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BIOSTRATIGRAPHY AND PALEOECOLOGY OF LOWER PALEOZOIC, UPPER CRETACEOUS, AND LOWER TERTIARY ROCKS IN U.S. GEOLOGICAL SURVEY NEW MADRID TEST WELLS, SOUTHEASTERN MISSOURI

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UNITED STATES GEOLOGICAL SURVEY

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I. ABSTRACT

The paleontology and biostratigraphy of Tertiary, Cretaceous, and Paleozoic rocks in the upper Mississippi embayment are incompletely known because marine fossils are only locally present in these rocks. This study concerns material from two U.S. Geological Survey test wells drilled in New Madrid County, southeastern Missouri, as part of earthquake hazard studies in the northern Mississippi Embayment.

Test well 1 sampled lower Tertiary strata to a depth of 146 ft; these strata were found to be late Eocene in age on the basis of sporomorphs. Test well 1-X, 29 ft northwest of well 1, provided cuttings and cores from lower Tertiary, Upper Cretaceous, and lower Paleozoic rocks to a total depth of 2,316 ft below the Kelly bushing (at an altitude of 288 ft). Lithologic evidence suggests that the base of the Jackson Formation may be at 270 ft, but sporomorphs indicate that the base of the Jacksonian Stage (upper Eocene) is possibly at a depth of about 350 ft in test well 1-X. Lithologic units of the Claibornian Stage (middle Eocene) here consist of the Cockfield(?) and Cook Mountain(?) Formations and Memphis Sand, in descending order. The Claibornian could not be subdivided using sporomorphs from cuttings, but sporomorphs show that the top of the Sabinian Stage (top of the lower Eocene) is at about 1,055 ft; lithologically, the top of the Wilcox Group (top of the Flour Island Formation) is at

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1,048 ft. Sporomorphs suggest that the top of the lower Sabinian (top of the Paleocene) is within the Flour Island Formation at about 1,105 ft. The next major lithologic break, the top of the Fort Pillow Sand at 1,186 ft, does not coincide with any detectable biostratigraphic boundary. Lithologically, the interval from 1,339 to 1,377 ft may belong to the Old Breastworks Formation; dinoflagellates from cuttings indicate that this interval is likely to be late Midwayan in age and, therefore, correlative with the Naheola Formation of the eastern Gulf Coast. The Porters Creek Clay extends from a probable top at 1,377 ft to 1,691 ft, and the base of the underlying Clayton Formation (Tertiary-Cretaceous contact) is at 1,703 ft. Calcareous nannofossils, dinoflagellates, foraminifers, mollusks, ostracodes, and sporomorphs from continuous cores of the Porters Creek Clay and Clayton Formation indicate that the upper half of the Porters Creek correlates with the upper part of the same formation or perhaps partly with slightly younger rocks in the eastern Gulf Coast, the lowermost Porters Creek appears to correlate with the upper part of the Clayton Formation of the eastern Gulf Coast and with the Kincaid Formation of Texas, and the thin Clayton of the test well probably correlates with only the lower part of the thicker Clayton of the eastern Gulf Coast. Sporomorphs from McNairy Sand (Upper Cretaceous) cores indicate Maestrichtian and perhaps latest Campanian Age. Lower Paleozoic dolostone from 2,023 ft to total depth at 2,316 ft is barren of identifiable fossils except for a probable fragment of the fish *Anatolepis;* the dolostone is probably Late Cambrian in age.

The McNairy Sand of New Madrid well 1-X seems to have been deposited in nonmarine to nearshore marine environments; the Clayton Formation and lower part of the Porters Creek Clay were deposited under marine conditions during an early Paleocene marine transgression. A major regression followed that continued through the end of Porters Creek time and perhaps into Naheola (late Midwayan) time; the Sabinian, Claibornian, and Jacksonian strata in southeastern Missouri were deposited primarily or entirely in nonmarine environments.

II. INTRODUCTION

The paleontology and biostratigraphy of Tertiary, Cretaceous, and Paleozoic rocks in the northern Mississippi Embayment are incompletely known because marine fossils are only locally present in these rocks. Many of the lower Tertiary and Cretaceous rocks were deposited in nonmarine environments, and some marine units lack calcareous fossils because of leaching (Lamar and Sutton, 1930; Shourd and Winter, 1980). The Paleozoic carbonate rocks are commonly coarsely crystalline, dolomitic, and only sparsely fossiliferous. Many papers have been written on the taxonomy of sporomorphs (spores and pollen grains) from the lower Tertiary and Cretaceous of the northern Mississippi Embayment, but much remains to be learned about the sporomorph biostratigraphy of these rocks. No papers have been published on the taxonomy or biostratigraphy of fossil dinoflagellates in this region.

In this study, we examined Tertiary and Cretaceous rocks for calcareous nannofossils (Bybell, Smith), dinoflagellates (Edwards), foraminifers (Gibson), mollusks (Ward), ostracodes (Hazel), and sporomorphs (Christopher, Frederiksen) and Paleozoic rocks for conodonts and vertebrate remains (Repetski). The lithostratigraphy is by Crone and Russ.

The material studied is from U.S. Geological Survey New Madrid test wells 1 and 1-X, drilled in the autumn of 1978 as part of the Survey's Earthquake Hazards Reduction Program. One of the prime goals of the wells was to obtain data about the active tectonic stress field from *in situ* hydrofracture stress measurements in the subsurface Paleozoic rocks. A second objective was to obtain good quality samples and modern geophysical logs of the stratigraphic section in the New Madrid area. The stratigraphy and structure of this part of the Embayment are poorly known because few deep wells and test holes have been drilled. Finally, as mentioned previously, relatively little is known about the biostratigraphy particularly of micro- and nannofossils in the northern Mississippi Embayment; sampling of the test wells provided an excellent opportunity to study a variety of fossils from the post-Paleozoic rocks of the New Madrid area, to correlate these rocks with much better known sections elsewhere in the Gulf Coast, and to compare the generally nonmarine to nearshore marine facies of the northern Mississippi Embayment with the more marine litho- and biofacies of the Gulf Coast.

New Madrid test wells 1 and 1-X are located in SW ¼ SW ¼ SE ¼ sec. 32, T. 21 N., R. 14 E., U.S.G.S. Point Pleasant 7½ minute quadrangle, New Madrid County, Mo., just west of Missouri State Highway 162 (fig. 1). Test well 1 is 323 ft (98.5 m) N. 40° W. of U.S.G.S. benchmark 283, and test well 1-X is 29 ft (8.9 m) northwest of well 1. Sample depths are measured below the Kelly bushing, which was at an altitude of 288 ft. (Measurements in this paper are cited in English units to maintain consistency with standard drilling usage). Small discrepancies of several feet are evident between depths marked on cutting bags and core boxes and depths recorded on the geophysical logs. In this paper, depths of fossil samples are those marked on the bags and boxes whereas depths of lithostratigraphic unit tops and bases are from the geophysical logs (see fig. 2), which are more accurate.

Preliminary reports on the drilling history and stratigraphy of test well 1-X were prepared by Crone and Russ (1979) and Russ and Crone (1979), and a detailed description of the samples from well 1-X is provided by Crone (1981). Test well 1 was drilled to a total depth of 237 ft and casing was set at 146 ft. Cuttings suggested that, below the Quaternary alluvium, the top of the lower Tertiary gray clay was at about 125-130 ft. The interval from 205-237 ft was cored, but the core barrel repeatedly snagged on the bottom of the casing as it was being retrieved. The casing had to be pulled, and the core from 205 to 237 ft was lost. Fortunately, a thick mass of lower Tertiary mudstone exhibiting well preserved stratification was lodged in the bottom of the casing; this mass represents a "core" within the interval between about 125 ft (the top of the preserved lower Tertiary) and 146 ft (the lower end of the casing).

The rig was moved, and drilling commenced for test well 1-X. This well was initially drilled to 142 ft; cuttings indicated the top of the lower Tertiary was at approximately 135 ft. Surface casing was set and cemented to 140 ft. The well was then drilled to 1,388 ft, near the top of the Porters Creek Clay (lower Paleocene); cuttings were collected at five-foot intervals from 140 to 1,388 ft. After the well was logged, eight sidewall cores were collected between 255 and 500 ft. The well was deepened to 1,400 ft, and a string of casing was set and cemented to that depth. Below the casing, continuous coring recovered nearly a complete section of the Porters Creek Clay between 1,415 and 1,691 ft and much of the Clayton Formation from 1,691 to 1,703 ft (1,696 to 1,704.5 ft according to the core boxes). In the Upper Cretaceous section from 1,703 ft to the top of the lower Paleozoic dolostone at 2,023 ft, only seven 1- to 10-ft intervals of clay, silt, and sand were recovered by coring, but samples of cuttings were collected at five-foot intervals. The Paleozoic dolostone was cored from 2,023 to 2,028 ft with minimal recovery, but cuttings were collected from 2,028 ft to total depth at 2,316 ft.

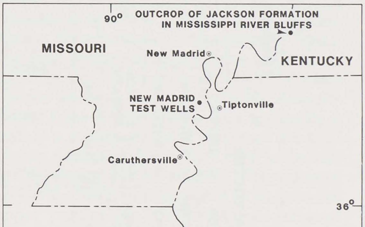

Figure 1. Location of the New Madrid and Fort Pillow test wells.

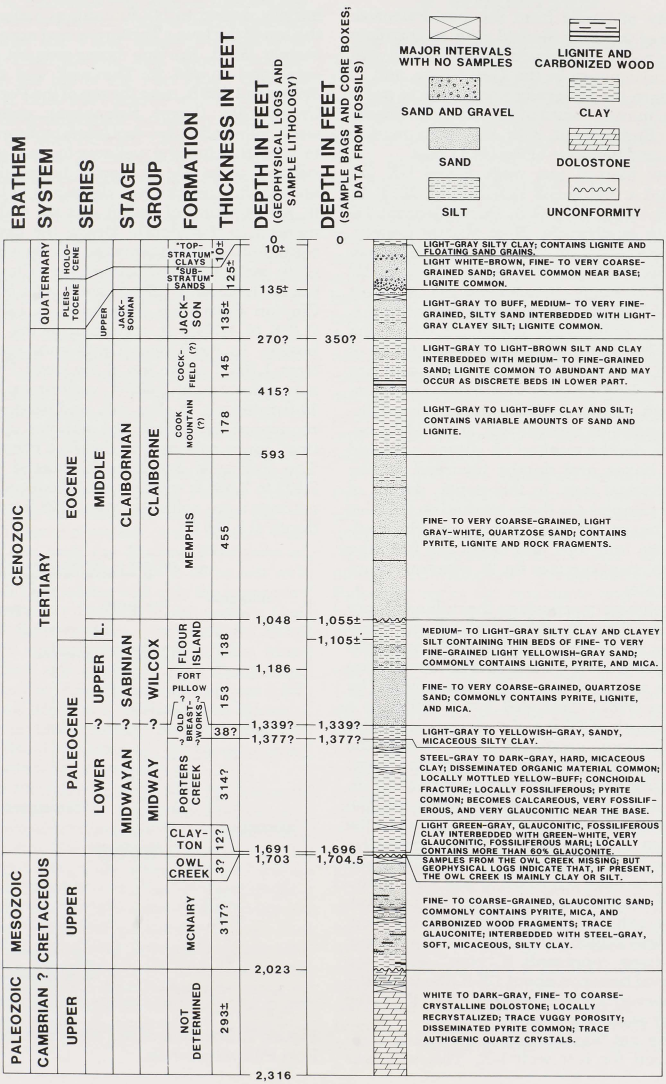

Figure 2. Diagram of rock and time-rock units below the Mississippi Valley alluvium in New Madrid test wells 1 and 1-X.

III. BIOSTRATIGRAPHY

Eocene and Paleocene

Useful samples available from the upper part of the Tertiary section in the test wells consist of the "core" (casing) sample from 125-146 ft in well 1 and sidewall core samples from 350, 395, and 500 ft in well 1-X. The sidewall core samples from 255, 270, 410, and 470 ft are barren or nearly barren of palynomorphs, and the sidewall core sample from 485 ft was not examined. Cuttings from the upper and middle Eocene of the test wells are difficult to use for sporomorph age determinations because they are heavily contaminated with cavings of upper Eocene material, and at the same time many of the samples contain reworked material of early Eocene to Cretaceous age.

Sixty sporomorph taxa have been identified in core samples from strata of the upper Eocene and the upper part of the middle Eocene in New Madrid wells 1 and 1-X (Table 1). However, the precise position of the upper Eocene-middle Eocene boundary in the Gulf Coast is not easily determined by sporomorphs. Many late Eocene sporomorph species are different from those of the middle part of the middle Eocene (Tschudy, 1973a; Elsik, 1974), but sporomorph assemblages of the upper Eocene are nearly identical to those in the uppermost part of the middle Eocene (Frederiksen, 1980a).

The "core" sample from 125-146 ft (Table 1) contains a rich sporomorph assemblage typical of the upper Eocene and the uppermost middle Eocene. The presence of *Momipites annulatus* indicates that the sample is not older than late Eocene. The cuttings sample from 305-310 ft of test well 1-X probably includes cavings; this sample contains *Parsonsidites conspicuus* Frederiksen 1973, which is only known from the upper Eocene and lower Oligocene. The youngest early Tertiary rocks exposed on the surface in southeastern Missouri are assigned to the Holly Springs Sand or Formation (Koenig, 1961), which is thought to be middle to early Eocene in age (references in Keroher and others, 1966, p. 1784-1785). However, the Jackson Formation was tentatively identified in the Fort Pillow test well 55 mi to the south-southwest of the New Madrid wells, in Lauderdale County, Tenn. (fig. 1; Moore and Brown, 1969), and the Jacksonian Stage has been identified on the basis of sporomorphs in southwestern Kentucky (by R.H. Tschudy; see Olive, 1980). This paper confirms that the Jacksonian Stage also occurs in the subsurface of southeastern Missouri.

The sidewall core sample from 350 ft could be from either the upper Eocene or the upper part of the middle Eocene, and we tentatively place the biostratigraphic boundary between the upper and middle Eocene (= the Jacksonian-Claibornian Provincial Stage boundary) at this level (fig. 2). Lithologically, the Jackson and Cockfield Formations are difficult to distinguish from one another; however, geophysical log correlations suggest that the formation contact might be at 270 ft. The sidewall core sample from 395 ft is probably late middle Eocene in age based on the occurrence of a fair number of specimens of *Gothanipollis* and aff. *Symplocospollenites* of Tschudy (1973a) and the presence of *Hippocrateaceaedites*. On the Gulf Coast, *Gothanipollis* is found mainly in the middle Eocene and is only sparsely represented in the upper Eocene; the form of *Symplocospollenites* in the sample from 395 ft is similar to one found only in the middle Eocene to Paleocene of the Gulf Coast by Tschudy (1973a); *Hippocrateaceaedites* has previously been found in North America only in the middle Eocene of California (Frederiksen, unpublished data). The first downhole appearance of *Gothanipollis* in the cuttings is at 445-450 ft; this sample also has the first probable *Alangiopollis*. Like *Gothanipollis*, *Alangiopollis* is mainly a middle Eocene genus on the Gulf Coast; *Alangiopollis* is very rare in the upper Eocene of that region. The sidewall core from 500 ft seems clearly to be from the upper part of the middle Eocene because *Celtis* and *Gothanipollis* are fairly abundant in this sample, which also contains probable *Alangiopollis*. *Platycarya* pollen may range to near the top of the middle Eocene on the Gulf Coast, but it is rare above the lower part of the middle Eocene. The specimen of *Platycarya* found in the sample from 500 ft may be reworked; several taxa of reworked lower Eocene to Cretaceous sporomorphs occur in this sample. Several specimens of *Graminidites* (grass family) were also found in the sample from 500 ft. This pollen form probably does not range far below the top of the middle Eocene on the Gulf Coast. The possibility cannot be excluded that the grass pollen grains in the sample could be modern contaminants. However, the only occurrence of grass pollen in the cuttings was at 490-495 ft; similar contamination of two samples collected and processed separately seems unlikely. The gradual change in the sporomorph assemblages from 125-146 to 500 ft suggests more or less continuous deposition across the upper Eocene-middle Eocene boundary in the area of the test well.

Dinoflagellates were examined from the "core" sample from 125-146 ft, and the following taxa were found:

Chatangiella sp.
Fibrocysta bipolare (Cookson & Eisenack, 1965) Stover & Evitt, 1978
Isabelidinium acuminata (Cookson & Eisenack, 1958) Stover & Evitt, 1978
Odontochitina costata Alberti, 1961
Callaiosphaeridium asymmetricum (Deflandre & Courteville, 1939) Davey & Williams, 1966

The specimens seem to be quite oxidized and represent a reworked Cretaceous assemblage. The known range of *O. costata* is from Campanian to Cenomanian; the assemblage seems to be late but not latest Cretaceous in age.

On the basis of lithologic correlation between New Madrid well 1-X and the Fort Pillow test well (Moore and Brown, 1969; Crone, 1981), the Claiborne Group in the New Madrid well is tentatively divided, in descending order, into the Cockfield Formation, Cook Mountain Formation, and Memphis Sand (fig. 2). However, the Claiborne Group could not be subdivided biostratigraphically on the basis of sporomorphs from the cuttings. Undescribed species were seen that are probably middle Eocene in age, but the relatively few marker species and genera for the middle Eocene listed by Tschudy (1973a) and Elsik (1974) were not found.

Reworked lower Eocene and Paleocene sporomorphs are consistently present in the upper and middle Eocene samples, but the reworked material is only a small percentage of total sporomorphs. At 1,055-1,060 ft, the cuttings sample contains quite a few specimens of *Platycarya platycaryoides*. This species is rare above the lowermost part of the middle Eocene and has its peak occurrences in the lower Eocene; therefore, we take the top of the lower Eocene as being at about 1,055 ft.

Lithologically, the contact between the Memphis Sand (lower part of the Claiborne Group) and the underlying Flour Island Formation (upper part of the Wilcox Group) in the New Madrid well is placed at 1,048 ft. In the Fort Pillow well in Tennessee, the lower part of the Memphis Sand contained sporomorphs typical of the lower part of the Claiborne Group (middle Eocene), whereas the upper part of the Flour Island Formation had sporomorphs found in the Wilcox Group (lower Eocene to upper Paleocene; R.H. Tschudy, *in* Moore and Brown, 1969).

Table 1. Sporomorphs in cores from the upper Eocene and upper part of the middle Eocene, New Madrid test wells 1 and 1-X. Depth in ft.

	Test well 1	Test well 1-X		
	125-145	350	395	500
Chrysophyllum brevisulcatum (Frederiksen, 1973) Frederiksen, 1980	X			
Ephedra hungarica (Nagy, 1963) Frederiksen, 1980	X			
Juglans nigripites Wodehouse, 1933	X			
Lymingtonia cf. *L. rhetor* Erdtman, 1960	X			
Planera? thompsoniana Traverse, 1955	X			
Tilia instructa (Potonie, 1931) Frederiksen, 1980	X			
Triatriopollenites sp. (*Comptonia* type)	X			
Ilex spp.	X	X		
Intratriporopollenites stavensis Frederiksen, 1980	X	X		
Liliacidites tritus Frederiksen, 1973	X	X		
Platanus sp.	X	X		
Quercoidites microhenricii (Potonie, 1931) Potonie, 1960	X	X		
Symplocos contracta Frederiksen, 1980	X	X		
Ailanthipites berryi Wodehouse, 1933	X	X	X	

	Test well 1	Test well 1-X		
	125-145	350	395	500
Caprifoliipites tantulus Frederiksen, 1980	X		X	
Cupanieidites orthoteichus Cookson & Pike, 1954	X		X	
Momipites annulatus Frederiksen & Christopher, 1978	X		?	
Myrtaceidites parvus Cookson & Pike, 1954	X		X	
Nyssa kruschii (Potonie, 1931) Frederiksen, 1980	X	X	X	
Rhoipites angustus Frederiksen, 1980	X	X	X	
Tetracolporopollenites lesquereuxianus (Traverse, 1955) Frederiksen, 1980	X	X	X	
Tetracolporopollenites longipollinius (Traverse, 1955) Frederiksen, 1980	X	X	X	
Triatriopollenites sp. (*Myrica* type)	X	X	X	
Alnus vera (Potonie, 1931) Martin & Rouse, 1966	X			X
Araliaceoipollenites granulatus (Potonie, 1931) Frederiksen, 1980	X	X	X	X
Carya (large grains)	X	X	X	X
Cupuliferoipollenites spp.	X	X	X	X
Momipites coryloides Wodehouse, 1933	X	X	X	X
Momipites microfoveolatus (Stanley, 1965) Nichols, 1973	X	X	X	X
Platanus occidentaloides Frederiksen, 1980	X	X	X	X
Polyatriopollenites vermontensis (Traverse, 1955) Frederiksen, 1980	X			X
Pseudolaesopollis ventosa (Potonie, 1931) Frederiksen, 1979	X	X	X	X
Quercoidites inamoenus (Takahashi, 1961) Frederiksen, 1980	X		X	X
Rhoipites latus Frederiksen, 1980	X	X		X
Salixipollenites parvus Frederiksen, 1980	X	X		X
Siltaria pacata (Pflug *in* Thomson & Pflug, 1953) Frederiksen, 1980	X			X
Siltaria cf. *S. scabriextima* Traverse, 1955	X	X	X	X
Tetracolporopollenites megadolium (Potonie, 1931) Frederiksen, 1980	X	X	X	X
Ulmipollenites undulosus Wolff, 1934	X			X
Verrutricolporites spp.	X	X		X
Rousea monilifera Frederiksen, 1980		X		
Araliaceoipollenites profundus Frederiksen, 1980			X	
Casuarinidites cf. *C. granilabratus* (Stanley, 1965) Srivastava, 1972			X	
Cyrillaceaepollenites megaexactus (Potonie, 1931) Potonie, 1960			X	
Ephedra claricristata Shakhmundes, 1965			X	
Ericipites aff. *E. ericius* (Potonie, 1931) Potonie, 1960			X	
Hippocrateaceaedites sp.			X	
Liliacidites vittatus Frederiksen, 1973			X	
Symplocos gemmata Frederiksen, 1980			X	
aff. *Symplocospollenites* of Tschudy, 1973			X	
Cyrillaceaepollenites kedvesii Frederiksen, 1980			X	X
Gothanipollis cockfieldensis Engelhardt, 1964			X	X
Alangiopollis spp.				?
Betula sp.				X
Celtis sp.				X
Eucommia type				X
Gleicheniidites senonicus Ross, 1949				X
Graminidites gramineoides (Meyer, 1956) Krutzsch, 1970				X
Lycopodium hamulatum (Krutzsch, 1959) Frederiksen, 1980				X
Platycarya platycaryoides (Roche, 1969) Frederiksen & Christopher, 1978				X

However, the sporomorphs in the upper part of the Flour Island Formation of the Fort Pillow well have rather long ranges and thus are not the most useful taxa for biostratigraphic correlation. In the New Madrid hole, the lithologic boundary at 1,048 ft between the Memphis Sand and the Flour Island Formation coincides well with the contact between the middle and lower Eocene determined probably to be at about 1,055 ft according to sporomorphs.

The top of the Paleocene in New Madrid well 1-X is probably at about 1,105 ft; in the cuttings sample from 1,105-1,110 ft, the following sporomorphs have actual or apparent range tops:

Basopollis obscurocostata Tschudy 1975 (2)
Faguspollenites sp. of Frederiksen 1980b (3)
Insulapollenites rugulatus Leffingwell 1971 (probable) (2)
Momipites tenuipolus group, cf. *Platycarya* (1)
Momipites strictus Frederiksen & Christopher 1978 (possible) (4)
Paraalnipollenites confusus (Zaklinskaya 1963) Hills & Wallace 1969 (3)
Pistillipollenites mcgregorii Rouse 1962 (2)
Retitrescolpites anguloluminosus (Anderson 1960) Frederiksen 1979 (4)
Tricolpites sp. (3)

The taxon marked (1), *Momipites tenuipolus* group with affinities to *Platycarya*, is probably an early Eocene form. Taxa marked (2) range from the lower Eocene to the Paleocene. Taxa marked (3) have ranges that are not yet definitely established, but thus far they have not been observed above the Paleocene in the Gulf Coast, whereas taxa marked (4) are those rather certain not to range above the Paleocene. In short, this sample is Paleocene but probably includes cavings from the lower Eocene. *Basopollis obscurocostata*, *Faguspollenites* sp., *Insulapollenites rugulatus* and *Paraalnipollenites confusus* are not known to range below the upper Paleocene (lower Sabinian) on the Gulf Coast.

Moore and Brown (1969) divided the Wilcox Group (which corresponds more or less to the Sabinian Provincial Stage) of the Fort Pillow well, in descending order, into the Flour Island Formation (mainly silt and clay), the Fort Pillow Sand, and the Old Breastworks Formation (mainly silt). In New Madrid test well 1-X, the top of the Fort Pillow Sand is at 1,186 ft, and the Old Breastworks Formation was tentatively identified as extending from 1,339 to 1,377 ft on the basis of cuttings and geophysical logs. The biostratigraphic contact between the Eocene and Paleocene in the Fort Pillow well could not be determined, but sporomorphs suggested that at least the lower half of the Old Breastworks Formation is Paleocene (R.H. Tschudy, *in* Moore and Brown, 1969). In the New Madrid well, the contact between the Eocene and Paleocene falls within the Flour Island Formation (fig. 2). Thus, the lower Eocene part of the Wilcox Group in the New Madrid well is much thinner than the upper Paleocene part of the Wilcox. Similar relative thicknesses of the lower Eocene and upper Paleocene are found throughout the Gulf Coast (Bennison, 1975).

Table 2. Dinoflagellates and other plankters in cuttings from 1,340-1,405 ft in New Madrid test well 1-X.

	1,340-1,350	1,350-1,360	1,360-1,370	1,370-1,380	1,380-1,390	1,390-1,405
Cordosphaeridium gracile (Eisenack, 1954) Davey & Williams, 1966	X					
Spiniferites spp.	X	X				
Spinidinium densispinatum Stanley, 1965	X	?		X		X
Small peridinioid forms	X	X	X	X	X	X
Reworked Cretaceous forms (*Chatangiella, Cyclonephelium, Spongodinium delitiense, Odontochitina costata*)	X	X	X	X	X	X
Pediastrum	X	X	X	X	X	X

Palynomorphs were examined from cuttings representing 10-15 ft intervals from 1,340 to 1,405 ft in order to determine, if possible, the position of the boundary between the upper and lower Paleocene (Sabinian-Midwayan Provincial Stage boundary) in the New Madrid 1-X well. These cuttings contain definite Paleocene sporomorphs, but the Paleocene species are few in number, and all have long ranges. Therefore, sporomorphs do not indicate whether the Sabinian-Midwayan boundary is within the interval studied. Table 2 is a list of the dinoflagellate taxa found in these samples. The specimens are poorly preserved, but all six samples contain similar dinoflagellate floras consisting mainly of small peridinioid forms and reworked Cretaceous specimens. If *Spinidinium densispinatum* is indigenous in these samples, its presence suggests a Midwayan age; this species has been found in the Naheola and Clayton Formations (Midwayan), but not in the Tuscahoma or Nanafalia Formations (lower Sabinian) in eastern Alabama and western Georgia (Edwards, 1980, and unpublished data). If the interval from 1,339 to 1,377 ft is Midwayan, then it may belong to the Porters Creek Clay, and the Old Breastworks Formation may be missing from the New Madrid test well. However, the interval correlates in stratigraphic position, and generally in lithology, with the Old Breastworks Formation of the Fort Pillow well. Furthermore, on the basis of its stratigraphic position and the dinoflagellate data, the interval seems likely to correlate with the upper Midwayan Naheola Formation of the eastern Gulf Coast. In short, study of the New Madrid samples suggests that correlatives of the Naheola Formation may extend as far north as southeastern Missouri and that the Old Breastworks Formation in the New Madrid well, and presumably also in the Fort Pillow well, may belong to the Midway Group rather than to the Wilcox Group to which the formation was assigned by Moore and Brown (1969).

Core samples from 1,417 to 1,702 ft were examined for calcareous nannofossils. Five of these samples, from 1,417 to 1,537.5 ft, are barren. Eleven samples from the lower part of the Porters Creek Clay at 1,544 to 1,671 ft contain an assemblage (Table 3) from Martini's (1971) Zone NP3 (Danian), and two samples from the Clayton Formation at 1,698.5 and 1,702 ft contain an assemblage possibly from Zone NP2 (Danian). Bybell (1980) examined calcareous nannofossils from the type area of the Midwayan Provincial Stage (lower Paleocene) in western Alabama. In that area, the upper member of the Porters Creek Clay, the Matthews Landing Marl Member, can be placed in Zone NP4, the upper member of the Clayton Formation, the McBryde Limestone Member, can be placed in Zone NP3, and

Table 3. Calcareous nannofossils in lower Paleocene core sample from New Madrid test well 1-X. Depth in ft.

	Porters Creek Clay 1,544-1,671 Zone NP3	Clayton Formation 1,698.5-1,702 Zone NP2?
Chiasmolithus consuetus (Bramlette & Sullivan, 1961)	X	
Neochiastozygus concinnus (Martini, 1961)	X	
Braarudosphaera bigelowi (Gran & Braarud, 1935)	X	X
Cepekiella aff. *C. lumina* (Sullivan, 1965)	X	X
Coccolithus pelagicus (Wallich, 1877)	X	X
Cruciplacolithus tenuis (Stradner, 1961)	X	X
Ericsonia subpertusa Hay & Mohler, 1967	X	X
Lanternithus sp. cf. *L. duocavus* Locker, 1967	X	X
Markalius inversus (Deflandre, 1954)	X	X
Thoracosphaera spp.	X	X
Zygodiscus sigmoides Bramlette & Sullivan, 1961	X	X
Braarudosphaera discula Bramlette & Riedel, 1954		X

the lower member of the Clayton, the Pine Barren Member, can be placed in either Zone NP3 or NP2. Therefore, the lower part of the Porters Creek Clay in the Missouri core is correlative with at least the upper part of the Clayton, and perhaps also with the lower part of the Porters Creek Clay, of western Alabama (fig. 3). The Clayton Formation in the Missouri core, on the basis of calcareous nannofossils, may be correlative with the lower part of the Clayton in western Alabama. Reworked Cretaceous calcareous nannofossils were also found in the core samples from 1,698.5 and 1,702 ft, including *Arkhangelskiella cymbiformis* Bekshina, 1959, *Micula staurophora* (Gardet, 1955), and *Zygodiscus spiralis* Bramlette & Martini, 1964, which range from the Maestrichtian to the upper Campanian in southwestern Tennessee, eastern and northeastern Mississippi, and western Alabama.

Ostracodes were found in 11 samples of the Porters Creek Clay and Clayton Formation of New Madrid well 1-X (Table 4), but identifiable specimens were recovered only from four samples between 1,670.5 and 1,699 ft (Table 5). The sample from 1,670.5 ft (lower part of the Porters Creek Clay) contains several species that have not been recorded below the Wills Point Formation in Texas (Alexander, 1934), and the assemblage (Table 5) is different from that of a reference sample from the middle part of the Porters Creek Clay of western Alabama. Thus, the test well sample from 1,670.5 ft seems to be correlative with the lower part of the Porters Creek Clay or the upper part of the Clayton Formation (McBryde Limestone Member) of Alabama and eastern Mississippi (fig. 3). The assemblage in the sample from 1,686.5 ft (Porters Creek Clay; Table 5) suggests that this sample is no younger than the faunal assemblages from the Kincaid Formation of Texas or the Clayton Formation of the eastern Gulf Coast (Alexander, 1934). The Clayton samples from 1,697.3 and 1,699 ft contain an early Paleocene (Danian) assemblage that indicates correlation with the lower part of the Clayton Formation (Pine Barren Member) of western Alabama and the lower part of the Kincaid Formation of Texas (Alexander, 1934; Hazel, 1968; Smith, 1978).

Thirty taxa of foraminifers were found in the Porters Creek Clay and Clayton Formation (Table 6). All were benthic forms except *Globorotalia compressa* at 1,670.5 ft in the Porters Creek Clay. This species has a known range from the middle of Blow's

SERIES	STAGE	TEXAS	NEW MADRID WELL 1-X, MISSOURI	WESTERN ALABAMA	
PALEOCENE (LOWER PART)	MIDWAYAN	WILLS POINT FORMATION	OLD BREASTWORKS (?) FORMATION	NAHEOLA FORMATION	
			PORTERS CREEK CLAY	PORTERS CREEK CLAY	MATTHEWS LANDING MARL MEMBER
					UNNAMED MEMBER
		KINCAID FORMATION		CLAYTON FORMATION	MCBRYDE LIMESTONE MEMBER
			CLAYTON FORMATION		PINE BARREN MEMBER

Figure 3. Tentative correlation of Midwayan (lower Paleocene) formations of New Madrid test well 1-X with lithologic units of the Gulf Coast. Thicknesses of units not to scale.

(1969) Zone P3 to the middle of Zone P1. This range is considered by Hardenbol and Berggren (1978) to be equivalent to calcareous nannofossil Zones NP4 through NP2, or earliest Thanetian to late Danian. Many of the benthic species in the two Porters Creek samples from New Madrid well 1-X have been reported from both the Porters Creek and Clayton of the Gulf Coast but do not extend up into the Naheola Formation, which overlies the Porters Creek. Detailed published foraminiferal biostratigraphies of the Midwayan are largely lacking, but several of the species found appear to be restricted to the Porters Creek and the uppermost part of the Clayton; they include *Clavulinoides midwayensis*, *Anomalina midwayensis*, and *Robulus* cf. *R. rosettus*. On the basis of these species, it appears most likely that the New Madrid 1-X samples from 1,670.5 and 1,686.5 ft are equivalent to the Porters Creek or uppermost part of the Clayton of the Gulf Coast and not to the lower half of the Clayton of that region. The benthic foraminifers in the Clayton samples from 1,697.3 and 1,699 ft in the New Madrid test well are Midwayan in age but have rather long ranges in the Gulf Coast; most of the species are known from the upper part of the Porters Creek Clay (Matthews Landing Marl Member) to the lower part of the Clayton Formation (Pine Barren Member).

Only three species of mollusks were found in the lower Paleocene core samples of test well 1-X. *Ledina smirna* (Dall, 1898) was found at 1,543, 1,567, and 1,608 ft, *Nucula* sp. at 1,543 ft, and *Gryphaeostrea pulaskensis* (Harris, 1894) at 1,686.5, 1,694.5, 1,695, and 1,699 ft. However, the two taxa identified to species level have well documented stratigraphic and geographic ranges. *Ledina smirna* has been reported from the Kincaid and Wills Point Formations (Midwayan, lower Paleocene) of Texas (Gardner, 1933), from Midwayan strata of Arkansas, Tennessee, Mississippi, and Alabama (Harris, 1896), and from the

Table 4. Protistan and animal fossils in lower Paleocene core samples from New Madrid test well 1-X.

Depth in feet	Lithology	Mollusks	Foraminifers	Ostracodes	Others
1,456	Clay, carbonaceous	—	—	—	—
1,470	do.	—	—	—	—
1,479	Clay	—	?	—	Fish scales
1,499	Clay, slightly silty	—	Scarce	—	—
1,509	do.	—	Scarce, small	—	—
1,543	do.	Common	Scarce, very small	—	—
1,567	do.	Fragments	Scarce, small, fragile	Scarce, small, fragile	—
1,577	do.	—	Fragments	Fragments	—
1,608	do.	Some present	Few, poorly preserved	Few, poorly preserved	—
1,646	do.	Trace	Rare	—	—
1,660	do.	—	Small, in pockets	—	Echinoid spine; fish scale
1,664	do.	—	Scarce, fragile	Scarce, fragile	Fish scales
1,670.5	Clay, silty, glauconitic	—	Common	Common	—
1,682	do.	—	do.	Fragments	—
1,686.5	do.	Common	do.	Common	Fish scales
1,694.5	do.	do.	do.	do.	—
1,695	do.	Fragments common	do.	do.	—
1,697.3	Sand, glauconitic, fine	do.	do.	do.	—
1,699	Sand, glauconitic, medium to coarse	Abundant	Abundant	Abundant	—

Matthews Landing Marl Member of the Porters Creek Clay in Alabama (Toulmin, 1977). This species is found mainly in silty and clayey strata (Porters Creek lithofacies) rather than in sandy strata (Clayton lithofacies). *Gryphaeostrea pulaskensis* occurs in the Kincaid Formation of Texas (Gardner, 1933), in Midwayan units of Arkansas, Tennessee, Mississippi, Alabama, and Georgia (Harris, 1896), and in the lower part of the Clayton Formation (Pine Barren Member) of Alabama (Toulmin, 1977). The occurrence data for *Ledina smirna* and *Gryphaeostrea pulaskensis* suggest a middle to lower Paleocene placement for the 1,543-1,699 ft interval of the core.

The lower part of the Clayton Formation contains reworked Late Cretaceous mollusks in many areas of Mississippi, Tennessee, and Missouri (Stephenson, 1955; Sohl, 1960). However, these were not identified among the fossils from the Clayton in test well 1-X.

Dinflagellate taxa in core samples from 1,417 to 1,698.5 ft are listed in Table 7. Dinoflagellates from 1,417 ft are poorly preserved, and most specimens are reworked Cretaceous forms. For example, the specimens of *Chatangiella* have omegaform periarcheopyles and 3I endarcheopyles; such forms are known only from the Campanian to Santonian (except in the Arctic) according to Lentin and Williams (1976). The genus *Dinogymnium* ranges from Maestrichtian to Coniacian. Some of the other forms, such as *Deflandrea* cf. *D. pannucea* and the small peridinioid forms, may possibly be indigenous to the Porters Creek Clay: the ranges of these forms are poorly known, but the specimens did not stain as darkly as those of the obviously reworked species. The core samples from 1,433-1,435 and 1,482 ft contain only a few dinoflagellates, mainly small peridinioid forms. The samples from 1,544 and 1,591 ft are very similar to each other in their dinoflagellate

Table 5. Ostracodes in lower Paleocene core samples from New Madrid test well 1-X. Depth in ft.

	Porters Creek Clay		**Clayton Formation**	
	1,670.5	**1,686.5**	**1,697.3**	**1,699**
Eucythere midwayensis Alexander, 1934	X			
Hermanites midwayensis (Alexander, 1934)	X			
Krithe perattica Alexander, 1934	X			
Opimocythere interrasilis (Alexander, 1934)	X			
Paracypris parapiculata (Alexander, 1934)	X			
Phacorhabdotus formosus (Alexander, 1934)	X			
Acanthocythereis washingtonensis Hazel, 1968	X		X	
Bairdia sp.	X		X	
Hazelina n. sp. A (=*Repandocosta* sp. A of Hazel, 1967)	X	X	X	
Brachycythere plena Alexander, 1934	X	X	X	X
Cytherella tumidosa Alexander, 1934	X	X	X	X
Acanthocythereis sp.		X		
"Cythereis" cancellosa Alexander, 1934		X		
Cytherelloidea sullivani Smith, 1978		X		
Haplocytheridea fornicata (Alexander, 1934)		X		
Loxoconcha cf. *L. perdecora* Alexander, 1934		X		
Phacorhabdotus sculptilis Alexander, 1934		X		
Xestoleberis truncata Alexander, 1934		X		
Hermanites gibsoni Hazel, 1968		X	X	
Clithrocytheridea sp.			X	
Cytherelloidea truncata Schmidt, 1948			X	
Haplocytheridea macrolaccus munseyi (Hazel, 1968)			X	
Hermanites cf. *H. hadropleura* Hazel, 1968			X	
Opimocythere hazeli Smith, 1978			X	
Phractocytheridea ruginosa (Alexander, 1934)			X	
Bairdia suborbiculata Alexander, 1934			X	X
Hermanites aff. *H. plusculmensis* (Schmidt, 1948)				X

floras, and the specimens are reasonably well preserved. This flora is Paleocene in age, but the species present either have long ranges, or else they are new species whose ranges are not yet known in detail. In contrast, the dinoflagellate assemblages from 1,646 ft (Porters Creek) and 1,698.5 ft (Clayton) can be assigned an early Paleocene age; very similar floras are found in the Brightseat Formation of Maryland and in the Clayton Formation of Alabama and Georgia (Edwards, 1980, and unpublished data).

Six core samples were examined for sporomorphs from the Porters Creek Clay, from 1,417 to 1,646 ft (Table 8). One useful core sample was examined from the Clayton Formation at 1,698.5 ft; the Clayton core sample from 1,702 ft was barren of palynomorphs. The upper half of the Porters Creek Clay in New Madrid well 1-X has a sporomorph flora that includes several elements not known to range below the Sabinian (below the upper Paleocene) on the Gulf Coast, including *Paraalnipollenites confusus*, *Labrapollis globosa*, and *Milfordia incerta*. However, all the species found in the lower part of the Porters Creek of the test hole have been found in the Clayton of the Gulf Coast except *Margocolporites cribellatus*. Of taxa found only or perhaps only in the Clayton in the New Madrid well, *Interpollis paleocenica* ranges throughout the Paleocene in the Gulf Coast, and *Momipites fragilis* may be reworked from the Cretaceous in samples from both the Gulf Coast and the New Madrid hole. Previous studies of the middle and lower Midwayan of the Gulf Coast and South Carolina also showed that the sporomorph taxa particularly of early Porters Creek age are very similar to those of Clayton age

Table 6. Foraminifers in lower Paleocene core samples from New Madrid test well 1-X. Depth in ft.

	Porters Creek Clay		Clayton Formation	
	1,670.5	1,686.5	1,697.3	1,699
Clavulinoides midwayensis Cushman, 1936	X			
Discorbis sp.	X			
Ellipsonodosaria plummerae Cushman, 1940	X			
Globorotalia compressa (Plummer, 1927)	X			
Pseudoparella cf. *P. exigua* (Brady, 1884)	X			
Anomalina midwayensis (Plummer, 1927)	X	X		
Vaginulina gracilis Plummer, 1927	X	X		
Robulus cf. *R. rosettus* (Gumbel, 1870)	X	X	X	
Dentalina colei Cushman & Dusenbury, 1934	X	X	X	X
Valvulinaria sp.	X	X	X	X
Cibicides alleni (Plummer, 1927)		X		
Cibicides praecursorius (Schwager, 1883)		X		
Cibicides sp. A		X		
Cibicides sp. B		X		
Ellipsonodosaria sp.		X		
Eponides sp.		X		
Gyroidina subangulata (Plummer, 1927)		X		
Marginulina cf. *M. glabra* d'Orbigny, 1826		X		
Nodosaria affinis Reuss, 1874		X		
Pseudoglandulina pygmaea (Reuss, 1851)		X		
Pullenia quinqueloba (Reuss, 1851)		X		
Globulina gibba d'Orbigny, 1846		X	X	
Cibicides cf. *C. neelyi* Jennings, 1936		X	X	X
Guttulina problema d'Orbigny, 1846		X	X	X
Robulus midwayensis (Plummer, 1927)		X	X	X
Cibicides howelli Toulmin, 1941			X	
Vaginulina longiforma (Plummer, 1927)			X	
Virgulina cf. *V. naheolensis* Cushman, 1944			X	
Globulina rotundata (Bornemann, 1855)				X
Guttulina sp.				X

(Herrick and Tschudy, 1967; Tschudy, 1973b, 1975; Frederiksen, 1980b, c).

To summarize the lower Paleocene core samples (fig. 3), sporomorphs suggest that in New Madrid well 1-X, the upper part of the Porters Creek Clay correlates with the upper part of the Porters Creek and possibly also in part with the overlying upper Midwayan Naheola Formation of the eastern Gulf Coast. Data from many kinds of fossils agree that the lowermost part of the Porters Creek in the test well probably correlates with the upper part of the Clayton Formation of the eastern Gulf Coast and with the Kincaid Formation of Texas. The entire thin Clayton of the test well probably correlates with the lower part of the thick Clayton of the eastern Gulf Coast.

Upper Cretaceous

Nine core samples from 1,770 to 1,901.5 ft in test well 1-X were examined for palynomorphs (fig. 4). Sporomorphs recovered from these samples were compared with those illustrated by Wolfe (1976) from the Upper Cretaceous of the Raritan and Salisbury embayments in the Middle Atlantic States (dashed range lines in fig. 4); the age assigned to the New Madrid samples is based on the range chart presented by Wolfe. All nine samples have a similar palynological composition. Spores and pollen are generally abundant and well pre-

TAXA	1,770.0	1,777.5	1,789.0	1,798.7	1,815.0	1,835.0	1,852.5	1,898.3	1,901.5
Pseudoplicapollis serena Tschudy, 1975 (NC-3)								X	
Proteacidites sp. A (PR-1)	X		X		X		X		
Holkopollenites? sp. C (CP3E-1)		X			X	X	X		X
Choanopollenites consanguineus Tschudy, 1973					X				
Osculapollis aequalis Tschudy, 1975 (NO-1)	X						X		X
Choanopollenites sp. E (NA-7)	X	X		X	X				X
Bohemiapollis? sp. B (NI-2)		X							
aff. *Plicapollis* sp. A (NN-1)	X	X			X		X		X
Proteacidites sp. G (PR-7)			X			X	X		X
Choanopollenites cf. C. transitus Tschudy, 1973 (NA-2)		X							
Triporate type A (NU-1)								X	X
"*Retitricolpites*" sp. I (C3B-4)	X								
Momipites sp. A (NP-1)	X					X	X	X	
Casuarinidites sp. A (NO-2)	X	X			X	X	X	X	X
Semioculopollis sp. A of Tschudy (1975)									X
Holkopollenites cf. *H. chemardensis* Fairchild in Stover et al., 1966 (CP3D-3)	X	X	X	X	X	X	X	X	X
Interpollis cf. *I. supplingensis* (Pflug in Thomson & Pflug, 1953) Krutzsch, 1960			X				X	X	
Baculostephanocolpites sp. A (MPH-1)			X			X	X		
Plicapollis usitatus Tschudy, 1975 (NE-3)	X	X	X	X	X	X	X	X	X
Choanopollenites sp. A (NA-3)					X	X	X	X	X
Triatriopollenites sp. B (NP-2)	X		X		X	X	X		X
"*Retitricolpites*" sp. H (C3B-3)						X			
Proteacidites sp. D (PR-4)	X		X				X		
Pseudovacuopollis involutus Tschudy, 1975 (NT-1)		X	X	X	X	X			
Choanopollenites cf. *C. conspicuus* (Groot & Groot, 1962) Tschudy, 1973 (NA-8)		X	X				X		
Casuarinidites sp. B (NO-5)								X	
Labrapollis sp. A (NV-1)	X	X		X	X	X	X		X
Brevicolporites sp. B (CP3F-2)					X	X	X		
"*Retitricolpites*" sp. D (C3A-4)		X				X			
Baculostephanocolpites sp. B (MPH-2)			X		X				
Vacuopollis munitus Tschudy, 1975	X	X			X	X	X		X
Extremipollis vivus Tschudy, 1975					X			X	
Betulaceoipollenites sp. A (NO-3)	X	X	X	X	X	X	X		X
Momipites tenuipolus Group (NK-3)								X	
Tricolporites sp. C (CP3A-3)	X								
Proteacidites sp. E (PR-5)									X
Plicatopollis cretacea Frederiksen & Christopher, 1978 (NN-2)	X	X	X	X	X	X	X		X
Tricolporites sp. N (CP3G-1)	X		X	X	X				
aff. *Bombacacidites* sp. A (MPB-1)	X								
Interpollis paleocenica (Elsik, 1968) Frederiksen, 1980						X			

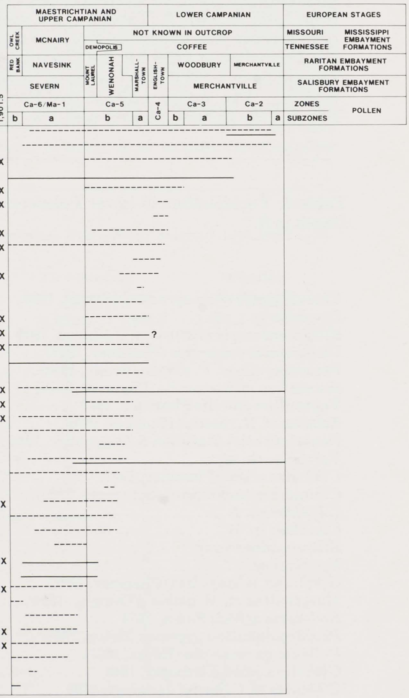

Figure 4. Late Cretaceous sporomorphs from samples between 1,770 and 1,901.5 ft in New Madrid test well 1-X. The alphanumeric code in parentheses following each binomen is Wolfe's (1976) species designation. Dashed range lines are from Wolfe's (1976) range chart; solid range lines are from Tschudy (1973b, 1975).

Table 7. Dinoflagellates and acritarchs in lower Paleocene core samples from New Madrid test well 1-X. Depth in ft.

	Porters Creek Clay				Clayton Formation
	1,417	1,544	1,591	1,646	1,698.5
**Chatangiella* spp.	X				
Deflandrea cf. *D. pannucea* Stanley, 1965	X				
**Dinogymnium* sp.	X				
Hystrichosphaeridium tubiferum? (Ehrenberg, 1838) Deflandre, 1937	X				
**Isabelidinium acuminata*? (Cookson & Eisenack, 1958) Stover & Evitt, 1978	X				
Spongodinium delitiense	X				
**Spinidinium vestitum*? Brideaux, 1971	X				
Fibrocysta bipolare (Cookson & Eisenack, 1965) Stover & Evitt, 1978	X		X		
Small peridinioid forms	X	X	X		X
Achomosphaera sp.		X	X		
Apectodinium cf. *A. homomorphum* (Deflandre & Cookson, 1955) Lentin & Williams, 1977		X	X		
Cordosphaeridinium gracile (Eisenack, 1954) Davey & Williams, 1966		X	X	X	
Deflandrea cf. *D. darmooria* Cookson & Eisenack, 1965		X		X	
Spiniferites ramosus granomembranaceous (Davey & Williams, 1966) Lentin & Williams, 1973		X	X	X	
Cordosphaeridium multispinosum Davey & Williams, 1966	X	X			X
Palaeocystodinium cf. *P. australinum* (Cookson, 1965) Lentin & Williams, 1976		X	X	X	X
Veryhachium hyalodermum (Cookson, 1956) Schaarschmidt, 1963		X	X	X	X
Cordosphaeridinium inodes (Klumpp, 1953) Eisenack, 1963			X		X
Deflandrea obscura Drugg, 1967			X		X
Fibradinium annetorpense Morgenroth, 1968			X	X	X
Andalusiella polymorpha (Malloy, 1972) Lentin & Williams, 1977				X	
Danea californica (Drugg, 1967) Damassa, 1979				X	
Impagidinium sp.				X	
Spiniferites cornutus (Gerlach, 1961) Sarjeant, 1970				X	
Trigonopyxidium ginella (Cookson Eisenack, 1960) Downie & Sarjeant, 1964				X	
Deflandrea cf. *D. diebelii* sensu Drugg, 1967				X	X
Membranosphaera maastrichta Norris & Sarjeant, 1965				X	X
Palaeoperidinium pyrophorum (Ehrenberg, 1838) Sarjeant, 1967				X	X
Palaeotetradinium caudatum Benson, 1976				X	X
Spiniferites septatus (Cookson & Eisenack, 1967) McLean, 1971				X	X
Adnatosphaeridium sp.					X
Deflandrea magnifica Stanley, 1965					X
Fibrocysta sp. A of Edwards, 1980					X
Spinidinium sp.					X
Spiniferites spp.					X
Thalassiphora pelagica (Eisenack, 1954) Eisenack & Gocht, 1960					X

* = Cretaceous taxa.

served. Each sample contains assemblages of two apparent ages (fig. 4). One assemblage consists of species indicative of a Maestrichtian to latest Campanian Age; the other assemblage consists of species indicative of an early late or early Campanian Age.

Two hypotheses that can be advanced to explain assemblages of two different ages in each sample are:

1. The ranges of the species in the Mississippi Embayment differ from those in the Middle Atlantic States, and
2. Lower upper or upper lower Campanian deposits have been reworked into deposits of Maestrichtian to latest Campanian Age.

We accept the second hypothesis as the best explanation because several forms were observed in the samples that according to Tschudy (1973b, 1975) and others have concurrent ranges only in Maestrichtian to uppermost Campanian deposits in the Mississippi Embayment (*Vacuopollis munitus*, *Semioculopollis* sp. A, *Choanopollenites consanguineus*, *Extremipollis vivus*, *Interpollis* cf. *I. supplingensis*, *Interpollis paleocenica;* solid range lines in fig. 4). Also included in these assemblages are a wide variety of triatriate forms of *Momipites* and *Plicatopollis* that are typically associated with deposits of early Tertiary or latest Cretaceous age. Reworking of Late Cretaceous fossils continued for millions of years in southeastern Missouri; Maestrichtian and Campanian palynomorphs are found throughout the lower Tertiary formations of the New Madrid wells, and Maestrichtian to late Campanian calcareous nannofossils are found in the Clayton.

The Cretaceous pollen zonation for the Gulf and Atlantic Coastal Plains was originally established on the basis of stratigraphic sections in the Middle Atlantic States, and it has not been ascertained to what extent this zonation can be applied to the Mississippi Embayment. However, figure 4 shows that if we assume reworking, all nine samples appear to fall into pollen zone CA-6/MA-1 of Wolfe (1976). A vertical line in figure 4 suggests the oldest possible age of the samples, based on assumed reworking. The entire interval between 1,770 and 1,901.5 ft in the New Madrid core would, therefore, correlate with the Navesink Formation and Red Bank Sand of New Jersey and with the Severn Formation of Maryland. These East Coast units are considered early Maestrichtian in age on the basis of dinoflagellates (Benson, 1976; Whitney, 1976; May, 1980a, b) or early Maestrichtian to late Campanian on the basis of mollusks (Sohl and Mello, 1970).

Dinoflagellates and acritarchs, which are generally indicators of brackish-water to marine environments of deposition, are rare in all nine core samples examined for palynomorphs from 1,770 to 1,901.5 ft. Of twelve core samples from this interval examined for calcareous nannofossils, all but one are barren. The sample from 1,835 ft contains *Cruciplacolithus tenuis*, *Ericsonia subpertusa*, *Markalius inversus*, *Thoracosphaera* spp., and *Zygodiscus sigmoides*, which are probably from Paleocene Zone NP2. However, this sample contains sporo-

Table 8. Sporomorphs in lower Paleocene core samples from New Madrid test well 1-X. Depth in ft.

	Porters Creek Clay						Clayton Formation
	1,417	1,433-1,435	1,482	1,544	1,591	1,646	1,698.5
Momipites dilatus Fairchild *in* Stover *et al.*, 1966	X						
Momipites flexus Frederiksen, 1979	X	X					
Paraalnipollenites confusus (Zaklinskaya, 1963) Hills & Wallace, 1969	X		X				
Trudopollis plena Tschudy, 1975	X	X	X				
Bombacacidites reticulatus Krutzsch, 1961	X			X			

	Porters Creek Clay						Clayton Formation
	1,417	1,433-1,435	1,482	1,544	1,591	1,646	1,698.5
Margocolporites cribellatus Srivastava, 1972	X			X	X	X	
Pseudoplicapollis limitata Frederiksen, 1978	?	X	X	X	X	X	
Ulmipollenites krempii (Anderson, 1960) Frederiksen, 1979	X		X	X		X	
Betula infrequens Stanley, 1965	X	X		X	X	X	X
Choanopollenites alabamicus (Srivastava, 1972) Frederiksen, 1979	?	X	X	X	X	X	?
Choanopollenites aff. *C. consanguineus* Tschudy, 1973	X					X	X
Classopollis spp.	X	X	X	X	X	X	X
Momipites microfoveolatus (Stanley, 1965) Nichols, 1973	X		X	X	X	X	X
Momipites tenuipolus group	X		X	X	X	X	X
Pseudoplicapollis serena Tschudy, 1975	X	X	X	X			X
Tricolpites asper Frederiksen, 1978	X		X	?			?
Momipites strictus Frederiksen & Christopher, 1978		X	X	?			
Momipites coryloides Wodehouse, 1933		X	X	X		X	?
Aesculiidites circumstriatus (Fairchild *in* Stover *et al.*, 1966) Elsik, 1968			?				
Labrapollis globosa (Pflug *in* Thomson & Pflug, 1953) Krutzsch, 1968			X				
Choanopollenites conspicuus (Groot & Groot, 1962) Tschudy, 1973			X	X	X	X	
Favitricolporites baculoferus (Pflug *in* Thomson & Pflug, 1953) Srivastava, 1972			X	X	X		X
Chenopodipollis spp.				X			
Milfordia incerta (Pflug & Thomson *in* Thomson & Pflug, 1953) Krutzsch, 1961				X			
Nudopollis thiergartii (Thomson & Pflug, 1953) Pflug, 1953				X			
Osculapollis? colporatus Frederiksen, 1980				X			
Choanopollenites discipulus Tschudy, 1973				X	X	X	
Interporopollenites turgidus Tschudy, 1975				X	X	X	
Nudopollis terminalis (Pflug & Thomson *in* Thomson & Pflug, 1953) Pflug, 1953				X	X	X	
Ephedra voluta type				X	X		X
Holkopollenites chemardensis Fairchild *in* Stover *et al.*, 1966				X	?	?	X
Momipites fragilis Frederiksen & Christopher, 1978						?	X
Interpollis paleocenica (Elsik, 1968) Frederiksen, 1980							X

morph assemblages of Maestrichtian to latest Campanian(?) and of Campanian Ages and has no sporomorphs restricted to the Tertiary. The sample was a medium-dark-gray, carbonaceous, very micaceous mudstone. We conclude that the nannofossils in the sample from 1,835 ft are probably from drilling mud infiltration.

Lithologically, the Upper Cretaceous strata recovered from New Madrid well 1-X are fine to coarse quartzose sand and subordinate micaceous, carbonaceous clay, and the whole recovered sequence is assignable to the McNairy Sand. In southwestern Tennessee and northern Mississippi, the Ripley Formation can be divided into members, and the McNairy Sand Member is in the upper part of the Ripley (figure 3; Sohl, 1960). However, to the north, in Missouri, Kentucky, and Illinois, strata of Ripley age are all nonmarine to nearshore marine sand and clay, similar to the McNairy Sand Member of the Ripley Formation to the south, and at the northern end of the Mississippi Embayment all strata of Ripley age are termed McNairy Sand.

No paleontological evidence was found that the Owl Creek Formation is present in New Madrid well 1-X. The Owl Creek forms the top of the Cretaceous section in much of the northern Mississippi Embayment (Sohl, 1960) and is probably middle to early Maestrichtian in age (Sohl and Mello, 1970); it overlies the Ripley Formation or the McNairy Sand as far north as Crowleys Ridge in Scott and Stoddard Counties, Mo., 50 miles to the northwest of the New Madrid test wells (Stephenson, 1955). In contrast to the McNairy, the Owl Creek is shelly and distinctly glauconitic; on Crowleys Ridge, the Owl Creek is as much as 11 ft thick, and it is thought to be as thick as 100 ft in the subsurface of southeastern Missouri (Grohskopf and Howe, 1961). The base of the Clayton Formation in New Madrid well 1-X is at 1,704.5 ft according to fossils in the core and footages marked on the core box; the base of the Clayton is at 1,703 ft on the basis of the geophysical logs (Crone and Russ, 1979, Appendix 2). The logs indicate that, if present, the Owl Creek Formation is mainly silt or clay and is perhaps only 3 ft thick in the New Madrid well (Crone, 1981). Unfortunately, no cores were recovered from 1,704.5 to 1,769 ft; thus, we have no reliable samples from the Owl Creek interval.

Marine to nonmarine strata of pre-McNairy, Campanian Age and more than 100 ft thick are reported in the subsurface of southeastern Missouri by Grohskopf and Howe (1961), but these strata were not identified in New Madrid well 1-X. However, no cores were recovered from the sand section between 1,902.5 ft and the top of the Paleozoic dolostone at 2,023 ft. Marine Campanian rocks must have been exposed updip from this area at least until late Eocene time because, as noted previously, reworked marine and terrestrial Campanian fossils are found in upper Eocene to Maestrichtian rocks of test wells 1 and 1-X.

In summary, all of the Cretaceous rocks recovered in New Madrid well 1-X are late Cretaceous, Maestrichtian and possibly latest Campanian, in age and are assignable to the McNairy Sand; the Owl Creek Formation overlying the McNairy, and Campanian rocks underlying the McNairy, may be present in this area but were not recovered by coring.

Lower Paleozoic

Nine samples of the lower Paleozoic dolostone in test well 1-X were examined for conodonts and vertebrate remains. These samples included one core, from 2,027-2,028 ft, and cuttings from various intervals between 2,045 and 2,305 ft. The cored segment is a medium- to coarse-grained, medium gray dolostone. It is chiefly a dolomitized grainstone and contains white sparry patches and stripes that probably represent originally shelly material. These "ghosts" are now dolomite and not identifiable. Each sample processed for conodonts and vertebrate remains weighed between 0.75 and 3.8 kg, and a total mass of 22.05 kg was processed.

The only identifiable fossil recovered was one pyritized fragment from 2,045-2,050 ft. This fragment is probably a scale-bearing piece of *Anatolepis* Bockelie and Fortey 1976, a genus that includes the oldest known fish (see Repetski, 1978). Unfortunately, the known range of this genus is rather long, from early Middle Ordovician to Late Cambrian, which spans the age range of dolostones in this part of the midcontinent

(Grohskopf, 1955). However, previous experience in processing relatively large samples of midcontinent Ordovician and Cambrian rocks for conodonts has shown that Cambrian rocks commonly are barren of these fossils, whereas Ordovician samples of this size normally contain them. Therefore, the lack of conodonts from all Paleozoic samples processed from the New Madrid test well suggests that the Paleozoic bedrock is Cambrian. A Cambrian age here is also wholly in accord with Grohskopf's (1955, Pl. III) geologic map of pre-Cretaceous strata in this region and with the reported presence of Late Cambrian fossils in a well in Lake County, Tennessee, only about 8.5 miles southeast of the site of test well 1-X (J. Bridge, in Grohskopf, 1955, p. 127). The fossils from the Lake County well may be slightly older, but they are from below the highest Paleozoic strata there, and that well is located nearer the axis of the Pascola Arch.

IV. CRETACEOUS-TERTIARY PALEOECOLOGY AND GEOLOGIC HISTORY

Upper Cretaceous strata of the McNairy Formation (Maestrichtian and possibly upper Campanian) recovered from New Madrid well 1-X probably formed in nonmarine to nearshore marine environments. They contain only rare (reworked?) dinoflagellates, and they apparently lack calcareous fossils. However, at least trace amounts of glauconite are found throughout the Upper Cretaceous strata of the test well, and, especially in the lower part of the section, glauconite is common in some samples (see Crone, 1981). Therefore, at least some of the Upper Cretaceous beds must be marine. As noted in the section on biostratigraphy, no strata were recovered from New Madrid well 1-X that could be assigned to the marine Owl Creek Formation, the youngest Cretaceous formation (middle Maestrichtian) of the northern Mississippi Embayment.

The Clayton of New Madrid well 1-X is a glauconitic shelly marl grading upward into a glauconitic shelly sand. Mollusks, foraminifers, and ostracodes are abundant particularly in the marl (Table 4), but apparent taxon diversities of the calcareous fossils may be influenced as much by preservation and difficulties of recovering specimens from the indurated beds of the cored Clayton as they are by actual faunal diversities in the formation. For example, only three species of mollusks were recovered from the Clayton in New Madrid well 1-X; however, many species of bivalves and gastropods have been collected in southeastern Missouri from the outcropping Clayton (Matthes, 1933; Farrar, 1935), which represents a beach deposit according to Shourd and Winter (1980). The subsurface Clayton, closer to the axis of the embayment, undoubtedly formed in deeper water than the part of the formation in present outcrops. Assemblages of calcareous nannofossils, dinoflagellates, foraminifers, mollusks, and ostracodes in the Clayton of New Madrid well 1-X suggest normal marine conditions of deposition in perhaps relatively shallow water, but they are not definitive as to water depth.

The lower part of the Porters Creek Clay represents a widespread transgression of the early Paleocene sea (Stearns, 1957). In the northern part of the Mississippi Embayment, the Porters Creek is a massive silty clay that locally becomes sandy in its upper part; in addition, fossils are more common near the base than near the top (Caplan, 1954; Stearns, 1957; Koenig, 1961; Moore and Brown, 1969). The decrease in fossil abundance and diversity from the base of the formation upward is obvious from the sample analyses presented in Table 4. Shelly glauconitic sand and clay of the upper part of the Clayton grades, rather abruptly, upward into glauconitic silty clay of the Porters Creek; the fossil content of the Porters Creek decreases markedly upward as the silt and glauconite content decreases. Upward decreases in species diversities of dinoflagellates (Table 7) and foraminifers (Table 6) are particularly noticeable. Fossil assemblages indicate a normal marine environment of deposition, no doubt with shoaling water as Porters Creek time progressed, represented by the core samples as high as 1,670.5 ft and probably as high as 1,544 ft, but the dinoflagellate assemblages from the samples at 1,544 and 1,417 ft (Table 7) and the lack of calcareous nannoplankton from samples above 1,544 ft suggest that the upper part of the Porters Creek Clay was probably deposited in brackish water. The absence or rarity of planktic foraminifers in all Porters Creek samples from the New Madrid well may reflect the distance of this area of deposition from the open Gulf, may indicate that the Porters Creek sea was too shallow to support depth-stratified planktic foraminifers, or may result from syndepositional or postdepositional leaching.

Fewer than half a dozen dinoflagellate species were found in the cuttings from 1,377 to 1,339 ft (Table 2), the silty interval probably of late Midwayan Age representing the uppermost part of the Porters Creek Clay or the Old Breastworks Formation. Futhermore, small peridinioid dinoflagellates and freshwater algae belonging to *Pediastrum* are present throughout this interval, also suggesting brackish water deposition or at least a nearby source of fresh water.

The history suggested by the New Madrid samples, of a transgression in Clayton-early Porters Creek time, followed by a regression that lasted until the end of Porters Creek and possibly until the end of Old Breastworks time, agrees well with the paleogeographic maps and interpretations of Stearns (1957). He shows the sea becoming progressively narrower during deposition of the Porters Creek Clay until, at the end of Porters Creek time, it occupied a long narrow bay that covered southeastern Missouri, northeastern Arkansas, western Tennessee, and southwestern Kentucky and had only a very restricted connection with the Gulf of Mexico.

The top of the Porters Creek Clay in outcrop is a surface of considerable relief that formed by subaerial erosion during Paleocene time in southeastern Missouri (Farrar, 1935), western Tennessee (Parks, 1975), and southernmost Illinois (Willman and Frye, 1975). The unconformity is generally considered to divide the Midway and Wilcox Groups. However, in the outcrop belt of western Tennessee, some strata immediately overlying the unconformity were tentatively assigned to the "Betheden" and "Fearn Springs Formations" by Parks (1975); MacNeil (1951) considered both these units to be correlative with the uppermost part of the Midwayan Naheola Formation of the eastern Gulf Coast. Thus, the unconformity may be within the Midway Group. This unconformity has not been recognized in the subsurface of the northern Mississippi Embayment (Stearns, 1957) but may exist there even though it is not obvious from lithology or fossils. Depending on the age of the strata immediately overlying the unconformity in outcrop, the unconformity, if present in the subsurface, may be at the top or at the base of the interval from 1,377 to 1,339 ft in New Madrid well 1-X; this interval is probably late Midwayan in age and is tentatively assigned to the Old Breastworks Formation.

The absence of calcareous fossils and definitely indigenous dinoflagellates in samples from the Fort Pillow Sand (upper Paleocene) upward to the Jackson Formation (upper Eocene) suggests that this whole sequence was deposited in nonmarine environments. Little has been published about the location of the Sabinian (late Paleocene to early Eocene) shoreline; however, the Sabinian Stage, corresponding to all or part of the Wilcox Group, is well known as a mainly nonmarine unit over much of the Mississippi Embayment.

Stearns (1957) considered his "1,400-foot sand" (Fort Pillow Sand of Moore and Brown, 1969, and of this paper) to be a marine sand deposited during a transgression that covered the northern Mississippi Embayment including southeastern Missouri. No marine fossils were found within this interval in New Madrid well 1-X. However, in the Fort Pillow well in west-central Tennessee (Moore and Brown, 1969), some glauconite was found in scattered samples from the Old Breastworks Formation, Fort Pillow Sand, and Flour Island Formation. Trace amounts of silt-sized, bleached, pale-green glauconite were found in samples from the Wilcox Group in the New Madrid well, but the characteristics of the grains suggest that they are detrital rather than primary glauconite (Crone, 1981).

Stearns (1957) considered the contact between the Wilcox Group and his "500-foot sand" (contact between the Flour Island Formation and the Memphis Sand of Moore and Brown, 1969, and of this paper) to represent a major unconformity. The Memphis Sand probably correlates with the Gulf Coast sequence from the lower part to the middle part of the middle Eocene (Moore and Brown, 1969). Unfortunately, the cuttings from the Memphis Sand were too poor to enable a determination based on sporomorphs as to whether or not the lowest part of the middle Eocene (equivalent of the Tallahatta Formation of the eastern Gulf Coast) is represented in the New Madrid well; in short, we cannot determine biostratigraphically the extent of a possible unconformity between the Sabinian and the Claibornian in the New Madrid well. However, a distinct unconformity is present at this boundary in the eastern Gulf Coast (Huddlestun, Marsalis, and Pickering, 1974; Bybell, unpublished data) and in the outcrop belt in the northern Mississippi Embayment (Parks, 1975).

On the basis of dinoflagellates in samples from southwestern Kentucky, it has been suggested that various parts of the middle and upper Eocene in that area were probably deposited in brackish-water to marine environments (R. H. Tschudy *in* Finch and Minard, 1966, Swanson, 1970, Finch, 1971, and Lee, 1974). In contrast, none of the Eocene samples from the New Madrid test wells contains indigenous dinoflagellates. One of us (L.E.E.) also checked for dinoflagellates in four samples from the Jackson Formation (upper Eocene) exposed in the Mississippi River bluffs in the NW ¼ of Oakton 7.5′ quadrangle, Hickman County, Ky. (Lee, 1974), approximately 34 miles northeast of the New Madrid wells (fig. 1). All four samples contain abundant sporomorphs and many specimens of the freshwater alga *Pediastrum*. One of the samples lacks dinoflagellates altogether, two others contain rare, poorly preserved reworked Cretaceous forms, and the fourth sample contains the following assemblage:

Chatangiella spp.
Cyclonephelium sp.
Hystrichosphaeridium sp.
Isabelidinium cooksoniae (Alberti, 1959) Lentin & Williams, 1977
Odontochitina costata Alberti, 1961
Palaeohystrichophora infusorioides Deflandre, 1935
Small peridinioid forms

These specimens, also poorly preserved, are reworked from the Upper Cretaceous and suggest a possible age ranging from Coniacian to Campanian. In summary, the lack of indigenous dinoflagellates in all Eocene samples from the New Madrid test wells and in our upper Eocene outcrop samples from southwestern Kentucky, and the presence of reworked Cretaceous dinoflagellates in many of these samples, suggest that the dinoflagellates reported by Tschudy were reworked specimens and that the entire Eocene section in southeastern Missouri and southwestern Kentucky may have been deposited in nonmarine environments.

The maximum northward extent of the middle Eocene shoreline in the Mississippi Embayment has not been established, but it is well known that this shoreline oscillated widely during several transgressions and regressions (Fisher, 1964). Elsik (1974, Text-fig. 6) suggested that the middle Eocene shoreline extended only as far north as central Arkansas and northern Mississippi. In the northern part of the Mississippi Embayment, marine Jacksonian invertebrate and vertebrate fossils have been reported from southeastern and east-central Arkansas (Palmer, 1939; Wilbert, 1953) and from southwestern Tennessee (H. N. Fisk *in* Wilbert, 1953, p. 103; F. C. Whitmore, Jr., *in* Moore and Brown, 1969). Thus, present evidence suggests that the maximum northward extent of the late Eocene shoreline was in west-central or northwestern Tennessee, just south of the New Madrid wells and of the southwestern Kentucky outcrops.

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