PALYNOMORPH BIOZONES IN THE CONTEXT OF CHANGING PALEOCLIMATE, MIDDLE EOCENE TO LOWER OLIGOCENE OF THE NORTHWEST GULF OF MEXICO

WILLIAM C. ELSIK
The MycoStrat Connection
P.O. Box 549
Snook, Texas 77878-0549
wmcelsik@txcyber.com

THOMAS E. YANCEY
Department of Geology and Geophysics
Texas A & M University
College Station, Texas 77843-3115
tyancey@tamu.edu

Abstract

Cooling paleoclimates over the period ca. 42 Ma to ca. 33 Ma were the driving force for the gradual disappearance of tropical and subtropical elements and the appearance of cooler elements in the palynofloras of east Texas. As a consequence, 11 palynomorph assemblage zones, one range zone and three biohorizons are recognized in 209 samples from 15 sections of the Crockett, Yegua, Caddell, Manning and Catahoula formations. From oldest to youngest, the succession of biozones is: middle Eocene *Nuxpollenites crockettensis* Assemblage Zone, *Bombapollis texensis* Assemblage Zone, *Bursera* Assemblage Zone, *Friedrichipollis claibornensis* Assemblage Zone, and *Reticuloidosporites pseudomurus* Assemblage Zone; late Eocene *Sequoiapollenites* Assemblage Zone, *Rhizophora* FAD, *Rhizophora* Assemblage Zone (which contains an ancestral Mutisieae pollen type in its lower part here designated the *Mutisiapollis* FAD and *Mutisiapollis* Zone), *Nudopollis terminalis* Assemblage Zone, *Nudopollis terminalis* LAD, *Bombacacidites* Assemblage Zone, and *Pseudolaesopollis ventosus* Assemblage Zone; and the early Oligocene *Hypoxylonites* Assemblage Zone. The age of the lower Catahoula Formation is early Oligocene based on the occurrence of *Kallosphaeridium biornatum* from a locality northwest of Huntsville, Texas. A short-term cooling event near the end of the Eocene set the stage for further changes in the early Oligocene. Use of these assemblage zones greatly increases the age resolution available for late middle Eocene to early Oligocene strata of the Gulf Coast.

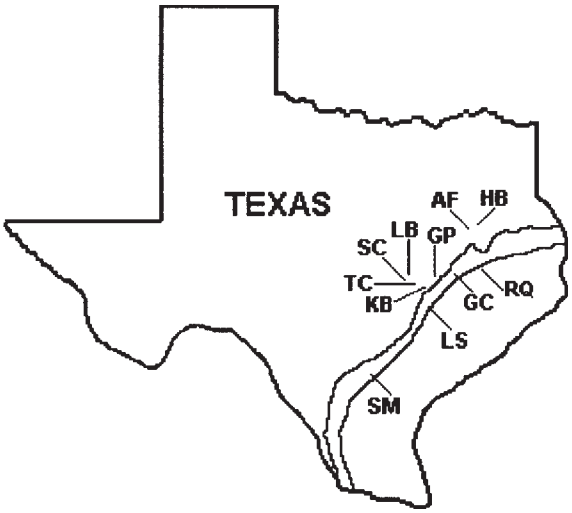
INTRODUCTION

The middle Eocene Claiborne Group and late Eocene Jackson Group of the northwestern Gulf Coast region are best documented from exposures in the Brazos River Valley and adjoining areas of central and east Texas. Exposures of these strata and strata lower in the section have been described in many field trip guidebooks (e.g., Smith, 1956, 1958; Russell, 1960; Berg, 1970; Zingula, 1974, 1984; Kersey and Stanton, 1979; Yancey, 1984) and summarized in regional reports (Fisher et al., 1970; Yancey and Davidoff, 1994). Numerous samples have been taken from this section for the study of palynomorphs: a number of those studies have been published (e.g., Elsik, 1974; Frederiksen, 1981; Ethridge Glass et al., 1987; Jones and Gennett, 1991; Gennett, 1994; Raymond et al., 1997) and some sections have been the subject of palynological theses (e.g., Ethridge, 1976; McMahon, 1997; Sancay, in progress).

Compilation of the occurrence data from these and unpublished studies of the senior author is part of the ongoing structure of the Gulf Coast PalynoDataBank (GCPDB) which covers most of the Cenozoic in the northwest Gulf of Mexico Basin. Sufficient data are now available to provide greater resolution in the interpretation of the paleoclimate for the interval from the late middle Eocene to the early Oligocene (Yancey et al., in press). For that study, 209 samples from 15 sections (Text-Figure 1; Appendix) track a changing paleoclimate that cooled from tropical during the late middle Eocene to marginally subtropical in the early Oligocene, and included a cooling event near the end of the Eocene.

A plot of the occurrence data from those samples reveals that during the interval of ca. 42 Ma to ca. 33 Ma a major portion of the tropical and subtropical indicators disappear from the Gulf Coast and a number of cooler elements appear. The changing character of those palynomorph

Palynology, 24 (2000): 177–186
© 2000 by AASP Foundation
ISSN 0191-6122



Text-Figure 1. Texas, generalized outcrop of the Jackson Group, and sample sites. Legend: SC, Stone City Bluff and core; LB, Little Brazos River; RB, Rocky Branch; HB, Hurricane Bayou; AF, Alabama Ferry; TC, Turkey Creek section; KB, Koppe Bridge section (including Hope Creek); GP, Greens Prairie core; GC, Gibbons Creek mine and core; LS, Lake Somerville outlet, spillway core and spillway section; SM, San Miguel mine; and RQ, Riverside quarries.

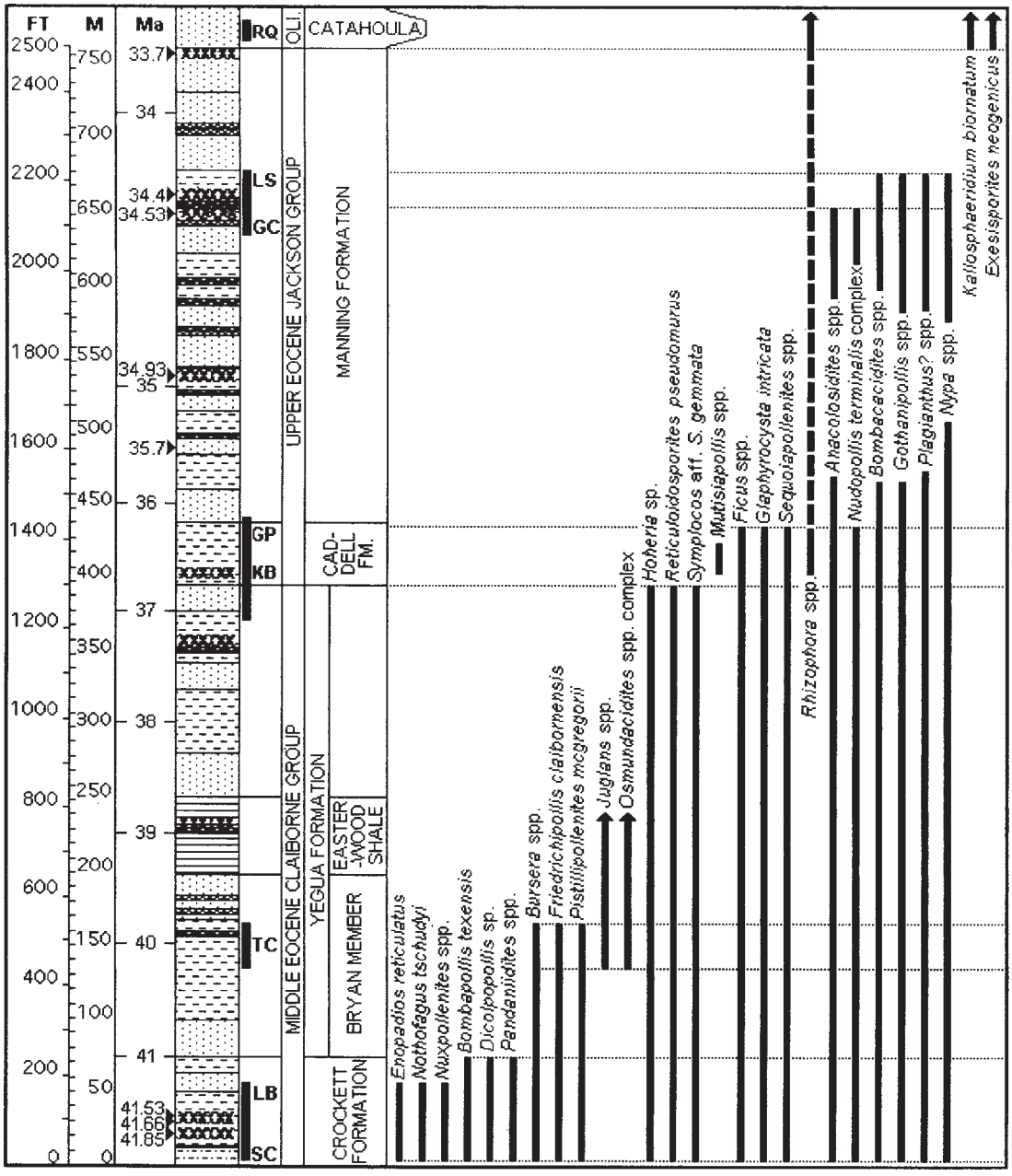
assemblages over time allows the definition of 11 assemblage zones, one range zone, and three biohorizons (Text-Figure 2). Twelve palynomorph zones and three biohorizons over a time span of approximately 9 million years (Text-Figure 3) offers a new potential for correlation of Gulf Coast upper Paleogene strata. These zones and biohorizons add to the late Eocene–early Oligocene Gulf Coast palynostratigraphy developed by Tschudy (1973, 1975), Elsik (1974) and Frederiksen (1980).

Marine Palynomorphs

Much of the Claiborne and the lowermost Jackson strata of east Texas are known to be marine or marginally marine in origin (e.g., Atlee et al., 1967), but most of the Jackson Group strata were assumed to be deltaic or nonmarine because of the presence of many lignite beds and the lack of carbonate in the strata. However, the presence of characteristic marine trace fossil assemblages, common occurrence of tidalite sedimentary structures, and some siliceous marine microfossils (Yancey, 1997) indicate most of the Jackson Group strata are marine in origin. These strata lack the calcareous microfossils historically used in age determination of strata in the Gulf Coast because of dissolution of the calcareous material. The loss of these calcareous fossils/microfossils in the late middle Eocene to early Oligocene of the Brazos River Valley and adjoining areas is mitigated by the occurrence of marine palynomorphs (dinoflagellates and foraminifera linings) in the section (Text-Figure 4). For example, age of the lower Catahoula Formation at the Riverside quarry in Walker County can be

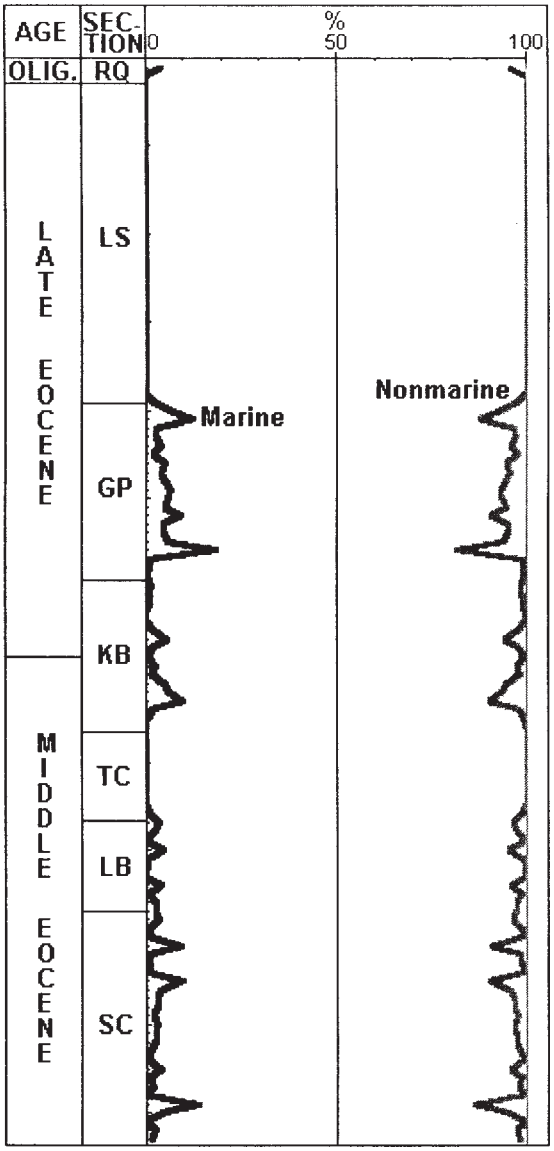
EPOCH	STAGE	GROUP	FORMATION	BIOZONE
OLIGOCENE	RUPELIAN		CATAHOULA	*Hypoxylonites* Assemblage Zone
EOCENE	PRIABONIAN	JACKSON	MANNING	*Pseudolaesopollis ventosus* Assemblage Zone
				Bombacacidites Assemblage Zone
				Nudopollis terminalis LAD
				Nudopollis terminalis Assemblage Zone
			CADDELL	*Rhizophora* Assemblage Zone
				Mutisiapollis Zone — *M.* and *R.* FADs
				Sequoiapollenites Assemblage Zone
	BARTONIAN	CLAIBORNE	YEGUA	*Reticuloidosporites pseudomurus* Assemblage Zone
				Friedrichipollis claibornensis Assemblage Zone
				Bursera Assemblage Zone
			CROCKETT	*Bombapollis texensis* Assemblage Zone
				Nuxpollenites crockettensis Assemblage Zone

Text-Figure 2. Palynomorph zones and biohorizons ca. 42 Ma to ca. 33 Ma in the northwestern Gulf of Mexico Basin. Not to scale.



Text-Figure 3. Composite section of the upper middle Eocene, upper Eocene and lower Oligocene and selected palynomorph occurrence ranges (Yancey et al., in press). Solid bars next to the stratigraphic column indicate interval of sampling: SC, Stone City Bluff and core in Burleson County; LB, Little Brazos River in Brazos County, including equivalent section at Rocky Branch in Burleson County, Alabama Ferry in Houston County, and Hurricane Bayou in Houston County; TC, Turkey Creek; KB, Koppe Bridge; GP, Greens Prairie core; GC, Gibbons Creek mine and core; LS, Lake Somerville outlet, spillway core and spillway section; RQ, Riverside quarries. See Appendix for description of localities and sample sets.

determined to be early Oligocene based on the occurrence of the marine dinoflagellate *Kallosphaeridium biornatum*. The potential exists for further refinement of the present biozones with fuller documentation of the common dinoflagellates (e.g., in the Yegua Formation and Caddell Formation at Koppe Bridge) and the portion of the profuse and diverse angiosperm microflora that is currently relegated to 'angiosperm pollen undifferentiated.'



Text-Figure 4. Ratio of marine dinoflagellates and foraminifera linings (M/M+NM) to nonmarine palynomorphs (NM/M+NM) in selected sample sets. Olig. – Oligocene; legend for section abbreviations are in the caption of Text-Figure 3. Not to scale.

Reworked Palynomorphs

A number of the palynomorphs present in parts of the Brazos River Valley section are reworked from older strata, although not in the diversity found by McLean (1968) in the older Paleogene of the eastern Gulf of Mexico. Reworked late Paleozoic *Densosporites* and *Lycospora* occur in strata exposed in the Turkey Creek section, indicating that Carboniferous strata were exposed in central Texas during the late middle Eocene. Reworked Mesozoic, particularly Cretaceous taxa, are present in middle and late Eocene and early Oligocene strata. These include *Aquilapollenites*, *Araucariacites*, *Classopollis*, *Dinogymnium*, *Ephedra voluta* (in part), *Odontochitina* and *Wodehouseia*. The general presence of these taxa indicates widespread exposure of Cretaceous strata across the sediment source area in central and northern Texas. While the presence of *Aquilapollenites* was already known for central Texas (Evitt, 1973), reworked *Aquilapollenites* and *Wodehouseia* together suggest a fuller component of the *Aquilapollenites* province in the sediment source area. The reworked palynomorphs from Paleocene and early Eocene strata include spinose forms of *Selaginella*, *Spinaepollis spinosus*, *Thomsonipollis magnificus* and *Tricolporopollenites baculoferus*. This suggests that early Paleogene Midway Group and Wilcox Group strata were available sources for reworked material, especially during sealevel lowstands. Most of the reworked early Paleogene palynomorphs occur in middle Eocene strata.

Biozonation

The biostratigraphy of the upper Claiborne Group, the Jackson Group, and the lower part of the Catahoula Formation is greatly enhanced by use of the following new biozones and biohorizons. All but one of the zones are assemblage zones based on the association of a few palynomorphs, and named for the most characteristic taxon of each interval. Many of the assemblage zones are in proximity to potential biohorizons consisting of last appearance datums (LADs) and first appearance datums (FADs), but are not defined here with the exception of two FADs and one LAD. The *Rhizophora* FAD is named because it coincides with the base of the *Rhizophora* Assemblage Zone and has the potential for long-distance correlation. The *Mutisiapollis* FAD is defined because it marks the first appearance of Asteraceae pollen in the Gulf Coast and coincides with the *Rhizophora* FAD. The *Nudopollis terminalis* LAD is defined because it appears to be of regional significance. All of the named assemblage zone taxa are potential range zone markers.

LATE MIDDLE EOCENE (BARTONIAN)

Nuxpollenites crockettensis Assemblage Zone

The *Nuxpollenites crockettensis* Assemblage Zone is characterized by the presence of the angiosperm pollen *Enopadios reticulatus*, *Nothofagus tschudyi*, *Nuxpollenites claibornensis* and *Nuxpollenites crockettensis*. *Enopadios reticulatus* and *Nuxpollenites* spp. are good markers of a

restricted stratigraphic interval within the upper middle Claiborne Group (Elsik, 1973, 1974) and the potential of last appearance datums (LADs) exist for those and *Nothofagus tschudyi*. This assemblage is present in the Stone City and Wheelock members of the Crockett Formation. In terms of the paleoclimate, this assemblage lived during the middle Eocene high paleotemperature interval of Andreasson and Schmitz (2000), with much of the palynoflora reflecting paleotropical vegetation, e.g., *Dicolpopollis*, *Bursera*, *Friedrichipollis claibornensis*, *Symplocos* aff. *S. gemmata*, *Ficus*, *Anacolosidites*, and *Nypa* (Text-Figure 3).

Bombapollis texensis Assemblage Zone

The *Bombapollis texensis* Assemblage Zone is based on the presence of *Bombapollis texensis*, *Dicolpopollis* sp., *Pandaniidites* spp., and *Triatriopollenites aroboratus* in the absence of *Enopadios reticulatus*, *Nothofagus tschudyi* and *Nuxpollenites* spp. This assemblage occurs in the uppermost Crockett Formation and possibly in the lower Yegua Formation below the level of the strata exposed at the Turkey Creek locality. The paleoclimate continued to be the driving force in the disappearance of tropical elements from the microflora, consequently *B. texensis*, *Dicolpopollis* sp., *Pandaniidites* spp., and *T. aroboratus* occur to at least the top of this interval but not in the Yegua Formation at Turkey Creek; all have the potential for designation as biohorizons at the top of the *Bombapollis texensis* Assemblage Zone or higher in the section.

Bursera Assemblage Zone

The *Bursera* Assemblage Zone is based on the association of *Bursera* spp., *Friedrichipollis claibornensis* and *Pistillipollenites mcgregorii* below occurrences of *Juglans* spp. and an undescribed *Osmundacidites* spp. complex, and above the last occurrences of *Bombapollis texensis*, *Dicolpopollis* sp., and *Pandaniidites* spp. Cooling paleoclimate is indicated by the first appearances of new taxa above the top of this assemblage zone.

Friedrichipollis claibornensis Assemblage Zone

The *Friedrichipollis claibornensis* Assemblage Zone is characterized by the combined occurrences of *Bursera* spp., *Friedrichipollis claibornensis* and *Pistillipollenites mcgregorii* with the lowermost occurrences of *Juglans* and the undescribed *Osmundacidites* spp. complex. The *Friedrichipollis claibornensis* Assemblage Zone is present within the Yegua Formation strata exposed in the Turkey Creek section. *Bursera*, *Friedrichipollis claibornensis*, and *Pistillipollenites mcgregorii* have not been seen higher than the middle Yegua, signifying the loss of three more tropical elements from the palynofloras and the potential for three more LADs.

Reticuloidosporites pseudomurus Assemblage Zone

The *Reticuloidosporites pseudomurus* Assemblage Zone is characterized by *Hoheria* sp. (a very small *Malvacipollis* type), *Reticuloidosporites pseudomurus*, and *Symplocos* aff. *S. gemmata*. The assemblage zone is above the last occurrences (e.g., potential LADs) of *Bursera* spp., *Friedrichipollis claibornensis*, and *Pistillipollenites mcgregorii*. The *Reticuloidosporites pseudomurus* Assemblage Zone occurs within the upper Yegua Formation in the Koppe Bridge section, but not in the Caddell Formation, suggesting potential LADs for all three of its characteristic species.

LATE EOCENE (PRIABONIAN)

Sequoiapollenites Assemblage Zone

The *Sequoiapollenites* Assemblage Zone is characterized by occurrences of *Sequoiapollenites*, *Ficus* spp., *Glaphyrocysta intricata*, and *Nudopollis terminalis* below the biohorizon *Rhizophora* FAD, and before the appearance of cooler, drier elements of the palynofloras. The assemblage zone is above the last occurrences of *Hoheria* sp., *Reticuloidosporites pseudomurus*, and *Symplocos* aff. *S. gemmata*, and below the *Mutisiapollis* FAD and the *Rhizophora* FAD. The *Sequoiapollenites* Assemblage Zone is seen in a short interval of the basal Caddell Formation exposed within the Koppe Bridge section.

Rhizophora FAD

The *Rhizophora* FAD is a biohorizon that is defined as the first appearance datum of *Rhizophora* in the Gulf Coast. The pollen morphology is distinctive, and matches very closely the pollen of extant plants of the genus. *Rhizophora* appears in the lower Caddell Formation in the Koppe Bridge section, very near the base of the late Eocene. Muller (1981) attributed the oldest *Rhizophora* in the world to the late Eocene of the Caribbean area, citing reports of the form species of *Rhizophora* pollen, *Zonocostites ramonae*,

by Germeraad et al. (1968). It is expected that this datum will be of regional magnitude.

Rhizophora Assemblage Zone

The *Rhizophora* Assemblage Zone is characterized by the sporadic occurrence of the pollen of the subtropical black mangrove, *Rhizophora*. Associated palynomorph taxa in this assemblage zone include *Ficus*, *Sequoiapollenites*, and *Glaphyrocysta intricata*. The *Rhizophora* Assemblage Zone encompasses most of the Caddell Formation. The disappearance of *Ficus* from the section is attributed to the cooling paleoclimate. The appearance of *Rhizophora* was probably due to migration into the area, although an ancestral type, *Pseudolaesopollis ventosus*, was already, and continued to be, present. Modern *Rhizophora* are tropical to subtropical (Watson and Dallwitz, 1992); tolerance of somewhat cooler paleotemperatures would have afforded an advantage over purely tropical mangrove elements.

Mutisiapollis FAD

The first appearance datum of *Mutisiapollis* spp. is in the lower Caddell Formation at the level of the *Rhizophora* FAD, e.g., it is a good biohorizon for the early late Eocene. *Mutisiapollis* is not seen in the late middle Eocene Yegua Formation.

Mutisiapollis Zone

The *Mutisiapollis* Zone is a range zone based on occurrences of *Mutisiapollis* spp.; the zone occurs from the base of the *Rhizophora* Assemblage Zone to about the middle of the Caddell Formation exposed at Koppe Bridge and sampled in the Greens Prairie core. The base of the *Mutisiapollis* Zone is set on the *Mutisiapollis* FAD and the *Rhizophora* FAD.

The undescribed ancestral Mutisieae pollen types that occur sporadically through the lower to middle part of the *Rhizophora* Assemblage Zone are referred to *Mutisiapollis* spp. Both first and last occurrences of the pollen are in the Caddell Formation. The appearance of ancestral Mutisieae pollen in the Caddell follows the appearance of grass pollen (Gramineae) in the uppermost Yegua Formation sample at Koppe Bridge; both are indicative of cooling, drying paleoclimate. The occurrence of this ancestral Mutisieae type is the oldest record of the Asteraceae in the Gulf Coast.

Nudopollis terminalis Assemblage Zone

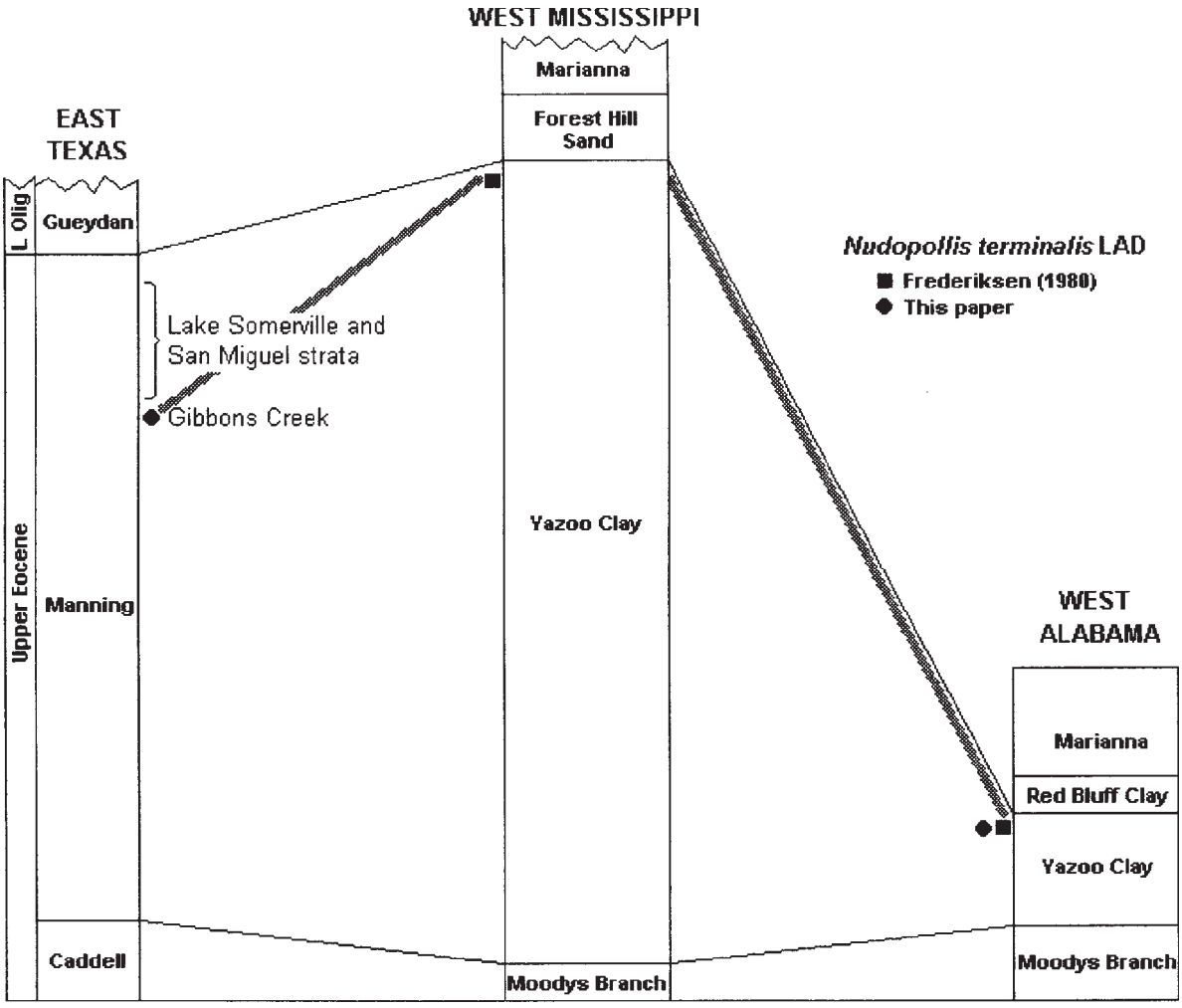
The *Nudopollis terminalis* Assemblage Zone is named for the presence of any of the *Nudopollis terminalis* species complex in combination with *Anacolosidites* spp. and *Gothanipollis* spp. *Ficus*, *Sequoiapollenites*, and *Glaphyrocysta intricata* are absent. *Nudopollis terminalis* does not occur above this assemblage zone, and the potential is also good for LADs amongst the other taxa in the assemblage. The *Nudopollis terminalis* Assemblage Zone is seen in Manning Formation strata at the Gibbons Creek mine.

Nudopollis terminalis LAD

The LAD of *Nudopollis terminalis* appears to be a good biohorizon of regional importance in the upper middle Manning Formation, although it occurs to near the top of the Yazoo Clay in Mississippi and Alabama (Text-Figure 5). Gennett (1996) found *N. terminalis* in the Manning strata exposed in the Gibbons Creek mine, Grimes County. However, *N. terminalis* has not been seen in the Manning at the Lake Somerville section (Elsik, study in progress; Sancay, study in progress), indicating that there is expanded section in the Lake Somerville area. The occurrence range of *N. terminalis* also has a bearing on the age of the San Miguel lignites in south Texas, where *N. terminalis* is absent (Gennett, 1993). The FAD of *N. terminalis* is much lower in the section; good specimens occur in the lignites of the upper Paleocene Calvert Bluff Formation (Elsik, 1968). *Nudopollis terminalis* is one of the last species of the Normapolles Complex to occur in the Gulf Coast region and persists into the late Eocene (Tschudy, 1975).

Bombacacidites Assemblage Zone

The *Bombacacidites* Assemblage Zone is named for the combined occurrences of *Bombacacidites* spp., *Gothanipollis* spp., *Plagianthus?* spp., and *Nypa* spp. above the *Nudopollis terminalis* LAD. Among these are some of the last tropical floral elements present in the section, which then disappear from the Brazos River Valley section, and all have good potential for biohorizons in the uppermost Jackson Group. They are last seen in strata of the Manning Formation in the Lake Somerville section, where there is good evidence for a short-term cooling event near the end of the Eocene (Sancay, in progress; Yancey et al., in press).



Text-Figure 5. Comparison of the LAD of the *Nudopollis terminalis* species complex in Texas, Mississippi and Alabama. Diagram for Texas to approximate scale of section in Mississippi and Alabama (after Frederiksen, 1980); datum drawn on top of middle Eocene.

Pseudolaesopollis ventosus Assemblage Zone

The *Pseudolaesopollis ventosus* Assemblage Zone is characterized by the occurrence of *P. ventosus* and *Rhizophora* spp. Both range below and above the *Pseudolaesopollis ventosus* Assemblage Zone, but they are the characteristic taxa for this interval. In this zone, however, *Bombacacidites* spp., *Gothanipollis* spp., *Plagianthus?* spp., and *Nypa* spp. are absent due to the cooling paleoclimate at the end of the Eocene. This is an interval zone between the late late Eocene *Bombacacidites* Assemblage Zone and the early Oligocene *Hypoxylonites* Assemblage Zone. *Pseudolaesopollis ventosus* occurs throughout the section and is suspected to be an ancestral mangrove, therefore its occurrence in dominantly marine and marginally marine paleoenvironments is expected.

EARLY OLIGOCENE (RUPELIAN)

Hypoxylonites Assemblage Zone

The *Hypoxylonites* Assemblage Zone is named for common occurrences of *Hypoxylonites* spp. in the lower Catahoula Formation. Other palynomorphs characteristic of the *Hypoxylonites* Assemblage Zone include *Quercus* spp., *Rhizophora* spp., *Exesisporites neogenicus*, and *Kallosphaeridium biornatum*. *Exesisporites neogenicus* is not seen below the *Hypoxylonites* Assemblage Zone, suggesting the potential for another FAD in the section. Species of *Hypoxylonites* occur earlier in the Eocene, but are common only from the early Oligocene to Recent (e.g., Elsik, 1969). Spores of this form genus are produced by extant Xylariaceae (Elsik, 1990), fungi

which are ubiquitous wood destroyers in the modern habitat.

ACKNOWLEDGMENTS

We thank J. A. Gennett for sharing her many contributions to the palynology of the late Eocene of Texas. Richard P. Zingula supplied samples from several localities in the Brazos River Valley and adjoining areas. The senior author expresses gratitude to his former employer, Exxon Company, U.S.A., for processing many of the field trip samples. This paper is one of a continuing series of contributions made possible by the Gulf Coast PalynoDataBank at The MycoStrat Connection.

References Cited

ANDREASSON, F.P., and SCHMITZ, B.
2000 Temperature seasonality in the early middle Eocene North Atlantic region: evidence from stable isotope profiles of marine gastropod shells. *Geological Society of America Bulletin*, 112: 628–640.

ATLEE, W.A., LOEP, K.J., ELSIK, W.C., ZINGULA, R.P., POINTER, G.N., and OGDEN, J.C.
1967 *Selected Cretaceous and Tertiary depositional environments*. Gulf Coast Section of the Society of Economic Paleontologists and Mineralogists Field Trip Guidebook, 50 pgs.

BERG, R.R.
1970 *Outcrops of the Claiborne Group in the Brazos Valley, southeast Texas*. Geological Society of America, South-central Section, Field Trip Guidebook, 79 pgs.

ELSIK, W.C.
1968 Palynology of a Paleocene Rockdale lignite, Milam County, Texas. II. Morphology and taxonomy (end). *Pollen et Spores*, 10: 599–664.
1969 Late Neogene palynomorph diagrams, northern Gulf of Mexico. *Gulf Coast Association of Geological Societies Transactions*, 19: 509–528.
1973 Differentiating the middle Eocene Claibornian Stage in the "Wilcox facies" of the southeastern United States. *6th Annual Meeting of The American Association of Stratigraphic Palynologists, Anaheim, Abstracts*; 1975, *Geoscience and Man*, 11: 156.
1974 Characteristic Eocene palynomorphs in the Gulf Coast, U.S.A. *Palaeontographica*, Abteilung B, 149(1–4): 90–111.
1990 *Hypoxylonites* and *Spirotremesporites*, form genera for Eocene to Pleistocene fungal spores bearing a single furrow. *Palaeontographica*, Abteilung B, 216(5–6): 137–169.
1993 Sequential palynostratigraphy of the Queen City and Weches formations (middle Eocene Claiborne Group), southeast central Texas. *26th Annual Meeting of The American Association of Stratigraphic Palynologists, Baton Rouge, Abstracts*, p. 22.

ETHRIDGE, D.L.
1976 *Palynology of the Manning Formation (Jackson Group - upper Eocene) in east and south-central Texas*. Sam Houston State University, Huntsville, unpub. M.S. thesis, 52 pgs.

ETHRIDGE GLASS, D.L., BROWN, D.D., and ELSIK, W.C.
1987 Fungal spores from the upper Eocene Manning Formation, Jackson Group, east and south-central Texas, U.S.A. *Pollen et Spores*, 28(1986): 403–420.

EVITT, W.R.
1973 Maestrichtian *Aquilapollenites* in Texas, Maryland and New Jersey. *Geoscience and Man*, 7: 31–38.

FISHER, W.L., PROCTOR, C.V., JR., GALLOWAY, W.E., and NAGLE, J.S.
1970 Depositional systems in the Jackson Group of Texas — their relationship to oil, gas, and uranium. *Gulf Coast Association of Geological Societies Transactions*, 20: 234–261.

FREDERIKSEN, N.O.
1980 *Sporomorphs from the Jackson Group (upper Eocene) and adjacent strata of Mississippi and western Alabama*. U.S. Geological Survey Professional Paper 1084, 75 pgs.
1981 Middle Eocene to early Oligocene plant communities of the Gulf Coast. *In*: Gray, J., Boucot, A.J., and Berry, W.B.N. (eds.), *Communities of the past*. Hutchinson Ross Publishing Company, Stroudsburg, Pennsylvania, pp. 493–549.

GENNETT, J.A.
1993 *Palynology and paleoecology of the San Miguel lignite deposit of late Eocene age, south Texas*. Texas A & M University, College Station, unpub. Ph.D. dissertation, College Station, 490 pgs.
1994 Palynology of a portion of the upper Manning Formation (late Eocene), Texas. *27th Annual Meeting of The American Association of Stratigraphic Palynologists, Inc., November 1–5, College Station, Texas, Program and Abstracts*, p. 15.
1996 Comparative palynology of clastics and lignites from the Manning Formation, Jackson Group, upper Eocene, Grimes Co., TX. *Gulf Coast Association of Geological Societies Transactions*, 46: 149–158.

GERMERAAD, J.H., HOPPING, C.A., and MULLER, J.
1968 Palynology of Tertiary sediments of tropical areas. *Review of Palaeobotany and Palynology*, 6: 189–348.

JONES, J.G., and GENNETT, J.A.
1991 Pollen and spores from the type section of the middle Eocene Stone City Formation, Burleson County, Texas. *Gulf Coast Association of Geological Societies Transactions*, 41: 348–352.

KERSEY, D.G., and STANTON, R.J.
1979 *Lower Tertiary of the Brazos River Valley*. Houston Geological Society Guidebook, 126 pgs.

McLEAN, D.M.
1968 Reworked palynomorphs in the Paleocene Naheola Formation of southwest Alabama. *Journal of Paleontology*, 42: 1478–1485.
McMAHON, J.M.
1997 *Palynology and paleoecology of the Stone City Member, Crockett Formation, middle Eocene, Burleson Co., Texas*. Texas A & M University, College Station, unpub. M.S. thesis, 244 pgs.
MULLER, J.
1981 Fossil pollen records of extant angiosperms. *The Botanical Review*, 47: 1–142.
RAYMOND, A.R., PHILLIPS, M.K., GENNETT, J.A., and COMET, P.A.
1997 Palynology and paleoecology of lignites from the Manning Formation (Jackson Group) outcrop in the Lake Somerville spillway of east-central Texas. *Coal Geology*, 34: 195–223.
RUSSELL, W.L.
1960 *Jackson Group, Catahoula and Oakville formations and associated structures of northern Grimes County, Texas*. Houston Geological Society and Gulf Coast Section of the Society of Economic Paleontologists and Mineralogists, Guidebook for Annual Field Trip, 50 pgs.
SMITH, F.E.
1956 *Guide book, lower Claiborne field trip, November 3, 1956*. Gulf Coast Association of Geological Societies, 7 pgs.
1958 *Upper and middle Tertiary of Brazos River Valley, Texas*. Gulf Coast Section of the Society of Economic Paleontologists and Mineralogists and Houston Geological Society Guidebook for Annual Field Trip, 41 pgs.
TSCHUDY, R.H.
1973 *Stratigraphic distribution of significant Eocene palynomorphs of the Mississippi Embayment*. U.S. Geological Survey Professional Paper 743B, 24 pgs.
1975 *Normapolles pollen from the Mississippi Embayment*. U.S. Geological Survey Professional Paper 865, 42 pgs.
WATSON, L., and DALLWITZ, M.J.
1992 *The families of flowering plants: descriptions, illustrations, identification, and information retrieval*. 19th August 1999 http://biodiversity.uno.edu/delta.
YANCEY, T.E.
1984 *The Cretaceous–Tertiary boundary and lower Tertiary of the Brazos River Valley*. Field Trip for the Annual Meeting of the American Association of Petroleum Geologists and the Society of Economic Paleontologists and Mineralogists, 137 pgs.
1997 Depositional environments of late Eocene lignite-bearing strata, east-central Texas. *Coal Geology*, 34: 261–275.
YANCEY, T.E., and DAVIDOFF, A.J.
1994 *Paleogene sequence stratigraphy of the Brazos River section, Texas*. Gulf Coast Association of Geological Societies, Fieldtrip Guidebook, 104 pgs.
YANCEY, T.E., and ELSIK, W.C.
1994 Paleoclimatological analysis of upper Eocene core, Manning Formation, Brazos County, Texas. *Gulf Coast Association of Geological Societies Transactions*, 44: 776.
YANCEY, T.E., ELSIK, W.C., and SANCAY, R.H.
in press The palynological record of late Eocene climate change, northwest Gulf of Mexico. *In*: Prothero, D.R., et al. (eds.), *From greenhouse to icehouse: the marine Eocene–Oligocene transition*. Geological Society of America Special Paper.
ZINGULA, R.P.
1974 *Field trip guide for paleontology of Texas seminar*. Continuing Education - University of Houston, and Houston Museum of Natural Science, 6 pgs.
1984 *Geology for non-geologists*. Houston Geological Society, Field Trip Guidebook (revised edition), 10 pgs.

APPENDIX

The 15 datasets from the GCPDB used in this study are centered on documentation of the Brazos River Valley section (Yancey, compilation in progress; Yancey et al., in press). Stratigraphic intervals (Text-Figure 3), number of samples, and sample sites are summarized below:

1. Stone City Bluff - Stone City Member of the Crockett Formation - 19 samples. Type section of the Stone City Member exposed along the southwest bank of the Brazos River in Burleson County.
2. Stone City core - Stone City and Wheelock members of the Crockett Formation - 28 samples (McMahon, 1997). A 26 m core drilled close to the type section of the Stone City Member in Burleson County.
3. Rocky Branch - Wheelock Member of the Crockett Formation - 7 samples. Exposures near Stone City Bluff, Burleson County.
4. Little Brazos River - Wheelock Member of the Crockett Formation - 2 samples. East bank of Little Brazos River upstream from Highway 21 bridge, Brazos County. The samples are above a bentonite bed dated at 41.85 Ma.
5. Alabama Ferry landing - Wheelock Member of the Crockett Formation - 2 samples. Exposures downstream along the banks of the Trinity River, Houston County. The samples are bracketed by bentonite beds dated at 41.66 Ma and 41.53 Ma.
6. Hurricane Bayou - Hurricane Lentil of the Crockett Formation - 3 samples. Exposures in the type locality of the Hurricane Lentil near Crockett, Houston County.
7. Turkey Creek - Bryan Member of the Yegua Formation - 10 samples. Exposures on the west bank of Turkey Creek downstream from Highway 46 crossing west of Bryan and College Station, Brazos County.
8. Koppe Bridge - top of Yegua Formation including the Rock Prairie Member and base of the Caddell Formation - 17 samples. One sample from the bottom of Hopes Creek and 16 samples from exposures along the east bank of the Brazos River south of College Station, Brazos County.
9. Greens Prairie core - upper part of the Caddell Formation - 20 samples. Core drilled beside Greens Prairie Road interchange on Highway 6, south edge of College Station, Brazos County. Preliminary palynology by Yancey and Elsik (1994).
10. Gibbons Creek mine - upper Manning Formation - 56 samples (Gennett, 1996). Exposures and core in the Gibbons Creek lignite mine, east of the Navasota River and south of Carlos, Grimes County. The lowest samples are underlain by a bentonite bed dated at 34.53 Ma.
11. Lake Somerville dam - upper Manning Formation - 4 samples. Exposures on the south bank of the Lake Somerville dam outlet channel, Yegua Creek, Washington County.
12. Lake Somerville core - upper Manning Formation - 46 samples (Sancay, in progress). Core drilled on the south slope of the Lake Somerville spillway channel, Washington County.
13. Lake Somerville spillway - upper Manning Formation - 36 samples (Raymond et al., 1997). Exposures on the south slope of the Lake Somerville spillway channel, Washington County.
14. Riverside new quarry - lower Catahoula Formation - 1 sample. Exposure in quarry near FR 274 north of Huntsville, Walker County.
15. Riverside quarry - lower Catahoula Formation - 2 samples. Exposures in the old Riverside quarry, now Blue Lagoon diving park, north side of Huntsville, Walker County.