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^{40}AR-^{39}AR AGES OF BENTONITE BEDS IN THE UPPER PART OF THE YAZOO FORMATION (UPPER EOCENE), WEST-CENTRAL MISSISSIPPI

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INTRODUCTION

Bentonite beds recorded from both outcrops and cores in the upper Eocene Yazoo Formation (Clay) of central and western Mississippi offer opportunities to date the uppermost Eocene of this region and to provide information on the age of the Eocene/Oligocene boundary. This report gives radiometric age dates for three bentonites sampled from the upper Yazoo Formation. Two bentonites are from outcrops near Satartia in western Mississippi and one is from a core hole at Society Ridge in west-central Mississippi. The upper bentonite at Satartia was studied independently at two laboratories using different techniques but with the same results, an age of 34.3 Ma (million years). Results from the Society Ridge bentonite gave the same age. This age is consistent with those reported from upper Eocene sediments at a proposed Eocene/Oligocene boundary stratotype in Italy (Montanari et al., 1988). However, it is significantly younger than ages given in widely used Cenozoic time scales such as that of Berggren et al. (1985), which places the Eocene/Oligocene boundary at 37 Ma. The latter age was revised upward in a more recent time scale by Berggren et al. (1992) due in part to the data presented here.

LITHOSTRATIGRAPHY

The upper Eocene Yazoo Formation is the younger of two formations of the Jackson Group recognized in the north-central Gulf Coastal Plain. In eastern Mississippi and southwestern Alabama, the Yazoo Formation has been subdivided by Murray (1947) into four members that are, in ascending order: (1) the North Twistwood Creek Clay Member, (2) the Cocoa Sand Member, (3) the Pachuta Marl Member, and (4) the Shubuta Clay Member. Figure 1 shows a generalized outcrop map of the Jackson Group in Mississippi.

In eastern Wayne County, Mississippi, near the Mississippi-Alabama border, the Yazoo Formation is 175 feet thick. The formation thickens westward to 515 feet in the subsurface of Warren County (Dockery and Siesser, 1984). The Cocoa Sand Member pinches out abruptly to the west within Wayne County. The Pachuta Marl Member can be correlated by its high resistivity character on electric logs as far west as Rankin County in central Mississippi. Where the Pachuta

Marl Member is absent, the Yazoo Formation is an undifferentiated clay sequence.

The threefold thickening of the Yazoo Formation in a westward direction across Mississippi does not represent a uniform increase of the members within the sequence. The North Twistwood Creek through the Pachuta interval decreases from 150 feet thick in eastern Wayne County to 60 feet thick in the western part of the county and is accompanied by the pinchout of the Cocoa Sand Member. This interval then maintains a rather uniform thickness into Rankin County, where the Pachuta grades laterally into a clay sequence. The Shubuta Clay Member thickens from 25 feet in eastern Wayne County to 295 feet in eastern Rankin County, a twelvefold increase in thickness.

The thick Shubuta-equivalent clay sequence in the upper undifferentiated Yazoo Formation of central and western Mississippi contains perhaps the best marine record of latest Eocene sediments in North America. Unfortunately, the Yazoo microfossil assemblage of this region is less diverse and not as well known as those of the differentiated Yazoo Formation to the east and age assignments are less definitive.

BIOSTRATIGRAPHY

The biostratigraphy of the Yazoo Formation is best known in its eastern outcrop belt (southeastern Mississippi and southwestern Alabama) where the formation is differentiated into members. The North Twistwood Creek Clay Member of the Yazoo Formation in southwestern Alabama has been assigned to planktonic foraminiferal Zone P14 (*Truncorotaloides rohri* Interval Zone, upper part) and to Zone P15 (*Porticulasphera semiinvoluta* Interval Zone, lower part) by Baker (in Blow, 1979) and to calcareous nannoplankton Zone NP17 by Siesser (1983). The Cocoa Sand Member has been assigned to Zone P15 (upper part) by Baker (in Blow, 1979) and to zones NP17 through NP19 by Siesser (1983). The Pachuta Marl Member has been assigned to the *Globorotalia cerroazulensis* (*sensu lato*) Interval Zone (zones P16 and P17; Mancini, 1979, and Mancini and Waters, 1986) and to zones NP19/NP20 by Siesser (1983). The Shubuta Clay Member occupies the uppermost part of the *G. cerroazulensis* (*s.l.*) Interval Zone (Mancini, 1979; Mancini and Waters, 1986; and Mancini and Tew, 1992) and zones NP20 (Siesser, 1983) and NP21 (Bybell, 1982; Siesser, 1983). The biostratigraphy of the Yazoo Formation in southwestern Alabama and eastern Mississippi is shown in Figure 2.

As one goes into central and western Mississippi, age diagnostic planktonic foraminifers and calcareous nannoplankton are less common, but generalized age assignments can still be made. This is important because bentonites have only been found in this region. The list in Table 1 summarizes the age assignments made by William Berggren, Marie-Pierre Aubry, Paul Huddlestun, and William Siesser (all personal communications) at the Satartia and Cynthia clay pit localities.

The section at the Miss-Lite clay pit at Cynthia, Mississippi, has been studied rather extensively with some rather different opinions being rendered as to the exact age of the fossils. Dockery and Siesser (1984) interpreted the calcareous nannoplankton assemblage as indicative of Zone NP21 based on the absence of *Discoaster saipanensis* and considered the single specimen of *Discoaster barbadiensis* as being reworked from older sediments. Byerly et al. (1988), however, placed considerable importance on the presence of the nannofossil *Pemma papillatum*. According to Hazel (1989), this nannofossil has its last appearance datum (LAD) just prior to the LAD of *D. saipanensis* and *D. barbadiensis* and indicates upper part of Zone NP20. In contrast, Bybell (1982) showed *P. papillatum* to occur in the middle part of the Shubuta Clay Member in eastern Mississippi and southwestern Alabama well above the LAD of *D. saipanensis* and *D. barbadiensis*. She showed the highest occurrence of these latter species to be at the Pachuta/Shubuta contact, a position supported by the work of Mancini and Waters (1986) but not by Siesser (1983). Keller (1985) found *Hantkenina alabamensis* throughout the Miss-Lite pit exposure and the first appearance datum (FAD) of *Globigerina ampliatura* (FAD near the base of P17) in her sample D and suggested a lower Zone NP21 assignment (Keller, 1985, figure 15). Huddlestun (written communication, 1988) found *H. alabamensis* throughout the Miss-Lite pit section along with *Globorotalia cerroazulensis cocoaensis*. Huddlestun concludes that the upper Yazoo Formation at Satartia and at the Miss-Lite pit are broadly correlative and that they are probably older than the youngest Shubuta farther east.

All in all, the biostratigrapahy is very suggestive of an upper NP19/20 zonal assignment for the lower part of the Miss-Lite pit and a lower NP21 zonal assignment for the upper part of the sequence at the pit. The question remains though as to the exact level of extinction of the *Hantkenina* spp. and the *G. cerroazulensis* spp. groups (i.e., the Eocene/Oligocene boundary) in the upper part of the Yazoo Formation of central and western Mississippi.

BENTONITES

A number of workers have reported the occurrence of bentonite in the uppermost part of the undifferentiated Yazoo Formation of central and western Mississippi. The farthest west outcrop is at Satartia while the farthest east is near Morton. These localities are shown in Figure 1 and the pertinent references are listed in the caption. Most of the reported occurrences cannot be recovered today due to extensive weathering of the outcrop, removal by excavation, or overgrowth by vegetation. A few of the reported occurrences are from the subsurface. On the basis of these, one can readily conclude that there are several bentonites in the stratigraphic sequence.

Two bentonites occur at Satartia and were collected respectively in an erosional scarp of the Mississippi-Yazoo River valley wall just south of the town (sample 1) in the center of the S1/2, SE1/4, sec. 31, T. 10 N., R. 3 W., and in a stream bank of an unnamed creek northwest of Mechanicsburg near a pipeline crossing (sample 2) in the NE1/4, NW1/4, sec. 9, T. 9 N., R. 3 W., Yazoo County. These

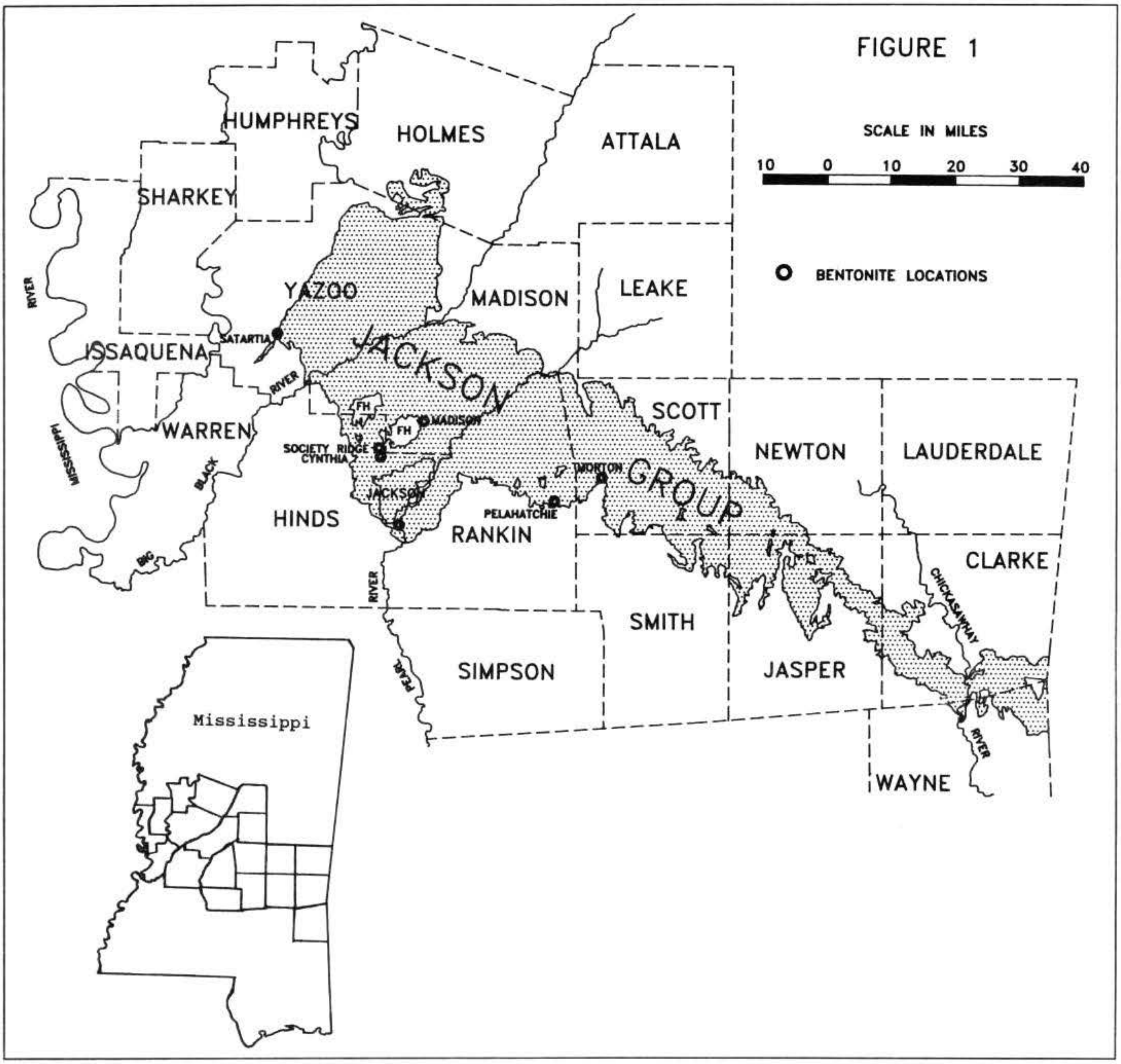

Figure 1. Generalized outcrop map of the Jackson Group of Mississippi. The outcrop belt terminates in the west where it is covered by the Mississippi River Alluvial Plain. FH = outliers of the overlying Oligocene Forest Hill Formation. Bentonite localities are described in Bay (1935), Bergquist (1942), Mellen (1940), Moore (1965), and Priddy (1960 and 1961).

bentonites were first noted by Mellen (1940), who mapped them as a single unit. He used these marker beds to prepare a structure contour map that outlined a part of the Tinsley dome, the first oil field in Mississippi. The locations of the bentonites are about 2.5 miles apart and both are at an elevation of about 200 feet above sea level. According to the structure contour map of Mellen (1940), sample 1 is the higher stratigraphically of the two samples. This bentonite is 7-8 inches thick and consists of a waxy, yellowish gray (5Y 7/2) clay enclosed above and below by slightly weathered, dark yellowish brown (10YR 4/2) clay all within the Yazoo. Sample 2 is a 4-5 inch thick bentonite and is light gray (N7) in color. It is enclosed above and below by relatively unweathered dark greenish gray (5GY 4/1) clay and is strongly burrowed with clay fillings from above. We estimate that samples 1 and 2 are 335 and 310 feet above the base

Table 1

Summary of planktonic foraminifers and calcareous nannoplankton recovered from levels near the lower bentonite at Satartia.

I. Planktonic foraminifers
   A. Huddlestun
      1. Above bentonite
         Globorotalia increbescens
         Globigerina eocaena
         Hantkenina primitiva
         Truncorotaloides inconspicua
      2. Below bentonite
         Globorotalia increbescens
         Globigerina eocaena
         Truncorotaloides inconspicua
         Comment: Broadly correlative with the Yazoo Formation of the Miss-Lite pit and older than the youngest Shubuta Clay Member farther to the east.
   B. Berggren: Downstream from site but at about the same stratigraphic position
      Dentoglobigerina galavisi
      Globigerina ampliatura
      Globigerina tripartita - *G. taupuriensis* group
      Turborotalia centralis
      Turborotalia increbescens
      Hantkenina alabamensis
      Truncorotaloides danvillensis
      Comment: Overlap of *G. ampliatura* (FAD in P17) and *H. alabamensis* (LAD at the top of P17) is indicative of latest Eocene or late *G. cerroazulensis* age, i.e., above the LAD of *P. semiinvoluta*.

II. Calcareous nannoplankton
   A. Siesser: above and below bentonite
      Ismolithus recurvus above R, below VR
      Discoaster saipanensis above R (4), below VR (1)
      Ericsonia formosa above F, below R
      Comment: A conservative zonal assignment to NP19-NP21 zonal interval based on the co-occurrence of the species of *Ismolithus recurvus* and *Ericsonia formosa.* Based on the recovery of 4 specimens of *D. saipanensis* in the better sample from above the bentonite and one specimen from below, the samples are in Zone NP19/NP20 based on the co-occurrence of *I. recurvus* and *D. saipanensis*. The lack of *D. barbadiensis* and *R. reticulata* are due to diagenesis or environmental controls. The samples could also be at the very top of Zone NP20 in an interval above where *D. barbadiensis* becomes extinct but prior to where *D. saipanenis* itself becomes extinct. If they are reworked, then the samples are in Zone NP21. Overall, the consensus would place the site in Zone P17 and upper part of Zone NP20.
   B. Aubry: Downstream from bentonite
      Ismolithus recurvus
      Discoaster saipanensis
      Discoaster barbadiensis (only half a discoaster)
      Ericsonia formosa
      Comment: Presence of relatively common *D. saipanensis* with common *I. recurvus* indicates zone NP20. Due to the quasi absence of *D. barbadiensis* this level is probably in the upper part of zone NP19-20.

of the Yazoo Formation respectively. A water well electric log at Mechanicsburg shows the Yazoo Formation to be 450 feet thick in this area.

Two bentonites were reported in the west wall of the Jackson Ready Mix Concrete, Miss-Lite aggregate quarry at Cynthia, northwest Hinds County, Mississippi, by Priddy (1960). Efforts to relocate these bentonites have been unsuccessful although the pit still provides the best exposure of the undifferentiated upper part of the Yazoo Formation.

An occurrence of a bentonite previously not recognized was noticed by William Moore (personal communication) near the top of the Yazoo Formation. It occurs just below shales of the Forest Hill Formation (lower Oligocene) in a creek draining a sand pit near Society Ridge Church in the NW1/4, NW1/4, sec. 24, T. 7 N., R. 1 W., Hinds County, just 1.8 miles north of the Miss-Lite pit. In an effort to recover this bentonite in a core, the Mississippi Office of Geology set up their Failing 1500 drill rig on a ridge adjacent to and 60 feet

Jackson Group Stratigraphy		Planktonic Foraminiferal Zone		NP Zone
Yazoo Fm.	Shubuta Clay Mbr.	*Globorotalia cerroazulensis* (*s.l.*) Interval Zone	P 17	NP 21
			P 16	NP 20
	Pachuta Marl Mbr.			NP 19
	Cocoa Sand Mbr.	*Porticulasphera semiinvoluta* Interval Zone	P 15	NP 18
	North Twistwood Creek Clay Mbr.	*Truncorotaloides rohri* Interval Zone	P 14	NP 17
Moodys Branch Fm.				

Figure 2. Biostratigraphy of the Yazoo Formation in southwestern Alabama and eastern and central Mississippi after Mancini and Tew (1992, fig. 2) and Berggren and Miller (1988).

above the bentonite outcrop. A test hole at this site encountered the top of the Yazoo Formation at 79 feet, below a thick channel sand that had cut out the lower shaly section of the Forest Hill Formation as well as the upper 20 feet of the Yazoo Formation. This sand was mapped as terrace deposits by Moore (1965) but may represent a fluvial sequence within the Forest Hill Formation. A 16-foot-long core of the upper part of the Yazoo Formation was taken from 80 to 96 feet. This core included three additional bentonites that had not been seen in outcrop. These bentonites occur 365 to 378 feet above the base of the Yazoo Formation and are higher in the formation than those noted by Priddy (1960) in the Miss-Lite pit. The Miss-Lite bentonites have not been found by the writers but the exposure presently extends from 227 to 351 feet above the base.

In a recent continuous core of the Yazoo Formation by the Mississippi Office of Geology at Mossy Grove in the SW1/4, SE1/4, sec. 31, T. 7 N., R. 1 W., Hinds County, 5.3 miles west-southwest of the Society Ridge test hole, one prominent bentonite was initially noted near the top of a 462-foot section of the Yazoo Formation (Dockery et al., 1991). This bentonite is 412 feet above the base of the formation and is the highest bentonite known in the Yazoo Clay. Six additional bentonites were subsequently reported from this core by Patrick et al. (1992) at 331, 240, 223, 187, 93, and 5 feet above the base of the Yazoo Formation.

All together, there may be as many as seven bentonites in the upper part of the Yazoo Formation of northwestern Hinds County, including the one in the Mossy Grove core, one on the outcrop, three in a core at Society Ridge, and two noted in the Miss-Lite pit. Of these, the Miss-Lite pit bentonites are the lowest within the formation known from outcrops and may correlate with those occurring at Satartia.

GEOCHRONOLOGY

Samples of bentonite from Satartia and from Society Ridge were processed and dated by the ^{40}Ar-^{39}Ar method. Sanidine from two bentonites at Satartia was analyzed by the incremental heating and total fusion methods (Tysdal et al., 1990). Only sample 1 (the upper bentonite) provided a plateau age utilizing the criteria of Fleck et al. (1977) and yielded an age of 34.32 ± 0.05 Ma standard error of the mean (SEM). Sample 2 did not provide a plateau age and has a total gas age of 35.1 Ma. One would not expect an age much older than that obtained for sample 1 considering that they are separated by only 25 feet. There is the possibility that the bentonite contains detrital feldspar that is contributing a minor amount of excess radiogenic argon to this analysis. Although no microcline was observed in petrographic examination of the mineral concentrate, a detrital feldspar would be difficult to detect in the presence of the 5,000-10,000 grains that make up the sample.

Single crystals of sanidine from sample 1 at Satartia were analyzed by the laser fusion approach utilizing an ultrasensitive rare gas mass spectrometer. Details of the methodology were presented by Deino and Potts (1990). A mean age of 34.31 $\pm$ 0.05 Ma (SEM) resulted in excellent agreement with the result from the incremental heating approach. The age of 34.32 ± 0.05 Ma is considered to be the best value for the timing of ash deposition at Satartia.

Although the bentonites at Society Ridge are currently undergoing study, only biotite from the uppermost bentonite at 80.3 - 81.0 feet in the Society Ridge core has been analyzed (Table 3). Six separate analyses result in an age of $34.28 \pm$ 0.04 Ma (SEM).

Despite the fact that all of the ^{40}Ar-^{39}Ar ages are essen-

Table 2. ^{40}Ar-^{39}Ar incremental heating spectra for sanidine from the upper bentonite at Satartia

Temp°C(step)	$^{40}Ar/^{39}Ar$	$^{37}Ar/^{39}Ar$	$^{36}Ar/^{39}Ar$	$^{40}Ar^*/^{39}Ar$	% $^{40}Ar^*$	% ^{39}Ar total	Ma ±1 sign age and error
500(1)	69.4438	0.20545	0.22895	1.83467	2.6	0.2	23.71±9.64
600(2)	4.8576	0.05593	0.05569	2.62601	54.1	0.9	33.84±0.34
700(3)	3.1127	0.03111	0.00166	2.62085	84.2	1.7	33.77±0.14
750(4)	2.7345	0.02284	0.00036	2.62964	96.2	2.9	33.88±0.23
800(5)	2.7173	0.01991	0.00021	2.65334	97.6	4.6	34.19±0.12
850(6)	2.6900	0.02067	0.00010	2.65980	98.9	8.8	34.27±0.09
900(7)	2.6886	0.01989	0.00007	2.66621	99.2	12.6	34.35±0.10
950(8)	2.6878	0.01858	0.00007	2.66599	99.2	14.8	34.35±0.09
1000(9)	2.6902	0.01764	0.00007	2.66687	99.1	19.4	34.36±0.09
1050·10)	2.7098	0.01763	0.00013	2.66861	98.5	14.3	34.38±0.09
1150(11)	2.7483	0.01618	0.00019	2.68972	97.9	18.1	34.65±0.10
1300(12)	3.9754	0.02140	0.00428	2.70716	68.1	1.7	34.87±0.26

*= radiogenic

Irradiation monitor mineral:MMHB-1, 520.4 Ma (Samson and Alexander, 1987).

Ca and K corrections for Oregon State University reactor.

J=0.00721±0.00002

$(36/37)Ca = 5.38 \pm 0.471 \times 10^{-4}$

$(39/37)Ca = 8.19 \pm 1.58 \times 10^{-4}$

$(40/39)K = 3.82 \pm 3.03 \times 10^{-3}$

tp = 34.32±0.05Ma (SEM) (Steps 5-10; 74.5% of total ^{39}Ar)

tially the same, it would be extremely difficult to say whether these results indicate that the two bentonites at Satartia are correlative with any two of the four bentonites recognized at Society Ridge. Factors such as different irradiations, different nuclear reactors, different monitors, and different mass spectrometers could all lead to accidental generation of similar values for the ages of the volcanic ashes that may differ in time by only a few hundred thousand years. In fact a solution to this problem might prove to be intractable even if all the analytical work were performed in one laboratory under ideal conditions. Equivalence, or lack of it, could be possibly demonstrated by examination of the heavy mineral suite (i.e., zircon, apatite, etc.) and also by microprobe analysis for specific elements in the more stable phenocrysts or instrumental neutron activation analysis (INAA). It is possible that the two samples at Satartia may correlate with the two as yet unrecovered bentonites at the Miss-Lite pit despite the similarity in ages for the bentonites at Satartia and Society Ridge.

DISCUSSION

The age of 34.32 ± 0.05 Ma for the upper bentonite at Satartia in association with the Zone P17 and upper Zone NP20 assignment provides a maximum age for the Eocene/Oligocene boundary (P17/P18 boundary or early within NP21). The precise datum for the Society Ridge sample that is still in the uppermost Yazoo Formation (and elsewhere to the east constrained to be latest Eocene in age) is at present without biostratigraphic control except to say that this level is younger than the Miss-Lite pit section. Nonetheless, all our results for the Yazoo bentonites are in good agreement with the proposed age of 33.7 ± 0.5 Ma for the age of the Eocene/Oligocene boundary in the pelagic sequence of the northern Appenines (Montanari et al., 1988). This value does not agree with the older estimates of Berggren et al. (1985) or Aubry et al. (1988), but does agree with the recently revised estimate of Berggren et al. (1992). The latter estimate revision was influenced in part by the prepublished data presented here.

Clearly more geologic work needs to be done in the Society Ridge area. Paleomagnetic studies, coupled with detailed biostratigraphic and geochronometric studies on a core covering much of the upper part of the Yazoo Formation would add to our knowledge of events around the Eocene/Oligocene boundary in an area far removed from the stratotype. It would be of value to see if seven, more or fewer, bentonites exist in the Cynthia-Society Ridge area. It would also be of interest to see if bentonites could be found in regions to the east of Morton (in areas having more open marine conditions) and closer to the type Shubuta, in a region where the biostratigraphy would be more definitive. If these bentonites could be chemically or mineralogically fingerprinted and correlated to those in the Society Ridge area, we could then establish a tie between the region where the geochronology was performed and a region where a more refined biostratig-

Table 3. $^{40}Ar/^{39}Ar$ laser total fusion analyses of selected sanidine and biotite grains from bentonites of the Yazoo Formation

L#	$^{40}Ar/^{39}Ar$	$^{37}Ar/^{39}Ar$	$^{36}Ar/^{39}Ar$	$^{40}Ar^*/^{39}Ar$	$\%^{40}Ar^*$	(Age (Ma)	±1σ	±SEM
Sanidine (Bluff line locality at Satartia, sample 1Ag)								
2550-01	1.09799	0.033217	0.000045	1.08495	98.8	34.230	0.183	
2550-02	1.13329	0.021258	0.000153	1.08742	96.0	34.308	0.171	
2550-03	1.10083	0.033641	0.000052	1.08564	98.6	34.252	0.120	
2550-05	1.12437	0.023144	0.000118	1.08878	96.8	34.350	0.115	
2550-06	1.12412	0.022322	0.000112	1.09043	97.1	34.401	0.105	
			Mean of 5 analyses (incl J error) =			34.31	0.12	0.05
Biotite (Society Ridge Core, base of 80.3 - 81 foot interval)								
2540-01	1.13445	0.035133	0.000162	1.08692	95.8	34.292	0.464	
2540-02	1.11983	0.011722	0.000106	1.08700	97.1	34.294	0.234	
2540-03	1.15530	0.001216	0.000231	1.08475	93.9	34.224	0.311	
2540-04	1.11133	0.026204	0.000079	1.08760	97.9	34.313	0.238	
2540-05	1.10145	0.011951	0.000045	1.08671	98.7	34.285	0.201	
2540-06	1.10004	0.021122	0.000043	1.08643	98.8	34.277	0.247	
			Mean of 6 analyses (incl J error) =			34.28	0.10	0.04

* = radiogenic

Irradiation monitor mineral: Fish Canyon Sanidine (27.84 Ma)

$\lambda_e + \lambda_e' = 0.581 \times 10^{-10}\ yr^{-1}$; $\lambda_\beta = 4.962 \times 10^{-10}\ yr^{-1}$; $^{40}K/^{40}K$ total = 1.167×10^{-4} (Steiger & Jager, 1977)

$J = 0.017655 \pm 0.000018$

Ca and K corrections for Omega West Reactor, Los Alamos

$(36/37)Ca = 2.557 \pm 0.046 \times 10^{-4}$

$(39/37)Ca = 6.608 \pm 0.253 \times 10^{-4}$

$(40/39)K = 2.4 \pm 0.7 \times 10^{-3}$

raphy could be established.

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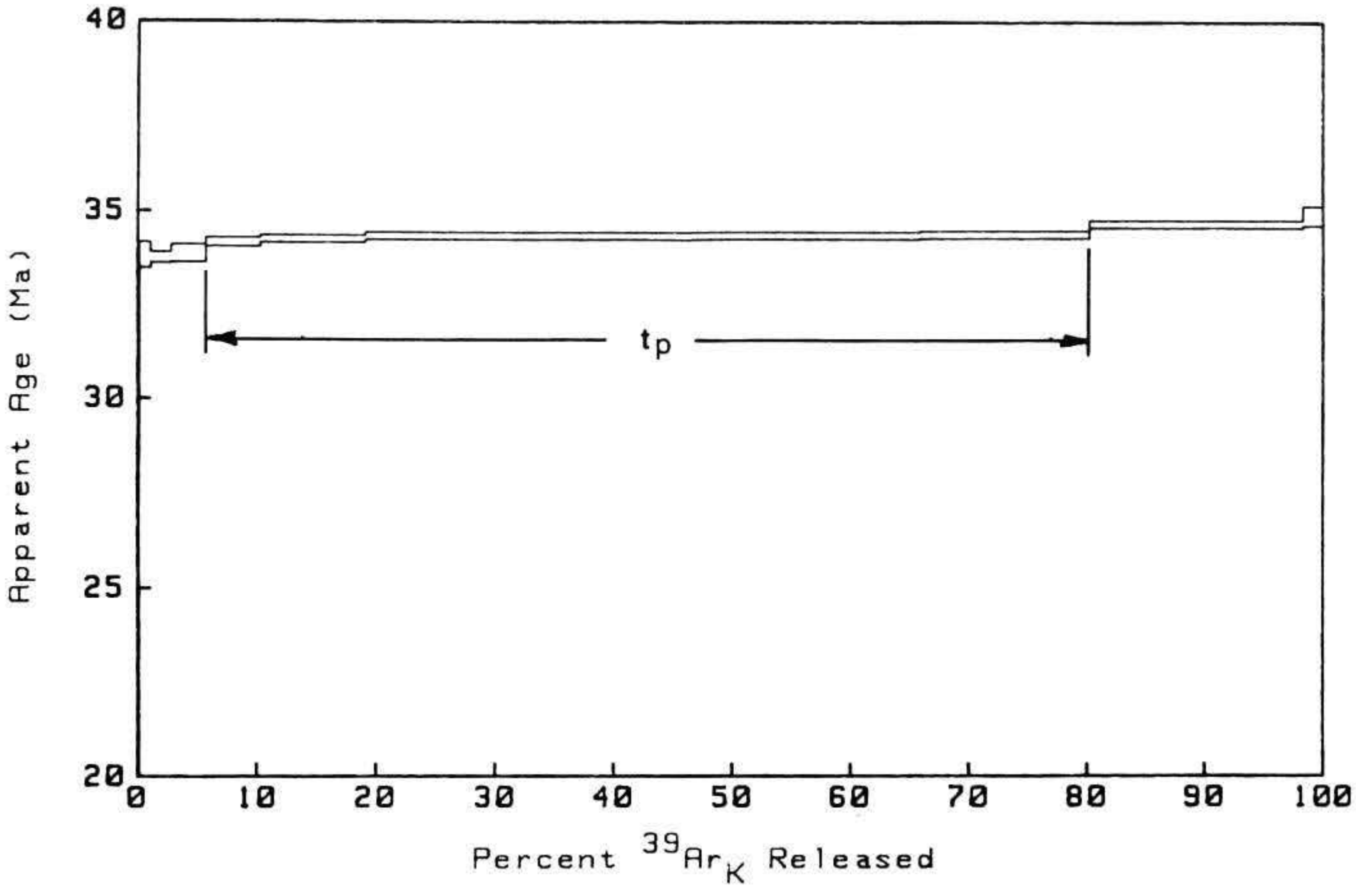

Figure 3. ^{40}Ar-^{39}Ar incremental heating age spectra for sanidine from the upper bentonite (sample 1) at Satartia.

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WETHERELLIA FRUITS AND ASSOCIATED FOSSIL PLANT REMAINS FROM THE PALEOCENE/EOCENE TUSCAHOMA-HATCHETIGBEE INTERVAL, MERIDIAN, MISSISSIPPI[1]

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ABSTRACT

Plant fossils are described from upper Paleocene and lower Eocene marine sediments of the Tuscahoma, Bashi and Hatchetigbee formations at Meridian, Mississippi. The water-worn material includes three-dimensionally preserved fruits, fern rhizomes, and gymnosperm and angiosperm wood fragments. Based upon the fifteen fruit specimens currently available, we recognize a low-diversity assemblage that includes *Wetherellia*, an extinct genus also known from other lower to middle Eocene marginal marine localities of eastern North America and western Europe, and one genus of unknown systematic position that is new to the paleobotanical record. The collection of fossil fruits provides the westernmost occurrence of *Wetherellia*, which may have been dispersed by marine currents along the Tethyan seaway.

INTRODUCTION

The purpose of this report is to illustrate and describe a small collection of plant fossils from nearshore marine sediments of the Tuscahoma, Bashi and Hatchetigbee formations in the vicinity of Meridian, Mississippi. The low-diversity assemblage includes abraded fern rhizomes and two angiosperm fruit types in the size range of 1 to 4 cm, and slightly larger gymnosperm and angiosperm wood fragments. We describe the fruit and fern remains and discuss their sedimentological and biogeographic significance. One of the fruit types is new and of uncertain affinities, and the other conforms to *Wetherellia*, a fossil genus known from various early Tertiary localities in eastern North America and Europe that apparently was dispersed along the Tethyan seaway.

Portions of the upper Paleocene Tuscahoma to lower Eocene Hatchetigbee interval are exposed at various localities in Meridian. The section at the Red Hot Truck Stop is rich in fossil material and has generated interest because it contains the TP2/TE1 coastal onlap sequence boundary (sensu Baum and Vail, 1988) and is the only surface outcrop at which TE1.1 lowstand deposits have been documented (Ingram, 1991). The Paleocene/Eocene boundary has been recognized at the locality on the basis of both pollen and dinoflagellate cyst data and corresponds in position to the sequence boundary (Ingram, 1991). A rich vertebrate assemblage that includes numerous species of bony and cartilaginous fishes (Case, 1986) and estuarine snakes (Holman et al., 1991) has been described. Remains of numerous land mammals have also been collected and are currently under study (Beard and Tabrum, 1991; S. Ingram, pers. comm.). Most of the plant fossils considered here were recovered from a lag deposit forming the lowermost unit of the early Eocene (Ypresian) Bashi Formation.

MATERIALS AND METHODS

Localities

Plant fossils were recovered from three localities in the Meridian South 7.5-minute quadrangle, Lauderdale County, Mississippi.

1. Red Hot Truck Stop [Mississippi Geological Survey (MGS) loc. 19; UF loc. 18071]. This locality is behind the restaurant on the frontage road south of Interstate 20E between the exits of Highways 19 and 45 (NW corner NW 1/4, NE 1/4, Sec. 20, T.6N., R.16E.). Plant remains were sieved from unconsolidated glauconitic lag deposits immediately above and below the Paleocene/Eocene boundary at an elevation of approximately 325 feet (Ingram, 1991, figure 2). One fern rhizome was collected from the uppermost sand unit of the late Paleocene Tuscahoma Formation [T4 channel sand, as designated by Ingram (1991)]. Several angiosperm fruit specimens, a second fern rhizome, and wood fragments with *Teredo*-like borings were recovered from early Eocene Bashi sediments at the base of the TE1.1 Coastal Onlap Sequence (Ingram, 1991).

2. Nelson General Motors Dealership (UF loc. 18143). The locality is in a drainage ditch behind the bodyshop on the frontage road on the south side of I-20E, approximately 1000

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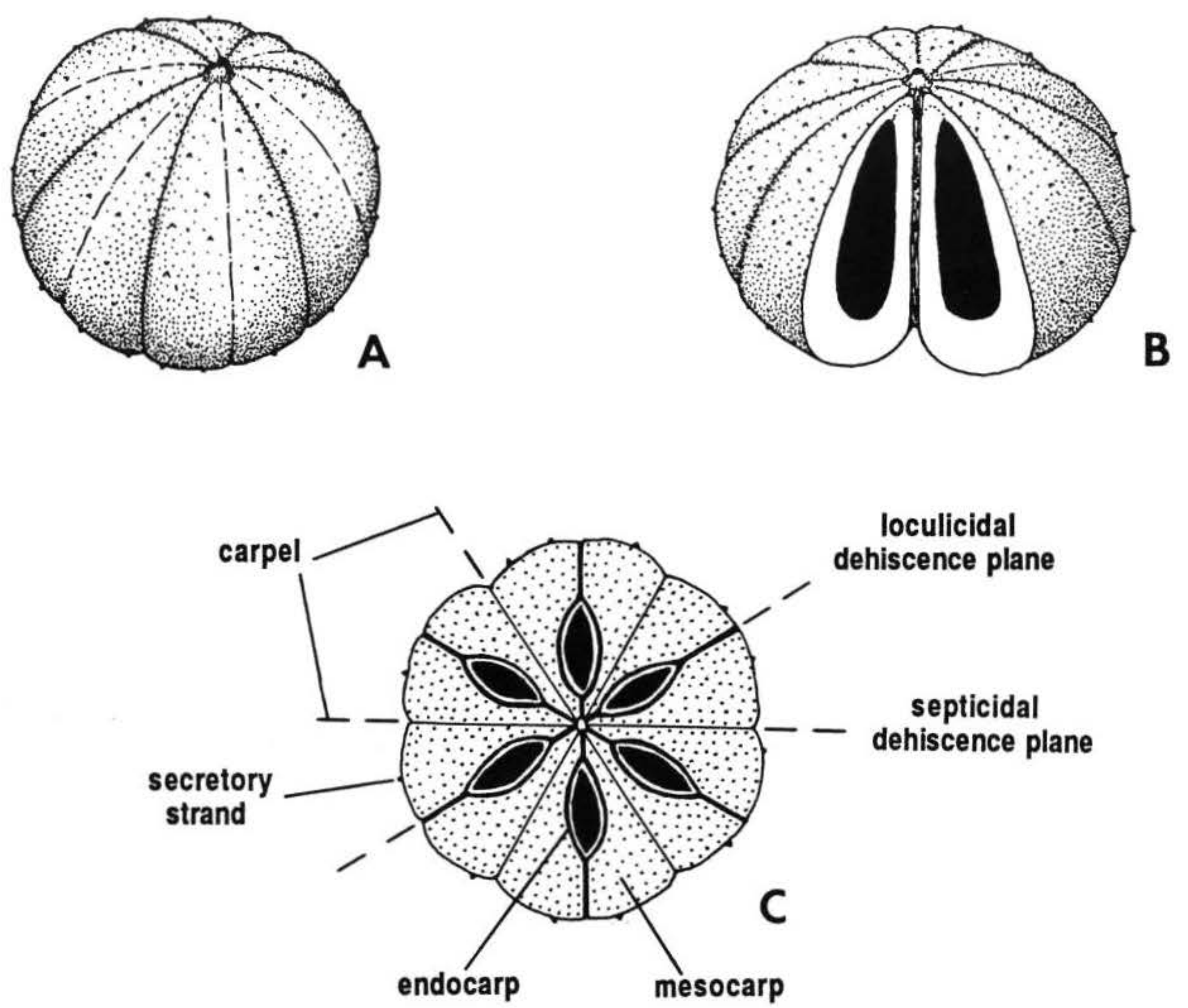

Text-Figure 1. Diagrammatic reconstructions of *Wetherellia* cf. *marylandica* fruits. (A) Whole fruit illustrating apex, 6 carpels and dehiscence planes. (B) Fruit with 2 locules exposed showing seeds (solid black areas) suspended from arching funiculi. (C) Transverse section of a 6-carpelate fruit demonstrating arrangement of carpels about the central axis, position of major tissues, dehiscence planes, and seeds (solid black ellipses).

feet west of MGS 19 (NE 1/4, NW 1/4, Sec. 20, T.6N., R.16E.). *Wetherellia* fruits were recovered near the top of the Tuscahoma Formation at approximately the same elevation as MGS 19.

3. Asylum Creek (UF loc. 18144). Creekside exposure behind the Walmart store on Highway 19N, northwest of Meridian Junior College (SW 1/4, SW 1/4, Sec. 11, T.6N., R.15E.). Three *Wetherellia* fruits were collected 3 feet above the Bashi/Hatchetigbee contact at an elevation of about 325 feet. This locality is approximately 3.9 miles northwest of the Red Hot Truck Stop locality.

Although the plant fossils were recovered from three different formations, the plant-bearing horizons probably lie within 20-25 vertical feet of one another (S. Ingram, unpubl. data). The fossils were made available for study by David Dockery and Stephen Ingram of the Mississippi Office of Geology, Jackson, Mississippi, and are housed in the Paleobotany Collections of the Florida Museum of Natural History, University of Florida (UF), Gainesville, Florida.

Specimen treatment and preparation

The partially pyritized, carbonaceous remains are usually wet when removed from the sediment, and they begin to crack upon exposure to air. Shrinkage of the specimens upon drying and reaction of the pyrites with oxygen to produce mineral salts cause the specimens to disintegrate. Rehydration and expansion of partially dried specimens after study and photography hastens their disintegration. To delay this undesirable consequence, specimens were stored in a 1:1:1 solution of glycerine, 50% ethanol, and water. They were prepared for photography by gentle rinsing in distilled water to remove the glycerine. In order to avoid reflectance of shiny wet surfaces, the fossils were carefully blotted on paper towelling and photographed while still damp after sufficient surface moisture had evaporated. Techniques developed to conserve pyritized fruits and seeds from the Eocene London Clay flora (Collinson, 1983) may prove useful for long-term storage of these fossils.

Four *Wetherellia* fruits were slowly allowed to dry completely. Resulting shrinkage fractures along dehiscence planes and across locules permitted study of the mesocarp, endocarp, loculicidal and septicidal planes, funiculus, seed chamber, and seeds, and facilitated comparison with specimens of *Wetherellia marylandica* previously collected by the first author from the Woodstock Member of the early Eocene Nanjemoy Formation exposed along Millpond Creek near Etna Mills, Virginia (USGS loc. 26418, UF loc. 18056; locality data in Mazer and Tiffney, 1982, and Ward, 1985).

Preservation of plant remains

The fossils are three-dimensionally preserved, with minimal compression, and show details of external and internal morphology. Carbonized tissues of the fossils have been infiltrated or replaced to varying degrees with pyrite. Anatomical and morphological details are readily observed in specimens where only a little pyrite has formed. Excessive pyrite formation in other specimens renders interpretation of anatomical details difficult. In some specimens, pyrite deposition was selective, and apparently dependent upon the type and location of specific tissues. In others, pyrite seems to have formed within and/or between adjacent tissues, resulting in a thick layer of pyrite that might be mistaken for a single tissue. Another complicating factor is that the form of the pyrite is not uniform throughout the specimens. In some areas, it occurs as minute, dark green to black, granular framboids and octahedra, while in other areas it forms thick, silver sheet-like masses.

DESCRIPTION OF SPECIMENS

***Wetherellia* cf. *marylandica* Mazer and Tiffney** (Plate 1, figures 1-15; Text-figure 1, A-C)

Fruits are subspheroidal, loculicidal- and septicidally dehiscent capsules, with four to eight radially arranged, wedge-shaped, single-seeded carpels (Plate 1, figures 1-9, 11, 12; Text-figures 1A, 1C). Specimens range from 0.8 to 1.83 cm in diameter. The exocarp has been abraded away, and the external surface of the fossils is composed of meso-

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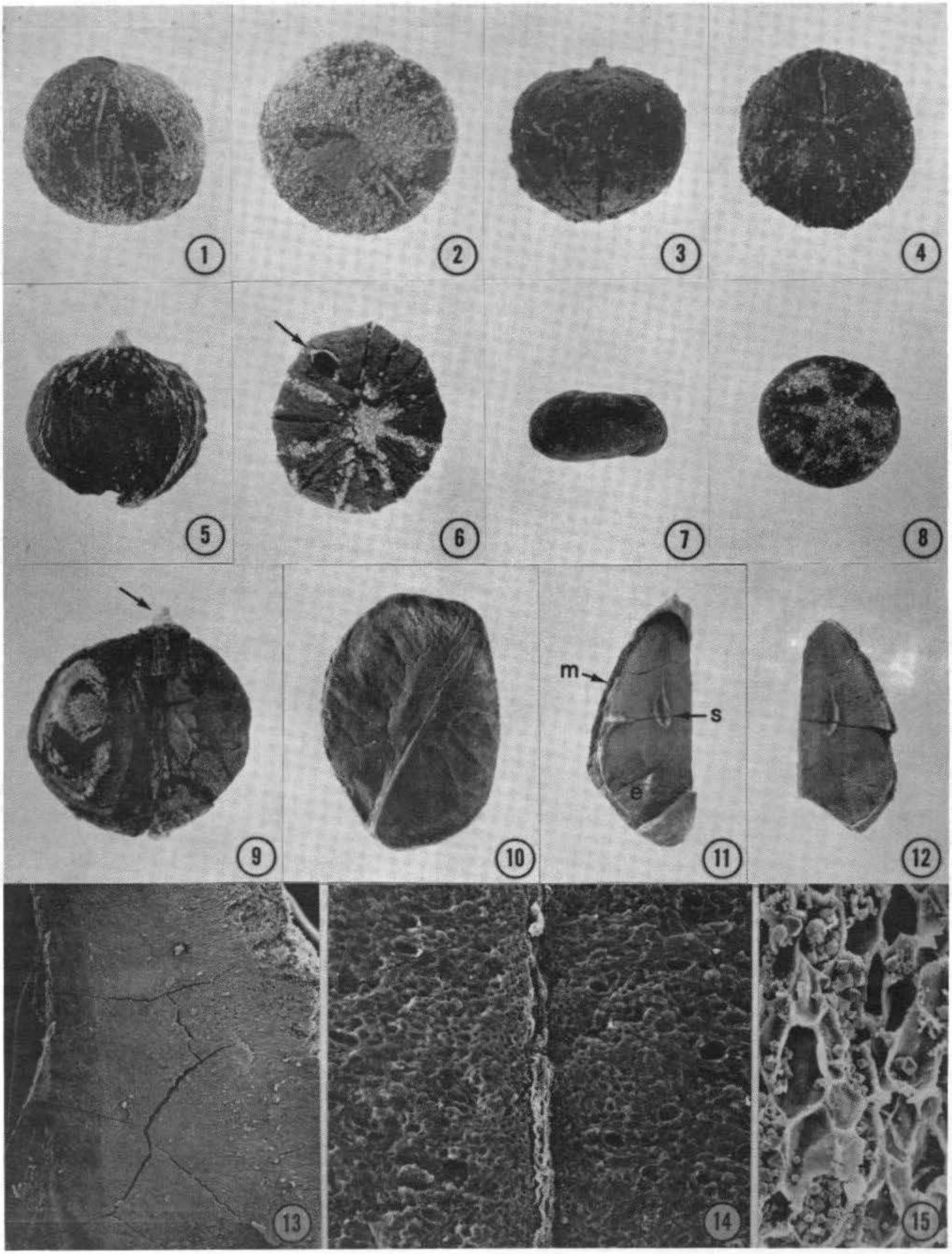
Plate 1

Figures 1-15. *Wetherellia* cf. *marylandica* Mazer and Tiffney. (1) Side view of largest specimen illustrating oblate shape. Longitudinal grooves of dehiscence planes filled by pyrite. 2X. UF 9972. (2) Apical view of specimen in previous figure. 2X. UF 9972. (3) Lateral view of a depressed obovate specimen with a conical projection at the apex. Note scattered warty protrusions representing pyritized secretory strands. 2X. UF 9973. (4) Basal view of specimen in figure 3 showing dehiscence planes. Note hexagonal outline of this 6-carpelate fruit. 2X. UF 9973. (5) Side view of slightly oblate specimen with clearly delineated dehiscence planes and conical apical projection. 2X. UF 9974. (6) Basal view of fruit in figure 5. The 16 dehiscence planes (8 loculicidal, 8 septicidal) provide a clear indication that this specimen has 8 locules. Note that abrasion of the specimen has partially exposed the hollow pyritic internal cast of one mature locule (arrow). 2X. UF 9974. (7) Small, transversely compressed specimen. 2X. UF 9975. (8) Apical view of specimen in the previous figure. 2X. UF 9975. (9) Fruit illustrated in figures 5 and 6 fractured longitudinally along loculicidal (left half of specimen) and septicidal (right half) dehiscence planes, illustrating remains of central column, conical apical projection (arrow), and the shape and orientation of the mature locule with respect to the central column. 4X. UF 9974. (10) Septicidal view of obliquely compressed carbonaceous specimen illustrating the organization of the ramifying secretory system in the septicidal plane. Base of fruit at the lower left of figure, apex at the upper right. 3X. UF 9976. (11) Loculicidal view of one immature carpel of the fruit in figure 10 showing an immature seed (s) suspended from a long narrow funiculus, smooth endocarp (e), and thin rind of abraded mesocarp (m). 3X. UF 9976. (12) Counterpart of carpel in figure 11. 3X. UF 9976. (13) SEM enlargement of carpel fragment of the specimen in figure 10 illustrating long narrow endocarp cells of the loculicidal plane. Darker region at left of specimen represents a portion of an immature locule. Exterior of fruit to the right, interior to the left. 23X. UF 9976. (14) SEM view of portion of a transversely fractured carpel showing a narrow zone of small-diameter endocarp cells on either side of the loculicidal dehiscence plane. Larger-diameter mesocarp cells are visible to the outside of the zone of endocarp cells. 150X. UF 9976. (15) SEM detail of mesocarp cells of same specimen. Note the numerous tiny pits in the cell walls and infilling of pyrite framboids and octahedra. 300X. UF 9976.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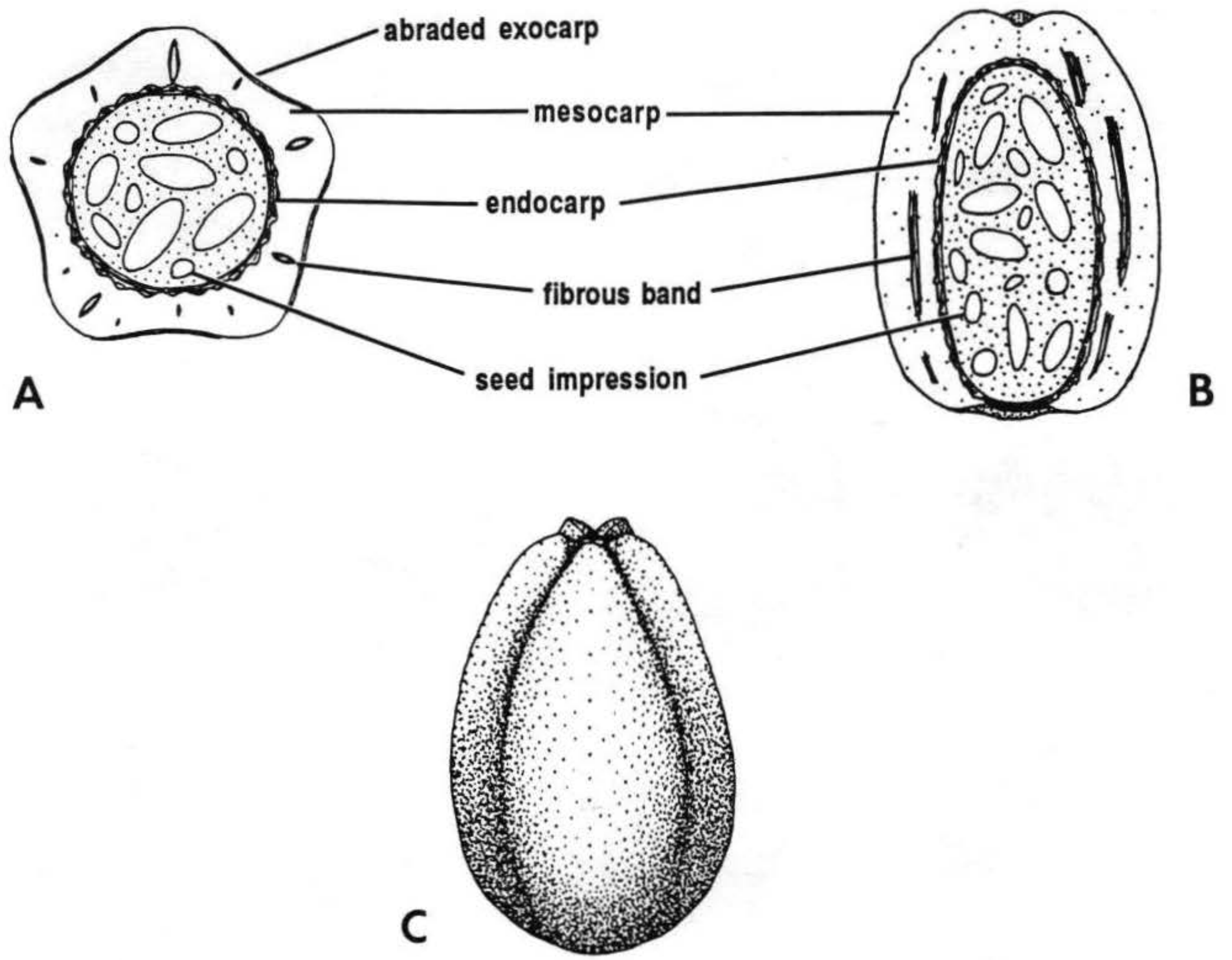

Text-Figure 2. Diagrammatic reconstructions of *Carpolithes bashiensis* sp. nov. (A) Transverse section of fruit showing arrangement of major tissues and structures. (B) Longitudinal section. (C) Whole fruit.

carp tissue. The mesocarp has a smooth rounded surface with scattered minute projections (Plate 1, figures 3, 4; Text-figure 1A). These projections apparently represent pyritized remains of secretory strands that arise from the central axis of the fruit, ramify through the mesocarp, and then intersect its surface (Plate 1, figure 10; Text-figure 1C). The mesocarp, which constitutes the majority of the fruit, is a spongy tissue composed of elongate cells (51-71 by 94-122μ) bearing numerous minute simple pits (Plate 1, figure 15). The endocarp consists of thin sheets (*ca.* 5-7 cells) of narrow elongate cells that line the inner surface of the locules, and extend radially from the central axis to the periphery (Plate 1, figures 13, 14; Text-figure 1C). Loculicidal dehiscence of the carpels occurs in the plane of this tissue. In transversely oriented angular specimens (Plate 1, figures 4, 6; Text-figure 1C) the angles correspond to the loculicidal dehiscence planes. Both loculicidal and septicidal dehiscence planes are expressed as pyrite-filled grooves on the surface of the fossils (Plate 1, figures 1-6, 8). The number of dehiscence planes provides a quick means of determining how many locules are present in each fruit without sectioning; locule number equals half the number of dehiscence planes. The number of locules in the present specimens varies from four to eight. An elliptical, anatropous seed is suspended from the apex of each locule by a narrow, arching funiculus that originates from the central axis near the fruit apex (Plate 1, figures 9, 11, 12; Text-figure 1B).

Material: Nine specimens, including five from Red Hot Truck Stop (UF 9972-9976), three from Asylum Creek (UF 9979-9981), and one from the General Motors dealership locality (UF 9978).

Horizons: Red Hot Truck Stop, basal unit of early Eocene Bashi Fm. (MGS loc. 19; UF loc. 18071); Nelson General Motors dealership, top of Tuscahoma Fm. (UF loc.

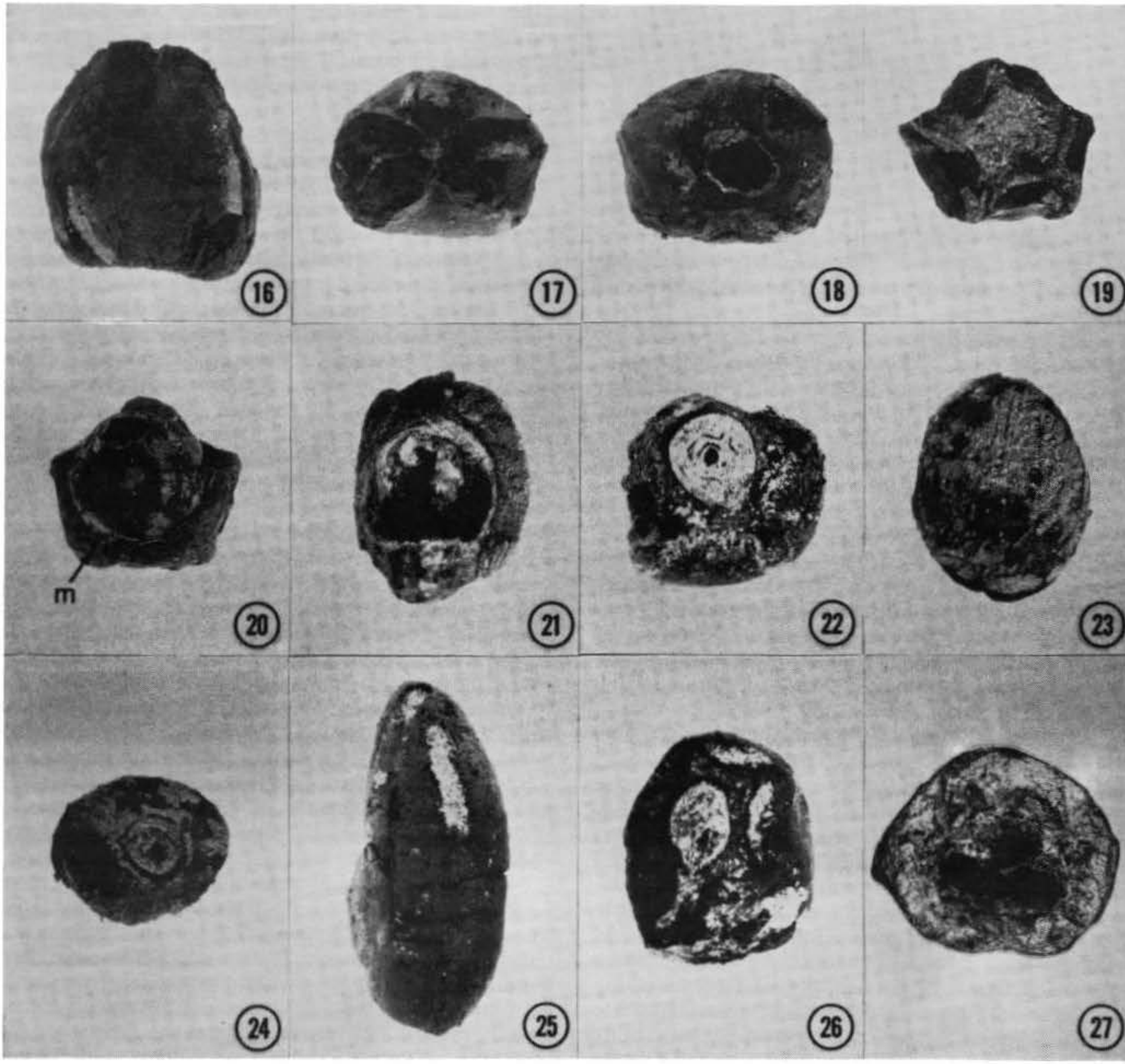

Plate 2

Figures 16-27. *Carpolithes bashiensis* sp. nov. (16) Lateral view of the largest specimen showing general outline of the fruit and remains of the exocarp (e). 1.5X. UF 9967. (17) Apical view of the same specimen illustrating fluted, pentagonal aspect, and small circular scar. 1.5X. UF 9967. (18) Basal view of UF 9967. 1.5X. (19) Basal view of a fragmentary specimen illustrating its pronounced pentagonal outline and central scar obscured by pyrite. 1.5X. UF 9968. (20) Locular view of the specimen in figure 19 illustrating the thick mesocarp (m) surrounding the large spherical single locule. 1.5X. UF 9968. (21) Another specimen, fractured longitudinally showing the thick mesocarp and locule. 1.5X. UF 9969. (22) Basal view of figure 21 illustrating large scar. 2X. UF 9969. (23) Lateral view of an ovoid specimen lacking the pentagonal fluting observed in previous examples. 1.5X. UF 9970. (24) Basal view of figure 23 showing a large circular scar. 1.5X. UF 9970. (25) Elongate specimen. 1.3X. UF 9971. (26) Basal view of specimen in figure 25 showing attachment scar obscured by pyrite. 2X. UF 9971. (27) Transverse view of the lower half of figure 25 illustrating partial impressions of three seeds. 2X. UF 9971.

18143); Asylum Creek, Hatchetigbee Fm., three feet above contact with Bashi Fm. (UF loc. 18144).

Remarks: This species, the most common in the present collection, represents *Wetherellia*, a fossil genus previously documented from early to middle Eocene strata of England and western Germany (Reid and Chandler, 1933; Collinson, 1983) and early Eocene of eastern North America (Mazer and Tiffney, 1982). Diagnostic features of this genus include subspherical capsules with 2-8 wedge-shaped carpels arranged radially about the axis, loculicidal and/or septicidal dehiscence, and pendulous seeds suspended from arching funiculi that arise from near the apex of the central axis (Text-figure 1, A-C).

The morphologically similar genus *Palaeowetherellia* from the Upper Cretaceous of Egypt and the early Eocene of Maryland differs from *Wetherellia* in having a higher number of carpels (up to twelve) and in the angle of orientation of seeds with respect to the fruit axis (Chandler, 1954; Mazer and Tiffney, 1982). *Crepetocarpon* Dilcher and Manchester (1987), another similar genus from fresh water swamp deposits in the middle Eocene Claiborne Formation of western Tennessee, is distinguished from *Wetherellia* by the concave, rather than convex, course of the funiculi, and by its more extensively developed endocarp. Dilcher and Manchester (1987) attributed *Crepetocarpon* to the Euphorbiaceae, documenting close morphological and anatomical similarity to fruits of the extant genus *Hippomane*. *Wetherellia* and *Palaeowetherellia* are also similar to *Hippomane*, and may belong to the Euphorbiaceae as well.

Three species of *Wetherellia* have been recognized: *W. variabilis* Bowerbank emend. Reid and Chandler (1933), *W. dixonii* (Carruthers) Chandler (1961), and *W. marylandica* (Hollick) Mazer and Tiffney (1982). Mazer and Tiffney (1982) provided a comparative treatment of *Wetherellia* and *Palaeowetherellia* species and tabulated the major characters of each. The Meridian fruits are most similar to *W. marylandica*, sharing characters such as subspherical to ovoid shape, weak to mild grooves and ridges over septicidal and loculicidal dehiscence planes, a well-developed network of probable secretory strands, and moderate external pitting of the fruits where these strands intersect the abraded surface (pits filled with resistant pyrite giving the specimens a warty appearance). However, they differ from *W. marylandica* in having up to eight carpels (a feature shared with *W. dixonii*) not six, in possessing a conical apical extension of the central axis, and by exhibiting both loculicidal and septicidal dehiscence (features of *W. variabilis* and *W. dixonii*) rather than solely loculicidal. Mazer and Tiffney (1982) noted several overlapping characters among the three *Wetherellia* species, and entertained the possibility that they may represent geographical variants of a single widespread species. Our investigation of the Meridian fruits leads us to concur with this possibility.

Carpolithes bashiensis sp. nov. (Plate 2, figures 16-27; Text-figure 2, A-C).

The fruits are ovoid to narrowly ellipsoidal, 2.4-4.1 cm long by 1.8-2.4 cm in diameter (Plate 2, figures 16, 23, 27). They are thick-walled (3-5 mm) and have a large spheroidal to ellipsoidal inner cavity 0.7-1.0 cm diam. indicating the fruits were unilocular (Plate 2, figures 20-21). The specimens vary from strongly pentagonal (Plate 2, figures 17-20) to nearly circular (Plate 2, figures 22, 24, 27) in transverse outline. One end of the fruit, interpreted as the base, has a conspicuous circular to pentagonal depression 7-9 mm diam. (Plate 2, figures 19, 22, 26). In the center of this recessed area is a slightly raised circular scar 0.4 cm diam. (Plate 2, figure 22). Both the scar and the depression are obscured by greenish-silver pyrite and cemented quartz sand. Portions of a thin, smooth exocarp are preserved on one specimen (Plate 2, figure 16; Text-figure 2A). Beneath the exocarp lies the mesocarp, a 3.5-5 mm thick zone composed primarily of long narrow cells oriented more or less perpendicular to the locule. Scattered conspicuous strands of silver pyrite resembling irregular bundles of fibrous cells traverse the mesocarp longitudinally and give this tissue a fibrous appearance (Text-figures 2A, 2B). Inside the thick mesocarp and surrounding the central cavity of the fruits is a 1-2 mm thick zone of reflective silver pyrite (Plate 2, figures 20-21). Positionally, this layer corresponds to the endocarp. The inner perimeter of this pyrite zone is smooth and the outer perimeter is somewhat crenate. Which tissue or tissues the pyrite layer represents is uncertain, because the pyrite formation may have occurred differentially; within a specific tissue layer, at the interface of different tissues, or simultaneously in adjacent tissues. A transverse cut of one specimen (UF 9970) revealed fragmentary pyritic molds of 4 or 5 elliptical, 1.5 x 2-3 mm diam. seeds loosely arranged within the locule (Text-figure 2A). Based on the size of these impressions, the locule could have accommodated several seeds.

Material: Five specimens, UF 9967-9971.

Horizon: Basal unit of the early Eocene Bashi Fm., MGS loc. 19 (UF loc. 18071).

Remarks: Although distinctive, these fruits have not, to our knowledge, been described elsewhere. Familial affinities remain to be determined. The five specimens vary in shape from ovoid to narrowly ellipsoidal and from circular to strongly ridged or fluted in transverse outline, yet they are all similar in possessing thick walls with scattered longitudinal bundles of fiber-like strands, a large circular scar at one end, a smaller scar at the other end, and a large spherical locule cavity surrounded by a thick layer of pyrite.

An alternative to the orientation and interpretation of the specimens outlined above is to consider the larger circular scar as occupying the apical or distal end of the fruit rather than the basal. Thus oriented, the general similarity of the fossil fruits to those of modern Lecythidaceae (brazil nut family) becomes evident. Under this interpretation the scar might then be compared to the operculum of the lecythidaceous capsule (pycnidium), a circular region at the apex of the thick-walled fruit which becomes detached and allows the seeds to disperse. The large hole in one specimen (Plate 2, figure 18) could represent an opening naturally present subsequent to the dehiscence of an operculum. All five of the specimens lack a circular portion of the mesocarp in this position.

Carpolithes Schlotheim is a form genus that is used as a repository for fruits and seeds whose systematic affinities are uncertain. The specific epithet *bashiensis* refers to the Bashi Formation whence the specimens were collected.

Fern rhizome (Plate 3, figures 28, 29)

Specimens consist of short, tapering, cylindrical sections of the rhizome. The outer surface of each specimen bears conspicuous, helically-arranged obovate scars, 0.7 to 0.9 cm long by 0.5 cm wide, representing the abraded remnants of leaf bases that sheathed the rhizome (Plate 3, figure 28). The specimen from the Tuscahoma Fm. is 3.4 cm long, and is slightly compressed. It is 1.3 cm diam. at the base and gradually widens apically to 1.9 cm. The specimen from the basal unit of the overlying Bashi Fm. measures 3.2 cm long, 1.1 cm diam. at the base and 1.4 cm diam. at the distal end. This specimen was cut transversely. Though the rhizome is heavily pyritized, features of the internal anatomy are visible (Plate 3, figure 29). The stele consists of a small 3 mm ring of vascular tissue surrounded by helically-arranged leaf bases and roots. Vascular tissues of the leaf bases appear circular in outline. Adventitious roots can also be observed among the leaf bases.

Material: UF 9965, 9966.

Horizons: T4 sand of the late Paleocene Tuscahoma Fm. and basal unit of the early Eocene Bashi Fm., MGS loc. 19; UF loc. 18071.

Remarks: This fern is represented by two specimens, each preserving a section of the rhizome, adherent leaf bases and adventitious roots. Morphological features of these fossils resemble those of modern and fossil species of Osmundaceae (Miller, 1971). The small size of these rhizomes suggests the plants were similar in stature to living osmundaceous species which inhabit the herbaceous understory in mesic deciduous woodland communities.

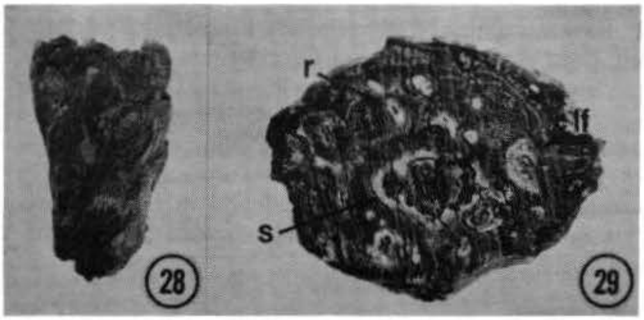

Plate 3

Figures 28, 29. Osmundaceous? fern rhizomes. (28) Exterior surface of rhizome showing prominent helically arranged ovate petiole bases. Paleocene Tuscahoma Fm. 1X. UF 9965. (29) Transverse section of another specimen with remains of central stele (s), leaf bases (lf) and adventitious roots (r). Eocene Bashi Formation. 3X. UF 9966.

DISCUSSION

Fossil plants have been recovered from several sites in the Meridian vicinity. In addition to the localities considered in this report, an exposure of the Hatchetigbee Fm. in southeastern Meridian yielded fossil plants described by E. W. Berry (1917). Berry's locality was situated "on a hillside immediately south of the Meridian & Memphis Railway, in an extensive excavation for the fill leading to the overhead crossing of the Mobile & Ohio Railroad, 200 yards east of that crossing" (Berry, 1917, p. 61), and probably not far from MGS 19. The remains were encountered near the top of about 30 feet of gray to brown and black hackly clays overlying the characteristic "boulder zone" of the Bashi Formation. Berry indicated the base of the exposed section was a little higher than the floodplain of Souwashee Creek. In contrast to the water-worn plant fossils described in the present report, which were clearly deposited in a nearshore marine setting, the remains documented by Berry included *in situ* waterlily-like plants rooted in what are apparently deposits of a small fresh water pond. Thus it is not surprising that these two plant assemblages have no taxa in common.

The fossil plants described here are relatively rare in the Meridian deposits. Sieving of about four cubic yards of unconsolidated sediments from MGS 19 yielded only about 30 fragments of wood, fern rhizomes, and fruits (D. Dockery and S. Ingram, pers. comm.). In contrast to this handful of plant fossils, thousands of shark and ray teeth and other vertebrate remains were obtained. The plant assemblage also appears to be limited in diversity, with only two fruit taxa and one fern taxon. While it may be expected that a larger number of specimens would reveal additional species, it is likely that these marine sediments contain only a fraction of the terrestrial flora. Most of the specimens are greater than a centimeter in diameter, and it is possible that there was a taphonomic bias against the incorporation of smaller fruits in these sediments. The size distribution and composition of the plant assemblage could be the result of the sorting of plant organs with similar buoyancies. The low diversity of the assemblage may be a function of distance from the paleoshoreline. The fruit types are similar in having walls that are unusually thick, and may have been adapted for marine dispersal and protection from prolonged exposure to salt water.

The plants that produced *Wetherellia* fruits are inferred to have occupied mangrove or coastal wetland habitats, and anatomical evidence suggests the fruits were adapted for water-dispersal (Mazer and Tiffney, 1982; Collinson and Hooker, 1987). The extant genus *Hippomane* occupies an ecologic setting similar to that which we envision for these fossils. It grows in coastal thickets in the Caribbean and the Atlantic and Pacific coasts of Central and South America and provides a good example of efficient marine fruit dispersal. Gunn and Dennis (1976) record that *Hippomane* fruits may retain buoyancy for up to two years and are commonly recovered as drift fruits along beaches, with seeds that are still viable.

Biogeographically, it is interesting to note that *Wetherellia* fruits from Virginia, Maryland, Great Britain, and Germany, and *Palaeowetherellia* fruits from Egypt and Virginia occur in nearshore marine environments of the greater Tethyan Ocean (Mazer and Tiffney, 1982; Collinson and Hooker, 1987). The occurrence of *Wetherellia* remains in the upper Tuscahoma-lower Hatchetigbee interval in Meridian extends the known range of this genus westward to the Mississippi Embayment.

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