus *Cambarus*, with the attachment surface shown at right.

snails from aqueous loess deposits and with whatever mollusks are presently living in the creek. The following are fresh-water taxa found *in situ* or as float at the second bluff locality on Ballground Creek.

SYSTEMATICS

Phylum: MOLLUSCA
Class: GASTROPODA
Order: CAENOGASTROPODA Cox, 1959
Family: VIVIPARIDAE Gray, 1847

CAMPELOMA Rafinesque, 1819
Campeloma decisum
Plate 2, figure 1

Description: Shell brittle, small to medium size; evenly rounded, generally convex and smooth whorls, crossed by faint growth lines; lip vertical in profile, aperture oval, with a continuous margin (after Walker and Ward, 1992, p. 119).

Dimensions of figured specimen: Height 31.1 mm, width 18.2mm.

Family: PLEUROCERIDAE Fischer, 1885

PLEUROCERA Rafinesque, 1818
Pleurocera acuta Rafinesque, 1831
Plate 2, figure 2

Description: Small to medium size, carinate, turreted shell with "anterior or 'basal' end of aperture prolonged into a short canal, producing an auger-shaped base to the shell" (Burch, 1989, p. 86-89, see fig. 39, 57-60.).

Dimensions of figured specimens: Height of middle specimen 11 mm, width 5 mm.

Class: BIVALVIA
Order: UNIONOIDA Stoliczka, 1871
Family: UNIONIDAE Fleming, 1828

MEGALONAIAS Utterback, 1915
Megalonaias nervosa (Rafinesque, 1820)
Plate 2, figures 3-4

Description: "Shell large, ponderous, broadly rhomboid, moderately inflated; post-dorsal ridge alated, sculptured with regular upcurved undulations; post-umbonal ridge broken with coarse plications running more or less parallel with it; beaks rather low, sculptured with coarse double-looped corrugations which extend out as nodules at base of post-ridge and as zigzag ridges all over umbonal region to upper part of disk; epidermis black; cardinals heavy; laterals long and straight; interdentum short; beak cavities narrowly deep; scars very deeply impressed-especially anterior retractor cicatrix; nacre white to pink" (Utterback, 1915, p. 124).

Dimensions of figured specimen: Incomplete left valve—small hole worn in center—heavily mineralized with an iron oxide coating: Height 90 mm.

Order: VENEROIDA Adams & Adams, 1856
Family: PISIDIIDAE Gray, 1857

PISIDIUM Pfeiffer, 1821
Pisidium supinum Schmidt, 1851
Plate 2, figure 5

Description: "Small to minute shells, oval or quadrate to subtriangular; shell texture thin to opaque, some forms appearing porous. Ligament partially or completely immersed (rarely external); hinge curved, narrow, with anterior and posterior lateral teeth in both valves; cardinal teeth small, not more than two, those of right valve straight or united into inverted valve, those of left valve wholly separate" (Keen *in* Moore, 1969, p. N669).

Dimensions of figured specimens: The specimen at bottom right of the photograph measures 10.9 mm in width, 8.3 mm in height and 5.9 mm in thickness.

Phylum: ARTHROPODA
Class: MALACOSTRACA
Order: DECAPODA Latreille, 1803
Family: ASTACIDAE Latreille, 1802

CAMBARUS Erichson, 1846
Cambarus sp.
Plate 2, figure 6

Description: Round, circular, gastroliths with an internal structure of small calcareous spheres; attachment side with a central, circular depression and rounded margins; opposite side rounded and cap-like.

Discussion: Modern crayfish use gastroliths to store calcium, which is used to mineralize and strengthen the exoskeleton after molting. Gastroliths are formed in the cardiac region wall of the foregut, amid the foregut's cuticular wall and the epidermis lying underneath. During the process of ecdysis in which the gut lining is shed, gastroliths are released into the lumen of the foregut where they are disintegrated. The gut epithelium and the hepatopancreas resorb small leftover bits of the gastroliths. Crayfish lose about 90% of their exoskeletons' calcareous content during the molting process. For this reason, gastroliths are very important since they store the calcium needed for the replacement exoskeleton after ecdysis (Holich and Lowery, eds., 1988).

Dimensions of figured specimens: Diameter 8 mm, thickness 4.5 mm. Figure at right shows attachment surface. The size of these gastroliths indicates that they came from a six-inch-long crayfish.

ACKNOWLEDGMENTS

Paul Hartfield of the U.S. Fish and Wildlife Service Endangered Species Field Office in Jackson, Mississippi, helped with the identification of the freshwater mollusks. Terrence Majure of the Mississippi Museum of Natural Science identified the crayfish gastroliths. David Dockery of the Mississippi Office of Geology took photographs and made the plates.

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HURRICANE CAMILLE TIDAL FLOOD MAPS

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This year marks the 30-year anniversary of Hurricane Camille's assault on the Mississippi Gulf Coast. Many residents of the Coast are too young to have witnessed the storm, or have moved to the area since 1969. The maps described in this report show the extent of the tidal floods caused by hurricanes Camille and Betsy. They will be of value to residents, government officials, and emergency planners in becoming better prepared for future hurricanes.

Hurricane Camille was a category 5 storm when it came ashore on the Mississippi Gulf Coast on August 17-18, 1969. It killed 139 people in Mississippi, destroyed thousands of structures, washed ashore three ships and scores of boats, and disrupted power and water service. The eye was 5 miles wide at landfall in the Bay of St. Louis area, with hurricane force winds extending 50 miles to the east and west.

Hurricanes cause death and destruction from sustained winds in excess of 74 miles per hour. Wind speeds over 200 mph were measured in Hurricane Camille. Hurricanes also cause problems from flooding resulting from large amounts of rain falling in a short time. In fact, Hurricane Camille killed many people in Virginia from devastating floods caused by torrential rains as the remains of the storm crossed the Appalachian Mountains. But the hurricane's most fearsome killing mechanism is the storm surge, or tidal flood. Generally, most deaths and property damage from hurricanes impacting the coastline are caused by the water in the storm surge. The storm surge is the bulge of sea water pushed up by the sustained winds of the hurricane. The storm surge is highest in the vicinity of the eye; the height of the surge in Camille was over 24 feet above mean sea level at Pass Christian. Along the Mississippi Gulf Coast the storm surge is also high in the right-front quadrant of an approaching hurricane; Camille's was over 15 feet in Back Bay of Biloxi. It is the storm surge or tidal flood caused by Hurricane Camille (and Hurricane Betsy) that is shown on the maps described in this article.

What has happened in the past can happen again. We certainly hope the Mississippi Gulf Coast is not soon visited by another storm with the intensity of Hurricane Camille, but just "hoping for the best" will not save lives—adequate preparation based on good information is necessary. The maps listed below show the areas susceptible to flooding by storm surges from any hurricane.

The U.S. Geological Survey in 1969 published a series of 14 maps showing the extent of coastal tidal flooding along the Gulf Coast caused by Hurricane Camille in August 1969. The maps also show the extent of flooding caused by Hurricane Betsy in September 1965. The authors of the maps are K. V. Wilson and James W. Hudson of USGS. The maps are published at the scale 1:24,000, except the Pascagoula Quadrangle, which is published at 1:62,500. USGS published the maps in their Hydrologic Investigations Atlas (HA) series. The Mississippi Office of Geology now has this series of maps available for sale in our Map and Publications Sales Office. The maps may be viewed in our office; they are available folded in envelopes. If ordering by mail, you may ask for the maps by the abbreviated series number and name highlighted in bold in the following list.

HA-395, Hurricane Camille Tidal Floods of August 1969 Along the Gulf Coast, **Logtown Quadrangle**, Mississippi

HA-396, Hurricane Camille Tidal Floods of August 1969 Along the Gulf Coast, **English Lookout Quadrangle**, Louisiana-Mississippi

HA-397, Hurricane Camille Tidal Floods of August 1969 Along the Gulf Coast, **Kiln Quadrangle**, Mississippi

HA-398, Hurricane Camille Tidal Floods of August 1969 Along the Gulf Coast, **Waveland-Grand Island Pass Quadrangles**, Mississippi

HA-399, Hurricane Camille Tidal Floods of August 1969 Along the Gulf Coast, **Vidalia Quadrangle**, Mississippi

HA-400, Hurricane Camille Tidal Floods of August 1969 Along the Gulf Coast, **Bay St. Louis Quadrangle**, Mississippi

HA-401, Hurricane Camille Tidal Floods of August 1969 Along the Gulf Coast, **Gulfport NW Quadrangle**, Mississippi

HA-402, Hurricane Camille Tidal Floods of August 1969 Along the Gulf Coast, **Pass Christian Quadrangle**, Mississippi

HA-403, Hurricane Camille Tidal Floods of August 1969 Along the Gulf Coast, **Gulfport North-South Quadrangles**, Mississippi

HA-404, Hurricane Camille Tidal Floods of August 1969 Along the Gulf Coast, **Biloxi Quadrangle**, Mississippi

HA-405, Hurricane Camille Tidal Floods of August 1969 Along the Gulf Coast, **Ocean Springs-Deer Island Quadrangles**, Mississippi

HA-406, Hurricane Camille Tidal Floods of August 1969 Along the Gulf Coast, **Pascagoula Quadrangle**, Mississippi

HA-407, Hurricane Camille Tidal Floods of August 1969 Along the Gulf Coast, **Kreole-Grand Bay SW Quadrangles**, Mississippi-Alabama

HA-408, Hurricane Camille Tidal Floods of August 1969 Along the Gulf Coast, **Grand Bay Quadrangle**, Alabama (very limited supply at the Office of Geology)

These maps may be purchased from the Office of Geology at Southport Center, 2380 Highway 80 West, Jackson, for $5.00 for each map. Mail orders will be accepted when accompanied by payment ($5.00 per copy, plus a postage and handling charge of $2.00 for 1-3 maps or $3.50 for 4 or more). Send mail orders (with check or money order) to:

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P. O. Box 20307
Jackson, MS 39289-1307

telephone (601) 961-5500; publication sales (601) 961-5523

The maps are also available from the U.S. Geological Survey for $4.00 each plus $3.50 handling charge for each order. Call them at 1-888-ASK-USGS or write to USGS Information Services, Box 25286, Denver, CO 80225.

USING THE MAPS

Each of these maps is based on a standard USGS topographic quadrangle (or two combined to save space), printed in the usual colors and including topographic contours. On top of this the areas flooded by high tides from Hurricane Camille in 1969 and Hurricane Betsy in 1965 are shown in blue shading. The maximum inundations are shown with a solid blue line for Camille and a dashed line for Betsy. Selected points throughout the maps indicate high-water marks with values given in feet above mean sea level. The maps include text describing the tidal flood information shown and giving additional information about tidal records and storm-tide recurrence intervals. Most also have one or two photographs of damage caused by Hurricane Camille.

A word of caution—these maps were published in 1969. That means that the topographic maps used as the base maps were the editions available at that time. Since these maps were made there has been extensive development all along the Mississippi Gulf Coast. Many roads, subdivisions, and buildings that have been in existence for decades do not appear on these older vintage maps.

The maps in this series remain extremely useful for delineating areas susceptible to storm-surge flooding and for planning evacuation routes when future hurricanes threaten the Coast.

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Sullivan, Charles L., 1986, Hurricanes of the Mississippi Gulf Coast: Gulf Publishing Company, 139 p.

NEW PUBLICATIONS BY THE MISSISSIPPI OFFICE OF GEOLOGY

NINE GEOLOGIC QUADRANGLES IN NORTHERN MISSISSIPPI

The Mississippi Office of Geology announces the availability of nine new geologic quadrangles in northern Mississippi. These 7.5-minute quadrangles, printed in color, are from our series of geologic maps created in a geographic information system using ARC/INFO software and printed on an inkjet plotter. The geologic units mapped are in the Tertiary Claiborne and Wilcox groups. Holocene alluvium is mapped also. The geologic maps provide vital information about the area's water-bearing sands and economically important lignite resources.

OF-75. Geologic Map of the Gore Springs Quadrangle, Grenada, Yalobusha, and Calhoun Counties, Mississippi: Stephen L. Ingram, scale 1:24,000, 1999. $5.00 ($5.00 postage rolled or $2.00 folded)

OF-76. Geologic Map of the Kincaid Quadrangle, Grenada and Yalobusha Counties, Mississippi: Stephen L. Ingram, scale 1:24,000, 1999. $5.00 ($5.00 postage rolled or $2.00 folded)

OF-77. Geologic Map of the Grenada Quadrangle, Grenada and Yalobusha Counties, Mississippi: Stephen L. Ingram, scale 1:24,000, 1999. $5.00 ($5.00 postage rolled or $2.00 folded)

OF-78. Geologic Map of the Coffeeville Quadrangle, Yalobusha County, Mississippi: Stephen L. Ingram, scale 1:24,000, 1999. $5.00 ($5.00 postage rolled or $2.00 folded)

OF-79. Geologic Map of the Benwood Quadrangle, Yalobusha and Calhoun Counties, Mississippi: Stephen L. Ingram, scale 1:24,000, 1999. $5.00 ($5.00 postage rolled or $2.00 folded)

OF-80. Geologic Map of the Skuna Quadrangle, Calhoun County, Mississippi: David E. Thompson, scale 1:24,000, 1999. $5.00 ($5.00 postage rolled or $2.00 folded)

OF-81. Geologic Map of the Banner Quadrangle, Calhoun County, Mississippi: David E. Thompson, scale 1:24,000, 1999. $5.00 ($5.00 postage rolled or $2.00 folded)

OF-82. Geologic Map of the Paris Quadrangle, Lafayette and Calhoun Counties, Mississippi: David E. Thompson, scale 1:24,000, 1999. $5.00 ($5.00 postage rolled or $2.00 folded)

OF-83. Geologic Map of the Yocona Quadrangle, Lafayette County, Mississippi: David E. Thompson, scale 1:24,000, 1999. $5.00 ($5.00 postage rolled or $2.00 folded)

These Open-File Reports may be purchased from the Office of Geology at Southport Center, 2380 Highway 80 West, for $5.00 per copy. Mail orders will be accepted when accompanied by payment ($5.00 per copy, plus a postage and handling charge of $5.00 for rolled maps (1-3 maps) or $2.00 for folded maps (1-3 maps)). Send mail orders (with check or money order) to:

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An up-to-date index of *Mississippi Geology* is available from the Office of Geology. Open-File Report 15, "Current Index to *Mississippi Geology*," compiled by Michael B. E. Bograd, is available for $2.00 (plus $2.00 postage by mail) from the Office of Geology, P.O. Box 20307, Jackson, MS 39289.

PROPOSED STANDARDIZED SYMBOLS FOR GEOLOGIC UNITS IN MISSISSIPPI

compiled by
Michael B. E. Bograd
Mississippi Office of Geology

Geologic symbols are a type of shorthand used on geologic maps to identify a formation's (or member's) outcrop distribution. These symbols may also be useful for subsurface units depicted on cross sections where space limitations preclude the use of complete names. Most geologic maps in Mississippi make use of geologic symbols but these have not followed any standardized guidelines for usage in this state.

This article proposes a standardized guideline for geologic mapping units, which will be followed by the Mississippi Office of Geology's surface mapping program. It does not include symbols for those units known only from the subsurface in Mississippi.

Effort has been made to use the same symbol and format as used in neighboring states on their geologic maps. The symbols begin with the letter for the system, not the series, a standard procedure used throughout the country. This is a change in format from the 1969 state geologic map and the county geologic maps published by this agency, where symbols for Tertiary epochs were used. Some Cretaceous and Quaternary symbols have been in use for decades on the state geologic and other maps and are unchanged here. All symbols consist of two or three letters, never four. An age/group/formation format has been suggested by some and considered, but many problems developed in assigning unique symbols of two or three letters to units. The use of subscripts in geologic symbols poses problems with typography and legibility.

Since the circulation of this list some six years ago, helpful comments have been received from Ervin Otvos, Paul Albertson, Charles Swann, Ernie Russell, and several geologists at the Office of Geology. Some suggestions have been accepted and others declined; some suggestions would require formal changes in stratigraphic nomenclature that are still under consideration.

The list is intended as a guide (not the law) for usage by the Mississippi Office of Geology. The new series of geologic quadrangles we began publishing in 1996 has been using this convention.

To save space in this listing, Formation is abbreviated as Fm and Member as Mbr. D=Devonian, K=Cretaceous, M=Mississippian, Q=Quaternary, T=Tertiary.

Dr	Ross Fm
Ka	Arcola Limestone Mbr
Kb	Bluffport Marl Mbr
Kc	Coffee Sand
Kcc	Coon Creek Tongue
Kch	Chiwapa Sandstone Mbr
Kck	Coker Fm
Kco	Coonewah Bed
Kct	Tupelo Tongue
Kd	Demopolis Chalk or Fm
Ke	Eutaw Group or typical Eutaw Fm
Ket	Tombigbee Sand Mbr
Kg	Gordo Fm
Km	Mooreville Chalk
Kmc	McShan Fm
Kms	McNairy Sand Mbr
Koc	Owl Creek Fm
Kpb	Prairie Bluff Fm
Kr	Ripley Fm
Ks	Selma Group
Kt	Tuscaloosa Group or Tuscaloosa Fm
MDc	Chattanooga Shale
Mfp	Ft. Payne Fm
Mh	Hartselle Fm
Mpm	Pride Mountain Fm
Mt	Tuscumbia Fm
Qal	Recent alluvium
Qb	Biloxi Fm
Qc	coastal deposits
Qg	Gulfport Fm
Ql	loess
Qp	Prairie Fm
Qt	pre-loess terrace (fluvial) deposits
Qtc	coastal terrace
Qth	high terrace
Qtl	low terrace
Tam	Archusa Marl Mbr
Tb	Byram Fm
Tba	Bashi Fm
Tbc	Basic City Shale Mbr
Tbu	Bucatunna Fm

Tc	Claiborne Group
Tca	Catahoula Fm
Tcb	Coal Bluff Mbr
Tch	Chickasawhay Fm
Tci	Citronelle Fm
Tcl	Clayton Fm
Tcm	Cook Mountain Fm
Tco	Cockfield Fm
Tcs	Cocoa Sand Mbr
Tcy	Chalybeate Limestone Mbr
Tdb	Dobys Bluff Tongue
Tfh	Forest Hill Fm
Tg	Glendon Limestone
Tgc	Gravel Creek Sand Mbr
Tgf	Graham Ferry Fm
Tgh	Grampian Hills Mbr
Tgs	Gordon Creek Shale Mbr
Th	Hatchetigbee Fm
Tha	Hattiesburg Fm
Tj	Jackson Group
Tk	Kosciusko Fm
Tm	Midway Group
Tma	Marianna Limestone
Tmb	Moodys Branch Fm
Tml	Matthews Landing Marl Mbr
Tmr	Meridian Sand
Tms	Mint Spring Fm
Tn	Naheola Fm
Tnf	Nanafalia Fm
Tns	Neshoba Sand Mbr
Tnt	North Twistwood Creek Clay Mbr
Toh	Oak Hill Mbr
Tp	Pascagoula Fm
Tpc	Porters Creek Clay or Fm
Tph	Paynes Hammock Fm
Tpm	Pachuta Marl Mbr
Tpt	Potterchitto Mbr
Trb	Red Bluff Fm
Ts	Shubuta Clay Mbr
Tsc	Shipps Creek Shale Mbr
Tt	Tallahatta Fm
Tts	Tippah Sand Mbr
Ttu	Tuscahoma Fm
Tv	Vicksburg Group
Tw	Wilcox Group
Twn	Winona Fm
Ty	Yazoo Clay
Tz	Zilpha Shale
Tzm	Zama Mbr

Readers are urged to send any comments they have on this list (additions, deletions, changes, suggestions) to:

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