Reports

Late Leonardian Plants from West Texas: The Youngest Paleozoic Plant Megafossils in North America

Abstract. *Abundant Permian plant megafossils were discovered in the Del Norte Mountains of Brewster County, Trans-Pecos Texas. The flora is dominated by a new and distinctive type of gigantopteroid leaves. Marine invertebrates are closely associated, and this admixture of continental and marine fossils indicates a deltaic depositional setting, probably on the southern margin of the Permian Basin. Conodonts indicate correlation with the uppermost Leonardian Road Canyon Formation in the Glass Mountains. These are the youngest Paleozoic plant megafossils known in North America; they add an important paleontological element to the classic Permian area of this Continent.*

The Permian geologic system of North America is defined in terms of a standard sedimentary rock section exposed in West Texas (*1*). This sequence contains four provincial series: the Wolfcampian, Leonardian, Guadalupian, and Ochoan, in ascending order. Some units, particularly in the Glass Mountains, contain abundant invertebrate fossils (*2*), but the rocks are largely of marine origin, generally unfavorable to preservation of land plants; only sparse plant fragments have been reported (*3*).

Farther east in Texas, and in some areas of Arizona, Kansas, New Mexico, Oklahoma, and Utah, continental facies of the Permian System contain a variety of plant megafossils. Several distinct floras have been recognized and documented (*4*). Two other North American occurrences of Permian plant megafossils are known, both distantly separated from the Texas deposits. These are the mideastern Dunkard Basin flora with its callipterid element (*5*), and a small assemblage from southern Alaska, apparently related to Asiatic Permian plants (*6*). These floras are at least as old as the Vale Formation (Clear Fork Group, Leonardian Series) of north central Texas, and all available evidence indicates that they are older than the material reported here.

The scarcity of identifiable plant megafossils in the area of the standard Permian section or, indeed, in any late Leonardian or younger Permian rocks has constituted a serious deficiency in American paleontology. Late in 1981, however, abundant plant megafossils were found in West Texas; preliminary collections indicate that this deposit will furnish important information on Permian paleobotany in North America.

The fossiliferous beds were discovered fortuitously by geologic mappers in the Del Norte Mountains in Brewster County, 1.7 km south of Bird Mountain, southeast of Alpine (30°N). These outcrops are predominantly shales and sandstones. Originally they were mapped by King (*1*) as components of the Guadalupian Word Formation, but Cooper and Grant (*7*) regard them as uppermost Leonardian (Road Canyon Formation). Notwithstanding, the Del Norte beds contain the youngest Paleozoic plant fossils known in North America. They are in sight of the nearby Glass Mountains with their extensive marine faunas (*2*).

The initial site contained leaf impressions and compressions with traces of coalification in a few thin, calcareous siltstone beds, intercalated among shales and sandstones. The entire plant-bearing sequence is several meters thick; it is partly overlain by a lenticular, graded conglomerate containing sparse, small fragments of silicified wood. Later, abundant silicified wood was found in a conglomerate about 200 m northwest and 75 m higher in the section than the original leaf deposit. Leaf remains are absent from this higher site.

A generous landowner provided a bulldozer, and about a half-acre of overburden was removed; the accessible lateral extent of the leaf beds proved to be about 50 m. The beds dip steeply away from their originally exposed faces, and further excavation may be difficult.

Vascular plant material is abundant but taxonomically limited in the leaf deposit. Five groups have been identified thus far: sphenopsids, pecopterids, conifers, taeniopterids, and gigantopteroids. Sphenopsid structures are rare, and only a few sterile, *Pecopteris*-like fern fragments are present.

Conifers occur as silicified wood and slender vegetative shoots, 5 to 10 cm long and densely clothed with small, needle-like leaves. Also rarely present are a few small, flattened seeds of cordaicarp or samaropsid affinity; these are consistent with a coniferous element in the flora. Further indication of a conspicuous coniferous population is shown by the silicified wood, occurring as log fragments up to 30 cm in diameter. These have simple wood structure with bordered pits and uniseriate rays; they are referable to the common Paleozoic genus *Dadoxylon*.

Taeniopteris, characterized by long, linear leaves with open, pinnate venation, is moderately abundant. At the Del Norte site it reaches 30 cm in length, 6 cm in width, and has midribs with basal widths of 18 mm. Three specimens are of special interest because they bear either *Samaropsis*-like ovuloid structures or closely spaced ovoid bodies, possibly immature polleniferous organs, along each side of the midrib. Affinity of these apparently fertile taeniopterids with the genus *Spermopteris* (*8*) is being considered.

The dominant and most distinctive plant in the Del Norte flora is represented by abundant detached leaves, provisionally referred to here as "gigantopteroid." This terminology is applied because the large size and complex reticulate venation of these leaves resemble the Asiatic genus *Gigantopteris* and certain Permian American leaves, heretofore called by the same formal name (*4*). True natural relationships aside, the Del Norte leaves are the most spectacular and phylogenetically enigmatic foliar organs in all of the American Paleozoic.

These leaves are simple and petiolate, with elongate-elliptical laminae reaching 20 cm in length and 7 cm in width; the smallest is about 3 cm long and 1.5 cm wide. The laminae are relatively unmodified, with regularly scalloped outlines; the shallow marginal sinuses are about 1 cm apart in the largest leaves. Relatively long (1/4 to 1/5 the length of the lamina), stout petioles are present on many of the better specimens (Fig. 1B). Some have a flaring base, suggesting a clasping function.

The complex vasculature of the gigantopteroid leaf involves four orders of venation (Fig. 1E). The midrib is straight, very stout, and produces strong, undivided secondary veins that depart alternately or suboppositely at broadly obtuse angles, each vein terminating in a marginal sinus of the lamina (Fig. 1A). Tertiary veins likewise are straight and simple, departing at broad angles and seemingly meeting at a groove or ridge halfway between and parallel to the secondaries; an overall "herringbone" design is thus formed (Fig. 1D), with rows of obliquely oblong reticulations in the lamina delimited by the confluences of the secondary and tertiary veins. An ultimate (fourth) order of veins arises from the tertiaries; the tips of opposing and adjacent quaternaries fuse to form a dense system of small, irregularly shaped areoles (Fig. 1E).

Two other features distinguish these leaves. The termination of the secondary veins in the marginal sinuses of the lamina rather than in alternating positions, as one would expect, is unknown among other Paleozoic plants. Furthermore, some of the better-preserved leaves have their midribs and secondary veins reinforced by a thick, coalified tissue that continues into and along the laminal margin, connects the ends of the secondaries, and sharply delineates the outline of the leaf (Fig. 1A). This border, probably a mechanical support rather than a conductive connection between secondary veins, distinguishes this leaf from all other gigantopteroids.

Associated with the flora is a sparse fauna consisting of marine gastropods and conodonts. The gastropods are shelly fragments lying on the same bedding planes as the plants. One bellerophontacean gastropod, possibly *Cymatospira* or *Patellilabia*, and several indeterminate pleurotomariaceans are present. These characterize late Paleozoic deltaic sequences in north central Texas and suggest that the plants were deposited in a marginally marine situation (*9*).

Conodonts occur in limestones closely bracketing the plant beds. These were recovered from acid residues by Wardlaw, who also collected the bulk samples (*10*). The conodonts not only indicate marine deposition, but also provide important stratigraphic control in regard to the standard Permian section. According to Wardlaw, the Del Norte conodonts indicate correlation with the lowermost Road Canyon Formation or the uppermost Cathedral Mountain Formation in the Glass Mountains Permian section. Their intermediate position between the conodonts thus places the plant fossils at a level very high in the Leonardian, and certainly above the Vale Formation, in which the next older known American floras occur. Thus there is no doubt that the Del Norte plants are younger than any other Paleozoic plant megafossils known in North America.

The Del Norte flora is extraordinarily significant because of its geographic isolation from related Paleozoic plants, its paleobotanical age relationships, the morphological innovations of its dominant plant (the gigantopteroid), and the paleogeographical implications of its biotic relationships.

This flora contains the southernmost Permian plant megafossils known in North America, and the only ones in Trans-Pecos Texas. The nearest Permian floras in Texas occur in the lower Leonardian Vale Formation of Taylor County, some 400 km to the northeast (*11*); these are also dominated by gigantopteroid leaves but they are sufficiently different from the Del Norte leaves in size, venation, and other features that taxonomic separation on the generic level seems justifiable. With its specialized margination and venation, the Del Norte gigantopteroid accentuates the biological intrigue attending the ancestry and progeny of this poorly understood group of circumboreal Permian plants, and invites intensified search for links with the earlier Vale forms and unknown later ones (*12*). Whether or not such unknowns are found, the Del Norte gigantopteroids are morphologically distinctive enough that, with their high Paleozoic position, they promise to assume utility as valuable nonmarine guide fossils; indeed, they probably will serve as the basis for an Upper Paleozoic floral zone that would climax the biostratigraphic zonation proposed by Read and Mamay (*4*).

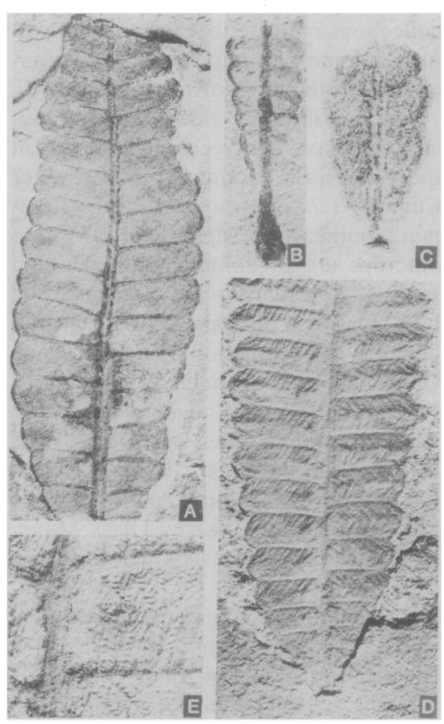

Fig. 1. Del Norte gigantopteroid leaves. (A) Nearly complete leaf, showing strong, reinforced midvein and secondaries, regularly scalloped and reinforced laminar margin, and secondary veins terminating at marginal sinuses (USNM 364416, × 1/2). (B) Base of large leaf, with stout, flaring petiole (USNM 364417, × 1/2). (C) Small, complete leaf with petiole intact (USNM 364418, × 1). (D) Basal half of large leaf, showing "herringbone" pattern formed by secondary and tertiary veins (USNM 364419, × 1/2). (E) Small area of leaf, showing four orders of venation, with dense reticulation formed by tertiary and quaternary veins (USNM 364420, × 1½).

Although we emphasize the paleobotanical significance of this new and isolated Permian flora, the paleogeographic importance of the fossiliferous site invites consideration. The local abundance of sizable fragments of fossil wood, along with the numerous associated leaves—many of them large and virtually undamaged—suggests a rich flora growing near the burial site and deposited with little destructive mechanical abrasion. Yet the close association with conodonts and other marine invertebrates certainly indicates proximity to a marine environment. The fossil deposit and associated conglomerates probably represent a deltaic setting involving a small area on the southern margin of the Permian Basin. This site introduces the possibilities of additional, similar discoveries that will contribute to an understanding of the positions of Permian shorelines in the Trans-Pecos region; likewise continued searches should produce Permian plants that significantly broaden our knowledge of the evolution and distribution of North American Paleozoic floras.

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11. S. H. Mamay, unpublished observations.
12. As this manuscript neared completion, another site containing Permian leaves, yet unstudied, was found approximately 2 km farther south.
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The Meteorite-Asteroid Connection: Two Olivine-Rich Asteroids

Abstract. *Two asteroids have clear indications of olivine-rich surface petrology without any indication of pyroxene or plagioclase, suggesting that the olivine may be quite pure. They provide probable examples of mantles of differentiated parent asteroids exposed by fragmentation and are good candidates for the parent bodies of the unusual olivine meteorite Brachina or the olivine-iron alloy meteorites called pallasites.*

Meteorites recovered on the earth represent, at least in part, fragments from collisions among the asteroids. The variety of compositional types among the asteroids, as deduced from their telescopically observed colors and spectral reflectivities, is at least comparable to the diversity of petrological types of meteorites. Associating specific meteorite types with particular asteroids is an endeavor that has met with increasing success in telescopic surveys and laboratory spectral studies (*1*).

Early spectrophotometry of asteroids in the wavelength range 0.3 to 1.1 μm (*1*), as well as the more recent eight-color photometric survey of asteroids (*2, 3*), revealed a small number of objects having a relatively steep rise in reflectance toward the red end of the photovisual spectrum but with a downturn at about 0.9 μm. The olivine absorption band was suspected as the cause of the downturn but, without measurements of the infrared side of the band, olivine was difficult to confirm as a principal mineral constituent (*1, 4*). Broadband photometry in the near infrared (1.2 to 2.2 μm) also suggested that this spectral class of asteroids may be olivine-rich (*5*), but the firm identification of olivine requires spectral information of higher resolution than broadband photometry can provide in this wavelength region. Such data exist for a small but representative selection of asteroids of widely recognized types (C, S, M, D, and others), but none shows the characteristic olivine spectral signature (a combination of three overlapping bands that appear as a single broad absorption band centered at 1.06 μm) without the interfering strong bands of pyroxene (*6*). Asteroids with nearly pure olivine spectra with no pyroxene bands were, we believe, unknown before this study.

The possible existence of olivine-rich asteroids is of interest because olivine is an igneous silicate mineral that is found in pure or nearly pure assemblages only as a result of differentiation. In terrestrial volcanic settings it is the material that settles to the bottom of a magma chamber, and it is sometimes erupted onto the surface in a late stage of basaltic volcanism. In once-melted asteroids it could be a major constituent of the mantle or of certain mantle zones. Extraterrestrial sources of such material must exist because we have two meteorites that are nearly pure olivine (Chassigny and Brachina). Their origin is of special interest because their existence indicates the occurrence of secondary events on asteroids, and their visibility requires the exposure of asteroid interiors.

We made spectrophotometric observations in the near infrared (0.8 to 2.6 μm) of two of the five known A-class asteroids found from JHK photometric surveys (*5*) and identified them as olivine-rich. We used the NASA 3-m Infrared Telescope Facility on Mauna Kea, Hawaii, with an indium antimonide photometer equipped with two circular variable-interference filters (CVF's) for wavelength separation. The first CVF has a wavelength bandpass of 3 percent over the range 0.75 to 1.5 μm, and the second has a 5 percent bandpass between 1.4 and 2.8 μm. When used in the step-and-integrate mode in the usual way for infrared photometry, the two filters allowed us to obtain a complete spectrum from 0.8 to 2.6 μm (where the telluric water absorption cuts off the signal) in about 15 minutes. Several individual runs were averaged and ratioed to the spectrum of a solar-type star observed on the same night at the same air mass in order to remove the effects of the telluric atmospheric absorptions and the color of the sunlight illuminating the asteroids (*7*).

The resulting spectra of 246 Asporina and 289 Nenetta are plotted in Fig. 1. Additional spectral data are available for Asporina in the region 0.3 to 0.97 μm (*8, 9*); these are included in our plot as open circles, normalized to our data in the region of overlapping wavelengths. Nenetta is significantly fainter than Asporina, and the data are correspondingly lower in quality. Both asteroids show the spectral signature of olivine without the pyroxene bands at 0.9 and 1.8 μm. Pyroxene and olivine are usually found together, as in the spectrum of 349 Dembowska (*6*) and in all 11 of a recently studied sample of S-type asteroids (*10*).

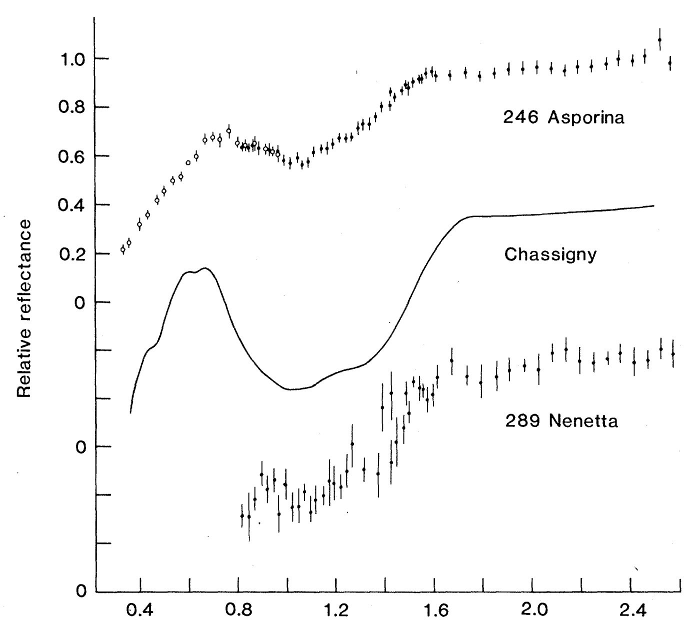

Fig. 1. Relative reflectance spectra of Asporina and Nanetta, obtained by ratioing the asteroids to solar-type stars and normalizing to 1.0 in the points at the longest wavelengths. The line in the middle is a reflectance spectrum of the olivine cumulate meteorite Chassigny, showing a pronounced olivine band at 1.06 μm. None of the spectra shows the commonly encountered pyroxene bands at 0.9 and 1.8 μm.