

## The Neogene biota of the Transantarctic Mountains

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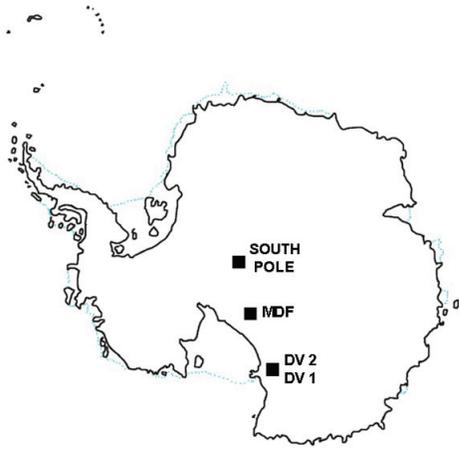
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**Summary** Neogene fossil assemblages are described from three localities in the Transantarctic mountains. The plant fossils, include diatoms and algal spores, megaspores of *Isoetes*, pollen of angiosperms and gymnosperms, wood and leaves of *Nothofagus*, cushion growth forms of a vascular plant and a moss species, mats of exceptionally well-preserved moss species with delicate leaves attached to stems, and achenes and fruits of vascular plant species including *Ranunculus*. The invertebrate fossils include disarticulated chitinous parts of beetles and flies, cypridoidean ostracods and the shells of freshwater molluscs. The only vertebrate fossil is that of a fish. The fossil assemblages require considerably warmer temperatures than are available within the Transantarctic Mountains today; estimated to be at least two to three summer months annually with mean temperatures of 4–5°C. Early interpretations allowed for the extinction of this terrestrial biota to have occurred as late as the Pliocene but a Miocene age now seems more probable.

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### Introduction

The first report of a Neogene terrestrial fossil from Antarctica was of wood from the Oliver Bluffs identified as *Nothofagus* (Carlquist, 1987). Since then numerous fossils have been discovered from the Oliver Bluffs section, some described and many currently being studied. Also, within the last few years two new deposits containing Neogene



**Figure 1.** Location of Neogene fossil sites in Antarctica; MDF = Meyer Desert Fm., Beardmore Glacier; DV 1 & 2 = Dry Valleys sites

fossils have been discovered in the Dry Valleys. These assemblages are being described and we can expect detailed reports within the next few years. What is particularly exciting is that the majority of the various types of algae, plants and animals being described are from families or even orders previously unknown to have existed in Antarctica. In this respect the fossils are a treasure trove for biogeographers who finally have fossils with which to test their various vicariance and dispersal hypotheses. The fossils are also important in that they are directly related to extant organisms and so their requirements for temperature and moisture during various developmental stages provide details of paleoclimate that are unavailable from any other source.

### Beardmore Glacier region

The Meyer Desert Formation (MDF), Sirius Group, fossil beds are located at the Oliver Bluffs on the Beardmore Glacier at 85.12° S, about 500 km from the South Pole (Fig. 1). A thick (80m) glaciogenic sequence of interbedded lodgement tills, glacio-fluvial, glacio-lacustrine, paludal deposits and paleosols, is exposed on the flanks of the modern glacier as a result of uplift and downcutting in the Transantarctic Mountains (TAM). The MDF is further subdivided into lower more oxidized and upper less oxidized beds by a disconformity. Preliminary pebble orientations from both sets of beds indicate sources generally to the south. Agglutinated foraminifera from the basal diamictites indicate the MDF was deposited near sea-level and has subsequently been uplifted by about 1300 m (Webb et al, 1996). At the northern end of the bluffs, the MDF is offset by a series of small normal faults which are associated with the larger Koski fault with a displacement of c. 300m (Ackert and Kurz, 2004). The age of MDF is controversial; an age based on reworked marine diatoms indicates that the deposits are < 3.8 Ma (Harwood, 1986) whereas exposure age

dating of surfaces associated with the Koski fault indicates an age of > 5.1 Ma and likely much older (Ackert and Kurz, 2004).

MDF fossils reported in several studies are those of plants, insects, molluscs and a vertebrate. Plant fossils are represented by wood, including *in situ* roots of *Nothofagus*. Most of the wood is small size and studies of the tree rings indicate growth was under stressed conditions (Francis and Hill, 1996). *Nothofagus* leaves occur at several horizons, the most prolific on a bedding plane representing a single season's accumulation. The deciduous leaves, with similarities to living species of *Nothofagus* in both South America and Tasmania, have been described as *N. beardmorensis* (Hill et al, 1996). The wood, leaves and a single *Nothofagus* pollen type (Prebble et al., 2006) suggest that just one species was present. Large c. 20 cm diameter cushions of both a vascular plant and moss species occur on bedding surfaces buried in growth positions by fine outwash deposits. Achenes and fruits are abundant; the majority are those of a *Ranunculus* (buttercup) but also include a species of Cyperaceae and other vascular plant species. Ashworth and Cantrill (2004) interpreted the plant assemblage to be that of an ice-marginal tundra vegetation.

Fragmented shells of freshwater molluscs and an ostracod occur within a marlstone bed. The abundant shells are thin-walled and fragile representing a lymnaeid gastropod species and the sphaeriid bivalve *Pisidium* (Ashworth and Preece, 2003). The *Pisidium* is a new species in the subgenus *P. Pisidium* and not a species within *P. Afropisidium*, a subgenus with a Gondwanan distribution. Various growth stages of the lymnaeids from juveniles to adults, indicate that summers were long enough to support reproduction and growth. Small hemispherical structures, c. 1 cm in diameter within the marlstone, are possibly of algal origin suggesting that biogenic carbonate was being deposited. Algal spores, possibly within a reproductive structure, were reported by Ashworth and Cantrill (2004). A single tooth and several small bones of an unidentified fish species, presumably freshwater, also occur within the marlstone.

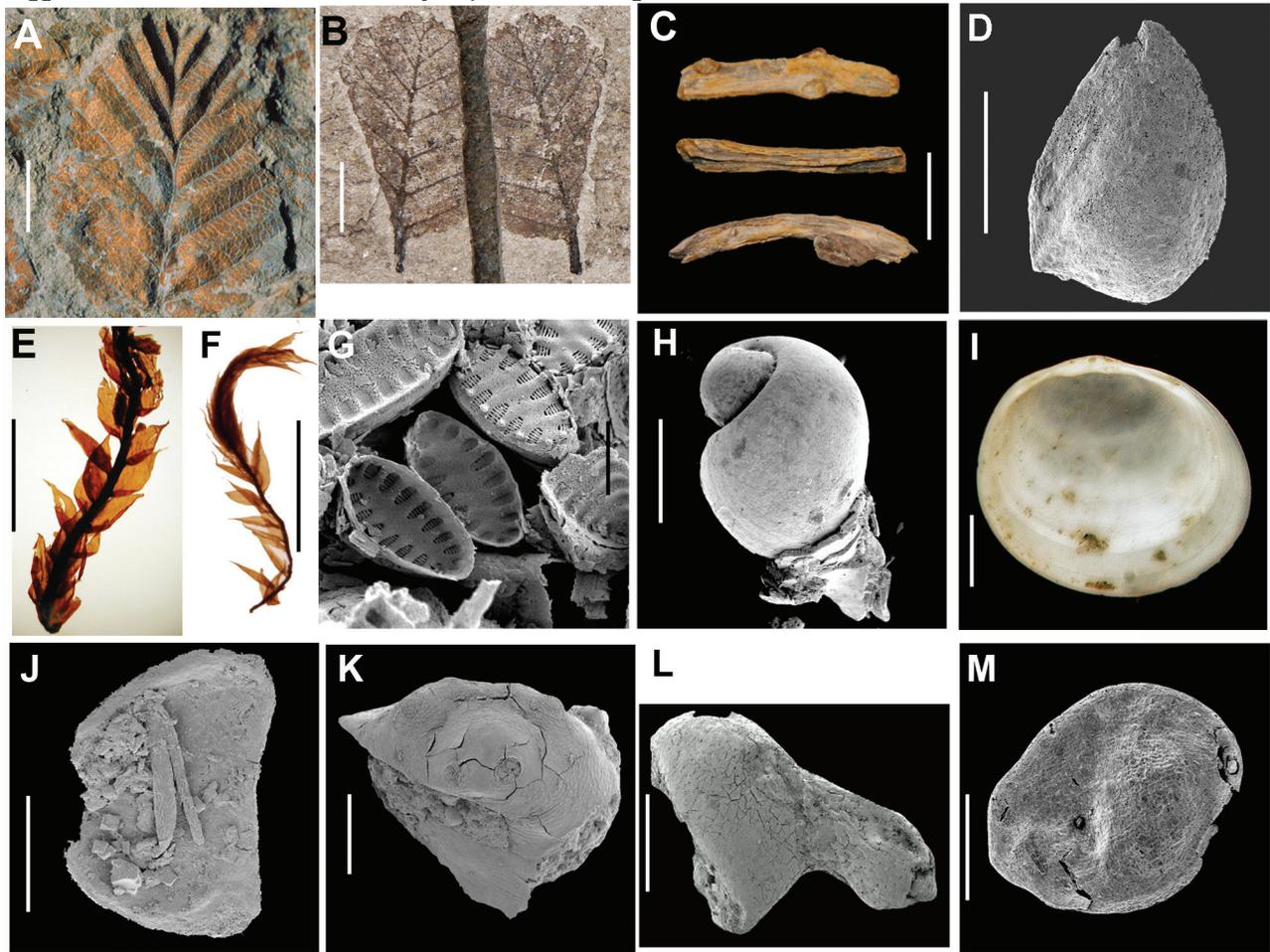
Coleoptera (beetles) remains include legs, a head, pronota and elytra. They represent two species of listroderine Curculionidae (weevils) (Ashworth and Kuschel, 2003) and a trechine Carabidae (ground beetle). Both the listroderine weevils and the trechine are small flightless beetles. Diptera (flies) remains are represented by a head capsule of a Chironomidae (midge) that has not been studied and Ashworth and Thompson (2003) reported the terminal segment of a puparium of a cyclorrhaphan (higher fly). Several oval structures, between 1-2 mm in length, are tentatively identified as insect eggs, possibly lepidopteran (butterflies and moths).

### Dry Valleys region

Fossil assemblages are currently being studied from two localities within the Dry Valleys sector (DV1, DV2) of the TAM. In the western Olympus Range, near Mt. Boreas (77.47°S), part of an ancient surface is preserved at elevations 600m above the floor of McKelvey Valley. Lag boulders mark the position of an ancient moraine. Behind the moraine in an up-ice direction, lacustrine sediments are preserved in a former lake basin. The sediments consist of diatomites with interlaminated moss peats. The lacustrine sediments were buried by fine-grained alluvial fan deposits which have subsequently been deflated to expose the basal lacustrine sequence. From a nearby valley in the Olympus Range, a volcanic ash bed from within intermorainal lacustrine sediments, in a related geomorphic setting to those of DV1, has an <sup>40</sup>Ar/<sup>39</sup>Ar age of 14.11 Ma (Lewis et al, this volume). Within the immediate region, geomorphic, stratigraphic and chronological evidence indicate that climates supporting cold-based glaciation began by c. 14 Ma (Lewis et al, in press).

Fossils recovered from the lacustrine beds include pollen, a beetle species and especially well-preserved mosses, diatoms and ostracods. Four species of mosses are represented, including both semi-aquatic and terrestrial taxa. Leaf attachments and cellular detail are preserved and for identification purposes the fossils were treated like modern dried museum specimens. The semi-aquatic mosses include two species of Amblystegiaceae, including a *Drepanocladus* species that is very similar to an extant species. *Drepanocladus* is widely distributed in the northern hemisphere but its range extends southward to Tierra del Fuego, the Falkland Islands and the subantarctic Kerguelen islands. *Drepanocladus* species occur in both mineral and nutrient rich mires. The interlamination of the moss bed with diatomites indicates that water levels fluctuated. Freshwater diatoms are abundant and well-preserved. The basal assemblages associated with the mosses is composed of colonial benthic species of Fragilariaceae. Upwards within the deposits this assemblage is replaced by a different suite of more acidophilous benthic taxa, and finally by planktonic species of *Aulacoseira* and *Asterionella*. The development of a diversified diatom flora containing both benthic and planktonic components implies that the water-body was both permanent and seasonally ice-free, and that the lake derived considerable nutrients from the catchment. Freshwater cypridoidean ostracods are abundant and well-preserved in some samples of the moss bed but not in others. Their carapaces represent growth series indicating that they were members of the lacustrine community and not just accidental occurrences. Soft anatomy, including appendages and mouth parts, are preserved in a few of the carapaces. In addition to the semi-aquatic species, two species of terrestrial haplolepidous mosses have been identified. These presumably were washed or blown in from the margins. Also, it is probable that the fragment of an elytron of a beetle is from a species that inhabited the margins. No wood, leaves or seeds have been found in the deposits perhaps indicating a sparse vegetation. No pollen was found in a small sample of the diatomite but spores of algae were abundant. Carbon and nitrogen isotopes have been extracted

from the diatomite and their analysis should provide more information about lacustrine productivity. All evidence suggests that the lake was surrounded by a sparse tundra vegetation.



**Figure 2.** Selected Neogene fossils from Antarctica **A.** MDF *Nothofagus beardmorensis* leaf, scale bar (sb)=1cm; **B.** DV2 *Nothofagus* leaf, sb = 1cm; **C.** DV2 *Nothofagus* wood, sb=1cm; **D.** MDF *Ranunculus* achene, sb=1mm; **E.** DV2 Moss stem, sb=0.5cm; **F.** DV 2 Moss stem, sb=0.5cm; **G.** DV1 Diatoms of the genus *Staurosirella* (Fragilariaceae), sb=10 $\mu$ m; **H.** MDF Submature lymnaeid snail, sb=0.5mm; **I.** MDF *Pisidium* valve, sb=0.5mm; **J.** Interior of a *Ranunculus* achene with complete cyclorrhaphan fly leg, sb=0.5mm; **K.** MDF Terminal segment of a cyclorrhaphan fly puparium, sb=0.5mm; **L.** MDF Head of a listroderine weevil, sb=0.5mm; **M.** MDF Possible insect egg, sb=0.5mm

The other locality from which fossils have been discovered in the Dry Valleys is located in the highlands adjacent to the Taylor Glacier and about 1000m above the floor of Pearse Valley, at 77.45°S. Here a valley fill of wet-based glacier deposits has been preserved between bedrock ridges. Wind erosion has excavated the surface and in several places exposed fossiliferous deposits interbedded with diamictites, lacustrine sediments and paleosols (DV2). At least five wet-based glacial advances have been documented and there are probably more. Between each advance and retreat there was time for soil development. The age of the sediments has not been determined but based on regional chronologic considerations an early to mid-Miocene age seems probable. The greater diversity represented in the fossil assemblages, as well as their regional geomorphic setting on a relict upland surface, suggests that they are likely older than the fossil assemblage from the western Olympos Range (DV1).

The pollen and spore assemblage is similar to the MDF assemblage, in that it is dominated by *Nothofagus*, lycophyte and bryophyte types. Algal spores are also abundant in both assemblages. Also, specific pollen types, notably *Nothofagidites lachlaniae* and *Tricolpites sp. A* of Prebble et al. (2006), occur in both sites and also in the upper part of the Cape Roberts and CIROS-1 borehole sequences. *Nothofagus* is represented by several taxa including *N. lachlaniae*, *Nothofagidites cf. flemingii*, *Nothofagidites* spp. (undifferentiated *Fuscospora* types, several species present). This is different than the MDF assemblage where *Nothofagus* is represented by only a single taxon *N. lachlaniae*. Plant macrofossils are represented by wood and leaves of *Nothofagus*, megaspores of *Isoetes* and mats of semi-aquatic moss species. The *Nothofagus* leaves appear to represent more than one species, which is supported by

the pollen evidence. One of the leaf types is of a similar size and morphology to *N. beardmorensis* from the MDF. Megaspores of the lycophyte *Isoetes* are abundant in all of the samples so far examined. *Isoetes* is an aquatic or semi-aquatic plant that inhabits shallow lakes and rivers. Moss mats are exceptionally well-preserved with individual stems and attached leaves preserving cellular detail. The mats are dominated by a semi-aquatic species of Amblystegiaceae but different from the *Drepanocladus* species from DV1. Insect chitin is also relatively abundant but pigments have not been preserved. The most abundant skeletal parts are those of Curculionidae, including listroderine weevils.

### Paleoclimate

The fossil assemblages from each of the sites are representative of tundra habitats. Based on diversity and the presence or absence of *Nothofagus*, the coldest site is DV1 and the warmest site is DV2. At the MDF site, based on the autecologies of various taxa, it was estimated that there had to be at least two months in the summer where the average temperatures were about 4° to 5°C. Mean annual temperature was estimated to be about -8°C compared to an estimated MAT for today of -26°C (Ashworth and Cantrill, 2004). Comparisons between sites are difficult because of uncertainties of age, differences in latitudinal position by up to 8°, and uncertainties regarding original elevations because of uplift. Even so, summer temperatures at DV1 had to be warm enough for the lake to be ice-free for one or two months and at sites DV2 and BG, warm enough for soils to develop during times of glacial retreat.

### Biogeography

Pollen evidence from the Cape Roberts borehole in the Ross Sea basin suggested that a tundra vegetation existed in East Antarctica from the Oligocene into the Early Miocene (Raine and Askin, 2001). The macroscopic fossil evidence we have from DV1 indicates that a tundra biota persisted until the mid-Miocene (14 Ma). At c. 14 Ma there was a shift in alpine glaciers from wet-based to cold-based regimes, which has persisted until today (Lewis et al, in press). We hypothesize that this climate change ultimately resulted in the extinction of the tundra biota. It seems probable that at least some of the mid-Miocene fossils, e.g. *Nothofagus* and possibly the flightless beetle species, were descendants from ancestors which evolved in Antarctica during the late Cretaceous. An important consequence of this hypothesis is that the climate of Antarctica from the late Cretaceous to the mid-Miocene was warm enough to support a vascular plant, insect and possibly freshwater molluscan biota. We stress that not all fossil taxa need be related to organisms whose ancestors evolved in Antarctica. Indeed it seems improbable that species that are indistinguishable from extant species (e.g. *Drepanocladus* and several diatom taxa) could have maintained species constancy in isolation from the time that the connection between Antarctica and South America was severed (c. 34 Ma) until the mid-Miocene (14 Ma). We further hypothesize that during warmer intervals up until the mid-Miocene warm interval (see Zachos et al., 2001) that oceanic gaps between Antarctica, New Zealand, Tasmania and South America may have been bridged by birds extending their ranges south into the interior of Antarctica. Dispersal by avian agents, or in the case of the diatoms by wind, could have been responsible for transporting mosses, ostracods, some insects and vascular plants, both to and from Antarctica.

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