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A CONTINUOUS CORE THROUGH THE UNDIFFERENTIATED YAZOO CLAY (LATE EOCENE, JACKSON GROUP) OF CENTRAL MISSISSIPPI

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INTRODUCTION

A continuous core of the Late Eocene undifferentiated marine clay of the Yazoo Formation in northwestern Hinds County, Mississippi, was begun on August 19, completed on September 4, and grouted on September 5, 1991. The core hole was a cooperative effort of the Mississippi Office of Geology and the Geology Department of the University of Southern Mississippi and was funded in part by a grant from the Mississippi Mineral Resources Institute. Its purpose was to study the clay mineralogy and geologic history of a complete section of the Yazoo clay in central Mississippi where the clay has a thickness greater than 400 feet. The core hole was drilled to a depth of 30 feet through a cover of Pleistocene loess and into lignites of the Early Oligocene Forest Hill Formation (28-30 feet). Coring with a 10-foot core barrel began at 30 feet and reached total depth at 530 feet. The 500-foot cored interval contains the basal Forest Hill Formation (30-38 feet), the Yazoo Formation (38-500 feet), the Moodys Branch Formation (500-512 feet), and the upper Cockfield Formation (512-530 feet). The total thickness of Yazoo clay cored was 462 feet.

PURPOSE

Weathered Yazoo clay underlies the soil cover under most of Jackson, Mississippi, and the surrounding area, including a belt of prairie land across central Mississippi known as the Jackson Prairie. Jackson is centrally located within the Jackson Prairie and is unique in that it overlies an extinct Cretaceous volcanic structure, the Jackson Dome, across which the base of the Yazoo clay rises to the surface and is truncated, exposing older units. Conversely, the base of the Yazoo clay dips downward in all directions from the dome's center (near the Belhaven area) until its upper contact with the Forest Hill Formation is encountered. Thus the Yazoo clay outcrop belt, which is notorious for its foundation problems, surrounds Jackson like a giant bull's-eye. A full section of the Yazoo clay is crossed by going either north or south of the downtown Jackson area.

One purpose in coring a complete section of the Yazoo clay in the Jackson area was to study the clay's unweathered (unaltered) mineralogy from top to bottom. Changes in mineralogy within this clay sequence could translate into increased instability of the weathered clay at the surface.

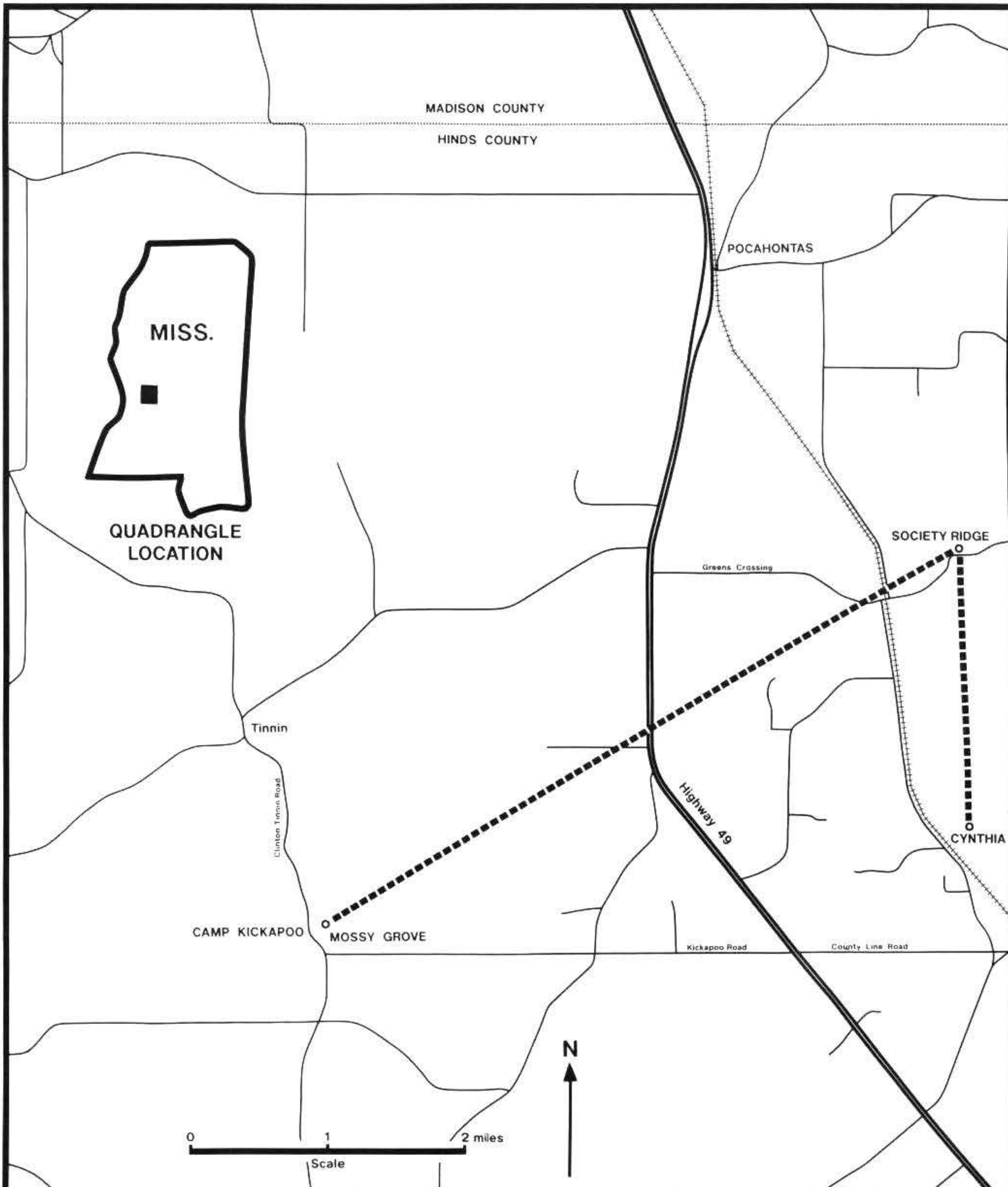

Figure 1. A modified planimetric version of the Pocahontas 7 1/2 minute quadrangle map showing the locations of the Mossy Grove, Society Ridge, and Miss-Lite (Cynthia) test holes.

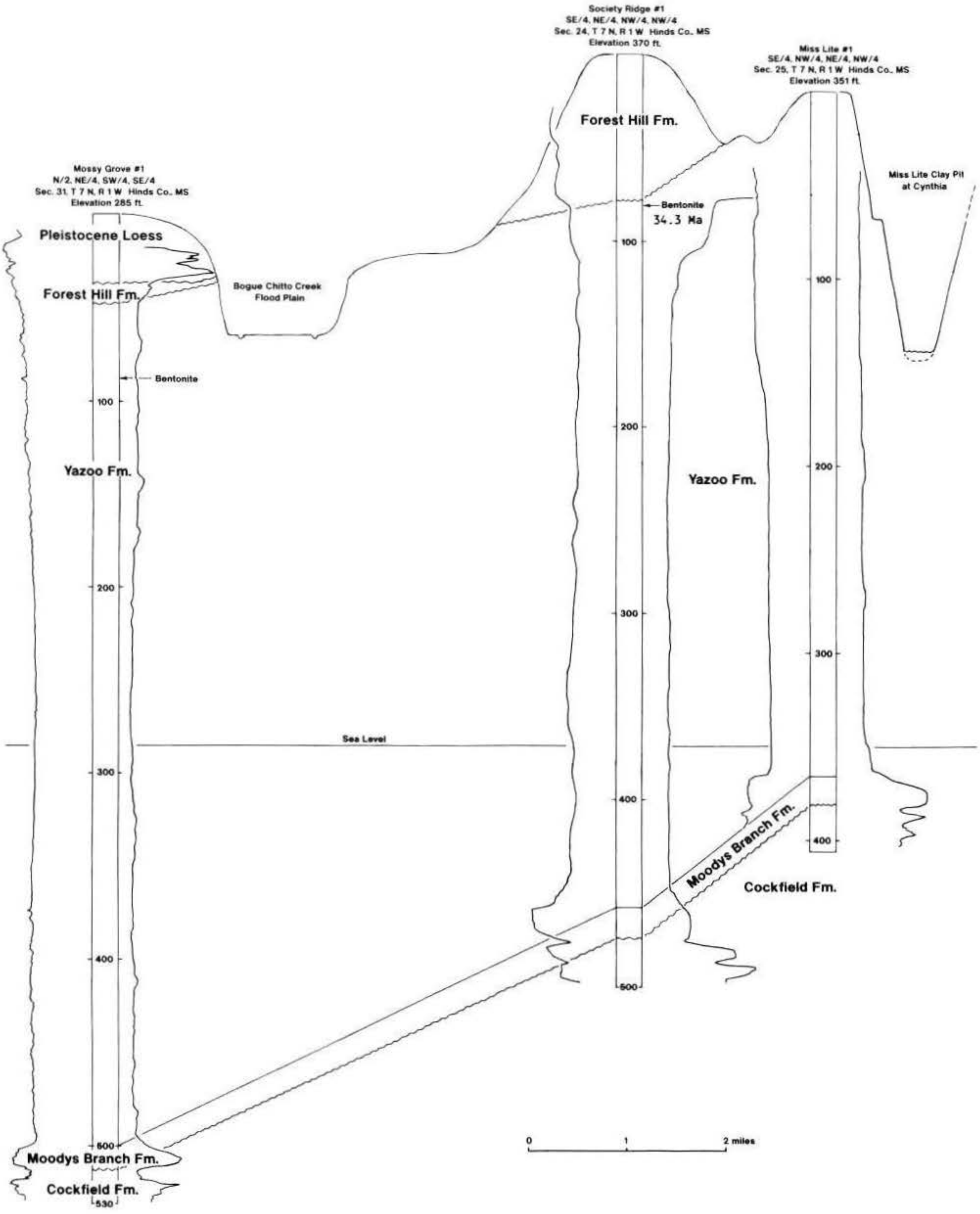

Figure 2. Cross section through the Mossy Grove, Society Ridge, and Miss-Lite test holes. Location of bentonites is given for the Mossy Grove and Society Ridge test holes. Multiple log runs were made for the Society Ridge and Miss-Lite test holes and the logs used here are at a different scale than those in the electric log files of the Office of Geology. The elevation at water level in the Miss-Lite clay pit shown at right is 212 feet above sea level, as surveyed by Charles Peel on June 7, 1988.

Zones suspected of increased instability could be projected to the surface and mapped in the Jackson area. A study of the clay's mineralogy could also have an economic value as the Yazoo clay is mined just north of Jackson at Cynthia to make light-weight aggregate for use in concrete blocks and other products. Of both economic and environmental importance is the study of the clay's competency as an aquitard to protect underlying ground waters.

A second reason for coring the Yazoo clay concerns the state's geologic history as revealed within the clay sequence. In eastern Mississippi and southwestern Alabama, the Yazoo Formation contains four members, which in ascending order are the North Twistwood Creek Clay, the Cocoa Sand, the Pachuta Marl, and the Shubuta Clay. Here the formation comprises less than 200 feet of section. To the west these members grade into an undifferentiated clay sequence that increases in thickness to over 400 feet in and west of the Jackson area. This expanded sequence may contain a largely uninterrupted record of Late Eocene geologic and biological events. Biostratigraphic studies of a complete core could provide a means of correlating the undifferentiated clay with members to the east. A preliminary correlation of geophysical logs indicates that the westward expansion of the Yazoo clay occurred entirely during the deposition of the Shubuta Clay Member.

A third reason for the core hole involves the presence of datable radioisotopes in bentonites in the upper Yazoo clay of western and central Mississippi. Two bentonites have been radiometrically dated at 34.3 million years old (Ma) by John Obradovich of the U.S. Geological Survey in Denver, Colorado, and Carl Swisher of the Institute of Human Origins in Berkeley, California. The agreement in age of these bentonites, one from an outcrop at Satartia and one from a core at Society Ridge just northwest of Jackson, as dated in different laboratories by different individuals supports their reliability. Both bentonites occur near the top of the Yazoo clay and give a maximum age limit for the Yazoo - Forest Hill contact and its equivalents, the Jackson-Vicksburg Group/Stage boundary, and the Eocene-Oligocene boundary.

SITE SELECTION

Site selection was based on several factors including: (1) a location in central or west-central Mississippi where the Yazoo was the thickest and near sites where radiometric dates had been obtained from bentonites near the top of the Yazoo clay, (2) the presence of a complete section of Yazoo clay near the surface but buried deeply enough to be unweathered, (3) the presence of a thin section of lignitic Forest Hill sediments overlying the Yazoo clay so that the Forest Hill - Yazoo contact (also the Eocene-Oligocene boundary) could be cored, (4) the presence of a thick Yazoo clay sequence (greater than 400 feet in thickness) that would presumably contain the most detailed geologic record, and (5) the availability of geophysical logs from nearby wells to show that the previous criteria could be met at the proposed site. Other generic test hole site criteria included a clear, flat place to drill and the availability of water.

The site selected for the core hole was adjacent to a lake at Mossy Grove on the east side of Clinton-Tinnin Road across the road from Camp Kickapoo, a Boy Scout camp, and just north of the Clinton-Tinnin and Kickapoo Road intersection (figures 1, 2, and 3). A recent water well for the North Hinds Water Association drilled at Camp Kickapoo showed the Yazoo clay in this area to be 450 feet thick and covered with lignitic sediments of the Forest Hill Formation. The basal Forest Hill is generally lignitic in central Mississippi except where channel sands of the formation have cut out this section and have eroded into the top of the Yazoo clay. Such was found to be the case at the Mississippi Office of Geology test/core hole at Society Ridge just northwest of Jackson and a few miles east of the Mossy Grove core hole (figures 1 and 2). This hole was drilled near a sand pit, below which a bentonite was noted in a drainage ditch. The purpose of the hole was to core the bentonite, which was 40 feet below the test hole site. Instead, an 80-foot thick channel sand was drilled before the top of the Yazoo clay was encountered. A 16-foot core of the upper Yazoo clay at this site revealed the presence of three additional bentonites, the upper of which was dated at 34.3 Ma by Swisher.

DRILLING PROCEDURE

The core hole was drilled with the Mississippi Office of Geology's Failing 1500 drilling rig. Because this rig has not been equipped with a wire line coring assembly, a ten-foot clay core barrel was used for the coring. The hole was first drilled through surficial loess deposits to a depth of 30 feet using a 7-inch clay bit. The basal Forest Hill sediments and the Forest Hill - Yazoo clay contact were cored in the next ten-foot interval. For the next 460 feet, the coring was in the Yazoo clay. That equates to 46 trips in and out of the hole with all the drill stem, which was broken in 20-foot sections and stacked against the monkey board (Figure 4). Additional trips were made at 30- to 40-foot intervals to ream the hole with the 7-inch clay bit. The final trip down the hole to 530 feet was made after the geophysical logs were run. The hole was then plugged by pumping cement grout down the drill stem and filling the hole from bottom to top. Before the cement could set, the 52 ten-foot drill pipes comprising the drill stem were broken apart, washed, and stacked on the water truck. The drilling crew consisted of the authors (especially the latter three) and the drillers Scott Mixon and Archie McKenzie.

While the coring of a 530-foot hole with a ten-foot clay barrel is time consuming, labor intensive, and just hard work, the clay barrel performed fairly well. It was designed for use in coring kaolin clays and has an outer and inner barrel

Figure 3. Core hole site at Mossy Grove on north side of lake in SW/4, SE/4, Section 31, T. 7 N., R. 1 W., Hinds County.

between which the drilling fluid passes to circulate the cuttings. Upon retrieving the core at the surface, the bit is removed from the core barrel (Figure 5), the mud hose of the drilling rig is inserted into a fitting at the top of the core barrel, and the core is forced out of the inner barrel by hydraulic pressure (Figure 6). The cores were extruded onto half sections (cut lengthwise) of PVC pipe (Figure 7), cut into five two-foot lengths, wrapped in plastic wrap, and placed in core boxes with a ten-foot core capacity. The cores were cut in half lengthwise at the University of Southern Mississippi Geology Department and half of the core (in 50 core boxes) was returned for storage at the Mississippi Office of Geology core warehouse.

STRATIGRAPHY

The core hole encountered, from top to bottom (see Figure 2), 28 feet of Pleistocene loess, 10 feet of lignites, sands, and shales of the Early Oligocene Forest Hill Formation (Vicksburg Group), 462 feet of the Late Eocene Yazoo clay (Jackson Group), 12 feet of glauconitic sand of the Late Eocene

Figure 4. Bringing the core out of the hole with 17 20-foot sections stacked against the monkey board and another being broken from the drill stem at the breakout table. Phillip Weathersby is on the monkey board (top) and on the ground from left to right are Scott Mixon, Wayne Stover, Archie McKenzie, and Steve Ingram.

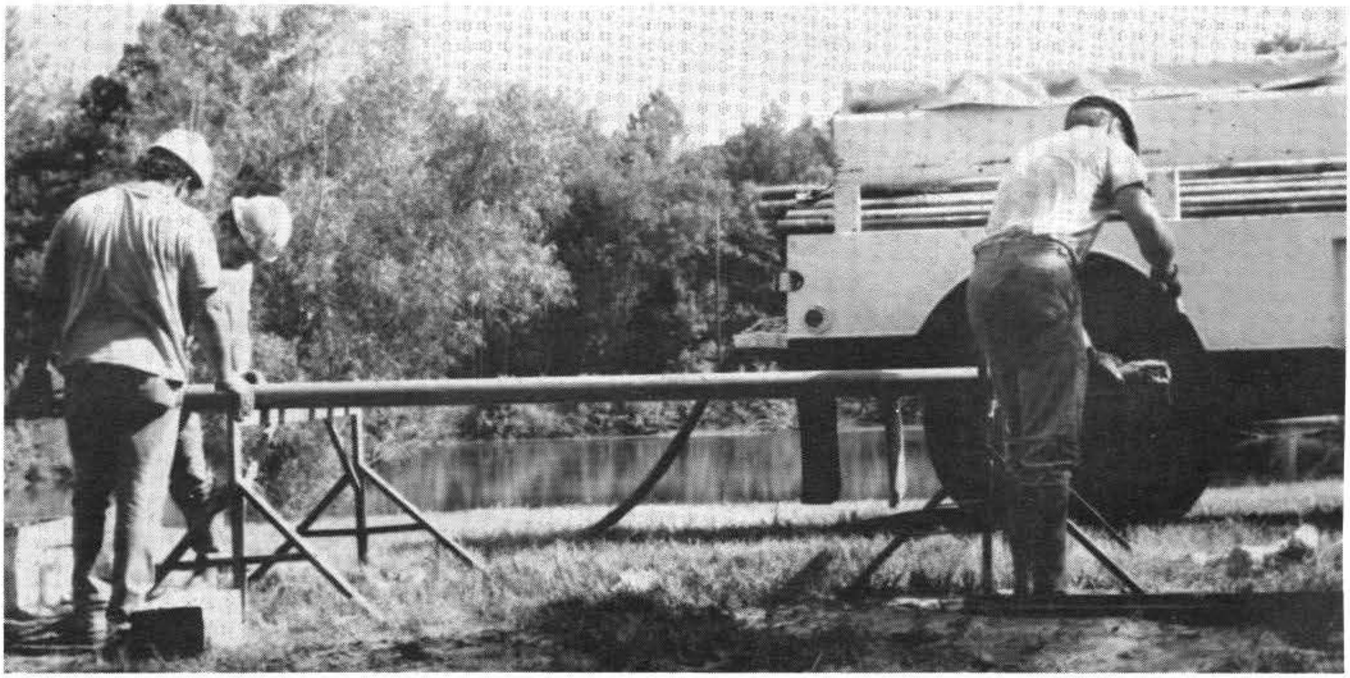

Figure 5. Breaking the bit loose from the core barrel (at right) and inserting the mud hose into fitting (at left).

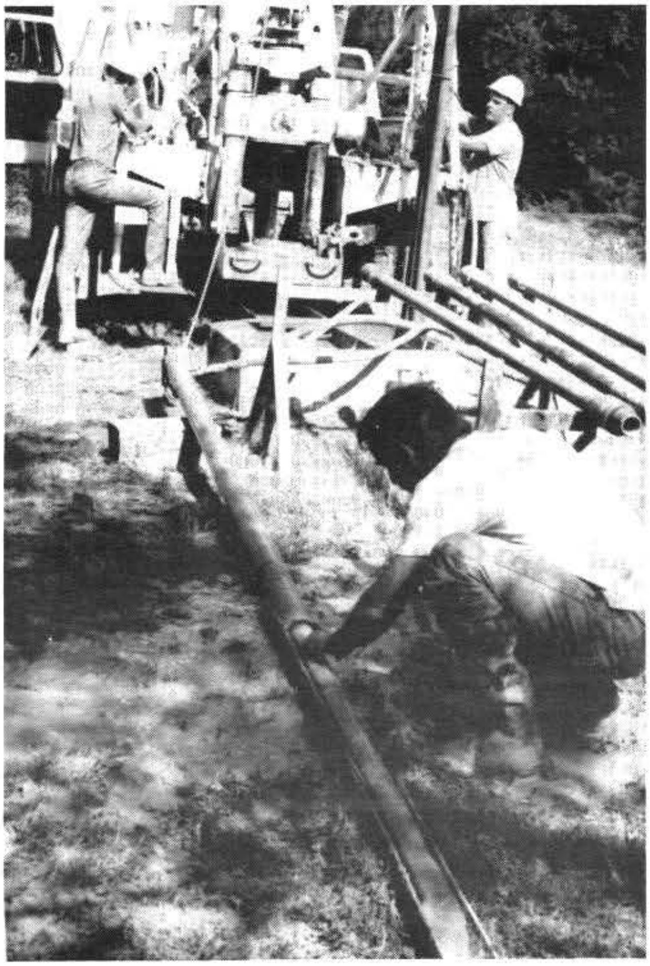

Figure 6. Extruding the core with hydraulic pressure.

Moodys Branch Formation (Jackson Group), and 18 feet of clays and sands of the Middle Eocene Cockfield Formation (Claiborne Group). The Forest Hill - Yazoo contact consisted of lignite unconformably overlying marine clay. The 462-foot thick interval of Yazoo clay present in the core hole is believed to represent as complete a section as is available for this formation in the Jackson area (compared to a thickness of 380 feet in the Society Ridge test hole). As observed when freshly cored, it consisted of grayish-green (GSA color chart 10 GY 5/2), montmorillonitic clay with variations in darkness and lightness of hue. In its upper 150 feet, the Yazoo clay was rich in mollusk shells and contained thin layers of shell hash. The only sandy unit noted within the clay was a 3-inch thick glauconitic sand (consisting largely of glauconite) 10 feet below the clay's top. A 4-inch thick bentonite was present at 50 feet below the clay's top. No limestone units were noted even though a prominent limestone marker bed is present in the Miss-Lite clay pit at Cynthia a few miles to the east-northeast of the core hole. Coring time for the clay averaged around five minutes per ten-foot core with the stiffest clay occurring in the bottom ten feet just above the Moodys Branch Formation and having a coring time greater than eleven minutes.

The Moodys Branch Formation consisted of dusky green (GSA color chart 5 G 3/2), fossiliferous, glauconitic sand. The basal contact with the Cockfield was sharp and marked by burrows and clasts. In its upper eight feet, the Cockfield

Figure 7. Stover and Stover examining the core.

Formation contained dusky yellowish brown (GSA color chart 10 YR 2/2), silty clay with intervals of crushed oyster shells. This estuarine unit is similar to that in the upper Cockfield Formation (=Yegua Formation) at Creola Bluff on the Red River in Louisiana, which was named the Creola Member by Stenzel (1940, p. 881). Stenzel also recognized the presence of this unit at Garland Creek in Clarke County, Mississippi. Dockery (1980, p. 51-52) noted a fossiliferous transition zone equivalent to this unit in the upper Cockfield Formation along the Chickasawhay River in Clarke County. The final core run was made to determine the thickness of the upper Cockfield estuarine interval. When no additional estuarine sediments were noted in the last core, dual induction and gamma ray geophysical logs were run and the hole was grouted and abandoned.

The 500-foot core taken at Mossy Grove is the longest continuous core completed by the Mississippi Office of Geology to date. Studies of the core's mineralogy and calcareous nannoplankton flora are underway at the University of Southern Mississippi Department of Geology. Scott Snyder of the East Carolina University Department of Geology has sampled the core for planktonic Foraminifera. Studies of other microfossil groups have been planned. Anyone wishing to study the core should contact the senior author at the Mississippi Office of Geology.

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CYPRAEDIA (*EUCYPRAEDIA*) *MULTICARINATA* (DALL, 1890); A LATE EOCENE OVULIDAE FROM FLORIDA, MISSISSIPPI, COLOMBIA, AND PERU

STUDIES ON PALEOGENE CYPRAEOIDEA (MOLLUSCA: GASTROPODA) FROM THE GULF COAST BASIN - III

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Saint Denis, France

INTRODUCTION

Cypraedia (*Eucypraedia*) *multicarinata* (Dall, 1890) is a rare Late Eocene species with one of the broadest distributions known for a Paleogene gastropod, occurring in Florida, Mississippi, Colombia, and Peru. Between 1890 and 1977 American authors have proposed several names for this taxon based on rare occurrences in different areas. An exceptionally well preserved specimen noted by David Dockery in the U.S. National Museum collections labelled by Dall as "*cf. C. subcancellata* Johnson" from the Moodys Branch Formation at Town Creek in Jackson, Mississippi, prompted this revision. This specimen (Figure 1a-b) was collected by E. N. Lowe, State Geologist of Mississippi (1909-1933), in September of 1912.

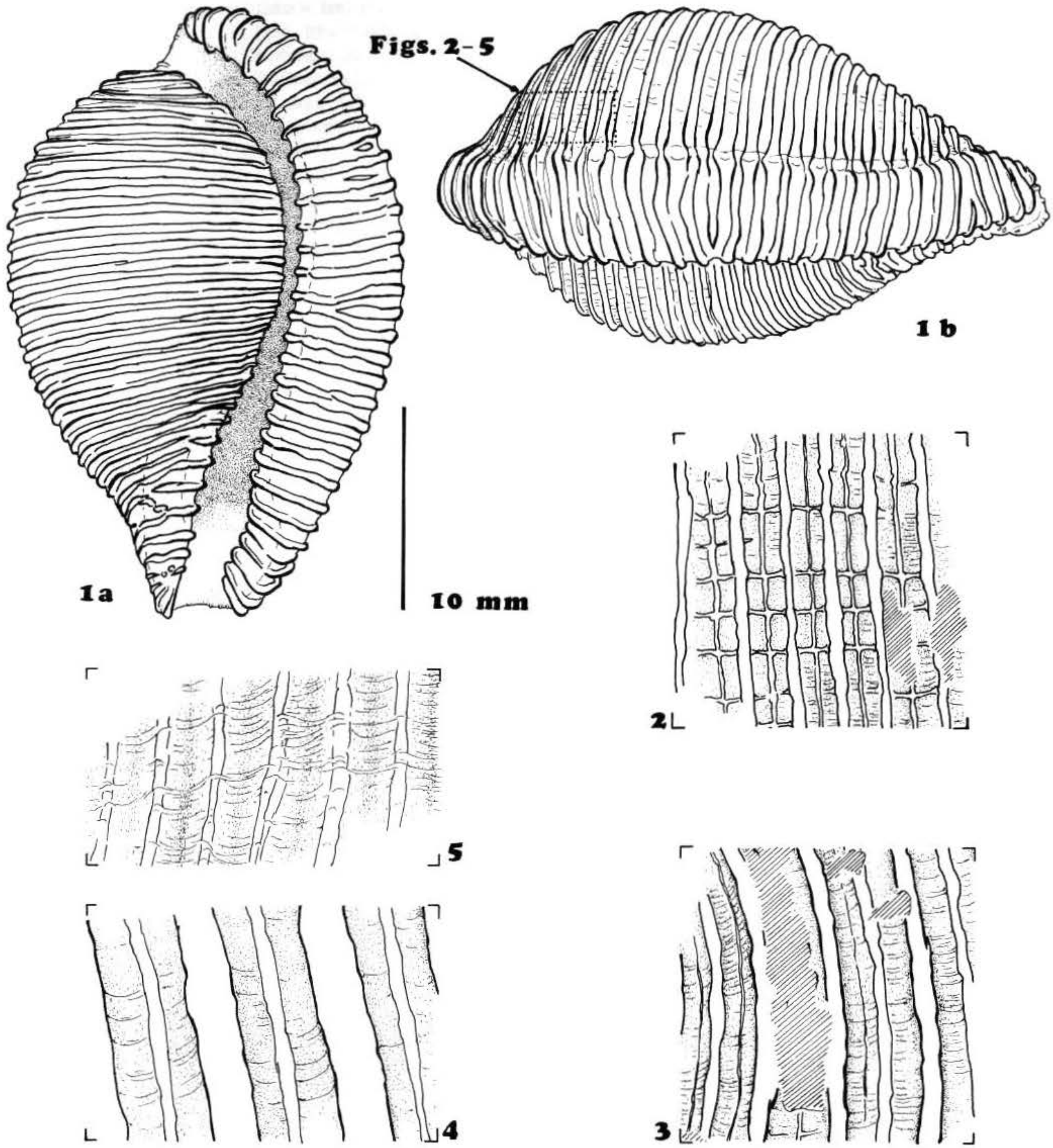
ACKNOWLEDGMENTS

The material on which this paper is based was generously placed at my disposal by Elena Benamy (Academy of Natural Sciences, Philadelphia), S. Cazalda (Museo y Laboratorio de Geologia del Seminario, Barcelona), Frederik J. Collier (U.S. National Museum, Washington, D.C.), Peter R. Hoover (Paleontological Research Institution, Ithaca), and David R. Lindberg (University of California Museum of Paleontology, Berkeley). I wish to extend my warmest gratitude to J. Biosca (University Politecnica de Catalunya) for his help and information.

1, 3-4 *Cypraedia* (*Eucypraedia*) *multicarinata* (Dall, 1890)
1a-b. Ventral and lateral view. USNM specimen 6467. E. N. Lowe collector (September 1912). Height 29.4 mm, maximum diameter 19.2 mm, dorsoventral diameter 15.8 mm. Moodys Branch Formation, Town Creek, Jackson, Mississippi.
3. Detail of *Cypraedia carmenensis* holotype 34988 UCMP. Specimen not complete, dorsoventral diameter 13.9 mm. Upper? Eocene, Bolivar, Colombia.
4. Detail of *Cypraedia pittsi* holotype 8237 PRI. L. P. Pitts collector. Height 42.8 mm (siphonal canal slightly damaged), maximum diameter 24.0 mm, dorsoventral diameter 24.0 mm. Moodys Branch Formation, Town Creek, Jackson, Mississippi.

2. *Cypraedia* (*Eucypraedia*) *subcancellata* (Johnson, 1899)
Detail of holotype 7119 ANSP. C. W. Johnson collector (October-November 1895). Height 15.2 mm (siphonal canal broken), maximum diameter 9.7 mm, dorsoventral diameter 7.3 mm. Weches Formation, Smithville, Bastrop County, Texas.

5. *Cypraedia* (*Eucypraedia*) *cailliaudi* (Vasseur, 1881)
Detail of MNHN specimen. L. Dolin collector (1979). Height 22.0 mm, maximum diameter 17.0 mm, dorsoventral diameter 14.7 mm. "Biarritzian" (= early Bartonian), "Pierre-Aigue", Saint-Aignan-Grandlieu, Loire-Atlantique, France.


Figs. 2-5
1a
10 mm
1 b
2
5
4
3

SYSTEMATICS

Family OVULIDAE Fleming, 1828
Subfamily CYPRAEDIINAE Schilder, 1927

The *Cypraedia s. l.* have a multispiral (sinusigeriform) planktotrophic protoconch with an obliquely decussate sculpture typical of the Ovulidae (Pezant, 1910, pl. 14, fig. 14a-c) and not a vertically squared sculpture as in the Cypraeidae nor perforate with a hollow columella as in the Eratoidae.

Genus *CYPRAEDIA* Swainson, 1840
Subgenus *EUCYPRAEDIA* Schilder, 1939

Cypraedia subgenus *Eucypraedia* Schilder, 1939, Archiv fur Molluskenkunde, v. 71, p. 167, 190.

Type species: *Cypraea sulcosa* Lamarck, by original designation.

Dolin and Dolin (1983, p. 33) justified the synonymy of *Eucypraedia* with *Cypraedia*. *Eucypraedia* is used here as a convenient taxon for the group of oblong *Cypraedia*.

Cypraedia (*Eucypraedia*) *multicarinata* (Dall, 1890)
Figures 1a-b, 2-5

1890. *Ovula* (*Transovula*) *multicarinata* Dall, Trans. Wagner Free Inst. Sci. Philadelphia, v. 3, no. 1, p. 164, pl. 10, fig. 10-11.

1927. *Cypraedia multicarinata* Dall. Schilder, Archiv. Naturgesh., v. 91, no. A/10, p. 68, 126.

1931. *Cypraea* (*Cypraedia*) *chira* Olsson, Bull. Amer. Paleont., v. 17, no. 63, p. 93-94, pl. 17, fig. 9, 12.

1946. *Cypraedia carmenensis* Clark, Geol. Soc. Amer. Mem. 16, p. 31-32, pl. 17, fig. 3-4.

1947. *Cypraedia chira* Olsson. Ingram, Bull. Amer. Paleont., v. 31, no. 120, p. 67, pl. 6, fig. 3-4.

1971. *Eucypraedia multicarinata carmenensis* Clark. Schilder and Schilder, Inst. Royal Sci. Nat. Belgique, Mem. (Ser. 2), no. 85, p. 24.

1971. *Eucypraedia multicarinata multicarinata* Dall. Schilder and Schilder, Ibid.

1971. *Eucypraedia multicarinata chira* Olsson. Schilder and Schilder, Ibid.

1977. *Cypraedia pittsi* Dockery, Mississippi Geol. Survey, Bull. 120, p. 61, pl. 17, fig. 4a-b.

Types: Holotype of *Ovula* (*Transovula*) *multicarinata* Dall, U.S. National Museum 112450 (Schuchert et al., 1905, p. 476).

Type locality: Martin's Station, Marion County, Florida.

Material examined: Plesiotype (UPMC, Cossmann Collection) of *Cypraedia* (*Eucypraedia*) *cailliaudi* (Vasseur); paratypes (USNM 112449, 11502) of *C.* (*E.*) *multicarinata* (Dall); holotype (ANSP 7119) of *C.* (*E.*) *subcancellata* (Johnson); holotype and paratype (PRI 2102, 2099) of *C.* (*E.*) *chira* Olsson; holotype (UCMP 34988) of *C.* (*E.*) *carmenensis* Clark; holotype (PRI 8237) of *C.* (*E.*) *pittsi* Dockery; topotypes (MLGS, Barcelona 13919, 5558) of *Cypraeovula funiculifera* Cossmann.

Distribution: "Ocala Limestone" (Upper Eocene) at Martin's Station and Richard's Quarry, Marion County, Florida. Moodys Branch Formation (Upper Eocene) at Town Creek (MGS 1), Jackson, Mississippi. Eocene Faunal Zone C of Clark *in* Clark and Durham (1946) from about 1.5 kilometers east of Loma de Viento near Carmen well number 2, Bolivar, Colombia. Chira Formation [Lower Oligocene according to Olsson (1931), but Upper Eocene according to Clark *in* Clark and Durham (1946)] near Casa Saman and Quercotilla, Peru. A few specimens questionably assigned to this species by Olsson (1931) are from the Punta Bravo grits of the Mancora Formation (Oligocene) of Caleto Sal, Peru.

Discussion: Schilder and Schilder (1971, p. 24) prudently placed *Cypraea* (*Cypraedia*) *chira* Olsson from the Upper Eocene and Oligocene? of northern Peru and *Cypraedia carmenensis* Clark from the Eocene of Bolivar, Colombia, as subspecies of *Cypraedia* (*Eucypraedia*) *multicarinata* (Dall), which is from the Upper Eocene of Florida. The material available on these Paleogene species is not sufficient to discriminate a geographic or stratigraphic transient; even the Oligocene occurrence of this species in the Mancora Formation of Peru is questionable. There is no difference between the three previously mentioned species and the Upper Eocene species *Cypraedia pittsi* from the Moodys Branch Formation of Jackson, Mississippi.

The oldest known *Eucypraedia* is *Cypraedia* (*Eucypraedia*) *interposita* (Deshayes, 1865) from the Ypresian (early Early Eocene) of Cuise-la-Motte, Oise, France (see Cossmann and Pissaro, 1911, pl. 33, fig. 162-14). Based on its thin and numerous ribs and its general shape, *C.* (*E.*) *interposita* belongs at the base of the Paris Basin Middle Eocene species complex of *C.* (*E.*) *sulcosa* (Lamarck, 1802) (Cossmann and Pissaro, 1911, pl. 33, fig. 162-15 = *parisiensis* Schilder, 1931, and fig. 162-16 = *sophia* Bernay in Deshayes, 1865) and *C.* (*E.*) *georgii* (Defrance, 1826) (see Cossmann and Pissaro, 1905, p. 60, pl. 15, fig. 9-11).

Cypraedia (*Eucypraedia*) *cailliaudi* (Vasseur, 1881) from the "Biarritzian" (= Bartonian: late Middle Eocene) of Bois-Gouet and Saint-Aignan de Grandlieu, Loire-Atlantique, France (see Cossmann, 1897, pl. 8, figs. 28-29, 31), is similar to *C.* (*E.*) *multicarinata* in the width of its shell but differs in its thin and more broadly spaced ribs and in its smooth intercostal zones (Figure 5), which lack the weak intercalary threads present in the *C.* (*E.*) *subcancellata*, *multicarinata* and *sulcosa* species complex. Based on this last criterion, Cossmann (1898, p. 339) suggested that *C.* (*E.*) *cailliaudi* was related to *Cypraeovula funiculigera* Cossmann, 1897 [as *funiculifera* in Cossmann, 1898, p. 25, pl. 9, fig. 1-2 = *C.* (*E.*) *barcinensis* (Gray, 1828) fide Schilder, 1927, p. 68, 126] from the lower "Biarritzian" (= Bartonian) of Sant Llorenc de Morunys, Lerida, Spain. This last species, however, is more spherical, an ancestral characteristic.

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SEISMIC STRATIGRAPHIC CONFIRMATION OF A BURIED LATE PROTEROZOIC TERRANE, SUNFLOWER COUNTY, MISSISSIPPI

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INTRODUCTION

The subsurface of the Mississippi River alluvial plain in western Mississippi and eastern Arkansas is one of very diverse and interesting geology. Quaternary sediments, which cover most of the area, make study of all pre-Pleistocene units very difficult. Oil industry exploration seismic and wells give us a unique opportunity to examine this unexposed section. A few of these wells drilled beneath the Mesozoic sedimentary sequences into either Mesozoic igneous or Paleozoic sedimentary/metasedimentary rocks (or both). These provide a glimpse into the earliest geologic periods recorded in western Mississippi. The Pan American No. 1 Word, Sunflower County, Mississippi, is one such well. Drilled originally in 1969 as a Jurassic Smackover test on a seismically-defined anticline, the well encountered over 3700 ft (1130 m) of igneous rocks below undifferentiated Jurassic Cotton Valley Group sediments. No identifiable Smackover was present. The target horizon reflector, originally thought to be the top of the Smackover Formation, turned out to be the Jurassic sedimentary unconformity contact with an underlying thick igneous section. This igneous section was dated using the K-Ar method and resulted in age ranges from 174 +/- 7 Ma to 785 +/- 34 Ma. These dates indicate that the Pan Am No. 1 Word was the first well in Mississippi to encounter Proterozoic rocks.

Failure to find a trend of Smackover fields extending the Dollarhide Field discovery discouraged further exploration in the area until the early 1980's. In 1983, Pruet Oil and PGI reprocessed Amoco's seismic data in the area. This effort substantially improved the seismic stratigraphic resolution of the data and finally permitted resolution of the previously undifferentiable igneous pile in the lower portion of the Pan Am No. 1 Word. Through an integration of seismic, well log, and drill cutting radiometric age dates, this report presents an interpretation of some of that data.

REGIONAL GEOLOGIC SETTING

The Mississippi Alluvial Plain overlies a tectonically active structural trough which has displayed major, recurring movement since the Late Proterozoic. This activity is associated with faulting within the Reelfoot Rift - New Madrid seismic zone and the Mesozoic Gulf of Mexico peripheral fault zone. These two tectonic provinces converge near the area of the Monroe-Sharkey Uplift (Figures 1, 3).

Proterozoic basement encounters have become more numerous with increased oil and gas company drilling for deeper objectives. The radiogenic age dates and lithologies of these basement rocks indicate that two thermotectonic provinces are present within the southeastern U.S.A. (Table 1). The structural trends of these provinces can be extrapolated using regional aeromagnetic and gravity maps (Zietz, 1982; Lyons and O'Hara, 1982) (Figure 1). These data, as well as previously published interpretations of the Midcontinent (Bickford et al., 1986; Bickford, 1988), suggest a progressive Proterozoic accretionary history on the (present) southeastern flank of the North American craton, culminating in the Grenvillian Orogeny between 1.3 and 1.0 Ga. This orogeny was followed by late Proterozoic rifting and creation of the early Paleozoic passive continental margin of Laurentia (0.8 to 0.6 Ga)(Hoffman, 1989). For the purposes of this discussion the Proterozoic is assumed to end about 570 Ma (Hoffman, 1989).

PAN AM NO.1 WORD DRILLING RESULTS

The Pan American Petroleum Corporation (now Amoco Production Company) drilled the No. 1 Mrs. A. J. Word, Jr., to a total depth of 11,988 feet (3654 m) in Sec. 4, T17N, R3W, Sunflower County, Mississippi. The test was originally planned as a Jurassic Smackover wildcat. Overlying Cretaceous igneous units were known to be present in the area, so encountering an igneous body prior to reaching the Smackover was not considered detrimental nor unusual. Consequently, the well drilled through 3705 ft (1129 m) of the lower Tertiary Wilcox and Porters Creek formations, 3675 ft (1120 m) of Cretaceous chalks, volcanic rocks, and interbedded shales and sandstones, and 840 ft (256 m) of Jurassic Cotton Valley Group sandstones and shales before reaching the top of the main igneous pile at a measured depth of 8280 ft (2524 m)(Figure 2). Drilling continued through a thick igneous section, ultimately penetrating approximately 3700 feet (1130 m) of continuous igneous lithologies. No Smackover was identified. At 11,988 ft (3654 m) the well was logged, plugged and abandoned without any oil or gas shows. Com-

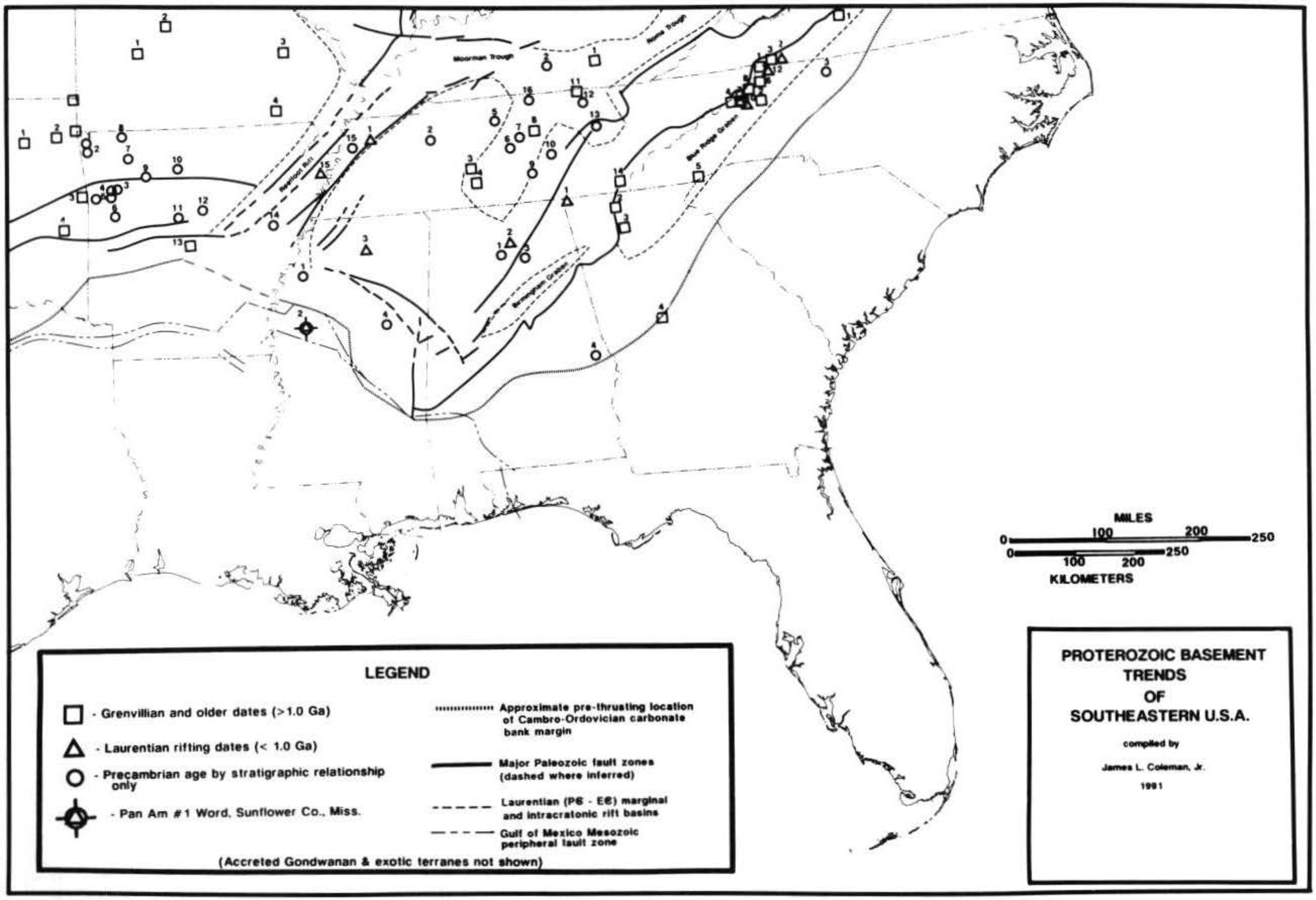

Figure 1. Proterozoic basement dates and structural trends in the southeastern United States. Age dates, locations, and data sources are identified in Table 1. Base map modified, in part, from Hale-Erlich and Coleman (1991, in review) and Jurick (1989).

TABLE 1
PROTEROZOIC BASEMENT PENETRATIONS AND OCCURRENCES S.E. U.S.A.
(LOCATIONS PLOTTED ON FIGURE 1)

STATE	WELL, MINE, ETC.	LOCATION	AGE (Ma)	METHOD	ROCK TYPE	REFERENCE SOURCE(S)
MISSOURI:						
	1) Union Carbide HHR-1	18-[illegible]N-21W Polk Co.	1532	U/Pb	granite	Van Schmus and others (1987)
	2) Exxon Minerals DB1	14-37N-17W Camden Co.	1633	U/Pb	gneiss	Van Schmus and others (1987)
	Exxon Minerals TD1	28-37N-17W Camden Co.	1633	U/Pb	gneiss	Van Schmus and others (1987)
	3) St. Francois Mtns.	SE Missouri	1180	U/Pb	rhyolite & granite	Bickford and Mose (1975)
	4) Gulf Oil FDW-2	29-25N-4E Ripley Co.	1482	U/Pb	granite	Van Schmus and others (1987)
OKLAHOMA:						
	1) Daniels & Smith #2 Vierhiller	Rogers Co.	1230	Rb/Sr	granite	Muehlburger & others (1966)
	2) Spavinaw Creek outcrop	Mayes Co.	1280	Rb/Sr	granite	Muehlburger & others (1966)
	3) Okla. Nat. Gas #1 Stockton	Sequoyah Co.	1230	Rb/Sr	rhyolite	Muehlburger & others (1966)
	4) Pan Am #1 Tackett	Leflore Co.	1200	Rb/Sr	granite	Muehlburger & others (1966)
ARKANSAS:						
	1) Lane & Western #2 Decatur	3-16N-26W Benton Co.	PC	strat. rel.	microgranite porphyry	Denison (1984)
	2) Ozark #1 Curry	33-18N-33W Benton Co.	PC	strat. rel.	rhyolite porphyry	Denison (1984)
	3) Tenneco #1 Conaster	17-10N-27W Franklin Co.	PC	strat. rel.	microgranite porphyry	Denison (1984)
	4) SEECO #5 Lessley	21-10N-28W Franklin Co.	PC	strat. rel.	granite	Denison (1984)
	5) Arkla #1 Ark. Valley	9-9N-28W Franklin Co.	PC	strat. rel.	micrographic granite	Denison (1984)
	6) Exxon #1 Tanner	15-6N-28W Logan Co.	PC	strat. rel.	metarhyolite	Denison (1984)
	7) Layne Western #1 Huntsville ww	3-16N-26W Madison Co.	PC	strat. rel.	metarhyolite	Denison (1984)
	8) St. Joe Min. #AK-CA-1	30-21N-25W Carroll Co.	PC	strat. rel.	micrographic granite	Denison (1984)
	9) Pan Am #1 USA	28-13N-22W Newton Co.	PC	strat. rel.	micrographic granite	Denison (1984)
	10) Petroplex #1 Wheeler	18-14N-16W Searcy Co.	PC	strat. rel.	granite	Denison (1984)
	11) Opello breccia	2-5N-17W Conway Co.	PC?	lith.	granite gneiss xenoliths	Denison (1984)
	12) Arco #1 Edgman	6-7N-12W Faulkner Co.	PC	strat. rel.	granite w/diabase	Denison (1984)
	13) Hominy Hill	Saline Co.	1025	K/Ar	metagabbro	Morris & Stone (1986)
	14) Cockerell #1 Carter	4-4N-1E St. Francis Co.	PC	unk.	"basement"	Schwalb (1982)
	15) Dow #1 Wilson	14-12N-9E Mississippi Co.	845	K/Ar	granitic gneiss	Howe (1985)
MISSISSIPPI:						
	1) Texaco #1 Ivy	36-27N-3W Coahoma Co.	PC	strat. rel.	microperthite granite	Harrelson & Bicker (1979)
	2) Pan Am #1 Word	1-17N-3W Sunflower Co.	785	K/Ar	syenite	Table 2, this paper
	3) Pruet & Hughes # 1 Dunlap	18-7S-1W Lafayette Co.	790	K/Ar	microperthite granite	Riggs (1976)
	4) Exxon #1 Fulgham	33-19N-12E Oktibbeha Co.	PC	strat. rel.	granite, "gneissic rock"	Harrelson & Bicker (1979), Mellen (1977)
ALABAMA:						
	1) Shenandoah #1 Smith	26-9S-2W Cullman Co.	PC	strat. rel.	alk. olivine basalt	Neathery & Copeland (1983)
	2) Saga #1 Skidmore	36-7S-1W Morgan Co.	752			
	3) Saga #1 Hudson	16-10S-2E Blount Co.	PC	strat. rel.	granodiorite	Neathery & Copeland (1983)
	4) Pine Mountain window	Lee Co.	PC	strat. rel.	granitic gneiss	Steltenpohl (1988), Steltenpohl & Moore (1988)
TENNESSEE:						
	1) Big Chief #1 Taylor	Gibson Co.	680	K/Ar	"basement rocks"	Corgan & Bradley (1983)
	2) DuPont #2 Fee	Humphreys Co.	PC	strat. rel.		unpubl. Amoco files
	3) Stauffer Chemical #1 Fee	Maury Co.	1326	K/Ar	rhyolite/ granite	Corgan & Bradley (1983), Neathery & Copeland (1983)
	4) California #1 Beeler	Giles Co.	1120	Rb/Sr	granite	Corgan & Bradley (1983), Wassenburg & others (1962)
	5) DuPont #1 Fee	Davidson Co.	PC	strat. rel.	"granite"	unpubl. Amoco files
	6) Street #1 Holden	Rutherford Co.	PC	strat. rel.		unpubl. Amoco files, Schwalb (1982)
	7) Texaco #1 Haynes	Wilson Co.	PC	strat. rel.		unpubl. Amoco files, Schwalb (1982)
	8) Amoco #1 Driver	DeKalb Co.	1073	----	gabbro	unpubl. Amoco files
	9) Amoco #1 Brothers	Coffee Co.	PC	strat. rel.		unpubl. Amoco files
	10) Conoco #1 Walker	Warren Co.	PC	strat. rel.		unpubl. Amoco files
	11) Assoc. O&G #1 Sells	Pickett Co.	849 1073	K/Ar	granite	Corgan & Bradley (1983)
	12) Monitor #1 Gernt	Fentriss Co.	PC	strat. rel.	gneiss	unpubl. Amoco files
	13) Ladd #1 Klemmer	Cumberland Co.	PC	strat. rel.		unpubl. Amoco files
	14) Calloway Mine Site 1 (Ducktown)	Polk Co.	1224	K/Ar	ore host rock	Corgan & Bradley (1983)
	15) Henderson #1 Rice	Dyer Co.	PC	strat. rel.	"basement"	Jurick (1989)
	16) Hoagland & Hardy #2 Go. 1	Macon Co.	PC	strat. rel.	"basement"	Schwalb (1982)

("PC" = undated, but presumed Precambrian age)

TABLE 1 (continued)
PROTEROZOIC BASEMENT PENETRATIONS AND OCCURRENCES S.E. U.S.A.
(LOCATIONS PLOTTED ON FIGURE 1)

STATE	WELL, MINE, ETC.	LOCATION	AGE (Ma)	METHOD	ROCK TYPE	REFERENCE SOURCE(S)
GEORGIA:						
	1) SONAT #1 Brown	Dade Co.	652	K/Ar	granodiorite	Neathery & Copeland (1983)
	2) Fort Mountain area	Murray Co.	1030	U/Pb	granitic gneiss	McConnell & Costello (1981)
	3) Salem Church Anticlinorium	Bartow-Cherokee Cos.	>1100	Pb/Pb Ar/Ar	granitic gneiss	McConnell & Costello (1980, 1981)
	4) Pine Mountain window	SW Georgia	1055 1078	Rb/Sr U/Pb	granitic gneiss	Steltenpohl (1988) Odom & others (1973, 1983)
VIRGINIA:						
	1) Blue Ridge Mtns.	SC Virginia	1041-1149	strat. correl.	granodiorite gneiss	Rankin & Others (1983)
	2) Striped Rock granite	S. Virginia Blue Ridge	646	Rb/Sr	granite	Odom & Fullagar (1981)
			772	Pb/Pb		Mose & others (1989)
			780	U/Pb		Odom & Fullagar (1981)
			681	Rb/Sr		Odom & Fullagar (1984), Mose & others (1989)
			740	U/Pb		Odom & Fullagar (1984)
			695	Pb/U		Odom & Fullagar (1981)
	3) Grayson gneiss		1150	----	gneiss	Fullagar & Odom (1973) Mose & others (1989) Rankin & others (1990)
NORTH CAROLINA:						
	1) Mt. Rogers area	NW No. Carolina	1280	U/Pb	layered gneiss	Rankin & others (1983)
	2) Grandfather Mt. window	WC No. Carolina	1005-1079	Pb/Pb, U/Pb, Rb/Sr	gneiss	Rankin & others (1983)
	3) Sauratown Mts. Anticlinorium	NC No. Carolina	PC	Pb/Pb	gneissic granite	Rankin & others (1983)
	4) Dayton Bend	NW No. Carolina	1280	U/Pb, Rb/Sr	layered gneiss gneiss	Rankin & others (1983), Mose & others (1989)
	5) Toxaway gneiss		1023	Rb/Sr	gneiss	Fullagar & others (1979), Mose & others (1989)
	6) Blowing Rock gneiss	NW No. Carolina	1006	Rb/Sr	gneiss	Fullagar & Odom (1973), Mose & others (1989)
	7) Cranberry gneiss		1227	Rb/Sr	gneiss	Fullagar & Odom (1973), Mose & others (1989)
			1042	Rb/Sr	gneiss	Fullagar & Odom (1973), Mose & others (1989)
			1018	Rb/Sr	gneiss	Fullagar & Bartholomew (1983), Mose & others (1989)
	8) Watauga River gneiss	NW No. Carolina	1177	Rb/Sr	gneiss	Fullagar & Bartholomew (1983), Mose & others (1989)
	9) Crossing Knob gneiss	NW No. Carolina	947	Rb/Sr	gneiss	Fullagar & Bartholomew (1983), Mose & others (1989)
	10) Crossnore pluton	NW No. Carolina, nr Grandfather Mtn.	706	Rb/Sr	granite	Odom & Fullagar (1989)
			728	Pb/Pb		Mose & others (1989)
			750	U/Pb		Odom & Fullagar (1981)
			646	Rb/Sr		Odom & Fullagar (1984), Mose & others (1989)
			780	U/PB		Odom & Fullagar (1981)
			772	Pb/Pb		Mose & others (1989)
	11) Beech granite outcrop	NW No. Carolina	706	Rb/Sr	granite	Odom & Fullagar (1984), Mose & others (1989)
			728	U/Pb		Mose & others (1989)
			750	U/Pb		Odom & Fullagar (1981)
	12) Lansing pluton outcrop	20 km so. Mt. Rogers	699	Rb/Sr		Odom & Fullagar (1984) Rankin & others (1990)
KENTUCKY:						
	1) Amerada #1 Edwards	24-H-60 Pulaski Co.	1457	U/Pb	syenite	Hoppe & others (1983)
	2) Denz #1 Nunnally	16-F-46 Metcalf Co.	PC	unk.	"basement"	Schwalb (1982)

("PC" = undated, but presumed Precambrian age)

posite samples were collected from several intervals in the igneous pile and dated by K-Ar method (Table 2). Three ages were determined:

1) basalt from 9613 ft (2930 m) at 174 +/- 7 Ma (M. Jurassic)
2) basic igneous rock from 11,210 ft to 11,984 ft (3417 m to 3652 m) at 468 +/- 19 Ma (M.-L. Ordovician)
3) hornblende syenite from 11,300 ft to 11,360 ft (3444 m to 3462 m) at 785 +/- 34 Ma (L. Proterozoic)

The Middle Jurassic basalt fits into a whole suite of similarly aged basic igneous rocks reported in some detail by Sundeen (1979, 1980, 1982, 1986), Harrelson and Bicker (1979), and others (see bibliography in Sundeen, 1986, Appendix C). These rocks extend over approximately 5300 sq. mi. (13,640 sq. km) in the Mississippi Embayment of Mississippi, Louisiana, and Arkansas (Figure 3). Within the well bore, Middle Jurassic igneous rocks rest on a metaquartzite of undetermined age which occurs between 10,905 ft (3324 m) and 10,960 ft (3340 m).

Beneath the Middle Jurassic section, a sequence of hornblende syenite with intruded(?) basic igneous rocks continues to the bottom of the well. The basic igneous rocks were originally dated at 459 +/- 23 Ma (Table 2). In the report of analysis of a re-sampling of the lower section, Krueger (1976) stated that the 459 +/- 23 Ma early Paleozoic age may be a minimum determination. If this assessment is correct, then the Middle to Late Ordovician date may be too young because of Mesozoic thermal alteration and radiometric resetting associated with the Jurassic basalt flows. This being the case, the basic igneous rock may be at least Cambrian in age, and is possibly related to regional igneous activity involved in early Paleozoic rifting of the Reelfoot Rift (Howe, 1985). Recalculation of the original data yields a slightly older age of 468 +/- 19 Ma (Table 2). If either age is valid, then they fall close to ages of Ordovician bentonites from eastern North America (457.1 +/- 1.0 Ma)(Samson et al., 1989). These bentonites are usually attributed to volcanic ash falls emanating from an, as yet, unidentified volcanic source in the southeastern U. S. A. This age is also within the age ranges of Carolina slate belt felsic metavolcanic rocks - 465 Ma (LeHuray, 1987). The volcanic source for the North American Ordovician bentonites was apparently underlain by Proterozoic crust because it contains inherited zircon with ages of 1100 and 1500 Ma (Samson et al., 1989). Data are insufficient to speculate further on the potential relationship between the occurrence of Ordovician age basic igneous rocks and the eastern North American bentonites of the same age.

The Ordovician basic igneous rocks of the Word well presumably intrude into the more sialic, hornblende syenite section dated at 785 +/- 34 Ma, although specific sample evidence is currently lacking to demonstrate this.

This Late Proterozoic age date is similar to other Late Proterozoic Laurentian dates in the area (Figure 1, Table 1). The samples which yielded these dates are all from localities near or within the Late Proterozoic rifted margin of Laurentia. It is reasonable to assume that these ages reflect the high temperature events associated with that major tectonic episode.

INCORPORATION OF SEISMIC STRATIGRAPHY

Since the samples that were dated were collected from drill cuttings from a 60-foot (18 m) interval, it is difficult to determine their precise stratigraphic level, and hence, the age to which they can be applied. Application of simple seismic stratigraphic techniques to a north-south seismic line through the well helps constrain the options. A synthetic seismogram (Figure 2) was created from the sonic and density logs run in the Pan Am No.1 Word borehole. This seismogram ties the well log stratigraphy and lithology to the seismic reflection packages. Two seismically interpreted unconformities are obvious below the top of the Cotton Valley reflector (Figure 4): one at the top of the volcanic pile (approximately 1.9 seconds on the right section margin) and a deeper one within the pile (approximately 2.2 seconds, also on the right margin). Initial correlation of this deeper unconformity back to the borehole places it at approximately 11,020 ft (3359 m) on the well log. This borehole intercept occurs 260 ft (79 m) above the uppermost sample depth yielding the late Proterozoic age and 180 ft (55 m) above the uppermost sample depth yielding the Middle to Late Ordovician age. It is 60 ft (18 m) below the contact between the quartzite and the coarse-crystalline igneous rock at 10,960 ft (3340 m). At this depth, the apparent 60 ft (18 m) mis-tie is approximately 6 milliseconds of two-way time, a pencil point width. While caution should be exercised when using an interpretation made from a single seismic line, in this case it appears reasonable to assign the lower seismic unconformity to the Mesozoic - Proterozoic regional unconformity.

The fundamental lithologic differences between the Ordovician and the Proterozoic samples suggest that the Ordovician basic igneous rocks intruded the Proterozoic syenite. The seismic data are insufficient to discern the accuracy of this assessment. However, the short-length, high amplitude reflectors below the Mesozoic - Proterozoic unconformity are characteristic of moderately thin-bedded, but fairly numerous, intrusive bodies within an otherwise "quiet" (i.e., low amplitude) seismic interval.

DISCUSSION

The identification of at least two distinct seismic packages within the 3700 ft (1130 m) igneous section of the Pan Am No. 1 Word indicates that the radiometrically dated igneous sections may be correlated with reasonable confidence to these seismic intervals. The upper igneous interval is of Middle Jurassic age and thickens from south to north across the study area (Figure 4). The lower interval is primarily of latest Proterozoic age. The date and lithologies are consistent with other occurrences along the margin of the Mississippi Embayment - Reelfoot Rift.

There is no clear geophysical evidence that the Word area was thrusted northward during the Ouachita Orogeny. Previous workers have placed it south of the various late Paleozoic disturbed zones in Mississippi (Gazzier and Bograd, 1988; Jurick, 1989; and others). The limits of the late Proterozoic igneous body cannot be further refined by the existing seismic data. It appears to extend beyond both ends of the illustrated seismic line, a distance of 12 mi. (19 km)(Figure 4a,b). Based on its seismic character in the Word area, it extends, on other seismic data, as much as 15 mi. (24 km)(north to south). This extent suggests that this late Proterozoic body may not be a local anomaly or exotic local crustal block, but rather may be part of the main North American Proterozoic craton.

While its age groups it with other Laurentian rifting ages, its potential significance is its apparent location south of what is thought to be the southern cratonic margin of Paleozoic North America (Figure 1). If this assessment is true, then the Word area may have been a part of the continental mass which rifted away from North America between 800 and 600 million years ago. The 785 Ma age for the basal igneous of the Word section is very similar to ages obtained from Blue Ridge igneous rocks (Table 1; also see Mose et al., 1989, for Blue Ridge dates just north of the map area of Figure 1). These dates are bimodal, ranging from 570 to 785 Ma and from 947 to 1280 Ma (Table 1; Mose et al., 1989). It is uncertain if the Word area is an isolated microcontinental block or a portion of a larger crustal block. Since its age is more in line with the dates associated with the late Proterozoic rifting of North America rather than the Cambrian intracratonic rifting of interior North America (Lowe, 1985; Reed et al., 1989; Thomas, 1991), it is conceivable that the Word area represents a localized block of North America left behind along the initial rifted cratonic margin. It is located north of the proposed track for the late Proterozoic - early Paleozoic Alabama - Oklahoma transform zone of Thomas (1991, Figure 2). It was this transfer zone which created the southern Paleozoic continental margin of North America.

CONCLUSIONS

The Precambrian age of a thick section of alkalic igneous rock encountered in the lower portions of the Pan Am No. 1 Word well can be confidently correlated with an identifiable seismic sequence. The upper unconformity boundary to this sequence separates the Precambrian igneous section from the Jurassic igneous section. The seismic character of the Precambrian section can be correlated for at least 12 mi. (19 km) across the study area and may have a north - south extension of at least 15 mi. (24 km). The 785 Ma age of this section is compatible with other igneous age dates in the region which are correlated with the late Proterozoic continental margin rifting of North America. A determination of the regional tectonic position of this section cannot be made at this time. Initial conclusions suggest that it is an abandoned, rafted block of North America, possibly caused by shear faulting along the Alabama - Oklahoma transform zone.

ACKNOWLEDGMENTS

Tom Steele, now deceased and formerly with Amoco Production Company, New Orleans, originally showed me the improvement Pruet Oil and PGI made in the old Amoco seismic lines. Appreciation is extended to Amoco Production Company and Pruet Oil for releasing the seismic and radiometric data. The author thanks Wendy Hale-Erlich, Ione Taylor, and Danny Harrelson for reviewing earlier versions of this manuscript, and the Mississippi Office of Geology for providing an outlet for short geological notes on the fascinating geology of Mississippi.

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TABLE 2

RADIOMETRIC ANALYSIS* OF PAN AMERICAN NO. 1 WORD SAMPLES

Depth (Intervals)	Lithology	Age	ave. Ar40 ppm	ave. K40 ppm	Ar40/K40
1) 9,613 ft	basalt (whole rock)	170 +/- 8 Ma	0.0120	1.157	0.0104
2) 11,210 - 11,984 ft	basic ign. rock (amph. concentrate)	459 +/- 23 Ma	0.01536	0.0505	0.03037
3) 11,300 - 11,360 ft	hornblende syenite (or diorite) (hornblende concentrate)	770 +/- 50 Ma	0.01145	0.2050	0.0559

* Analysis performed by Krueger Enterprises in 1969 and 1976 for Amoco Prod. Co.

In 1985, the Miss. Bureau of Geology had these analyses re-calculated by Geochem Labs utilizing new decay constants of Steigner and Jager (1977, Earth and Planetary Sci. Ltrs., v. 36, p. 359-362):

1) 174 +/- 7 Ma
2) 468 +/- 19 Ma
3) 785 +/- 34 Ma

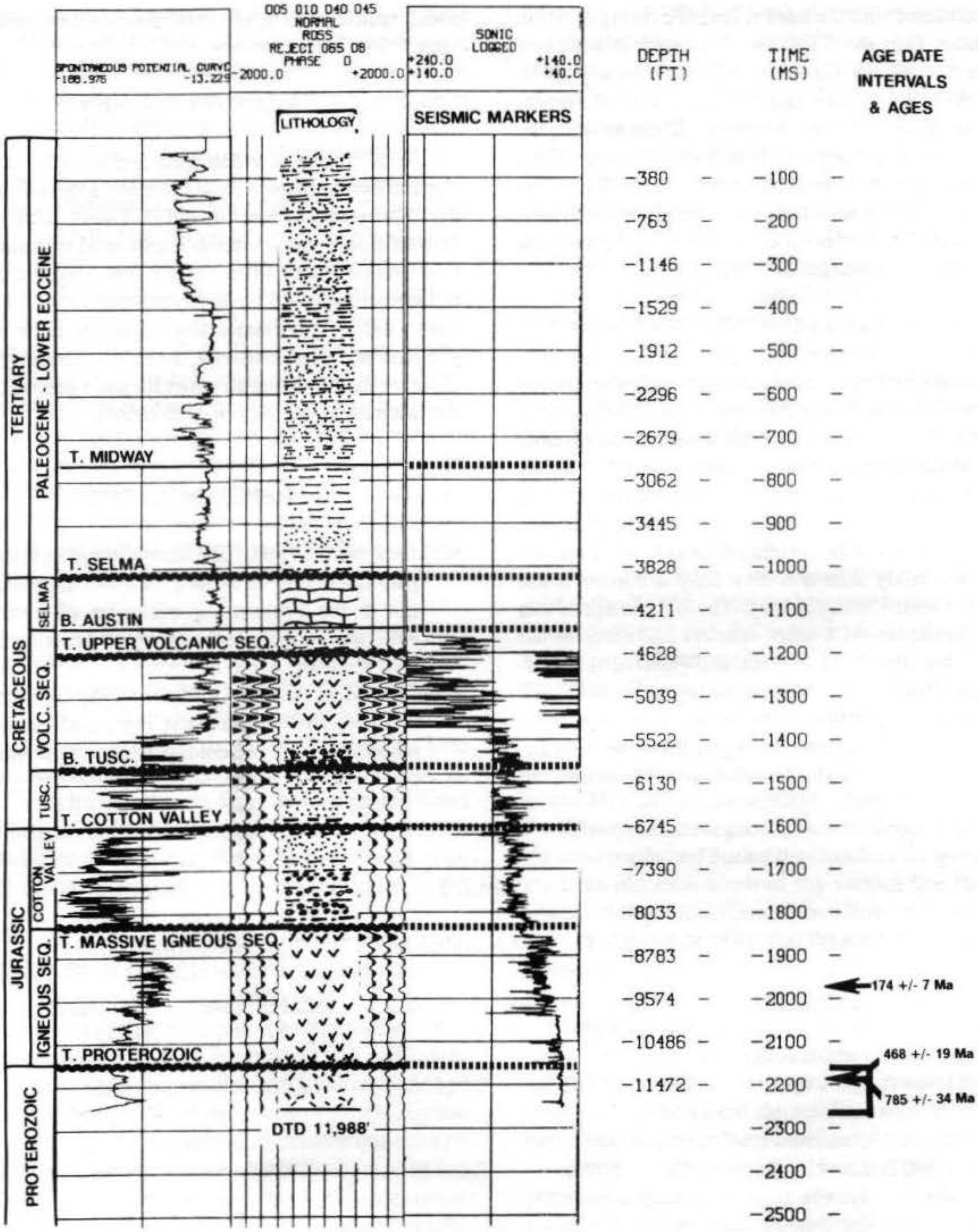

Figure 2. Stratigraphy of the Pan Am No. 1 Word.

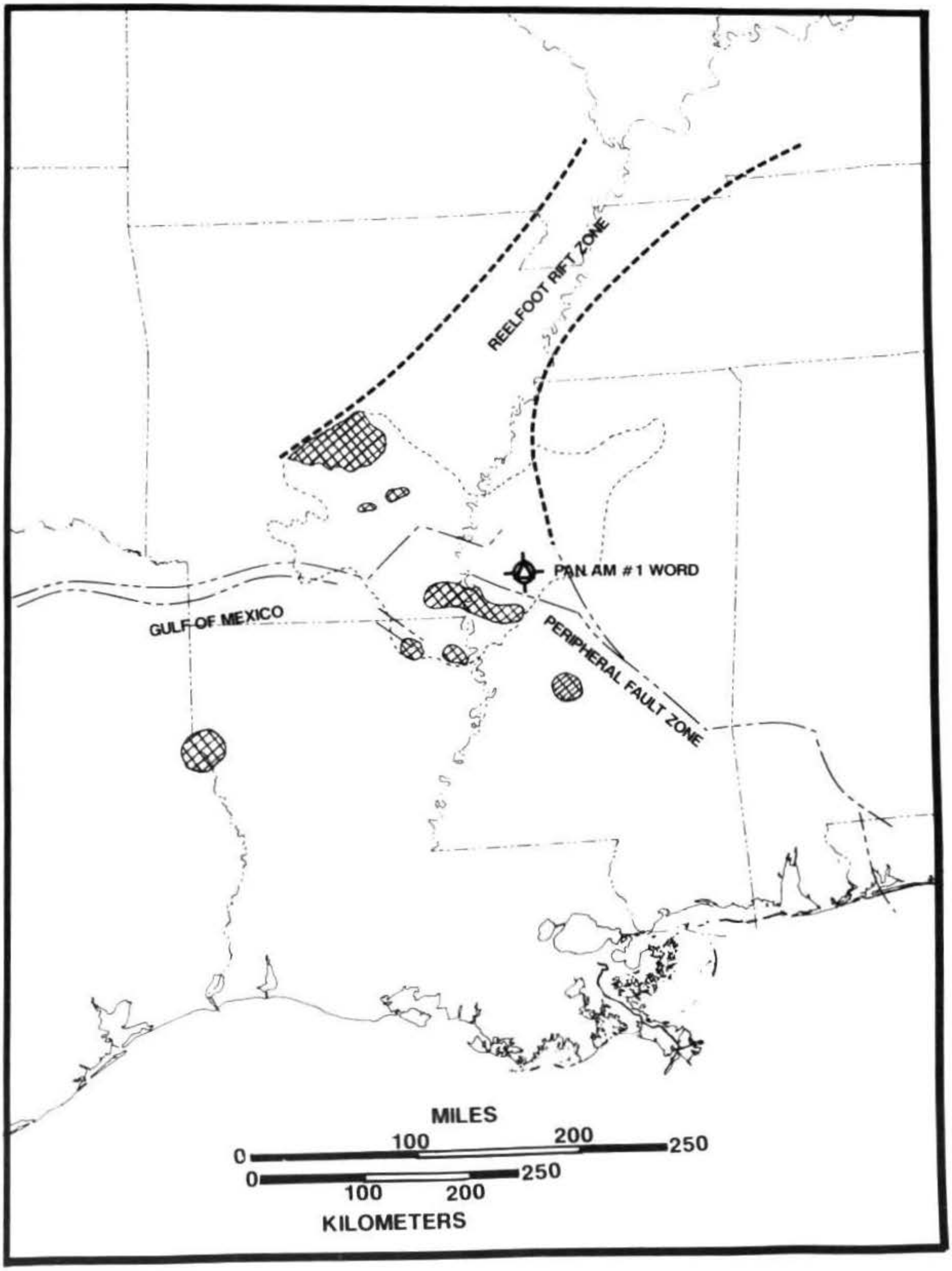

Figure 3. Approximate extent of Middle Jurassic igneous province, based on regional aeromagnetic and gravity trends of Zietz (1982) and Lyons and O'Hara (1982), plus well data. Cross-hatched areas are high amplitude, aeromagnetic anomalies of apparent or actual Mesozoic origin.

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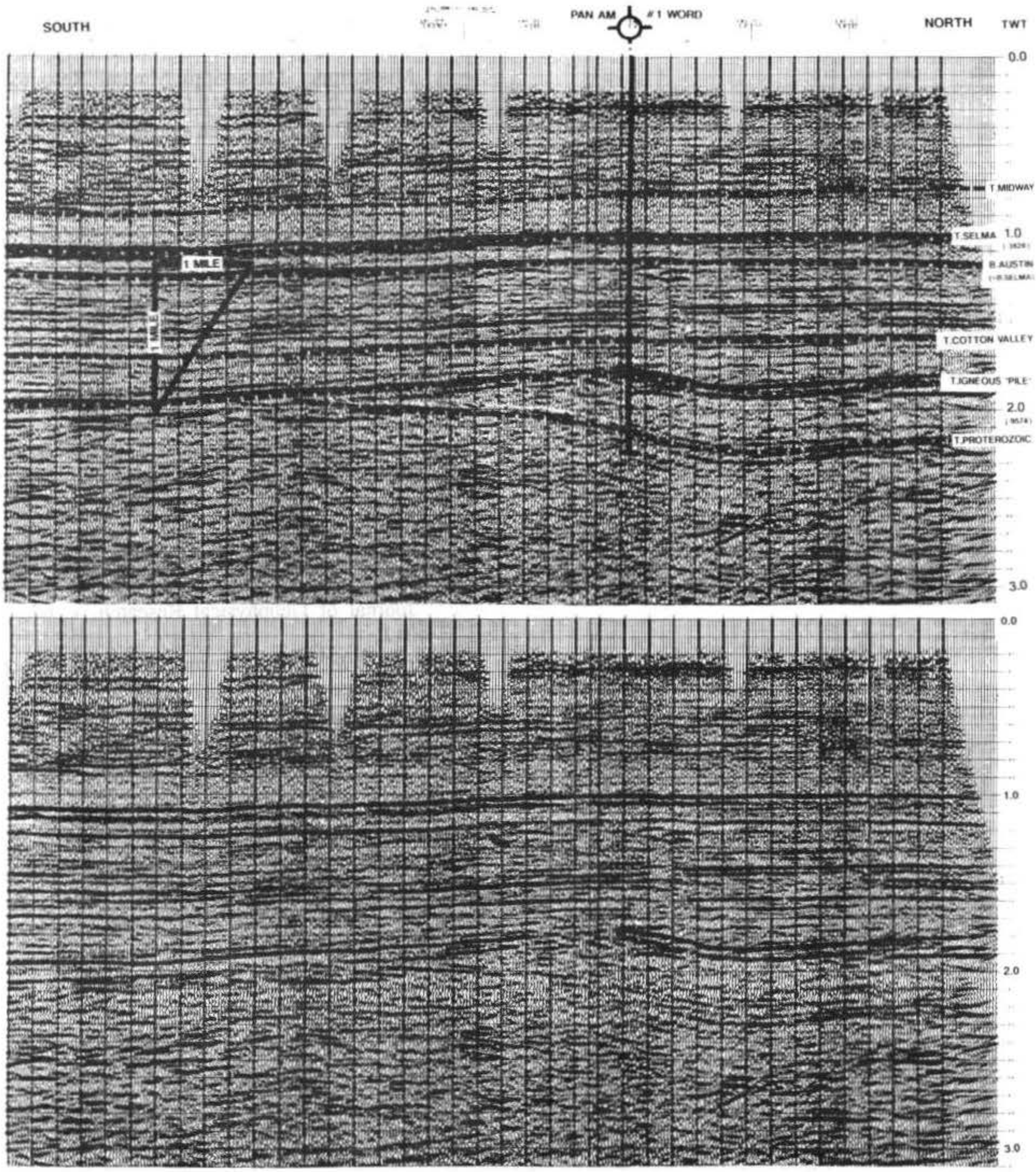

Figure 4a. Migrated, north-south seismic line through Pan Am No. 1 Word (interpreted).
b. Same as 4a, but uninterpreted.

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