An Early Permian Coastal Flora from the Central Basin Platform of Gaines County, West Texas

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Fossil plants are abundant in dolomite of the Clear Fork Group (Leonardian; late Early Permian) in the North Robertson Unit of the Robertson Clear Fork oil field of Gaines County, West Texas. The unit is a portion of the larger Robertson field. Thirty-seven separate collections were made from drill cores taken in three wells, spanning an interval 300 m thick from a depth below the surface of > 2000 m. The flora is depauperate, comprised of Comia *sp. (most abundant),* Taeniopteris *sp.,* Delnortea abbottiae*, callipterid-like foliage of uncertain affinity, calamite stems, and unidentified foliage of cycad-like character. Plants occur in discrete intervals that are a few cm to 3 m thick and have limited lateral continuity (less then 0.5 km). Plant-bearing dolomites contain interspersed fossil roots and burrows, weakly developed soil horizons, thin coaly accumulations of organic material, and pedogenic and collapse breccias. Fusain is common throughout. Between the plant-bearing layers are heavily bioturbated dolomites with anhydrite-filled burrows, interpreted as lagoonal to shallow subtidal in origin, up to 50 m thick. Contacts between marine units and plant-bearing beds are sharp.*

The North Robertson Unit and the field is believed to be internal to the Central Basin Platform and bordered by a shallow seaway to the east. The Central Basin Platform probably represented a broad peninsula between the Midland Basin to the east and the Delaware Basin to the west. The site probably consisted of innumerable little islands separated by a network of waterways. Plants occur in "island complexes" consisting of deposits formed in ponded water, beach fronts, and lagoons. Vegetation must have been tolerant of salt or salt spray, seasonal drought, wind, and storms; all species were robust in construction, with either thick leaves or heavy cuticles. This flora, although clearly allied with other Early Permian floras from western North America, is sufficiently peculiar to indicate that habitat differentiation was well developed within the tropical lowlands during the Late Paleozoic.

INTRODUCTION

The record of Early Permian plant fossils is based largely upon collections gathered from alluvial to coastal plain deposits. On occasion, subsurface samples from the oil and gas industry become available and provide data that enrich and extend our understanding of the surface record. In this paper, such an example is reported based upon cores recovered from the deep subsurface of the Central Basin Platform in Gaines County, West Texas (Fig. 1).

The Early Permian was a time of transition from the stereotypical Carboniferous flora of everwet climates to seasonally dry floras, which contained many of the elements that would characterize Late Permian and early Mesozoic vegetation (Frederiksen, 1972; Broutin et al., 1990; DiMichele and Aronson, 1992). The everwet flora was dominated in its later phases by marattialean tree ferns, pteridospermous seed plants, and lycopsids. The seasonally dry flora was dominated by seed plants, including callipterids, conifers, and a variety of other forms, some not yet linked clearly to established clades. Although the place of origin of the seasonally dry flora is uncertain, it is clear that it did not arise within, and then gradually displace the everwet flora. The rise of the seasonally dry flora in the tropics appears to have been a replacement driven by changing environmental conditions, especially a change from year-round rainfall to seasonal rainfall, spreading eastward across the tropics (Knoll, 1984; Phillips and Peppers, 1984).

The flora described here is clearly allied with others of seasonally dry aspect from late Leonardian of the southwestern United States. It seems not to be the remnants of an ancestral flora. Rather, it appears to be a coastal biofacies, an ecological variant of the broader, more diverse regional Early Permian biota.

GEOLOGY

Study Area

The North Robertson unit (NRU) of the Robertson Clear Fork field is located in Gaines County, West Texas, near the border with New Mexico (Fig. 1). Oil is produced from

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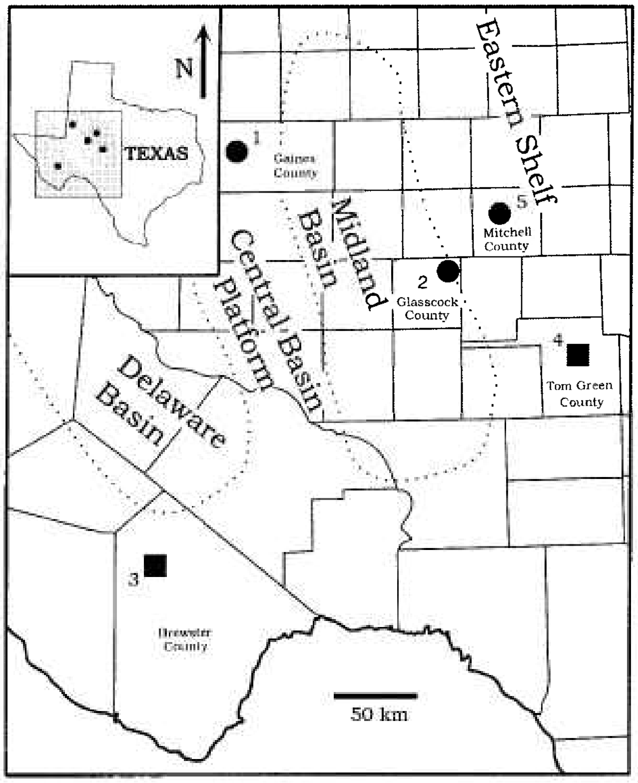

FIGURE 1—Location of plant collections discussed in this paper. Dots = core collections; squares = surface collections. (1) North Robertson Unit cores, Gaines County (details of NRU core locations are shown in FIGURE 2). (2) Specimen reported in core by Adams (1933), Glasscock County. (3) Flora reported by Mamay et al. (1988), Brewster County. (4) Flora collected in fall of 1999 by the authors, Tom Green County. (5) SE Westbrook field.

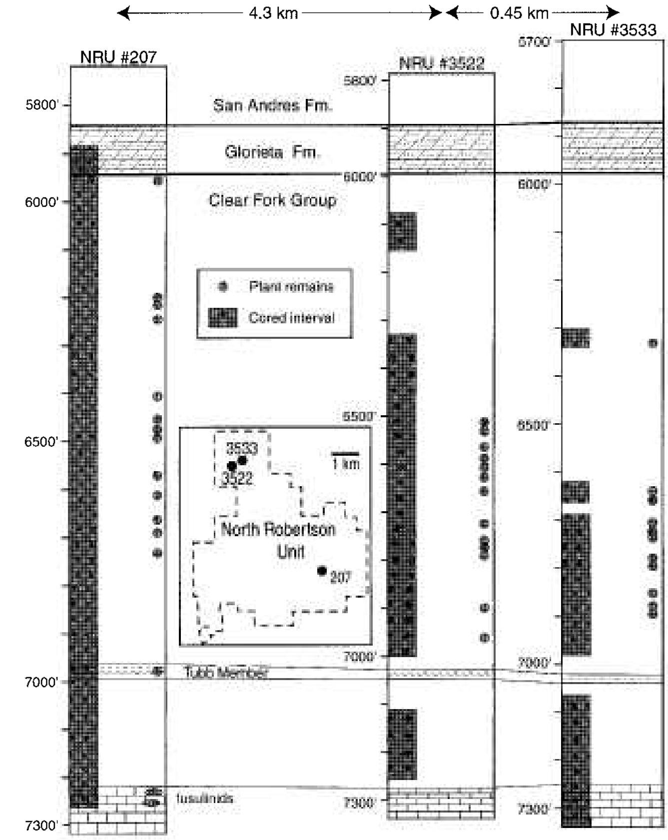

FIGURE 2—Comparative stratigraphy and relative location of North Robertson Unit cores examined in this study. Depths are given in feet below the surface.

multiple pay zones within the Clear Fork Group at depths of 1,780 to 2,255 m below the surface. Oil is found within virtually the entire thickness (424 m) of the Clear Fork, yet the reservoir is highly "compartmentalized," meaning that zones from which oil can be produced are thin and discontinuous. In an effort to discover how oil production from this and similar fields might be enhanced, a multi-year study of NRU was conducted jointly by oil companies and universities, with major funding from the U.S. Department of Energy. Part of this study entailed drilling many continuous cores of the reservoir interval, each approximately 10 cm in diameter and as long as 417 m (Montgomery, 1998; Montgomery and Dixon, 1998; Atchley et al., 1999; Pregger and Dixon, in press). The coring program at NRU presented a rare opportunity to collect fossil-plant specimens from the subsurface.

The NRU is situated near the eastern margin of the Central Basin Platform, a broad tectonic uplift that separates the Midland Basin, on the east, from the Delaware Basin, on the west (Fig. 1). Platform and basins developed during mid- to late Carboniferous time as a consequence of the Ancestral Rockies orogeny, which affected a vast area of the western and south-central United States. A complex set of steeply dipping, basement-seated fault zones separate the Central Basin Platform from the basins. By Early Permian time, the region generally became tectonically stable, but the Central Basin Platform remained as a shallow subtidal to intertidal platform, somewhat like the modern Bahama Banks (Pregger and Dixon, 1998). Meanwhile, the Delaware and Midland Basins, intracratonic basins hundreds of meters deep, progressively were filled by carbonate and fine-grained siliciclastic sediments.

Lithostratigraphy

The Clear Fork Group originally was defined on the basis of outcrops along the Clear Fork of the Brazos River north of Abilene, Texas, on the Eastern Shelf of the Midland Basin (Cummins, 1890, 1891). In the North-Central Texas type area (Fig. 1), the Clear Fork is composed dominantly of red mudstone, with minor amounts of gray mudstone, deposited on coastal plains and mudflats, sandstones of fluvial-channel origin, and thin but laterally extensive beds of intertidal to shallow-subtidal dolomite (Nelson et al., in press). Although correlative rocks on the Central Basin Platform are totally different lithologically, the name Clear Fork Group is traditionally applied in the subsurface of West Texas.

The Clear Fork is more than 400 m thick at NRU (Fig. 2), and consists dominantly of dolomite that contains common nodules of anhydrite and occasional interbeds 1-to-60 cm thick of gray-to-black dolomite. These dark gray to black fissile rocks resemble shale in hand sample but thin sections indicate a dolomitic composition. Such organic intervals yield high, or "hot", readings on gamma-ray logs, and are characteristic of the plant-bearing facies. An interval of siltstone to very fine sandstone, 3-to-10 m thick and a little over 300 m below the top of the Clear Fork, is correlated with the widespread Tubb Sandstone Member. The Clear Fork is overlain by the Glorieta Formation, which averages 35 m thick, and consists of interbedded siltstone, silty dolomite, and anhydrite. The Glorieta, in turn, is overlain by dolomite of the San Andres Formation. Carbonate rocks of the Abo or Wichita-Albany Group presumably underlie the Clear Fork but no wells at NRU reach this unit.

Age

Well-preserved fusulinids are abundant in limestone near the base of the cored interval, 70-to-80 m below the oldest fossil plants (Fig. 2). Fusulinids from this interval were examined by V. I. Davydov, who reports that they "show high similarity with those from unit A of the Leonard Formation. . . .or from sequence 1 of the Hess Formation in the Glass Mountains of Texas." Thus, the samples are correlative with the lower part of the type Leonardian Series and with the lower part of the Kungurian Series of Russia (V.I. Davydov, personal communication, 1999).

No biostratigraphically useful fossils were found in younger beds cored at NRU. However, King (1942) and Skinner (1946) reported that fusulinids, from an unstated locality, in the upper part of the Clear Fork are diagnostic of upper Leonardian rocks. Skinner (1946) also stated that the upper Leonardian fusulinid *Schubertella melonica* occurs in limestone interbeds of the San Angelo (Glorieta) Formation. Mear (1984) concurred in assigning the Glorieta to the uppermost Leonardian Series. However, other authors, such as Wilde (1975), have placed the Glorieta in the basal Guadalupian. Based on the above-cited information, fossil plants at NRU probably range from the middle to the latest part of the Leonardian Series.

Depositional Environments

Core data from NRU indicate that the lower part of the Clear Fork (below the Tubb Member) accumulated under shallow subtidal, open-marine conditions. The remainder of the unit represents a complex of shallow lagoons, shoals, tidal flats, beaches, and vegetated islands (Pregger and Dixon, 1998, in press). The oldest rocks cored at the NRU comprise at least 30 m of limestone: mostly light gray skeletal and oncolitic wackestone, packstone, and grainstone (Fig. 2). Fusulinids are abundant, along with brachiopods, bivalves, cephalopods, corals, echinoderm fragments, and algae. The limestones are interpreted as offshore shoals (Montgomery, 1998; Pregger and Dixon, 1998).

Overlying the limestone is about 70 m of dark-colored dolomite that is micritic and thoroughly burrowed. Anhydrite nodules represent 5% to 10% of the rock volume. The dolomite contains a marine fauna similar to that of the limestone, but specimens are sparser and less well preserved. The dolomite is believed to represent low-energy, offshore, subtidal settings (Montgomery, 1998; Pregger and Dixon, 1998).

The Tubb Member consists of faintly laminated and burrowed siltstone and silty dolomite, having a gradational lower contact and sharp upper contact. The Tubb is regionally widespread around the margins of the Midland Basin. This unit presumably reflects a progradational event, but little information has been published. The oldest plant fossil at NRU, a leaf of *Cordaites* sp., was recovered from the Tubb.

The remainder of the Clear Fork is close to 300 m thick, and consists of several varieties of dolomite that contain scattered thin (1 to 50 cm) carbonaceous layers. Among the of dolomite lithofacies are:

(1) *Lagoonal facies:* heavily mottled and burrowed, drab gray-brown dolomite to wackestone containing abundant anhydrite nodules. This facies occupies the largest volume and forms the thickest intervals (commonly 3-to-12 m thick).

(2) *Reef facies:* micritic dolomite having a framework of bryozoans in growth position and a diverse open-marine fauna. These were probably patch reefs less than 3 m high.

(3) *Reef debris facies:* large, rotated blocks of the reef facies (described above), surrounded by thoroughly burrowed carbonaceous dolomite and skeletal wackestone. Reefs and reef debris are mostly found below, or a short distance above, the Tubb Member.

(4) *Pond facies:* gray to olive-gray, sublithographic to very fine-grained, massive to faintly churned dolomite, generally 0.6-to-1.5 m thick. A few fossil plants are present.

(5) *Algal mat facies:* light gray, highly porous dolomite composed of algal mats either intact, or ripped up and redeposited. Rooting and dessication cracks (filled with anhydrite) are present near the top. This facies occurs as units less than 1.5 m thick. Upper and lower contacts typically are sharp and bounded by laminae of carbonaceous dolomite.

(6) *Beach facies:* yellowish-brown to mottled brownish-gray wackestone to grainstone with faint, inclined lamination or crossbedding. Dispersed organic matter and fossil plants are common. Contacts may be gradational or scoured. Units are typically less than 2 m thick.

(7) *Island facies:* yellowish-gray to dark brown, organic-rich dolomite to wackestone, having faint disrupted layering, burrows, and root traces. Vitrain stringers, fusain, and fossil plants are abundant. Intervals are commonly 0.5-to-2 m thick.

These lithofacies recur multiple times in succession in the cores examined. No particular order or cyclicity of rock types is evident. Interbeds of laminated dolomite and some plant-bearing, organic-rich dolomite layers are represented by "spikes" of high gamma-ray and low density readings on these logs. When the first three cores are compared (Fig. 2) it is evident that plant-bearing zones match only in a general way between wells NRU 3533 and NRU 3522, which are only 450 meters apart. When these two wells are compared with NRU 207, which lies 4.3 km away, hardly any plant-bearing intervals correspond. Limited lateral continuity of individual "spikes," representing clastic or organic layers, can be demonstrated using closely-spaced wireline logs, 200-to-300 m apart throughout the NRU. The Tubb is the only unit correlative across the entire NRU.

The Glorieta Sandstone crops out extensively in northern and central New Mexico, where it ranges up to 90 m thick and is interpreted as aeolian dune sand (Presley and McGillis, 1982). The Glorieta thins toward the southeast and grades to siltstone, mudstone, and evaporites. It has been traced onto the Central Basin Platform, pinching out near the margin of the Midland Basin (Silver and Todd, 1969). Thus, the NRU lies near the southeastern limit of the Glorieta, where it grades into carbonate rocks.

MATERIALS AND METHODS

Specimens examined come from three cores taken in the NRU. All cores were slabbed vertically, curated, and stored in a specially designed facility in Midland, Texas. All fossil plant specimens removed from the selected cores are housed in the Paleobotanical Type Collection of the National Museum of Natural History. USNM specimen numbers are assigned to all illustrated specimens and are referred to in the figure captions.

Specimens were collected from the following cores: NRU 207, NRU 3522, and NRU 3533. All wells are located on the Paynes Corner 7.5' topographic quadrangle, Gaines County, TX. Different oil companies have different names for these wells. Because work was conducted in the FINA core facility in Midland, TX, FINA's names for these wells have been used in this paper, although the other names are provided as well.

(1) FINA Oil and Chemical NRU 207 also is known as Tenneco Oil Co. NRU 201-B. The API number (a unique number assigned to every well when drilled) is 42–165–33599. The well is located 2530 ft. from south line, 2640 ft. from east line, Section 5, Block AX, Public School Land Survey. UTM 13SGG09371553.

(2) FINA Oil and Chemical NRU 3522 is also known as Tenneco Oil Company NRU 3510-B. The API number is 42-165-33604. The well is located 2640 ft. from south line, 2640 ft. from west line, Section 329, Block G, Corpus Christi, San Diego and Rio Grande Narrow-Gauge Railroad Survey. UTM 13SGG06001874.

(3) FINA Oil and Chemical NRU 3533 is also known as Tenneco Oil Company NRU 3533. The API number is 42-165-34970. The well is located 2650 ft. from south line, 1981 ft. from east line, Section 329, Block G, Corpus Christi, San Diego and Rio Grande Narrow-Gauge Railroad Survey. UTM 13SGG06211876.

Cores from the three boreholes were described in their entirety and well-to-well correlations were based on these cores and wire-line logs (gamma-ray, neutron, and density) from nearby wells within the NRU. The organic-rich and laminated intervals were split to reveal plant fossils. Forty-eight plant-bearing intervals of varying thickness were identified. Collections were made from 37 of these intervals. An additional 11 collections came from miscellaneous core segments not tied to specific depths. A collecting interval was identified as a continuously fossiliferous sequence without significant lithological discontinuities. A total of 239 unique surfaces were collected for plant fossils (part and counterpart are considered the same surface).

The flora was analyzed quantitatively by treating each unique surface as a sampling quadrat (quadrat = a standard sampling unit). The basic method described by Pfefferkorn et al. (1975) was employed (see also DiMichele et al., 1991). The presence of a species on a surface was counted only once, regardless of how many distinct leaves or axes were identifiable or how large the fragments might have been. Therefore, the resulting data are reported as frequencies rather than as absolute abundances.

Photographs were made of each interval from which plants were collected. Cores had been slabbed longitudinally, revealing the lithological characteristics of the rocks. A photographic slide set from these cores is deposited with the specimens in the Paleobotany Collections of the National Museum of Natural History. All illustrated specimens are housed in the Paleobotanical Type Collections.

Two additional USNM specimens from well cores, but not from the NRU, are mentioned in this paper. The first was collected from Fina Oil and Chemical Company well 718, from the Northeast Westbrook Oil Field. This small field is located 2 miles due west of Westbrook, Mitchell County, TX, in the Westbrook 7 ½' Quadrangle (latitude 32.3583, longitude 101.0666). The second specimen, of *Delnortea,* was described by Adams (1933). It is from the Currie No. 3 well of northeastern Glasscock County, TX, in the Forsan 7 ½' Quadrangle. The well location is W & NW Railroad Survey, Blk. 29, Section 219, 330 ft. from the center point of the north line (latitude 32.0171023, longitude 101.3741102).

PALEOBOTANY

Abundance of Taxa

The most abundant plant in the collection is *Comia* sp., which appears in 165 out of 239 total quadrats. This is followed by *Taeniopteris* sp. in 76 quadrats, *Delnortea abbottiae* in 40 quadrats, and a callipterid-like compound leaf in 13 quadrats. Calamite stems were identified in four quadrats. Only six occurrences of seeds were noted. Fusain was identified in 44 quadrats and was observed, but not sampled, in many other intervals within the three cores.

The order of importance of taxa is the same in individual boreholes NRU 207 and NRU 3522. In borehole NRU 3533 the callipterid-like foliage is more common than *Delnortea abbottiae.* Also, NRU 3533 was the only core that contained spirorbid worm tubes, identified in eight quadrats.

Analyses of individual sampling intervals, based upon quadrat occurrences of taxa within those intervals, reveals that *Comia* sp. ranks first in 25 of the 37 collecting intervals. *Taeniopteris* sp. ranks first in six, *Delnortea* ranks first in one. The callipterid-like foliage and calamite stems do not rank first in any sampling interval. In five intervals, rank abundance was tied.

Flora

Comia

Comia Zalessky is a genus of pteridophyllous foliage, probably from seed plants related to the callipterid peltasperms. The genus was described by Zalessky (1934) based on sterile material from the Late Permian of the Russian Pechora Basin. Many species, all of Late Permian age, have been described from Russia and China (Burago, 1983; Huang, 1977). Leaves are pinnately compound

(Figs. 3A, 3B, 3C). There are three orders of venation in each pinna, organized in distinct fascicles (Fig. 3G). Secondaries arise from a main vein. At regular intervals some secondaries give rise to non-anastomosing, open dichotomous, strongly upswept tertiaries that form a fascicle. Between fascicles are one or more individual secondaries that do not divide further. This distinct venation, though clearly related to callipterid venation, is often difficult to differentiate from the latter when preservation is poor or fragmentary.

Species of *Comia* are common in the later Early Permian (Leonardian) of the southwestern United States. The genus can be a numerical dominant locally. Mamay et al. (1996) identified three species in north-central Texas; these have yet to be typified formally. One of these species appears to be that found in the NRU cores. The distinctly thick lamina and cuticle form a somewhat flexible organic sheet in the rock matrix. Large fragments of leaves are preserved, suggesting minimal transport.

Delnortea

Delnortea abbottiae Mamay, Miller, Rohr and Stein, is a monotypic genus of American gigantopterids, first described from surface exposures of the Road Canyon Formation of the Del Norte Mountains in Brewster County (Fig. 1), southwestern Texas (Mamay et al., 1988). At present, this is the youngest reported occurrence of a gigantopterid in North America. The species also occurs in core from the upper Clear Fork in Glasscock County, Texas (Adams, 1933), and has been found by the authors in surface exposures in Tom Green County, Texas. The relationship of the taxon to other gigantopterids is uncertain, although it shares the basic morphological features of the other western taxa known from more than fragmentary specimens (*Gigantopteridium, Cathaysiopteris, Zeilleropteris,* and *Evolsonia*). Like other American gigantopterids, it is morphologically distinct from Chinese gigantopterids. American forms are characterized by forked or simple leaves. Venation is complex with a strong midvein and pinnate secondaries; tertiaries arise from the secondaries and anatomose to form a reticulum, in some cases with areoles. A sutural vein may form where tertiary or higher order veins that originated from one secondary encounter those from the adjacent secondary.

Delnortea abbottiae is unique in that the secondary veins terminate in the sinuses of the crenulate margin and that the secondaries extend all the way to the lamina margin and there fuse with a marginal indurated border (Figs. 3D, 3E, 3F). An indurated border is not known in other gigantopterids. The lamina is vaulted between the secondaries and is relatively robust. *Delnortea abbottiae* is known to vary in size from 1.2 to 35 cm long and 0.8 to 8.5 cm wide.

The *Delnortea abbottiae* in the NRU cores is easily identifiable and conforms well to the original circumscription of the species.

Taeniopteris

Taeniopteris is one of the most widespread, common form genus of Permian foliage. The genus is not monophyletic, and includes both ferns and seed plants. Some Permian species appear to be related to cycads (Mamay, 1976). Remy and Remy (1975) provide one of the most comprehensive surveys of the species from the Late Carboniferous and Permian. Although some species stand out due to combinations of characters such as size, shape, and venation, a great deal of intergradation among species is found in most floristic studies, which makes species distinctions difficult.

Taeniopteris specimens from NRU are not assigned to any species, new or previously described; however, the collection appears to be monospecific. All specimens are fragmentary and frequently occur in dense mats. Midrib and lamina width do appear to correlate strongly. The maximum laminar width encountered was 3 cm, with a midrib width of 0.25 cm (Fig. 4B). In a specimen with a lamina width of 2.5 cm, the midrib was 0.35 cm wide (Fig. 4C). The apical portion of the lamina is elongate and tapers gradually (Figs. 4D, 4E), although the ultimate tip was not found. Midveins are straight. Laterals depart at a steep angle then straighten, approaching the margin at angles of 12-to-15 degrees and flex upward slightly near the margin, giving them an overall sinusoidal shape (Figs. 4F, 4G). Venation is open dichotomous and most dichotomies are concentrated near the midrib. Preservation prevents a clear assessment of the frequency of branching, but there do appear to be some vein dichotomies in the middle portion of the lamina. There are approximately 35-to-40 veins per cm of margin in the widest portions of the lamina.

Pinnate Foliage

A few specimens appear to be at least bipinnate leaves (Figs. 5A, 5B). Primary pinnae are borne suboppositely and measure a maximum of 3 cm long, shortening acropetally, toward the apex of the leaf (not observed), to small lobes. They are borne at an acropetal angle of 30 degrees from the horizontal and are separated by their width from the adjacent pinna, making the whole aspect very open. The primary pinnae bear pinnules or lobes. The lobes are subopposite, up to 0.6 cm wide and project approximately 0.1-to-0.3 cm from the broader pinna lamina, which can be as wide as 1.1 cm. Up to 6 lobes per side were observed. The apex of the primary pinna is rounded. The laminae of these leaves must have been very thick and fleshy, perhaps almost succulent. This is inferred from the lack of surface features, except for wrinkles on some specimens (Fig. 5B), and from frequent coalification of the laminae, which is unusual for leaf tissue.

The affinities of these organs are uncertain. They bear some similarities to *Peltaspermum martinsii* known from the Late Permian Zechstein flora of Europe (Schweitzer, 1986; Poort and Kerp, 1990). *Peltaspermum martinsii* has small, subopposite pinnae and a thick lamina, with small rounded pinnules, somewhat better individuated than those in the specimens from the NRU cores.

Other Rare Elements

A few probable calamite stems were encountered. They have weakly developed nodes, but ribbing typical of calamite stems. No associated foliage or reproductive organs were found.

Two small, broken specimens appear to be pinnate fo-

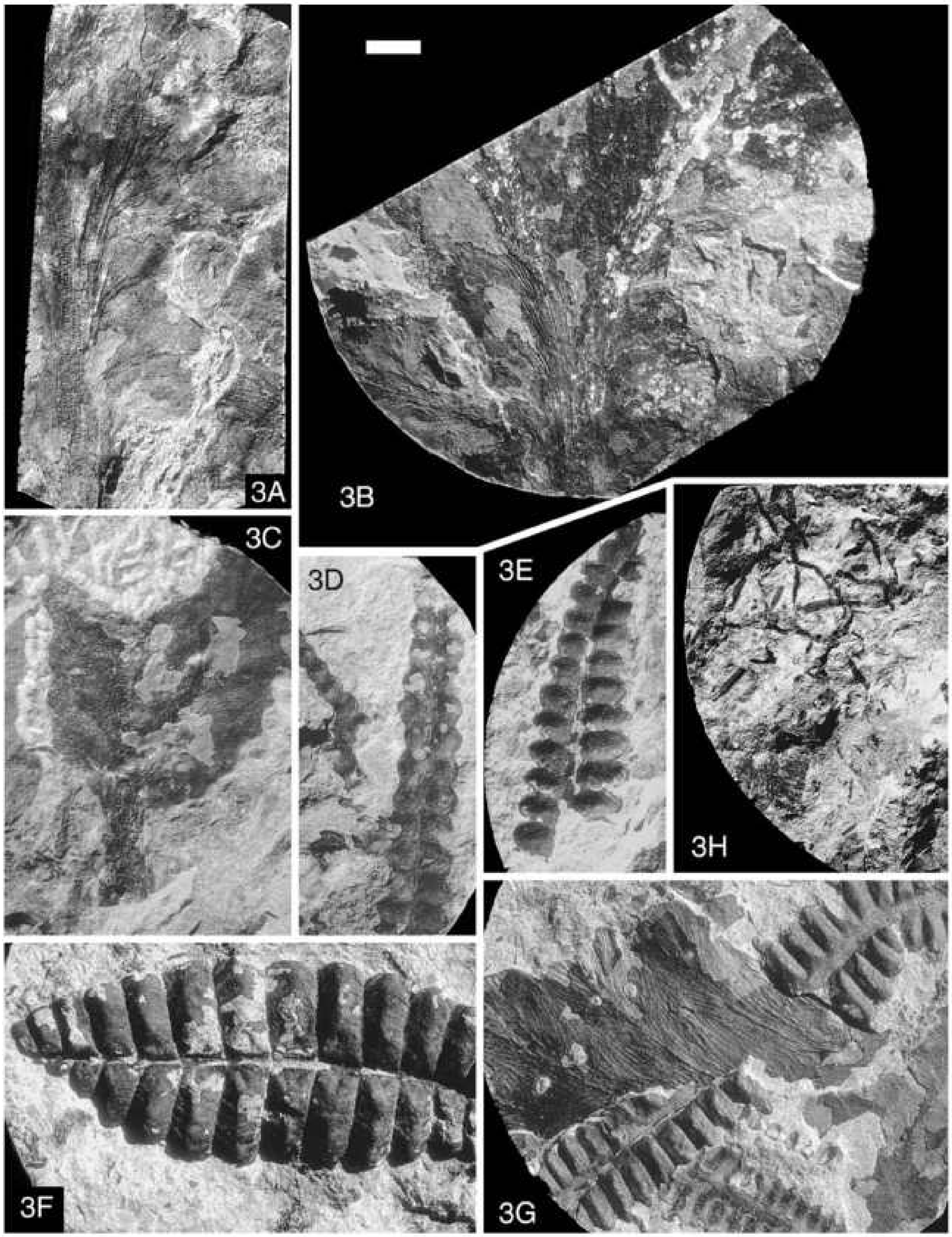

FIGURE 3—Specimens from North Robertson Unit cores. All specimens at same magnification; bar scale at top of figure = 1 cm. (A) *Comia* sp., leaf segment illustrating forked rachis. USNM 508171. (B) *Comia* sp., leaf segment illustrating pinnae and main rachis. USNM 508172. (C) *Comia* sp., leaf segment illustrating base of leaf or base of lateral pinna. USNM 508173. (D, E, F) *Delnortea abbottiae,* successively wider specimens, each with characteristic crenulate margin and sutural veins that end in sinuses. USNM 508174, 508175, 508177. (G) *Comia* sp. and *D. abbottiae.* Veins on *Comia* sp. illustrate distinctly fasciculate venation. USNM 508178. (H) Roots of indeterminate affinity. USNM 508176.

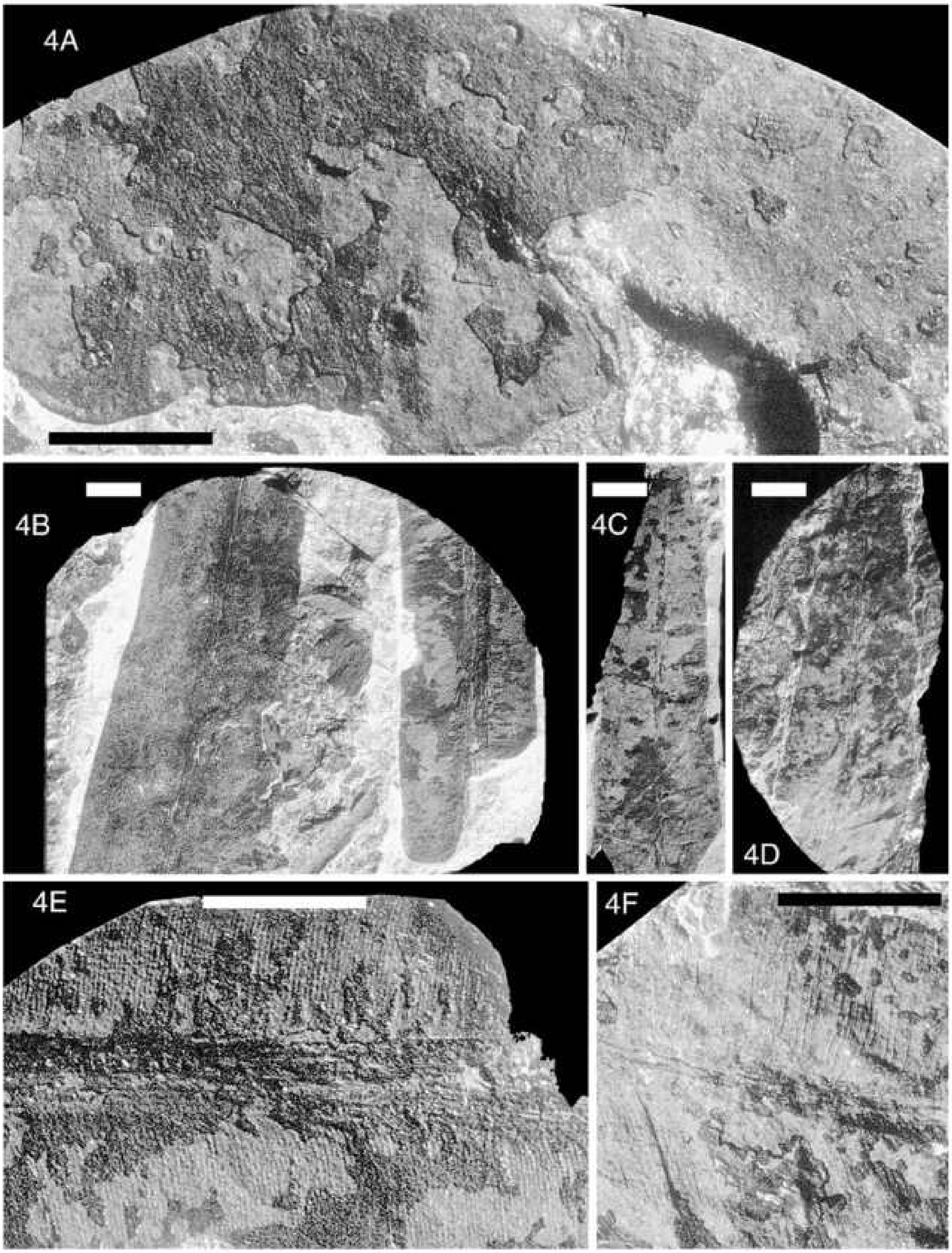

FIGURE 4—Specimens from North Robertson Unit cores. (A) *Comia* sp. lamina with numerous spirorbid worm tubes attached to surface. Scale = 1 cm. USNM 508179. (B) *Taeniopteris* sp., fragments of laminae from mid-portions of leaves illustrating relative proportions of lamina and midvein. USNM 508180. (C, D) *Taeniopteris* sp., fragments of apical portions of leaves illustrating tapering of the lamina. USNM 508181, 508182. Scale in B = 1 cm and applies to B—D. (E) Magnification of portion of specimen illustrated in B, illustrating venation. (F) Magnification of portion of specimen illustrated in D, illustrating venation. Scale in E = 1 cm and applies to both D and E.

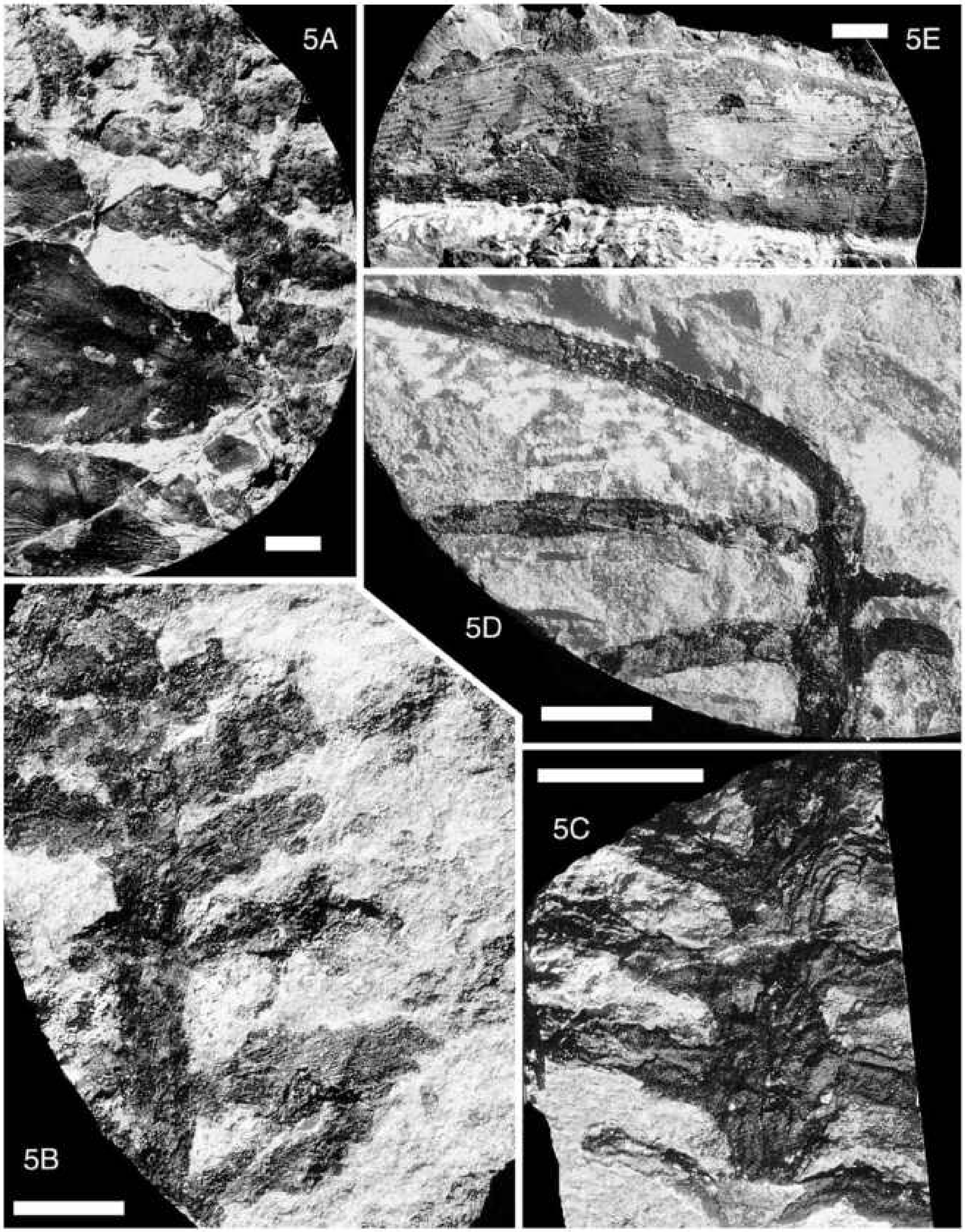

FIGURE 5—Specimens from North Robertson Unit cores. (A) Callipterid-like pinnate foliage, on right side of specimen. Surface of lamina is punctate, pinnae are lobed. Laminae on lower side of specimen are *Comia* sp. Scale = 1 cm. USNM 508183. (B) Callipterid-like pinnate foliage. Great thickness of lamina is illustrated by the wrinkled nature of the lamina surfaces. Scale = 1 cm. USNM 498845. (C, D) Fragments of unidentified pinnate foliage of cycad-like character. USNM 498846, 498844. Scale bar in 5C = 1 cm and applies to both C and D. (E) Cordaite-like leaf with parallel veins. Scale bar = 1 cm. USNM 508184.

liage (Figs. 5C, 5D). They are characterized by central rachises 0.6-to-0.7 cm in diameter bearing subopposite pinnules. Pinnules are approximately 0.2-to-0.3 cm wide, and are separated on the same side of the rachis by approximately 0.2 cm. The maximum observed length of an incomplete pinnule is 5 cm. The lamina was thick, indicated by its wrinkled surface, probably resulting from a combination of compaction and dessication. Venation is not clearly visible; there are faint traces of fine, parallel veins, but these are not developed continuously enough to be certain of their nature. The specimens are far too fragmentary to identify, but they resemble *Pseudoctenis middridgensis* from the Late Permian English Zechstein (Stoneley, 1958).

One specimen of a possible cordaite leaf was found (Fig. 5E). The specimen is somewhat deformed and has strongly developed parallel striations that appear to be veins. No further identification is possible.

DISCUSSION

The flora of the North Robertson Unit appears to represent coastal vegetation, probably scrubby and growing in a habitat where it was stressed. Colonization surfaces were likely of low relief and relatively short-lived, suggested by weakly developed paleosols, the biogenic and chemical-precipitate nature of the deposits, the superposition of beach front, pond, and lagoonal facies, and the development of these facies as numerous, thin beds that comprise the plant-rich zones. The plants probably were subject to salinity from salt spray and/or groundwater. Plants probably grew amid a mosaic of small islands separated by open water. Colonization of new islands must have involved physical means such as water and air transport of seeds and spores, considering that some of the biological means by which plants disperse their seeds today, such as birds, did not exist during the Permian.

The only clearly identifiable disturbance agent in this terrestrial system is fire. Fusain is common in many collecting intervals. It also occurs apart from macrofossil remains in many parts of all three cores, but generally in terrestrial facies. All charred tissues are woody, indicating that at least some of the plants were trees or shrubs. The sheer abundance and wide distribution of fusain in the cores indicates a substantial woody standing biomass and, thus, ground water availability sufficient to support it. Widespread evidence of burning on these islands also implies periods of dryness and the accumulation of woody debris.

The composition of the vegetation is not particularly unusual for the late Leonardian. *Comia, Taeniopteris,* and gigantopterids are common elements in floras of similar age in north-central Texas and Oklahoma. However, the NRU flora is significantly less diverse than temporally equivalent floras from floodplain settings, which are encountered more commonly in the fossil record. Conspicuously missing are conifers, so abundant in most of the Early Permian in seasonally dry environments. Also lacking are some of the more mesomorphic seed plants, such as *Autunia conferta* and *Compsopteris.* Nothing in the flora had a sprawling or rampant, ground-cover habit. Thus, the flora appears to have been specialized for growth in this demanding environmental setting. Every element is highly xeromorphic, even possibly the calamites, for which a few stems but no foliage is known. The unidentified, callipterid-like foliage displays this to the maximal extent, to the point of being preserved in a coalified, vitrinized state, which implies great thickness to the leaves.

Similar florules have been discovered around the margins of the Midland Basin and on other possible islands in the Permian Basin complex (Fig. 1). Material from the Del Norte Mountains (Mamay et al., 1988) was recovered from surface outcrops of Roadian age (early Guadalupian, Middle Permian; Glenister et al., 1999). Another surface deposit was discovered recently in Tom Green County, in the Choza Formation, Clear Fork Group, of late Leonardian age. Adams (1933) reported a single fossil, now recognized as *Delnortea* from the upper part of the Clear Fork Formation in Glasscock County. Thus, the larger flora is known from late Leonardian through early Guadalupian, in a broad area of West Texas maintaining its character whenever larger samples can be obtained. A single specimen of indeterminate affinity has been collected from 3107 foot depth in well number 718 of the Southeast Westbook oil field in Mitchell County, Texas.

In general, *Comia* sp. is widespread and abundant in a range of habitats during the Early Permian. *Taeniopteris* from NRU does not fit easily into any known species; the genus, however, is widespread and clearly included a wide range of habitat specialists. *Delnortea abbottiae* is known from only three other sites, all of similar age and paleogeographic setting—near the rim of a deep basin in West Texas (Fig. 1). The report of this fossil by Mamay et al. (1988), in the Road Canyon Formation (type Roadian Stage) of the Del Norte Mountains, may be coeval with the youngest plant-bearing beds at NRU. A gigantopterid that Adams (1933) collected and illustrated, as a probably fragment of *Gigantopteris americana,* from a drill core in Glasscock County, Texas, is *D. abbottiae* (Sergius Mamay, oral communication, 1999; this specimen resides in the collections of the National Museum of Natural History as specimen number USNM 41167). This fossil came from the upper part of the Clear Fork Group on the Eastern Shelf, near the margin of the Midland Basin. Adams (1933) considered it to have grown in a near-coastal, possibly island habitat, similar to that inferred in this study. The third occurrence, discovered in the fall of 1999 in Tom Green County, is from a silty gray mudstone located immediately below a dolomite bed, within an interval of interbedded dolomites and mudstones, near the top of the Choza Formation, again, apparently, in a near-coastal setting. The callipterid-like foliage and the pinnate laminate foliage both resemble plants more characteristic of the Late Permian Zechstein flora of Germany and England, elements of which have been found near the Lower-Middle Permian boundary in North-Central Texas; the Zechstein flora also is thought to have grown in an arid regime.

Although the floras from Tom Green and Brewster Counties are comparable to that from the North Robertson Unit in their low diversity, the composition and dominance patterns differ. In Tom Green County, the small flora, collected from a single excavation, is dominated by *D. abbottiae. Taeniopteris* sp. and a conifer with fleshy, scale-like foliage are common. Occurring rarely are sphenopterid-like foliage, possibly *Sphenopteridium,* and fragments of pecopterid-like pinnules. The flora from Brewster County, reported by Mamay et al. (1988), is dominated by *Delnortea abbottiae* with only a few specimens of *Taeniopteris* sp., unidentified conifers, and fragments of sphenopsid axes and pecopterid foliage. Thus, it is more like the Tom Green flora than that from NRU. The low diversity of all these floras is consistent with a widespread, depauperate flora specialized for growth in stressful coastal habitats, dominated by a mixture of taxa drawn from the larger regional flora, such as *Comia* sp. and *Taeniopteris* sp., and including some coastal specialists, such as *D. abbottiae,* and perhaps the coniferous elements.

Quantitative analysis of the NRU flora does not reveal any particular patterns of environmental partitioning among the several subenvironments in which plants have been found. Given the small size of sampling "quadrats" and the general abundance of *Comia,* there is no reason to believe that differences among sampling intervals reflect anything more than natural patchiness in an otherwise common flora.

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