

Pollen-spore assemblages of the Navarro Group (Maastrichtian) of Texas, USA: biostratigraphical and palaeoecological significance

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ABSTRACT

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Diverse assemblages of spore-pollen floras are present in all formations in the Navarro Group (Maastrichtian) in outcrops of the Austin Section and the subsurface Frio Section. The stratigraphic ranges and relative abundance of spore, pollen, dinoflagellate cysts and acritarchs were used to establish four biozones (A, B, C and D). Biozone A corresponds to the undifferentiated Neylandville Marl–Nacatoch Sand Formation; Biozone B corresponds to the Corsicana Marl Formation; Biozone C corresponds to the lower half of the Kemp Clay Formation; and Biozone D corresponds to the upper half of the Kemp Clay Formation. Biozonal boundaries do not always correspond to formation boundaries. Biozones A, B, C and D of the Austin section are correlated with the subsurface Frio section. The zonal boundaries based on spore-pollen distribution in the Austin and the Frio sections correlate well with the timelines established in these two sections based on dinoflagellate cysts and acritarchs. All Navarro Group formations except the Olmos were deposited in marine environments ranging from intertidal to outer shelf. Olmos Formation sediments were deposited in a range of coastal terrestrial environments with occasional minor influences of the sea. Three transgressive phases (T1, T2 and T3) separated by four regressive phases (R1, R2, R3 and R4) are recognized. During the Maastrichtian the floral composition in Texas changed from predominantly pteridophytic and bryophytic in the early Maastrichtian to predominantly angiospermous flora in the middle and late Maastrichtian. Tropical to subtropical climates prevailed in Texas throughout the Maastrichtian but highland regions such as Llano Uplift and nearby Marathon and Arbuckle Mountains were cooler regions with a temperate to sub-temperate climate. The upper part of the Navarro Group records a gradual cooling trend suggested by the dominance of temperate angiosperm pollen taxa.

Key-words—Navarro Group of Texas, Gulf Coast of USA, Palynology, Maastrichtian, Gulfian Series.

संयुक्त राज्य अमेरिका टैक्सास में नवेरो समूह (मास्ट्रीच्टियन) की पराग-बीजाणु समुच्चएः जैव स्तरिकीय एवं पुरापारिस्थितिकीय महत्ता

अरुण कुमार

सारांश

ऑस्ट्रिन खंड एवं उपपृष्ठीय क्रायो खंड के दृश्यांश में नवेरो समूह (मास्ट्रीच्टियन) के समस्त शैलसमूहों में बीजाणु-पराग वनस्पति-जातों की विविध समुच्चएं विद्यमान हैं। स्तरिक शृंखलाएं और बीजाणु, पराग, धूर्णीकशाभ पुटियों व एक्रिटार्चों की आपेक्षिक प्रचुरता चार जैवमंडल (क, ख, ग एवं घ) स्थापित करने हेतु प्रयुक्त की गई थीं। (क) जैवमंडल उदासीन नीलेंडविले मार्ल-नकाटॉच बलुइ शैलसमूह के अनुरूप है; (ख) जैवमंडल कॉर्सिकेना मार्ल शैलसमूह के अनुरूप है; (ग) जैवमंडल कॅप क्ले शैलसमूह के अधो अर्ध के अनुरूप है तथा (घ) जैवमंडल कॅप क्ले शैलसमूह के उपरि अर्ध के अनुरूप है। जैवमंडलीय सीमाएं सदैव शैलसमूह सीमाओं के अनुरूप नहीं होतीं। ऑस्ट्रिन खंड के क, ख, ग एवं घ जैवमंडल उपपृष्ठीय क्रायो खंड से सहसंबंधित हैं। इन दो खंडों में स्थापित, धूर्णीकशाभ पुटियों एवं एक्रिटार्चों पर आधारित ऑस्ट्रिन व क्रायो खंडों में बीजाणु-पराग वितरण पर आधारित मंडलीय सीमाएं, समय सीमा के साथ भली-भांति सहसंबंध रखती हैं। ऑल्मोज के अलावा समस्त नवेरो समूह शैलसमूह

अंतःज्वारीय से बाह्य उपतट तक समुद्री पर्यावरणों में निश्चेपित हो गए थे। ऑल्मोज शैलसमूह अवसाद समुद्र के अनियत असर के साथ तटीय स्थलीय पर्यावरणों की पहुंच में निश्चेपित हो गए थे। चार प्रतिक्रामी प्रावस्थाओं (आर1, आर2, आर3, एवं आर4) से वियुक्त तीन अतिक्रामी प्रावस्थाएं (टी1, टी2 व टी3) मान्य की गई हैं। मास्ट्रीचिट्यन के दौरान टैक्सास में पुष्पी संघटन मध्य व विलंबित मास्ट्रीचिट्यन में प्रारंभिक मास्ट्रीचिट्यन से प्राधान्यपूर्वक आवृतबीजीय वनस्पति—जात में प्रबलता से टेरिडोफाइटी और ब्रायोफाइटी में तब्दील हो गया। मास्ट्रीचिट्यन के दौर में टैक्सास में उष्णकटिबंधीय से उपउष्णकटिबंधीय जलवायु व्याप्त थीं परंतु पहाड़ी मैदान अंचल जैसे कि लल्लोनो अपलिफट व नजदीकी मैराथन एवं अर्बुकले पर्वत शीतोष्ण से उप—शीतोष्ण जलवायु के साथ शीतलित्र भू—भाग थे। नवेरो समूह का ऊपरी भाग शीतोष्ण आवृतबीजी पराग टैक्सा की प्रबलता से व्यक्त क्रमिक शीतलन प्रवृत्ति अभिलेख करता है।

सूचक शब्द—टैक्सास का नवेरो समूह, यूएसए का गल्फ तट, परागाणुविज्ञान, मास्ट्रीचिट्यन, गल्फीयन शृंखला।

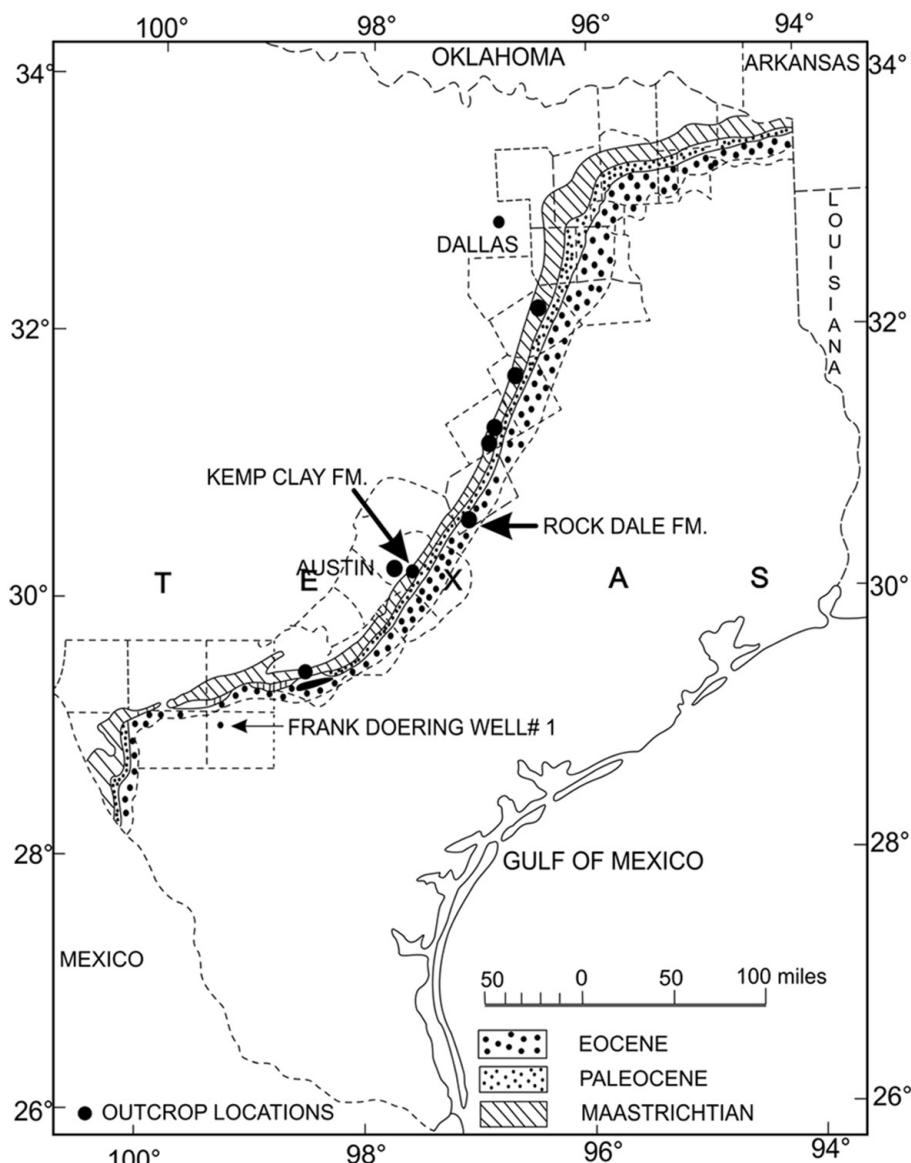


Fig. 1—Map of eastern Texas showing the outcrops of Maastrichtian, Paleocene and Eocene sediments that parallel the present day coast line. It also shows the outcrop locations of various formations of the Navarro Group and of the Frio section of the Navarro Group which is a subsurface section of Frank Doering well #1 in Frio County of southern Texas. The Navarro Group sediments in the well is represented by the Escondido and the Olmos formations (modified after Zaitzeff, 1967).

INTRODUCTION

S RIVASTAVA (1995) published a comprehensive study on the palynology and dinocyst biostratigraphy of the Late Cretaceous (Santonian–Maastrichtian) formations of the Gulf Coastal Plain of Texas, USA in which he stated “*dinocysts dominate the palynomorph assemblages recovered from these formations, and spore–pollen taxa have rare occurrences in these sediments*” (p. 250). This conclusion might be true for Santonian and Campanian sediments, but certainly not for Maastrichtian sediments. I present here an extensive list of spore–pollen taxa recovered from various formations of the Navarro Group (Maastrichtian) of Texas indicating rich and diverse spore–pollen assemblages (Kumar, 1976). The spore–pollen assemblages from the Navarro Group are sufficiently rich and diverse enough to establish four biostratigraphic zones useful for correlating outcrop sections with a distant subsurface well section (Kumar, 1980) and also for the demarcation of the Cretaceous–Tertiary boundary in the Texas Gulf Coastal Plain (Kumar, 1992). However, the Navarro Group sediments are also rich in dinoflagellate cysts and acritarchs that have been proven useful for zonation and correlation of these sediments in the Austin and the Frio sections (Zaitzeff & Cross, 1970).

Srivastava (1995) studied only the Corsicana Marl and Kemp Clay formations belonging to the Navarro Group (Maastrichtian). The objective of this paper is to demonstrate the presence of rich and diverse pollen–spore assemblages from various formations in the Navarro Group, including the Corsicana Marl and Kemp Clay formations. Palaeoecology and provenance of the spore–pollen assemblages are discussed as well.

STRATIGRAPHY

The Navarro Group represents the youngest Cretaceous sediments in the Gulf Coast region of Texas and comprises the uppermost part of the Gulfian Series (Stehli *et al.*, 1972). These sediments outcrop in a belt almost 23 miles wide that

runs parallel to the present day coastline of Texas (Fig. 1). Their most complete development is in Navarro, Kaufmann and Hunt counties (Fig. 2) where this group was subdivided into four formations by Stephenson (in Adkins, 1933, p. 516). These formations in ascending order are Neylandville Marl, Nacatoch Sand, Corsicana Marl and Kemp Clay (Table 1). The locations of outcrops sampled for this study are shown in Figs 3, 4, 5 and 6. The aggregate outcrop thickness of the Navarro Group is estimated to be from 550–570 feet but down dip its thickness increases to over 1,000 feet.

The Neylandville Marl Formation consists of grey sandy, calcareous clay or marl that rests unconformably on the Taylor Marl Formation (Campanian) and is unconformably overlain by the Nacatoch Sand Formation which consists of grey, massive, calcareous, marine sandstone with hard, calcareous concretions of various sizes and shapes. The overlying Corsicana Marl Formation is a grey chalk. The Kemp Clay Formation is the youngest unit in the Navarro Group and overlies the Corsicana Marl Formation. Its lithology varies from place to place; however, generally it is dark grey clay with low carbonate content.

Southwest of Navarro County, the Kemp Clay Formation changes along strike into rocks of different lithologies comprising of dark clays and marls interbedded with limestones, shales and sandstones of variable thicknesses known as the Escondido Formation. This lithological change is gradational and the distinction between these two formations is rather arbitrary. In Bexar–Medina counties there is an unconformity between the Escondido Formation and the underlying Taylor Marl Formation (Campanian). This stratigraphic gap is in part filled in by nonmarine clays, shales and sandstones interbedded with seams of coal known as the Olmos Formation. In the Rio Grande Embayment area, the Olmos Formation is overlain by the Escondido Formation.

Geological Sections Studied

The following sections were studied from different parts of Texas.

Table 1—Stratigraphy of the Navarro Group of Texas (Modified after Kumar, 1980).

ERA	SYSTEM	SERIES	STAGE	GROUP	FORMATION
Cenozoic	Tertiary	Paleocene	Danian	Midway	Wills Point
					Kincaid
Mesozoic	Cretaceous	Gulf	Maastrichtian	Navarro	Kemp Clay
					Corsicana Marl
					Nacatoch Sand
					Neylandville Marl
			Campanian	Taylor	Upper Taylor Marl

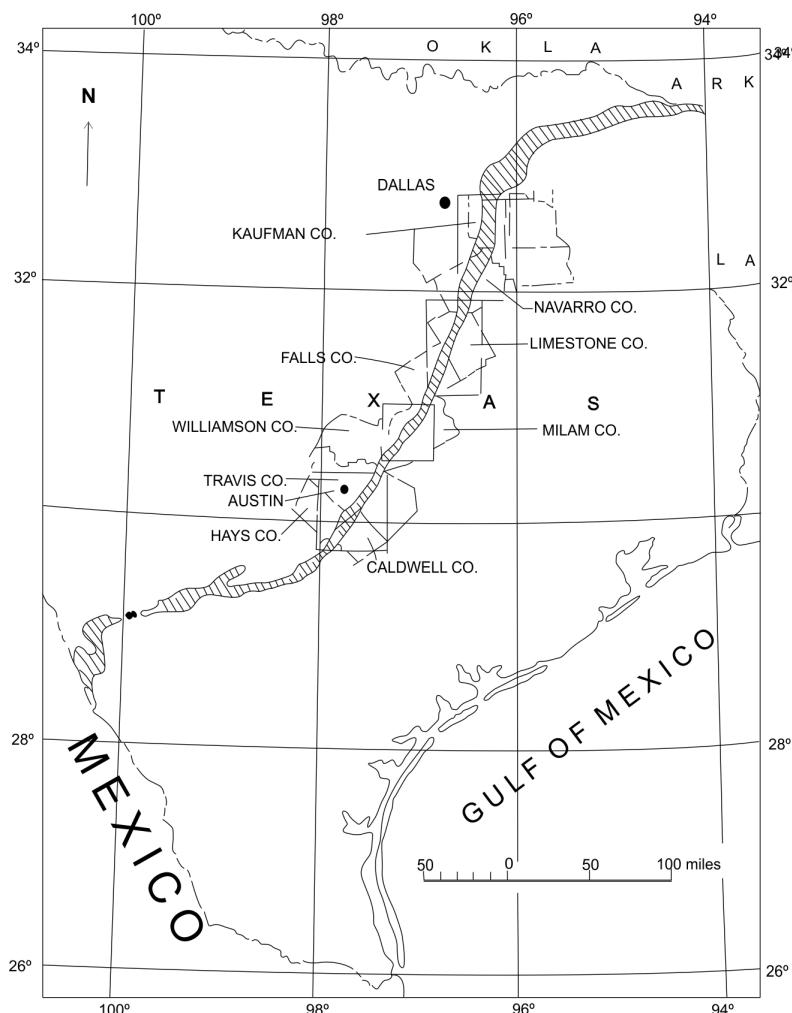


Fig. 2—Index map of eastern Texas showing the boundaries of different counties where various formations of the Navarro Group outcrop. The county maps showing outcrop details of the Navarro Group (after Stephenson, 1941).

Austin Section—This section is a composite stratigraphic section including three separate measured sections and sampled in Travis County in the vicinity of Austin. Fig. 7 shows the lithology and sample position in sections A, B and C. The locations of these sections are given in Fig. 6. Section A represents a complete outcrop of the Corsicana Marl Formation which is underlain by undifferentiated Neylandville Marl and Nacatoch Sand formations and overlain by the Kemp Clay Formation. Section B includes only the Kemp Clay Formation. Section C is an outcrop of undifferentiated Neylandville Marl and Nacatoch Sand formations.

Frio Section—This section consists of the cores from the Frank Doering well # 1 in Frio County in southern Texas (Fig. 1). The thickness of the Navarro Group in this well is 1,220 feet; top and bottom are at 3,050 feet and 4,270 feet respectively. The cored section studied was between 3,102 feet and 4,272 feet (1,170 feet thick). The Navarro Group in this section is represented by the Escondido Formation and underlying Olmos Formation.

Brazos River Section—This section covers the Cretaceous-Tertiary (KT) boundary sediments (Section D; Fig. 8). Bottom part of the section consists of the Kemp Clay Formation.

Walker Creek Section—This section also includes the Cretaceous-Tertiary (KT) boundary sediments and is located in the Milam County (Section E, Fig. 9).

RESULTS

A total of 170 species of pollen and spores belonging to 102 genera are listed in this paper. Each formally published species is provided with its author and the year of its publication. Informal species are listed as species A, B, etc. and are not described. Formal descriptions of spore-pollen are beyond the scope of this paper. No illustrations of the taxa are provided because stratigraphically significant pollen and spores from this study were illustrated in several plates published earlier by the author (Kumar, 1980, 1992).

Pollen are grouped into morphological categories; porate and colporate (16 genera and 29 species); colporate and sulcate (19 genera and 31 species); saccate, zonate and inaperturate (16 genera and 27 species); and Normapolles (3 genera and 3 species). Spores are a very diverse group and classified as trilete (41 genera and 69 species) and monolete (7 genera

and 11 spores). Several taxa belonging to algal and fungal remains are present, but not considered further in this paper. Dinoflagellate cysts also occur in these formations and were reported by Zaitzeff and Cross (1970) and Kumar (1992). Pollen and spores of the Navarro Group are listed below with their relative abundances (rare: < 1.0%; few: 1–5%; common: 5.1–10%; and abundant: > 10%). The formation(s) from which each taxon was found are also provided.

A. POLLEN GRAINS

Porate and colporate pollen

1. *Alnipollenites quadrapollenites* (Rouse) Srivastava, 1966 (rare to few in Escondido)
2. *Betulaepollenites claripites* (Wodehouse) Wilson, 1978 (common throughout the Navarro Group)

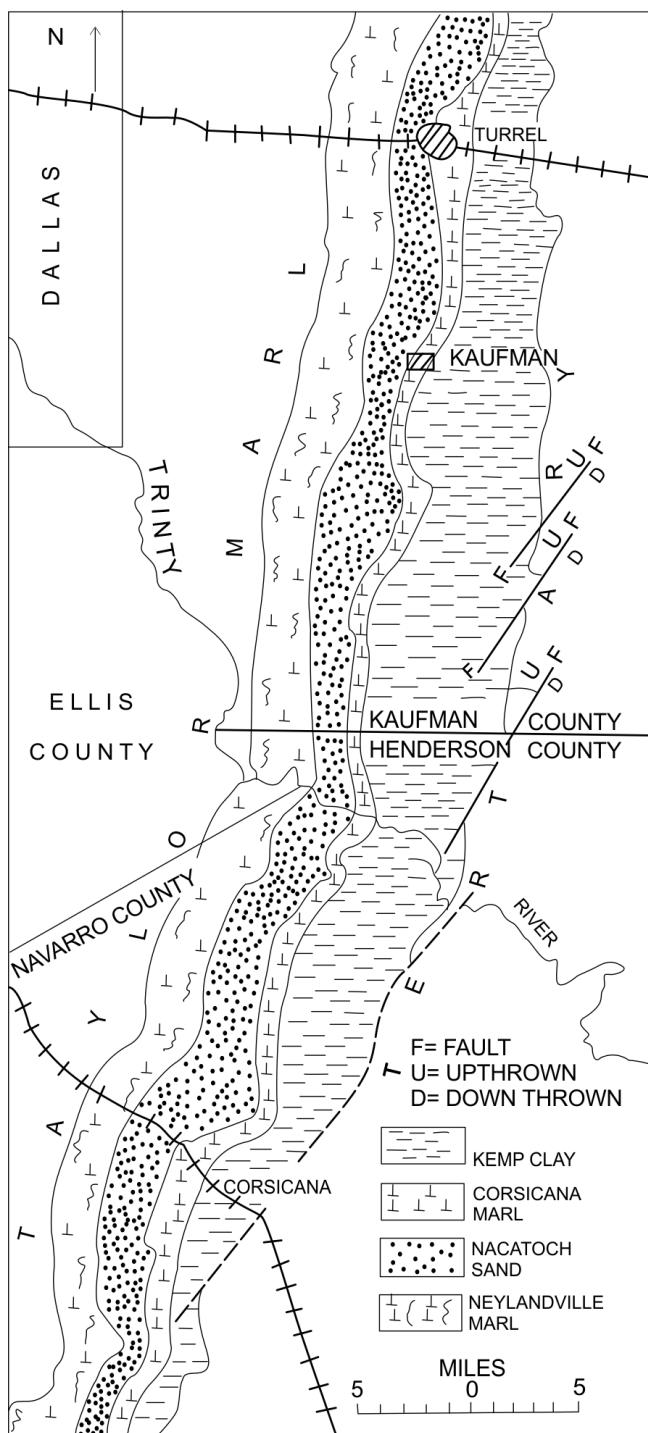


Fig. 3—Outcrops of the Navarro Group in Kaufman and Navarro counties (modified after Stephenson, 1941).

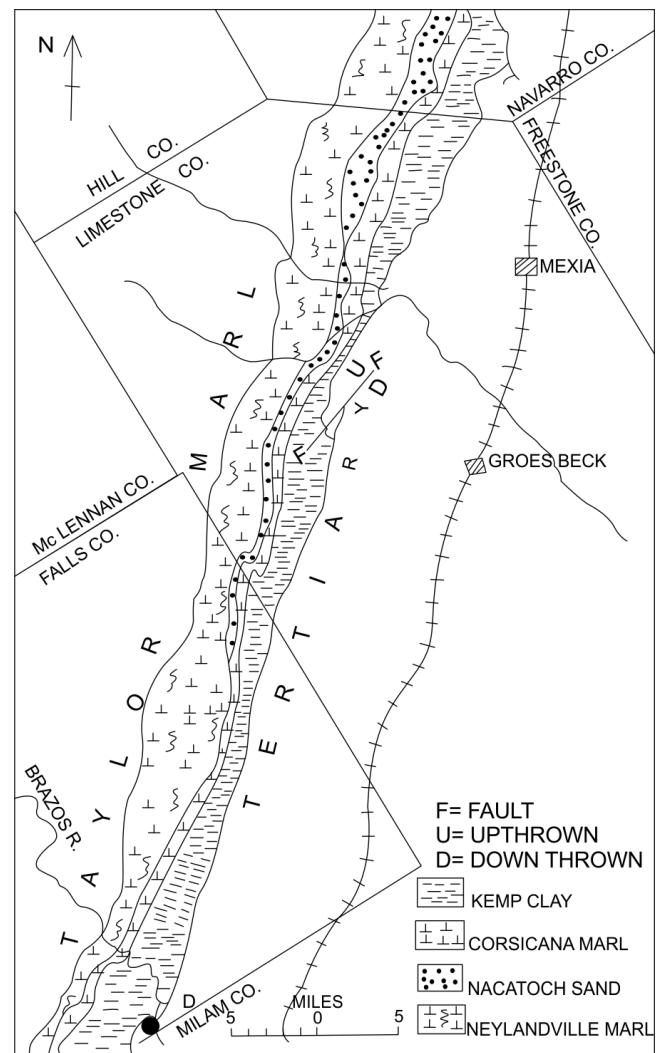
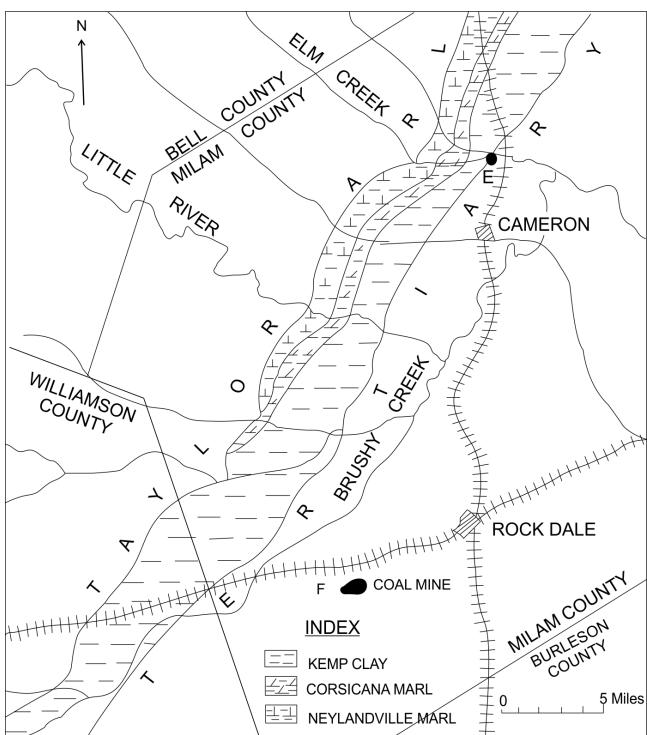
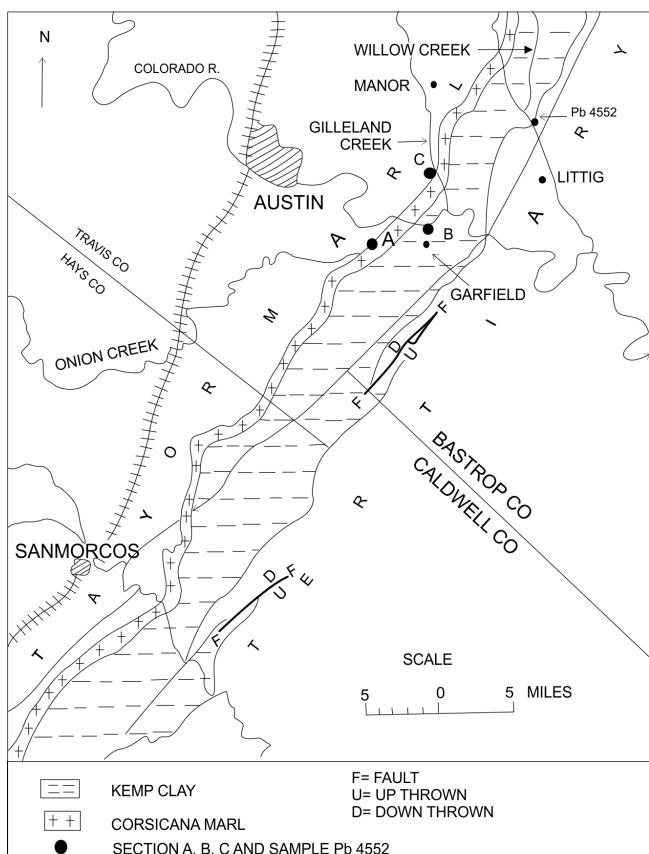


Fig. 4—Outcrops of the Navarro Group in Limestone and Falls counties (modified after Stephenson, 1941). Location D: Brazos River Section.



3. *Betulaepollenites* sp. A (rare throughout the Navarro Group)
4. *Betulaepollenites* sp. B (rare in Kemp Clay and Escondido)
5. *Bombacacidites nacimientoensis* (Anderson) Elsik, 1968 (rare to few in Kemp Clay)
6. *Bombacacidites reticulatus* (Groot and Groot) Srivastava, 1972 (rare to few in Kemp Clay, Escondido and Olmos)
7. *Chenopodipollis multiplex* (Weyland and Pflug) Krutzsch, 1966 (rare to few in Kemp Clay)
8. *Momipites quietus* (Potonié) Nichols, 1973 (rare to few in Kemp Clay)
9. *Momipites tenuipolus* Anderson, 1960 (common throughout the Navarro Group)
10. *Momipites* sp. (rare: Kemp Clay)
11. *Nyssoidites rodderensis* (Thiergart ex Thomson and Pflug) Potonié, 1960 (rare in Kemp Clay)
12. *Nyssoidites* sp. (rare: Olmos)
13. *Potamogetonacidites senonicus* Takahashi and Sugiyama, 1990 (rare to common in Kemp Clay and Escondido)
14. *Proteacidites retusus* Anderson, 1960 (common throughout the Navarro Group)
15. *Proteacidites thalmani* Anderson, 1960 (common throughout the Navarro Group)
16. *Retistephanoporites* sp. (rare in Kemp Clay)
17. *Rhoipites bradleyi* Wodehouse, 1933 (common throughout the Navarro Group)



18. *Rhoipites cingulus* (Potonié) Srivastava, 1972 (common throughout the Navarro Group)
19. *Rhoipites cryptoporus* Srivastava, 1972 (Rare to common in Kemp Clay, Escondido and Olmos)
20. *Subtriporopollenites annulatus* Pflug and Thomson in Thomson and Pflug, 1953 (rare to few in Neylandville Marl–Nacatoch Sand)
21. *Thomsonipollis magnificus* (Pflug and Thomson) Krutzsch, 1960 (rare to few in Kemp Clay and Escondido)
22. *Thomsonipollis paleocenicus* Elsik, 1968 (rare to few in Escondido and Olmos)
23. *Triatriopollenites bituitus* (Potonié) Thomson and Pflug, 1953 (rare to few in Kemp Clay and Olmos)
24. *Triorites* sp. A (rare throughout the Navarro Group)
25. *Triorites* sp. B (rare in Corsicana Marl and Escondido)
26. *Triporopollenites* sp. A (rare in Escondido)
27. *Triporopollenites* sp. B (rare in Kemp Clay)
28. Trisyncolporate pollen (rare in Kemp Clay)
29. *Ulmipollenites* sp. (rare in Kemp Clay and Escondido)

Total number of porate and colporate pollen genera: 16
Total number of porate and colporate pollen species: 29

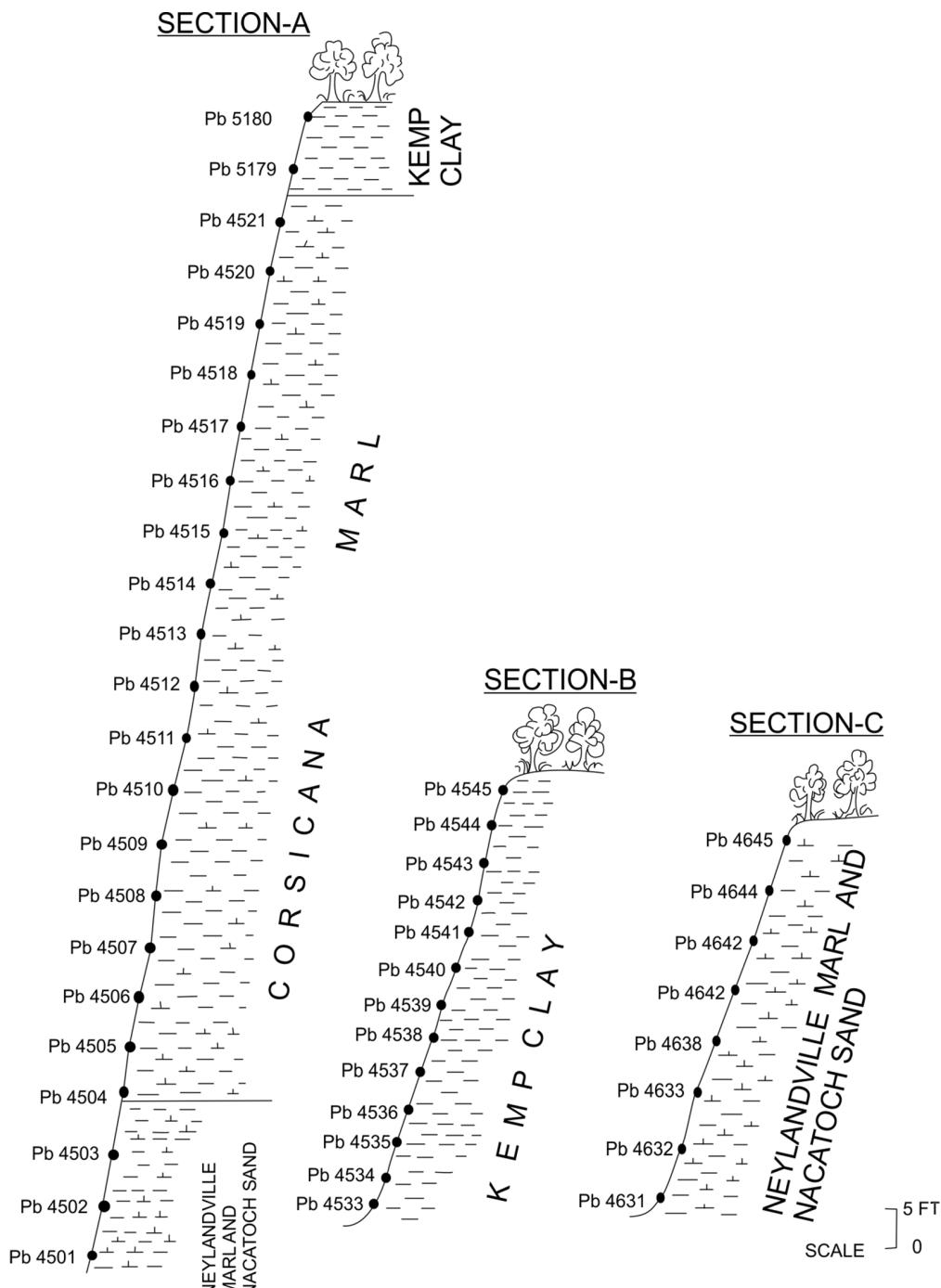


Fig. 7.—Lithology and sample locations of the composite Austin Section (see Fig. 6 for location of these sections).

Colporate and sulcate pollen

1. *Aesculidites circumstriatus* (Fairchild) Elsik, 1968 (rare in Kemp Clay and Escondido)
2. *Asteropollis* sp. (rare to common in Escondido, Corsicana Marl and Olmos)
3. *Arecipites columellus* Leffingwell, 1971 (common throughout the Navarro Group)
4. *Arecipites inequalis* Elsik, 1974 (common throughout the Navarro Group)
5. *Arecipites* sp. (Rare to few in Kemp Clay)
6. *Cupuliferoidae pollenites parvulus* (Groot and Penny) Dettmann, 1973 (rare to few in Kemp Clay)
7. *Cupuliferoidae pollenites* sp. (rare in Kemp Clay)
8. *Cycadopites giganteus* Stanley, 1965 (common throughout the Navarro Group)

9. *Cycadopites scabratus* Stanley, 1965 (few to common in Escondido, Kemp Clay)
10. *Cycadopites* sp. A (few throughout the Navarro Group)
11. *Cycadopites* sp. B (few in Escondido)
12. *Holkopollenites chemardensis* Fairchild in Stover *et al.* 1966 (few to common throughout the Navarro Group)
13. *Magnopolis* sp. (rare to few throughout the Navarro Group)
14. *Monocolpopollenites texensis* Nichols *et al.* 1973 (common throughout the Navarro Group)
15. *Monocolpopollenites* sp. (rare in Escondido)
16. *Nupharipollis* sp. (few throughout the Navarro Group)
17. *Nyssapollenites albertensis* Singh, 1971 (few throughout the Navarro Group)
18. *Palmidites maximus* Couper, 1953 (rare to few in Neylandville Marl–Nacatoch Sand)
19. *Quadratopollenites vagus* (Stover in Stover *et al.*) Elsik, 1968 (few in Kemp Clay)
20. *Retitrescolpites anguloluminosus* (Anderson) Frederiksen, 1979 (few in Escondido)
21. *Retitricolpites maximus* Singh, 1971 (common to rare in Escondido, Olmos and Kemp Clay)
22. *Rousea georgensis* (common to few throughout the Navarro Group)
23. *Striatocolporites* sp. (rare to few in Kemp Clay and Escondido)
24. *Trichotomosulcites* sp. A (rare in Kemp Clay)
25. *Trichotomosulcites* sp. B (few in Olmos)
26. *Trichotomosulcites* sp. C (few in Kemp Clay)
27. *Tricolpites hians* Stanley, 1965 (few to rare in Kemp Clay and Corsicana Marl)
28. *Tricolpites micromunus* (Groot and Groot) Singh, 1971 (few to rare throughout the Navarro Group)
29. *Tricolpites microreticulatus* Belsky *et al.* 1965 (few to rare throughout the Navarro Group)
30. *Verrumonocolpites* sp. A (few in Olmos)
31. *Verrumonocolpites* sp. B (few throughout the Navarro Group)

Total number of colporate and sulcate pollen genera: 19

Total number of colporate and sulcate pollen species: 31

Saccate, zonate and inaperturate pollen

1. *Alisporites bilateralis* Rouse, 1959 (rare to few in Kemp Clay, Olmos and Neylandville Marl–Nacatoch Sand)
2. *Alisporites plicatus* Phillips and Felix, 1971 (rare to few in Kemp Clay and Escondido)
3. *Callialasporites dampieri* (Balme) Dev, 1961 (rare to common in Escondido, Olmos and Kemp Clay)
4. *Callialasporites segmentatus* (Balme) Dev, 1961 (rare to few throughout the Navarro Group)
5. *Callialasporites* sp. A (rare in Kemp Clay)

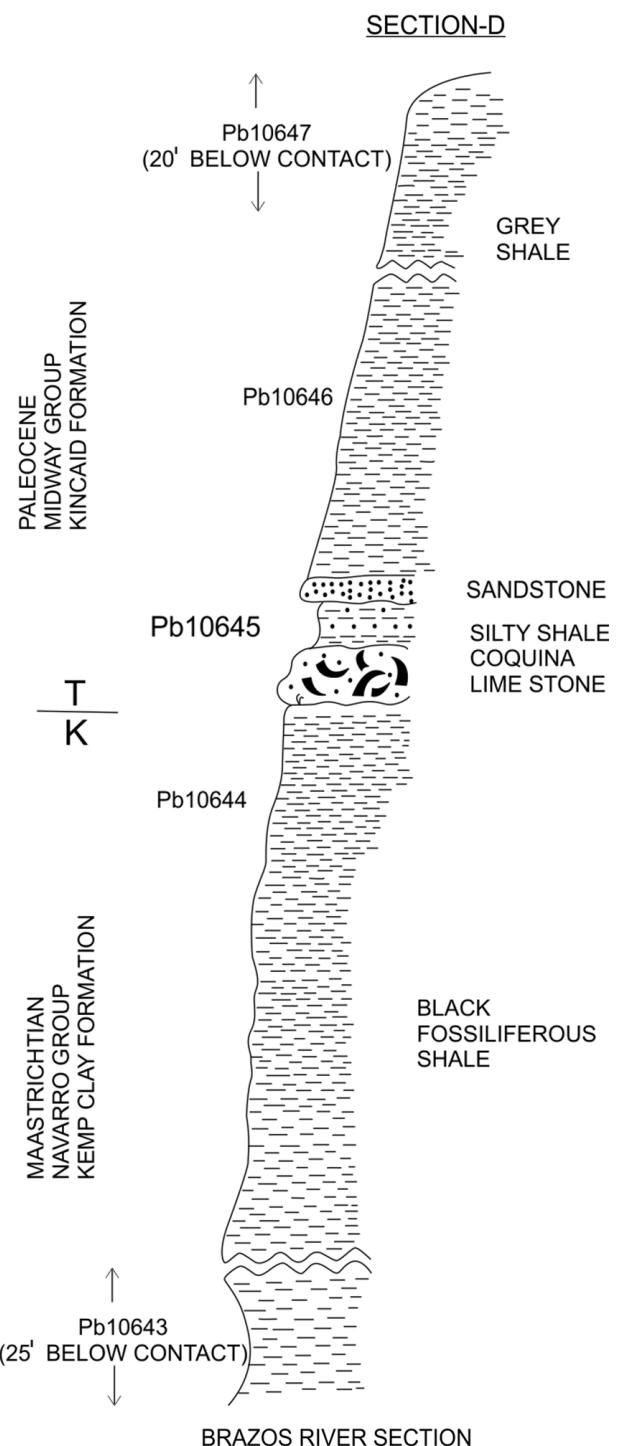


Fig. 8—Lithology and sample locations of the Brazos River Section (Location D in Fig. 4).

6. *Circulina parva* Brenner, 1963 (rare to few throughout the Navarro Group)
7. *Classopollis classoides* Pflug, 1953 (rare to few throughout the Navarro Group)

8. *Ephedra voluta* Stanley, 1965 (rare to common throughout the Navarro Group)
9. *Equisetosporites amabilis* Srivastava, 1968 (few to abundant throughout the Navarro Group)
10. *Equisetosporites chinleana* Daugherty, 1941 (rare to few in Corsicana Marl)
11. *Equisetosporites multicostatus* (Brenner) Srivastava, 1968 (rare to few in Kemp Clay and Escondido)
12. *Equisetosporites* sp. A (rare to few in Kemp Clay)
13. *Equisetosporites* sp. B (rare to few in Kemp Clay)
14. *Equisetosporites* sp. C (rare to few in Kemp Clay, Olmos and Escondido)
15. *Eucommiidites minor* Groot and Penny, 1960 (rare to few throughout the Navarro Group)
16. *Fustispollenites* sp. (rare in Corsicana Marl)
17. *Gnetaceaepollenites* sp. (rare to few in Kemp Clay and Escondido)
18. *Inaperturopollenites dubius* (Potonié and Venitz) Thomson and Pflug, 1953 (common to abundant throughout the Navarro Group)
19. *Perinopollenites elatoides* Couper, 1958 (rare to few in Escondido and Neylandville Marl–Nacatoch Sand)
20. *Pityosporites alatipollenites* (Rouse) Takahashi and Sugiyama, 1990 (few to common throughout the Navarro Group)
21. *Pityosporites* sp. A (rare in Kemp Clay)
22. *Pityosporites* sp. B (rare in Kemp Clay)
23. *Psophosphaera aggereloides* (Maljavkina) Chlonova, 1960 (few to common in Escondido and Kemp Clay)
24. *Quadriporites krempii* Drugg, 1967 (rare in Olmos)
25. *Schizosporis microfoveatus* Stanley, 1965 (rare to few in Olmos)
26. *Wodehouseia fimbriata* Stanley, 1961 (rare to few in Kemp Clay)
27. *Wodehouseia spinata* Stanley, 1961 (rare to few in Kemp Clay)

Total number of saccate, zonate and inaperturate pollen genera: 16

Total number of saccate, zonate and inaperturate pollen species: 27

Normapolles

1. *Complexiopollis microverrucosus* Tschudy, 1973 (rare to few in Kemp Clay, Escondido and Neylandville Marl–Nacatoch Sand)
2. *Conclavipollis wolfcreekensis* Newman, 1965 (rare to few in Kemp Clay, Escondido and Neylandville Marl–Nacatoch Sand)
3. *Sporopollis* sp. A (rare to few in Kemp Clay)

Total number of Normapolles genera: 3

Total number of Normapolles species: 3

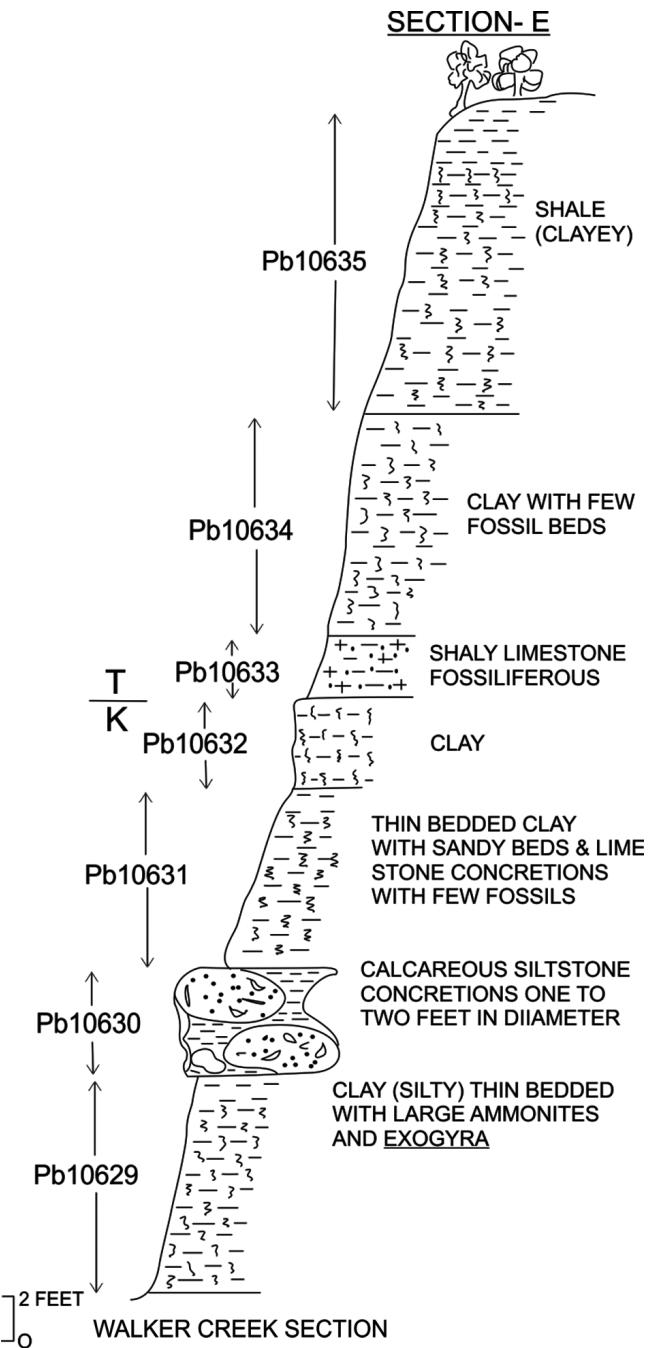


Fig. 9—Lithology and sample locations of the Walker Creek Section (Location E in Fig. 5).

B. TRILETE SPORES

1. *Aequitriradites ornatus* Upshaw, 1963 (rare to few in Kemp Clay)
2. *Appendicisporites erdtmanii* Pocock, 1964 (rare to few in Kemp Clay)
3. *Appendicisporites matesovae* (Bolkhovitina) Norris, 1967 (rare to few in Upper Escondido)

4. *Appendicisporites problematicus* (Burger) Singh, 1971 (common throughout the Navarro Group)
5. *Appendisporites* sp. (rare in Neylandville Marl–Nacatoch Sand and Escondido)
6. *Baculatisporites comaumensis* (Cookson) Potonié, 1956 (rare to few in Kemp Clay and Neylandville Marl–Nacatoch Sand)
7. *Biretisporites potoniaeai* Delcourt and Sprumont, 1955 (common throughout the Navarro Group)
8. *Camarozonosporites annulus* (Pierce) Waanders, 1974 (common throughout the Navarro Group)
9. *Camarozonosporites heskemensis* (Pflanzl) Krutzsch, 1959 (rare to common in Neylandville Marl–Nacatoch Sand and Olmos)
10. *Camarozonosporites vermiculaesporites* (Rouse) Krutzsch, 1963 (rare to common in Neylandville Marl–Nacatoch Sand and Escondido)
11. *Ceratosporites morriniculus* Srivastava, 1972 (rare to few in Kemp Clay and Neylandville Marl–Nacatoch Sand)
12. *Cicatricosisporites australiensis* (Cookson) Potonié, 1956 (rare to few in Kemp Clay)
13. *Cicatricosisporites dorogensis* Potonié and Gelletich, 1933 (rare to few in Kemp Clay, Escondido and Neylandville Marl–Nacatoch Sand)
14. *Cicatricosisporites hallei* Delcourt and Sprumont, 1955 (common throughout the Navarro Group)
15. *Cicatricosisporites imbricatus* (Morkova) Singh 1971 (rare to few in Neylandville Marl–Nacatoch Sand)
16. *Cicatricosisporites ornatus* Srivastava, 1972 (common throughout the Navarro Group)
17. *Cicatricosisporites venustus* Deak, 1963 (rare to few in Corsicana Marl and Escondido)
18. *Cicatricosisporites* sp. (rare in Neylandville Marl–Nacatoch Sand)
19. *Cingulatisporites dakotaensis* Stanley, 1965 (common throughout the Navarro Group)
20. *Concavissimisporites variverrucatus* (Couper) Brenner, 1963 (rare to few in Kemp Clay and Escondido)
21. *Cyathidites minor* Couper, 1953 (common throughout the Navarro Group)
22. *Cyathidites punctatus* (Delcourt and Sprumont) Delcourt et al. 1963 (rare to few in Kemp Clay)
23. *Deltoidospora hallii* Miner, 1935 (common throughout the Navarro Group)
24. *Deltoidospora junctum* Singh, 1964 (few in Corsicana Marl, Kemp Clay and Escondido)
25. *Deltoidospora psilostoma* Rouse, 1959 (few throughout the Navarro Group)
26. *Densoisporites perinatus* Couper, 1958 (rare to few in Neylandville Marl–Nacatoch Sand)
27. *Divisporites* sp. (rare in Olmos)
28. *Echinatisporis levidensis* (Balme) Srivastava, 1972 (common throughout the Navarro Group)
29. *Echinatisporis spinilabia* Srivastava, 1972 (few in Kemp Clay)
30. *Echinatisporis varispinosus* (Pocock) Srivastava, 1972 (rare to few in Kemp Clay and Neylandville Marl–Nacatoch Sand)
31. *Foveotriletes* sp. (rare in Kemp Clay)
32. *Foveosporites* sp. (rare in Kemp Clay and Escondido)
33. *Gabonisporis bacaricumulus* Srivastava, 1972 (rare in Kemp Clay and Olmos)
34. *Ghoshispora minor* (Norton in Norton and Hall) Srivastava, 1978 (rare in Kemp Clay and Olmos)
35. *Ghoshispora* sp. (rare in Kemp Clay and Olmos)
36. *Gleicheniidites senonicus* (Ross) Skarby, 1964 (rare to few in Escondido, Corsicana and Kemp Clay)
37. *Gleicheniidites* sp. A (rare to few in Neylandville Marl–Nacatoch Sand, Corsicana Marl and Olmos)
38. *Hamulatisporis albertainis* Srivastava, 1972 (few in Kemp Clay and Escondido)
39. *Heliosporites altmarkensis* Schulz, 1962 (rare in Corsicana Marl and Escondido)
40. *Heliosporites* sp. (rare in Kemp Clay)
41. *Ischyosporites disjunctus* Singh, 1971 (few in Neylandville Marl–Nacatoch Sand)
42. *Jimboisporites senonicus* Miki, 1972 (rare in Corsicana Marl)
43. *Kuylisporites scutatus* Newman, 1965 (rare to few in Kemp Clay, Escondido and Olmos)
44. *Leiotriletes* sp. (rare in Escondido)
45. *Leptolepidites major* Couper, 1958 (few in Olmos)
46. *Leptolepidites verrucatus* Couper, 1953 (few in Olmos)
47. *Lycopodiumsporites cerniidites* (Ross) Delcourt and Sprumont, 1955 (common throughout the Navarro Group)
48. *Microreticulatisporites* sp. A (rare in Kemp Clay)
49. *Microreticulatisporites* sp. B (rare in Neylandville Marl–Nacatoch Sand, Corsicana Marl and Olmos)
50. *Neoraistrickia speciosa* Srivastava, 1972 (rare to few in Neylandville Marl–Nacatoch Sand, Corsicana Marl and Kemp Clay)
51. *Pilosporites* sp. (rare in Kemp Clay)
52. *Psilatrilletes detortus* (Weyland and Krieger) Potonié, 1956 (rare in Olmos)
53. *Radialisporites radiatus* (Krutzsch) Krutzsch, 1967 (rare to few in Kemp Clay)
54. *Retitriletes nidus* Srivastava, 1972 (rare in Kemp Clay)
55. *Retitriletes* sp. (rare in Kemp Clay, Escondido and Neylandville Marl–Nacatoch Sand)
56. *Rotaspora rugulatus* Gray and Groot, 1966 (rare to few in Kemp Clay, Escondido and Neylandville Marl–Nacatoch Sand)
57. *Saxosporis* sp. (rare in Olmos, Escondido and Neylandville Marl–Nacatoch Sand)
58. *Stereisporites antiquasporites* (Wilson and Webster) Dettmann, 1963 (common throughout the Navarro Group)

59. *Stereisporites australis* (Cookson) Krutzsch, 1959 (few throughout the Navarro Group)
60. *Stereisporites congruens* (Pierce) Krutzsch, 1963 (rare to few in Olmos, Kemp Clay and Escondido)
61. *Stereisporites cristalloides* Krutzsch in Doring *et al.* 1966 (rare to common in Kemp Clay, Neylandville Marl–Nacatoch Sand and Corsicana Marl)
62. *Taurocuspores segmentatus* (Stover) Playford and Dettmann, 1965 (common in Kemp Clay)
63. *Todisporites major* Couper, 1958 (few in Olmos, Escondido and Neylandville Marl–Nacatoch Sand)
64. *Todisporites minor* Couper, 1958 (few in Escondido)
65. *Triporoletes reticulatus* (Pocock) Playford, 1971 (common in Kemp Clay, Escondido and Olmos)
66. *Triporoletes* sp. (rare in Kemp Clay)
67. *Trizonites* sp. A (rare in Corsicana Marl)
68. *Trizonites* sp. B (rare in Kemp Clay)
69. *Undulatisporites undulapolus* Brenner, 1963 (few in Kemp Clay, Escondido, Olmos and Corsicana Marl)

Total number of trilete spore genera: 41

Total number of trilete spore species: 69

C. MONOLETE SPORES

1. *Cicatricosporites drumhellerensis* Srivastava, 1971 (few in Escondido)
2. *Cicatricosporites norrisii* Srivastava, 1971 (few in Escondido)
3. *Extrapunctatosporis* sp. A (rare in Kemp Clay)
4. *Extrapunctatosporis* sp. B (rare in Kemp Clay)
5. *Hazaria sheopiarii* Srivastava, 1971 (rare in Kemp Clay)
6. *Laevigatosporites hardtii* (Potonié and Venitz) Thomson and Pflug, 1953 (common throughout the Navarro Group)
7. *Laevigatosporites discordatus* Krutzsch, 1959 (common in Kemp Clay, Escondido and Neylandville Marl–Nacatoch Sand)
8. *Laevigatosporites* sp. (rare in Kemp Clay)
9. *Polyopodiidites inangahuensis* Couper, 1953 (few in Escondido)
10. *Reticulosporis* sp. (rare in Escondido, Olmos and Kemp Clay)
11. *Verrucatosporites* sp. (rare in Olmos)

Total number of monolete spore genera: 7

Total number of monolete spore species: 11

D. MISCELLANEOUS PALYNOmorphs

Several types of fungal spores, filaments and fructifications
Several types of algal remains

DISCUSSION

Biostratigraphy

The stratigraphic ranges and relative abundances of 121 spore–pollen taxa were used to establish four biozones A, B, C and D in the Austin Section by the author (Kumar, 1980). Biozone A corresponds to the undifferentiated Neylandville Marl–Nacatoch Sand Formation; Biozone B corresponds to the Corsicana Marl Formation; Biozone C corresponds to the lower half of the Kemp Clay Formation; and Biozone D corresponds to the upper half of the Kemp Clay Formation (Fig. 10). These biozonal boundaries do not always correspond to formation boundaries; at times formation boundaries cross the biozonal boundaries, but more often biozonal boundaries and formation boundaries correspond. Since stratigraphic distribution of spore–pollen in various formations of the Navarro Group has already been published (Kumar, 1980), there is no need to illustrate the biozonation charts for the Austin and Frio sections here.

Correlation of the Austin and Frio sections

The four biozones were correlated between the Austin and Frio sections (Kumar, 1980) based on the presence of key species having restricted stratigraphic ranges and/or having significant percentage representation of certain species or palynomorph groups in the sample assemblage.

Biozone A of the Austin Section is correlated with lower 4170–4270 feet of the Frio Section on the basis of significantly higher percentages of spore–pollen and conspicuous presence (2.5–9.0%) of *Saxosporis* sp. and *Stereisporites dakotaensis*, whereas most other species have < 1.9 % representation.

Biozone B of the Austin Section is correlated with 3450–4170 feet of the Frio Section based on the restricted stratigraphic presence of *Heliosporites altmarkensis* and the first appearance of *Appendicisporites problematicus*, *Gleicheniidites senonicus*, *Chenopodipollis multiplex*, *Asteropollis* sp., *Equisetosporites multistatus* and *Equisetosporites* sp. C. Both of these zones are characterized by higher proportions of dinoflagellate cysts and acritarchs at the base, with this proportion gradually decreasing upwards.

Biozone C of the Austin Section is correlated with 3250–3450 feet of the Frio Section based on the following stratigraphically restricted species: *Cicatricosporites norrisii*, *Camarozonosporites albentensis*, *Triplanosporites sinuosus*, *Stereisporites congruens*, *Trizonites subrugulatus*, *Undulatisporites undulapolus*, *Reticulosporis* sp., *Bombacacidites reticulatus*, *Betulaepollenites* sp. B., *Rhoipites cryptoporus*, *Ulmipollenites* sp., *Aesculidites circumstriatus* and *Trichotomosulcites* sp. C. *Kuylisporites scutatus* appears for the first time in biozone C in both sections.

Biozone D of the Austin Section is correlated with the top 3100–3250 feet of the Frio Section based on the following

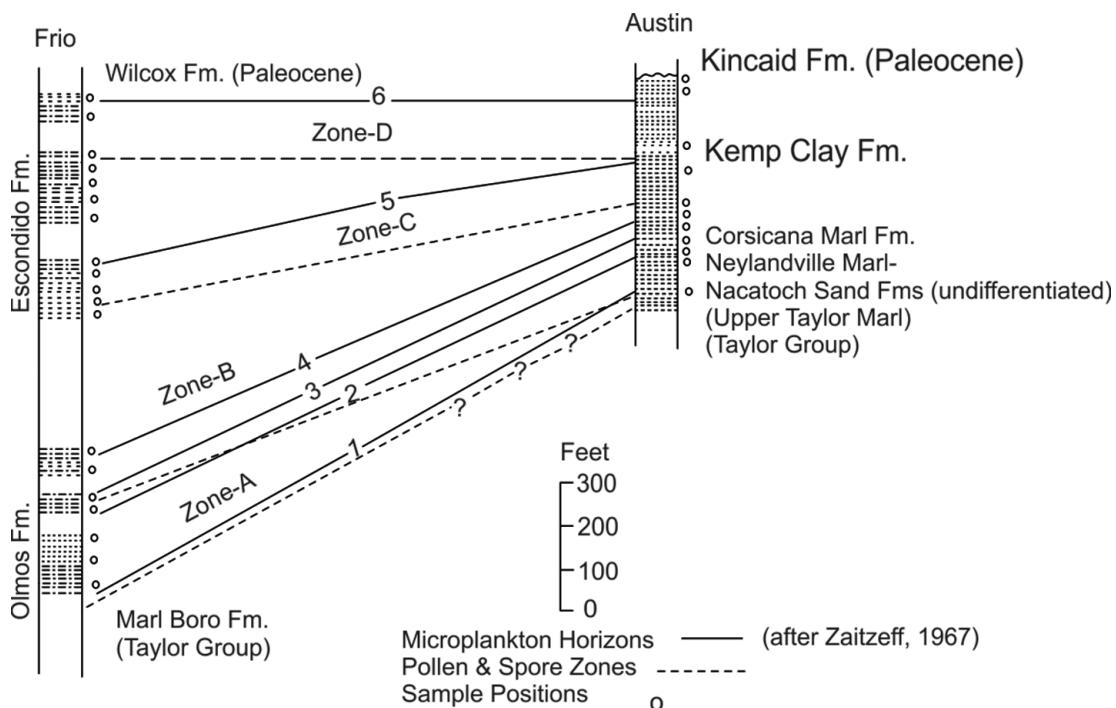


Fig. 10—Correlation of the Austin and Frio sections: A. based on microplankton (dinoflagellate cysts and acritarchs) after Zaitzeff and Cross (1970) and B. based on pollen and spore after Kumar (1980).

stratigraphically restricted species: *Foveosporites* sp., *Triplopollenites* sp., *Alisporites plicatus* and *Equisetosporites amabilis*. This biozone is also characterized by lower percentages of dinoflagellate cysts and acritarchs and this trend continues upwards. The zonal boundaries based on spore-pollen distribution between the Austin and Frio sections are found to correlate well with the timelines established between these two sections on the basis of dinoflagellate cysts and acritarchs (Fig. 10) by Zaitzeff and Cross (1970).

Depositional environments and palaeoecology

As already described above, the Austin Section is a composite section of outcrops located in different counties in northeastern and east-central Texas. The Frio Section is a subsurface core section of Frank Doering Well # 1 in Frio County in southern Texas. These two sections are 150 to over 200 miles apart. All the Navarro Group formations except the Olmos Formation were deposited under marine environments. In marine sediments the ratio of allochthonous (spore-pollen) versus autochthonous (dinoflagellate cysts and acritarchs) elements of a palynomorph assemblage indicates relative distance of the site of deposition in relation to the paleo-shoreline. This model can be influenced by many other factors; however, it is based on the assumption that higher proportions of dinoflagellate cysts and acritarchs would indicate environments away from the shoreline, more towards the open sea. In the present study these conclusions are substantiated by sedimentological and palaeontological

evidence as well. Using this model, paleo-shorelines were interpreted for the Austin and the Frio sections and three transgressive phases separated by four regressive phases were identified (Figs 11 & 12).

The Olmos Formation is a terrestrial deposit that forms the lower part of the Frio Section. This formation has a very high proportion of spore-pollen and very low dinoflagellate cysts and acritarchs, indicating that during this time the shoreline was located towards east and the Olmos sediments were deposited in a range of diverse coastal terrestrial environments with only an occasional influence of the sea.

Biozone A: Austin Section

The lithology of this biozone comprises brownish-grey clay with glauconite and thin concretionary limestone, clay ironstone nodules and glauconitic sand. It is characterized by significantly higher percentages of spore-pollen and lower percentages of dinoflagellate cysts and acritarchs (Fig. 11). Presence of the mineral glauconite in these sediments is very significant because its presence suggests depositional environments and palaeoclimate. Glauconite is an authigenic clay mineral that forms in low-oxygen, shallow marine environments where the rate of sediment deposition is slow. It is most abundant at unconformities, for example, at the base of marine transgressive sequences (Triplehorn, 1965). Later studies indicate that glauconite predominantly forms in mid-shelf to upper slope in modern oceans with slow rates of sediments accumulation (Chafetz & Reid, 2000). Amount of

glauconite in sediments increases from near-shore to outer-shelf environments (Owens & Sohl, 1973); the present day distribution of this mineral is in shallow water tropical oceans (Porrenga, 1967). Thus it is a good indicator of palaeoclimate.

Many species representing the families Lycopodiaceae, Selaginellaceae, Schizaeaceae and Polypodiaceae among the pteridophytes; Sphagnaceae among the bryophytes; Taxodiaceae among the gymnosperms; and Proteaceae and Juglandaceae among the angiosperms occur in this biozone. Most of these families have their distribution in either tropical or subtropical regions of the world. Presence of Taxodiaceae and various pteridophytic families indicate the presence of swampy environments along the palaeo-coastline from which various types of spores and pollen were transported into the sea.

Based on the composition of palynomorph assemblages and sediment characteristics Biozone A in the Austin Section is interpreted to have been deposited in near-shore, shallow marine, inner to middle shelf environments. The overall evidence suggests that coastal swampy environments existed in tropical to subtropical humid climate.

Biozone A: Frio Section

This is a biozone of clays, shales and sandstones with seams of coal. It has abundant and diverse spore-pollen assemblages and the bottom section has dinoflagellate cysts and acritarchs comprising < 8% which decreases upwards to < 5 %. The spore-pollen taxa and their respective families present in this biozone co-occur in biozone A in the Austin Section. They indicate diverse terrestrial environments ranging from coastal swamps, riparian communities and plants growing in near-shore environments along the palaeo-coastline as indicated by the common presence of *Classopollis* (Herngreen, 1973). Most spore-pollen families in this biozone indicate tropical to subtropical palaeoclimate, but these assemblages also include *Pinus* pollen (*Pityosporites*) that grows in a temperate climate. Most temperate pollen such as *Pinus* and pollen representing angiosperm families Betulaceae and Juglandaceae in this biozone are most likely derived from highland areas in central Texas such as the Llano Uplift or the nearby Marathon and Arbuckle Mountains.

Sediments in Biozone A in the Frio Section were deposited in a range of coastal terrestrial environments left by regression of the sea that included marshes, swamps, rivers and lakes. Climate was mainly humid tropical to subtropical.

Biozone B: Austin Section

Sediments in this biozone are comprised of dark grey calcareous clay, brownish grey sand and in the basal part sandy clay with glauconite. Dinoflagellate cysts and acritarchs dominate the lower half of this biozone forming up to 70–90 % of the sample assemblages. This fact, coupled with

the presence of the mineral glauconite, indicates that these sediments were deposited in marine, middle to outer shelf environments. Gradual upward decrease in percentages of dinoflagellate cysts and acritarchs and corresponding increase in spore-pollen percentages indicates a marine regression. The presence of Chenopodiaceae pollen which primarily inhabits salt marshes also marks changes in the shoreline (Erdtman, 1943). This biozone has many spore-pollen taxa that co-occur with the Biozone A of the Austin Section; many are new such as *Equisetosporites* and *Gnetaceaesporites*. During this time plants inhabited various inland environments and were transported to the basin most likely by wind and also by streams flowing in to the sea. The climate continued to be humid tropical to subtropical.

Biozone B: Frio Section

Sediments in this biozone are comprised of yellowish grey clays, thin brownish grey limestone beds with silty and sandy limestone and includes the undifferentiated rocks between the Olmos and the Escondido Formations. This biozone has very high percentages of dinoflagellate cysts and acritarchs, ranging between 50–90 % in various sample assemblages. The depositional environment and palaeoclimate of the biozone is similar to the Biozone B of the Austin Section.

Biozones C and D: Austin Section

Since these two biozones correspond to the Kemp Clay Formation, they are discussed here together. Sediments in these biozones are comprised of grey to brown calcareous sands containing clay-ironstone nodules with sandy and silty beds at the top. These biozones have higher percentages of spore-pollen and lower percentages of dinoflagellate cysts and acritarchs that range between 5–10 % with two peaks at 25 %. Sediments of these biozones were deposited in various coastal and marginal marine environments and partly in marine environments ranging from intertidal to inner shelf. The high peaks of dinoflagellate cysts and acritarchs indicate short term fluctuations in sea-level (transgressions).

Taxa representing the family Sphagnaceae and palynomorphs like *Stereisporites* spp., *Aequitriradites ornatus* and *Triporoletes reticulatus* indicate marshy and swampy ground flora with a humid tropical to subtropical climate. The presence of Pteridophyte families like Cyathaceae, Lycopodiaceae, Schizaeaceae and Gleicheniaceae indicates a tropical to subtropical climate as well. The angiosperm pollen *Wodehouseia* is significant in Biozone D. The botanical relationship of this genus is unknown; it is probably related to some extinct group of plants with uncertain botanical affinity. Thus nothing can be said about its palaeoecology. Angiosperm pollen dominates the flora of Biozones C and D in the Austin Section with common occurrences of taxa belonging to

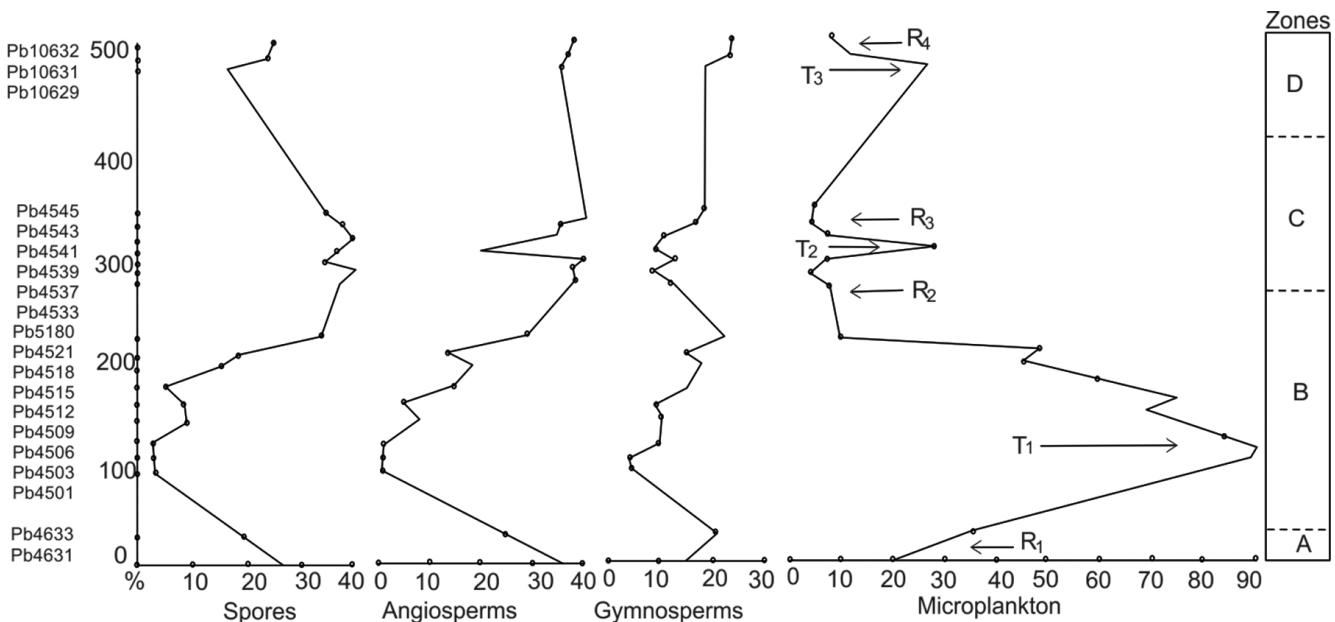


Fig. 11—Percentage distribution of terrestrial palynomorphs (spores, angiosperm and gymnosperm pollen) and microplankton (dinoflagellate cysts and acritarchs) in the Austin Section shows three transgressive phases (T1, T2 and T3) and four regressive phases (R1, R2, R3 and R4). Four biozones A, B, C and D are defined in this section.

families Betulaceae, Ulmaceae and Juglandaceae indicate a cooling trend in the area.

Biozones C and D: Frio Section

These biozones are comprised of grey clays, brownish grey limestone beds with silty limestone beds representing the Escondido Formation. The palynomorph assemblages of these biozones are remarkably similar to the palynomorphs assemblage of Biozones C and D in the Austin Section. These biozones have high percentages of dinoflagellate cysts and acritarchs that range between 45–60 % especially in the samples at the lower levels. However, dinoflagellate cysts and acritarchs gradually decrease upward in the section and there is a corresponding increase in the percentage of spores–pollen, indicating a gradual regression of the sea.

Sediments of Biozone C were deposited in sub-littoral to middle shelf environments and Biozone D was deposited in shallower near-shore, intertidal to shallow marine environments as regression continued in the area. The climate remained tropical to subtropical with an increasing cooling trend.

Movement of shoreline in Texas during Maastrichtian

Three transgressive phases (T1, T2 and T3) are interpreted in the Austin (Fig. 11) and Frio (Fig. 12) sections. The lowermost part of the Frio Section is the Olmos Formation deposited primarily in coastal non-marine environments with minor marine influences. This indicates that the shoreline

was located to the east of the site of Olmos deposition. The lower-most part of the Frio Section is correlated with Biozone A of the Austin Section, because both represent a regressive phase (R1). Biozone B in both sections represents a transgressive phase (T1). In the Austin Section this biozone is represented by undifferentiated Neylandville Marl–Nacatoch Sand formations and the Corsicana Marl Formation. These formations have higher percentages of dinoflagellate cysts and acritarchs in various samples that range between 30–90 %, indicating that these sediments were deposited in marine environments ranging from inner to outer shelf and beyond in the open sea. This interpretation is substantiated by the presence of the clay mineral glauconite in these sediments.

The beginning of regressive phase two (R2) was gradual and marked by two minor transgressions in the Austin Section and one major transgression in the Frio Section possibly indicating some local tectonic subsidence that might have caused the major reversal in the movement of the shoreline in the Rio Grande region but not affecting central and northeastern Texas. Transgressive phases two (T2) and three (T3) are relatively minor events in both the Austin and Frio sections.

According to Haq *et al.* (1987), the Maastrichtian spans the time period from 74.0 to 66.5 Ma; that is the duration of 7.5 Ma. During this period they identified three transgressions; one from 73.5 to 74.5 Ma, second between 69.5 to 70.0 Ma and the third at 67.5 Ma. The three cycles of shoreline movement identified in the present study correlates very well with the three Maastrichtian transgressions identified by Haq *et al.* (1987).

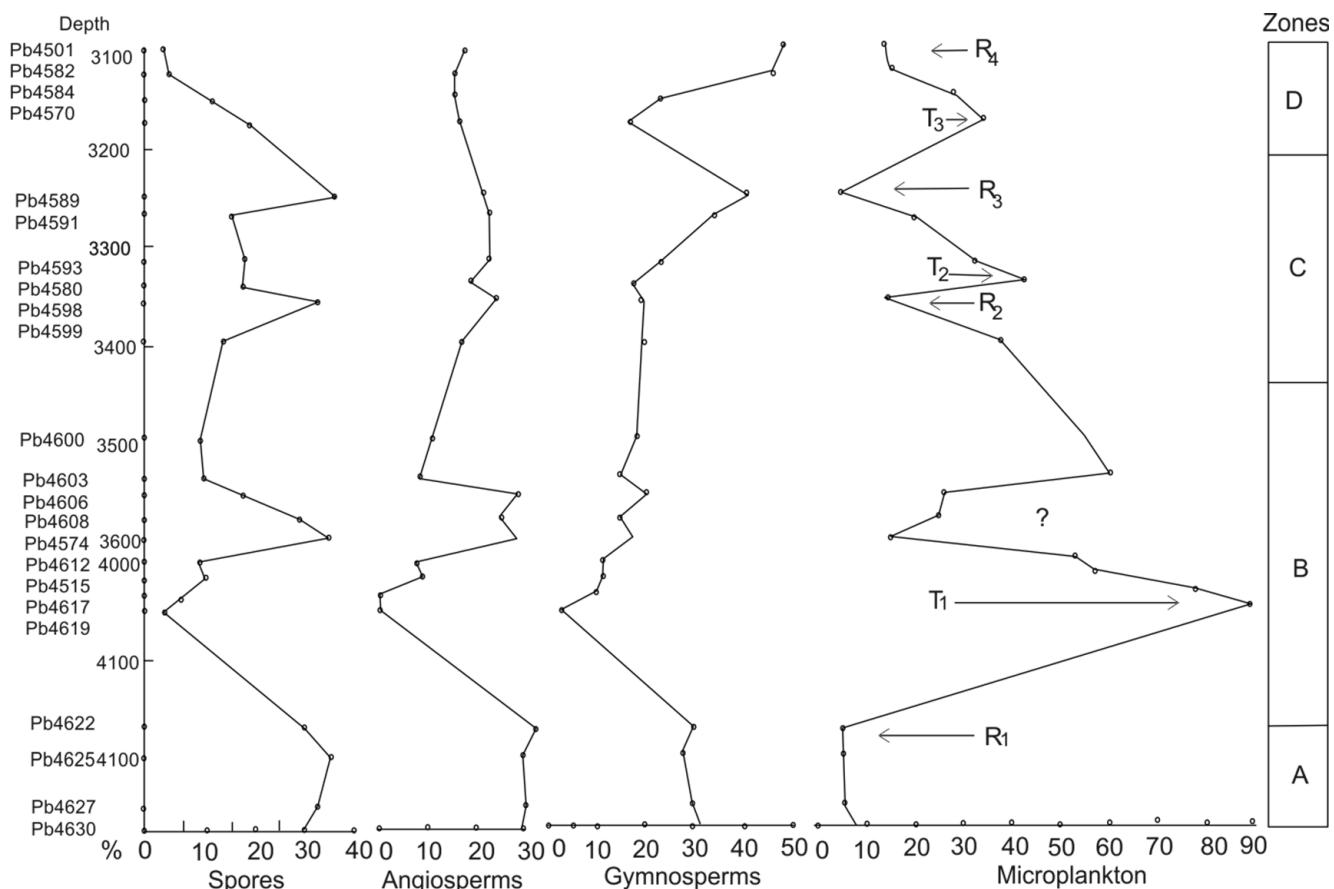


Fig. 12.—Percentage distribution of terrestrial palynomorphs (spores, angiosperm and gymnosperm pollen) and microplankton (dinoflagellate cysts and acritarchs) in the Frio Section (Frank Doering well # 1) shows three transgressive phases (T1, T2 and T3) and four regressive phases (R1, R2, R3 and R4). Four biozones A, B, C and D are defined in this section. There is an additional regressive phase between R1 and R2 not recognized in the Austin Section.

Maastrichtian flora of Texas

The duration of the Maastrichtian stage was relatively short in comparison with other stages of the Cretaceous and this has been calculated to be 7.5 Ma (Haq *et al.* 1987). During this period of time, the floral composition in Texas changed from predominantly pteridophytic and bryophytic floras in the early Maastrichtian to predominantly angiospermous floras in the middle and late Maastrichtian. Conifers were an important group throughout the Maastrichtian. The Llano Uplift was a highland area in central Texas and the nearby Marathon and Arbuckle Mountains were a source of the temperate elements of the Maastrichtian floras. Pollen belonging to the families Pinaceae, Betulaceae, Juglandaceae and Oleaceae inhabited these highlands and contributed to the palynomorph assemblages of Navarro Group sediments. The families Gingkoaceae, Cupressaceae, Cycadaceae, Araucariaceae, Ulmaceae, Nyssaceae, Symplocaceae and Bombacaceae formed woodlands on flood plains and river banks along lakes and seashores. Representatives of the families Ephedraceae, Proteaceae and Chenopodiaceae may

have been present in dry and halophytic regions formed as a result of marine regressions. The families Sparganiaceae, Liliaceae and Taxodiaceae inhabited coastal marshes, swamps and other wetlands; such habitats along with humid coastal forests and floodplain woodlands were also occupied by members of the families Lycopodiaceae, Selaginellaceae, Osmundaceae, Schizaeaceae, Gleicheniaceae, Cyathaceae and Polypodiaceae. Overall a warm tropical to subtropical climate prevailed throughout Maastrichtian time but highland regions were cooler temperate to sub-temperate.

CONCLUSIONS

Abundant and diverse spore-pollen floras are present throughout the Navarro Group.

The stratigraphic ranges and relative abundance of 121 spore-pollen taxa were used to establish four biozones (A, B, C and D) in the Austin Section by the author (Kumar, 1980). Biozone A corresponds to the undifferentiated Neylandville Marl-Nacatoch Sand Formation; Biozone B corresponds to the Corsicana Marl Formation; Biozone C corresponds to

the lower half of the Kemp Clay Formation and Biozone D corresponds to the upper half of the Kemp Clay Formation (Fig. 10). These biozonal boundaries do not always correspond to formation boundaries.

Biozones A, B, C and D in the Austin Section correlate to 4170–4270 feet; 3450–4170 feet; 3250–3450 feet and 3100–3250 feet in the Frio Section respectively.

The zonal boundaries based on spore–pollen distribution between the Austin and Frio Sections correlate well with the timelines established between these two sections on the basis of dinoflagellate cysts and acritarchs (Figure 10) by Zaitzeff and Cross (1970).

All the Navarro Group formations except the Olmos Formation were deposited under marine environments ranging from intertidal to outer shelf or even in the open sea environments. The Olmos Formation sediments were deposited in a range of coastal terrestrial environments with occasional minor influence of the sea.

Three transgressive phases (T1, T2 and T3) separated by four regressive phases (R1, R2, R3 and R4) are recognized in the Austin (Fig. 11) and Frio (Fig. 12) sections. These three cycles of shoreline movement identified in the present study correlate well with the three Maastrichtian transgressions identified by Haq *et al.* (1987).

During the Maastrichtian, the floral composition in Texas changed from predominantly pteridophytic and bryophytic in the early Maastrichtian to predominantly Angiospermous in the middle and late Maastrichtian.

Generally warm tropical to subtropical climate prevailed in Texas throughout the Maastrichtian but highland regions such as the Llano Uplift and the nearby Marathon and Arbuckle Mountains were cooler regions with temperate to sub-temperate climate.

The upper parts of the Navarro Group show a gradual cooling trend suggested by the dominance of temperate angiosperm pollen taxa.

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