Reports

Petrified Peat from a Permian Coal Bed in Antarctica

Abstract. *Petrified plant remains that composed a Permian peat deposit occur at a coal horizon in a local area of Mount Augusta near the Beardmore Glacier in Antarctica. This discovery is the first in the entire Gondwana area that yields plant materials as exquisitely preserved as the materials of the well-known coal-ball localities of the Northern Hemisphere. A sampling of anatomical details is illustrated.*

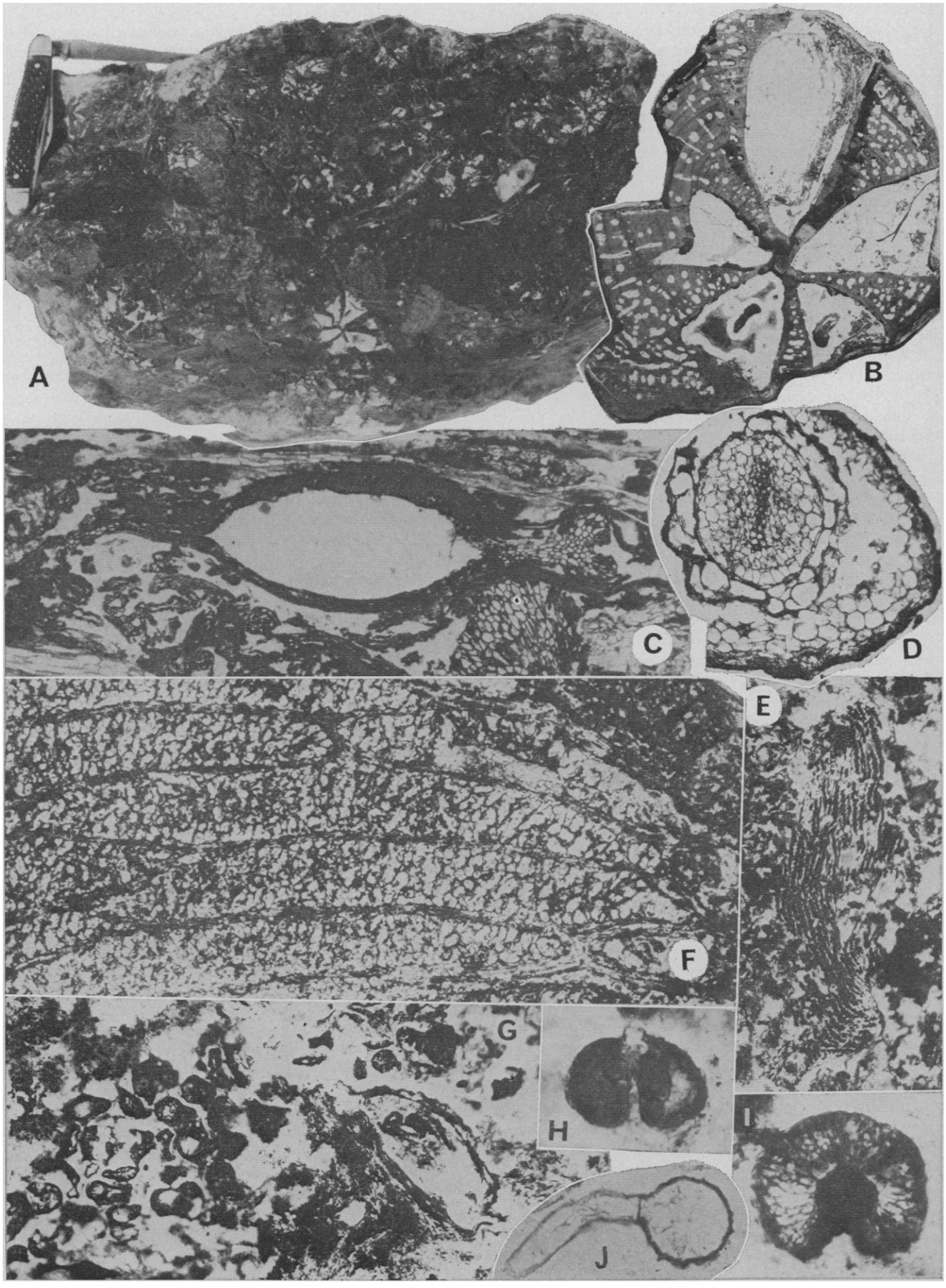
Permineralized peat of Permian age, which preserves well the varied plant components that elsewhere are compressed in coal, was discovered in central Antarctica on Mount Augusta, overlooking Beardmore Glacier, during the 1969–70 field season. This deposit promises to provide detailed information about the histologic anatomy of dominant members of the *Glossopteris* flora. No similar deposits have been found in the Permian and Triassic coal measures of the other Gondwana continents—namely, Australia, India, Africa, and South America. In the Northern Hemisphere, "coal balls" occurring in Upper Carboniferous deposits (*1*) are similar in mode of plant preservation to the remains at Mount Augusta and have provided the best botanical information for interpretation of the contrasting types of plants that occur in the coal measures there. Previous knowledge of the quite different Gondwana plants has depended on a most difficult, uncertain, or impossible reconstruction of plant organization, which at best was based only on coalified compressions of plant parts isolated in shale or sandstone. As a consequence, without a basis in comparative anatomy, phyletic understanding of most of the taxa has been lacking, and the significance of many evident and unusual features has remained uncertain. The new deposit of material, which essentially corresponds to the famous coal balls of northern Carboniferous coal measures, should be of great aid in subsequent study of the *Glossopteris* flora.

The deposit was initially located by John Mercer and John Gunner, of the Ohio State University Institute of Polar Studies, who visited the moraine at Lizard Point for glaciologic studies and explored on the southeastern spur of Mount Augusta. The several permineralized plant fragments they collected, of which Fig. 1B is an example, led to two visits by the writer and to more extensive collections. It is of interest that this locality high above the Beardmore Glacier overlooks the scene of Shackleton's and Scott's polar exploration routes of some 60 years ago (*2*). It was Scott's expedition that first recovered evidence of a *Glossopteris* flora in Antarctica at Buckley Island, 16 to 20 km southeast of the present collection site, thus providing the tangible initial evidence of ligation between Antarctica and the other parts of Gondwanaland (*3*).

The geologic section on the northeast face of the southeast spur of Mount Augusta has subsequently been studied by William J. Gealy, also of the Institute of Polar Studies 1969–70 field party, who found abundant specimens of normally preserved *Glossopteris* leaves in adjacent strata. A similar section that was previously measured by Barrett (*4*) is 1 km or more to the southwest. Both are in the type area that Grindley (*2*) assigned to the Buckley Coal Measures. According to Gealy, the silicified deposit is about 250 m above the base of the Buckley Formation. In his recent stratigraphic study of the central Transantarctic Mountain area (*4*), Barrett gives the total thickness of the Buckley Formation as about 745 m. This measurement excludes, however, the lower part of Grindley's Buckley Coal Measures, which both Barrett and Gealy distinguish as the Fairchild Formation. Previous collections from the Buckley Formation obtained by George Grindley, of the New Zealand Geological Survey, and by Peter Barrett, who led previous expeditions to this region for the Institute of Polar Studies, disclose a *Glossopteris-Gangamopteris* flora that is characteristic of the middle and upper parts of the Permian sections of Antarctica.

The deposit seems to be limited to an area of 1 or, at most, 2 hectares on one of the benches of the shelving nose of the long southeastern spur of Mount Augusta (*5*). The benched surfaces there are nearly horizontal, sloping slightly to the southwest, where, within a distance of 100 to 200 m, they become covered by a snowfield. All the exposed surface southwest of the crest is patterned and frost-heaved. The black siliceous material is most abundant and least disturbed near the crest above the steep northeast face of the spur, where it is associated with weathered coal. The darker trace of coal blossom can be seen continuing northwestward for at least a short distance below sandy, more resistant beds of the northeast face. The coal is nowhere well exposed in vertical section, but, to judge from the coal blossom, it may be more than 1 m in thickness. Where silicified, the peat deposit was probably twice this

Fig. 1. (A) Weathered surface of siliceous "coal ball." White chalcedonic fillings of lysigenous cavities in numerous *Vertebraria* roots are evident (× 0.26). (B) Transverse section of large *Vertebraria* root with five large air spaces; the wood has also been perforated by fungi. Growth rings are evident, and several "zones" of false growth rings are present in this specimen (× 1.0). (C) Seedlike structure (× 50). (D) Diarch rootlet showing excellent preservation of exarch protoxylem and other tissues within the pericycle (× 100). (E) Sporangium of *Arberiella* showing sinuous walled cells with dark (secretory?) contents. Preparation from an etched fracture surface (× 50). (F) Section of a *Glossopteris* leaf fragment, substantially parallel with the major plane of the lamina, showing venation enclosing three complete areoles. Midrib may be adjacent to the areole in the upper right. Preparation from an etched fracture surface (× 30). (G) Abundant bisaccate pollen associated with degraded plant material forming the matrix in which the leaves are preserved (× 200). (H) Uncompressed bisaccate pollen grain (× 500). (I) Monosaccate (?), or possibly abnormal, pollen grain (× 500). (J) Fungal zygospore (?), with germinal hypha (× 200).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thickness originally. Such an estimate is somewhat conjectural because of the long-continued intensity of frost disturbance. Over a stratigraphic interval of 2 or 3 m and for a distance of about 70 m, the black siliceous boulders, as much as 50 cm in diameter, so dominate the regolith that many must be near their site of origin. Talus on the steep slope below the site is littered with erratic fragments, which tail out toward the Lizard Point moraine. Some of these fragments were, in fact, the first specimens collected. There seems to be no doubt that all are derived from the one coal horizon near the top of the mountain. Except for this one bench, the top of the southeastern spur of Mount Augusta is covered by the usual assemblage of large and small diabase boulders and cobbles resting on a thin regolith of sandy shale and sandstone. I assume they are derived from a diabase sill that at one time extended above the siliceous deposit separated by a stratigraphic interval of 100 or 200 m.

It is important to note that the diabase intrusions (generally regarded as Jurassic) could in no way have been responsible for silicification of this peat deposit. The uncompressed nature of the plant material shows that silicification was contemporary with the peat and preceded accumulation of overburden. The source of petrifying silica must be sought in mineral springs or some similar source. Barrett (*4*) has reported that the Buckley Formation includes much volcanic sandstone with an altered tufaceous component. Thus, there may have been many sources of mineralized water during deposition of the Buckley Formation, but this occurrence is the only one known to have resulted in permineralization of a peat deposit.

Between 250 and 300 kg of dense siliceous rock similar to the block shown in Fig. 1A was obtained on two helicopter trips. No substantial collections would have been possible without the helicopter support provided by the Navy Air Support Squadron VXE-6. At this collection site no other means of transportation would serve to obtain substantial collections. The 1969–70 season was probably the first in which this particular outcrop area has been visited.

Only field determinations of the plants preserved can be given except for details from a few small specimens personally transported by air. It is evident that root material is most abundant (see Fig. 1, A–D) and that *Vertebraria* roots occupy a position in these southern "coal balls" analogous to the roots of *Psaronius* or the roots and rhizophores of *Stigmaria* in the true coal balls of the north. A great variety of roots and rootlets in all ontogenetic stages penetrate and ramify in this deposit. One small diarch rootlet is shown in Fig. 1D. Others that show triarch to nonarch construction have been observed. In *Vertebraria* roots, lysigenous spaces develop opposite exarch protoxylem points from an early period soon after inception of secondary growth. The same organization, lacking preservation of primary wood, was shown by the one limonitic petrifaction of *Vertebraria* previously described from the Ohio Range in Antarctica (*6*).

Only one small seedlike structure (Fig. 1C) has been observed in material available for study now. A few others were apparently observed in the field on weathered surfaces. Naturally, great interest attaches to the interpretation of such material. A few *Arberiella* sporangia have thus far been noted, of which Fig. 1E is the best available example. Anatomical evidence provided by fertile structures should provide much-needed evidence of the ancestral derivation of the glossopterids. It may be of some significance that the associated seedlike and microsporangial structures illustrated here are of about the same size.

Some large blocks of material contain a large number of matted leaves, evidently chiefly referable to *Glossopteris*. The fragment illustrated (Fig. 1F) mostly shows palisade tissue in which the cells contain dark coagulated contents. Three complete areoles and characteristic features of venation are shown. A variety of spiral and scalariform and a few border-pitted elements have been seen in veins of such leaves. The more ample material in the collections will certainly disclose important unknown features about the anatomy of the glossopterid midrib. On the nature of this feature hinges the hitherto uncertain distinction between the two most abundant genera of the Gondwana flora, *Glossopteris* and *Gangamopteris* (*7*).

The plant detritus, similarly permineralized, is particularly rich in uncompressed, bisaccate pollen grains. A spot showing a high concentration of pollen is illustrated in Fig. 1G. Examples at higher magnification are shown in Fig. 1, H and I. All these photographs are from peel preparations. Thin sections may disclose vestiges of gametophytic stages like those described by Florin from the siliceous deposits at Grand Croix in France (*8*). The dominance of bisaccate pollen grains in association with a predominance of glossopterid leaves and *Arberiella* sporangia must weigh heavily in favor of the close botanical alliance of these floral elements.

Preservation is not perfect, however. Abundant evidence of fungal decay is shown by lesions that could only have come from this source. The spiny spore with septate germinal tube (Fig. 1J) may represent a fungal zygospore. Branched septate mycelium is present near the outer margins of lysigenous cavities of the *Vertebraria* root shown in Fig. 1B. Fungal decay may be responsible for some of the marginal irregularity shown by this specimen, as it most certainly is for the small perforations that dot the secondary wood. Further studies of abundant root material should disclose whether any symbiotic or mycorrhizal relationship is likely, or whether the fungi were chiefly saprophytic.

Field observations of plant fragments on weathered surfaces suggested that rare examples are arthrophytic [*Paracalamites* as given by Rigby (*9*)] and possibly a few linear veined leaf fragments are allied with *Noeggerathiopsis*. Some few of the intrusive rootlets show an aerenchymatous cortex reminiscent of ferns, but the greater part of the material in one context or another may be regarded as glossopterid.

In addition to the new anatomical information, this silicified peat provides an unusually fine opportunity to study a favorable sampling of all the elements that contributed to a deposit of Gondwanaland peat. When compared with plants observed in coal balls from the Northern Hemisphere, it should provide further information about the important contrasts between the northern and southern plant communities. It should disclose much about the ecological relationships that existed in a peat swamp in Gondwanaland.

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10. This material was obtained as part of the work of the "Beardmore" expedition of 1969–70, which was led by David Elliot and supported by NSF grant GA-12315 and by the Institute of Polar Studies of the Ohio State University. Invaluable logistic support was provided by Naval Air Support Squadron VXE-6. Publication authorized by the director, U.S. Geological Survey.

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Marine Fossils at Rancho La Brea

Abstract. *Marine assemblages of foraminifera, ostracods, mollusks, and echinoids were recovered from deposits stratigraphically beneath the classic vertebrate assemblages from the tar pits at Rancho La Brea. The marine fossils indicate deposition in quiet, shallow water and suggest that accumulation of the type Rancholabrean material began during Wisconsin time.*

The Rancho La Brea tar pits in Los Angeles, California, famed for their rich yield of Late Pleistocene vertebrates, form the type locality of the Rancholabrean mammalian provincial age (*1*). The absolute age range represented by the locality is uncertain, although radiocarbon dates on material from the pits range from 4450 ± 200 for recent Indian artifacts to over 40,000 years B.P. for the tar itself (*2–4*). The time at which these deposits began to accumulate has not been determined. Newly discovered marine Pleistocene invertebrate fossils from strata (unit D, Fig. 1) that are stratigraphically beneath the classic vertebrate-bearing beds (unit E, Fig. 1) suggest that the type Rancholabrean fauna was deposited no earlier than the Wisconsin age.

The marine fossils were recovered from a building site excavation (for the Mutual Benefit building) across Wilshire Boulevard from Hancock Park, on the corner of Wilshire Boulevard and Ogden Drive. Various bore holes in the Hancock Park region have also penetrated the marine sand of unit D, which has yielded shell debris from depths between about 50 and 75 feet (16 and 22 m) below the surface (*5*). Borings at the edge of a tar pit have encountered marine shells at depths between 45 and 50 feet (14 and 16 m) (*6*). The fossiliferous stratum is thus rather widespread in the region of the La Brea deposits. The fossils reported here come from a fine, tar-impregnated quartzose sand near 117 feet above sea level (Fig. 1).

The 22 molluscan species are all represented by living populations in the eastern Pacific. Their living habits suggest that the association inhabited shallow, quiet water on a soft-sediment substrate. There are no species characteristic of intertidal conditions or of rocky substrates. Several of the bivalve specimens are articulated. These species could probably have lived in association in a sandy bottom community in the shallow inner sublittoral zone of a relatively protected marine embayment. The environmental preferences that are recorded for living populations of the other fossils, which include 21 species of foraminifera and 14 species of ostracods, are consistent with this interpretation, except for a few moderately deep-water foraminiferans. These latter specimens appear to be reworked from older Lower Pleistocene or Pliocene sediments which contain the deeper forms in abundance in the Los Angeles Basin.

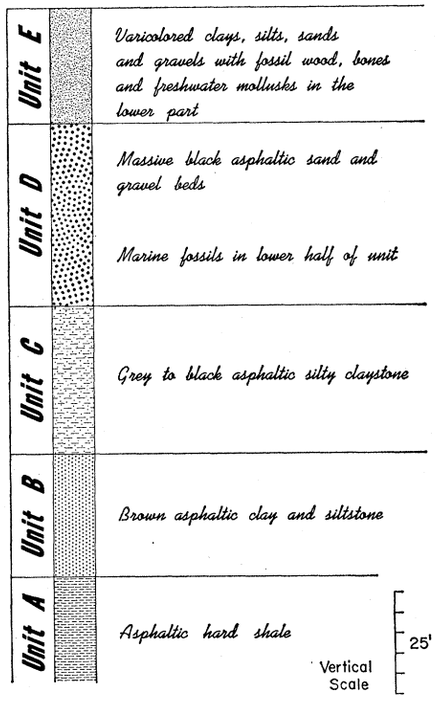

Fig. 1. General stratigraphic column near the southwest corner of Rancho La Brea (*5*). Rock units are generally recognizable throughout the Rancho La Brea region, but their thicknesses vary.

The bivalve species *Crassinella branneri* (Arnold), which is represented in the collection by a single relatively large valve, is a member of a southern faunal association that occurs commonly in late Pleistocene fossil assemblages from southern California (*7*, *8*). Many of the species in this southern element live today only south of Cedros Island, Baja California. A small form of *C. branneri*, however, may live as far north as San Diego (*8*). Nevertheless, the presence of *C. branneri* suggests that the assemblage from the Mutual Benefit excavation belongs to the upper Pleistocene biozone that is characterized by the southern element.

Radiometric dates are available for marine fossil associations from several southern California localities that belong to this biozone. Ratios of helium to uranium and ^{230}Th to ^{238}U for the Palos Verdes Sand suggest an age between 110,000 and 140,000 years B.P. or possibly slightly younger (*9*). Age estimates based on thorium-uranium dating have been reported from a terrace at Cayucos, California (*10*), as 130,000 ± 30,000 to 140,000 ± 30,000 B.P. and from San Nicolas Island (*11*) as 120,000 ± 20,000 B.P. Even considering the uncertainties of methods of age estimation, an age of about 100,000 years or more is suggested for the biozone.

The sand of unit D may have accumulated somewhat over 100,000 years ago along the quiet margin of a marine embayment which extended into the Los Angeles Basin. The sea eventually withdrew and the sands were succeeded by freshwater clays and fluvial and alluvial sediments of varying textures that comprise unit E. Unit E includes the present alluvial fan that descends from the "Hollywood Hills" section of the Santa Monica Mountains and the terrestrial sediments that contain the famous tar pits of Rancho La Brea (*12*). Radiocarbon age estimates of the vertebrates (*2–4*), taken together with compositional studies of the assemblages recovered from separate pits (*13*), suggest that there was a fairly long period, and in some pits intermittent periods, of accumulation, and that the