Deterioration and/or cyclicity? The development of vegetation and climate during the Eocene and Oligocene in Antarctica

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Summary The late Eocene to early Oligocene is a time interval in earth history with major changes in both the global environment and the biota. To understand the vegetation history of this time, ODP and "Islas Orcadas" core samples from the Antarctic Peninsula area and the Tasman Sea were analysed using qualitative and quantitative palynological methods. Both floras represent a *Nothofagus*-Podocarpaceae forest association with a high percentage of ferns. The mid-Eocene flora of the Antarctic Peninsula region is an indicator of a warm-temperate, humid climate. The younger Tasman Sea flora shows a similar *Nothofagus*-Podocarpaceae forest association, but with a different composition of Nothofagaceae as well as a smaller percentage and diversity of ferns and the presence of *Casuarina*, a dryness indicator. Cryptogams, gymnosperms and angiosperms show tectonically or orbitally forced temperature changes in the time period examined.

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Introduction

During the Eocene and Oligocene substantial changes occurred in both the global environment and the biota (Prothero and Berggren, 1992). Climate cooled from an earlier Eocene warm period, culminating during the earliest Oligocene in Antarctic glaciations. Several reasons for this gradual cooling are well established, in particular the plate-tectonic driven separation of Australia from Antarctica, which allowed a circum-polar ocean circulation system to develop, thermally isolating the Antarctic continent (Kennett, 1977). Impact events (Popigai, Chesapeake Bay, Tom's Canyon) and volcanic eruptions (Yemen and Ethiopian traps) might have also caused cooling. An additional, if not the most important factor that may have influenced the growth of ice sheets during the Eocene-Oligocene time interval was possibly decreasing atmospheric CO_2 levels. Simulations of decreasing CO_2 levels over a time span of 10 Ma suggest the formation of highly dynamic ice caps that expand rapidly with orbital variations and lead to a continental-scale East Antarctic Ice Sheet (DeConto, and Pollard, 2003).

In the southern high latitudes *Nothofagus*-Podocarpaceae forests were dominant since the Campanian (Greenhalgh et al., 2003, Francis et al., 2003). This flora was disturbed by cooling and the development of the Antarctic ice sheet at the Eocene/Oligocene boundary. The climatic optimum in the Early Eocene caused a poleward movement of climate zones and a global dominance of tropical and subtropical vegetation. This process was reversed with the beginning of global cooling. The modern distribution patterns of plant associations have developed since the Oligocene.

Vegetation history was reconstructed, using standard qualitative and quantitative palynological analyses. Samples from Ocean Drilling Program (ODP) Leg 113, Site 696 and the "ARA Islas Orcadas" (IO) core 1578-59, both from the Antarctic Peninsula region, and from ODP Leg 189, Site 1168 from the Tasman Sea were used for these investigations. The ages of these sections determined by microfossils (nannoplankton and diatoms) and paleomagnetics, range from mid-Eocene through early Oligocene. Additionally, we studied links between terrestrial vegetation change, climate change, and impact events.

Results and discussion

The analysed material generally indicates *Nothofagus*-Podocarpaceae forest associations. The Nothofagaceae are common with four pollen types (*brassii*, *fusca*-a, *fusca*-b, *menziesii*), so that all extant subgenera are represented, evergreen as well as deciduous forms. Podocarpaceous plants occur in high abundance and diversity with *Podocarpus, Dacrycarpus, Dacrydium, Lagarostrobus, Phyllocladus* and *Microcachrys*. Additional gymnosperms include Araucariaceae and Cupressaceae. Angiosperms are also diverse: Gunneraceae, Proteaceae, Asteraceae, Casuarinaceae, Myrtaceae, Apiaceae, Liliaceae and other taxa. Ferns, as indicators for humidity (Mohr, 2001) are represented by Cyatheaceae (e.g. *Lophosoria*, *Kuylisporites*), Gleicheniaceae, Schizaeaceae, Dicksoniaceae, and Osmundaceae; various bryophyte spores are also present.

The mid-Eocene "Islas Orcadas" cores (44-46 Ma) from the Antarctic Peninsula region show a very high diversity of spores and pollen with a high percentage of angiosperms. This flora represents a *Nothofagus*-Podocarpaceae forest association with a very high abundance of ferns, especially the Cyatheaceae. The vegetation clearly indicates a warm-temperate, humid, non-tropical climate. Varying percentages of fern and seed plant sporomorphs suggest cyclicity during the studied time interval.

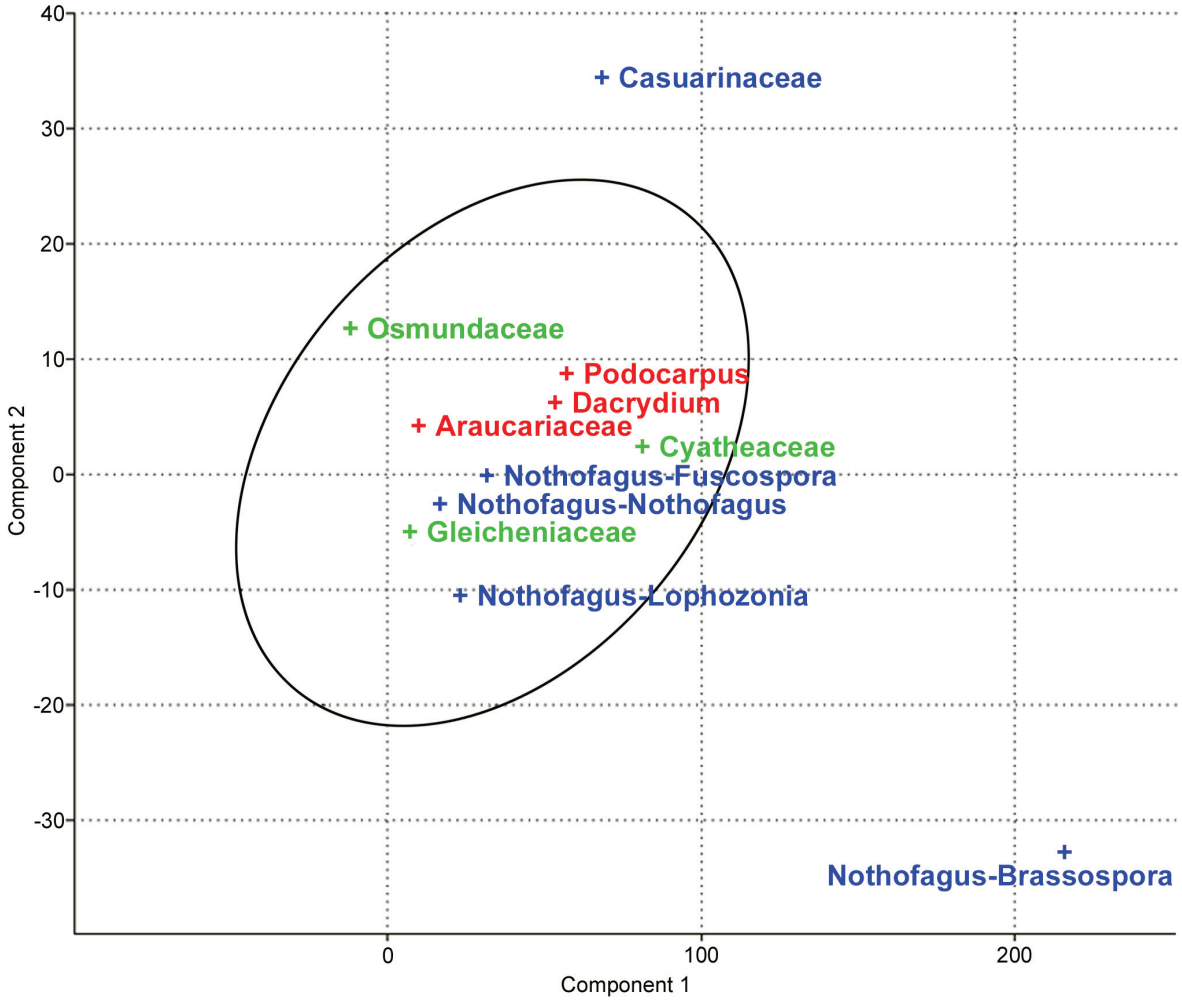

Figure 1. Principal component analysis of sporomorphs from the Tasman Sea samples from ODP Leg 189, Site 1168.

The Tasman Sea flora of Late Eocene to early Oligocene age shows a similar *Nothofagus*-Podocarpaceae association, but with a different composition of the Nothofagaceae (more *Brassospora*) and a lower percentage plus a lower diversity of ferns on one hand and the presence of *Casuarina* (a dryness indicator) on the other hand. The Principal component analysis (Figure 1) supports these results. All taxa except *Casuarina* and the evergreen subgenus *Brassospora* of *Nothofagus* belong to this association. Extant *Brassospora* taxa are restricted to more tropical conditions in New Guinea, New Caledonia and smaller islands in the neighbourhood.

The abundance-time-chart in Figure 2 shows the floral development during the uppermost Eocene and the Lower Oligocene in the Tasman Sea location. Within the angiosperms the Nothofagaceae are the most important groups; among the gymnosperms the Podocarpaceae and among the cryptogams a few well-known fern families (Cyatheaceae, Dicksoniaceae, Gleicheniaceae, Schizaeaceae, Osmundaceae). The strong dominance of Nothofagaceae (especially of the evergreen subgenus *Brassospora*) arose before the E/O boundary at about 34.5 Ma. From this time interval on the overall diversity of angiosperms declines and the percentages of various angiosperm groups such as Gunneraceae, Proteaceae, Myrtaceae show also clearly a substantial decline. In addition the percentage of *Nothofagus* subgenus *Lophozonia* (*menzesii* pollen type) that includes evergreen and deciduous species, increases slightly. Casuarinaceae are less prominent from 33.7 Ma to 32.7 Ma, after the Eocene-Oligocene boundary. The Araucariaceae mostly benefit from the periodic decrease of the angiosperms, as well as the ferns Dicksoniaceae and Cyatheaceae. About 0.2 Ma after the E/O transition, the Osmundaceae were replaced by Schizaeaceae and Gleicheniaceae.

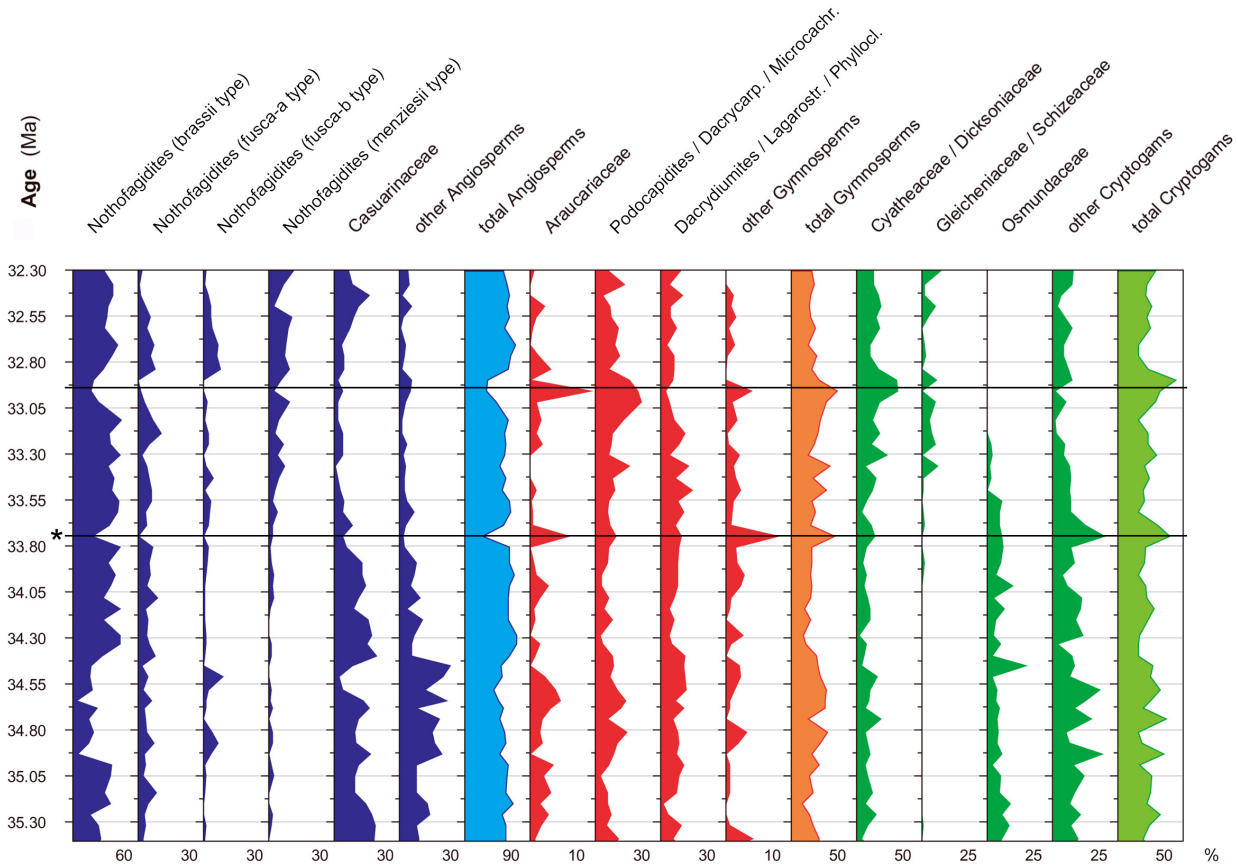

Figure 2. Relative abundance (%) of sporomorphs in the Tasman Sea samples from ODP Leg 189, Site 1168. Asterisk: Eocene/Oligocene boundary, lines: palynological "events".

Two short term events are prominent, at about 33.7 Ma (near the E/O boundary) and at about 32.9 Ma. The percentage of angiosperms was reduced from 60 percent to 30 percent. A third event at about 34.6 Ma is not so pronounced.

The shifts in sporomorph percentages may be interpreted as results of three overlapping factors:

1. Long term (cooling) trends as evidenced by a steady decrease/increase, such as the steady decline of angiosperm diversity and decrease in "other angiosperms",
2. Possible cyclicity (three Araucariaceae peaks in ca. 0.8 Ma intervals plus a dramatic decrease in "total angiosperms"),
3. Larger scale tectonic movements (northward movement of Australia) during this time period. This may be possibly evidenced by a stable percentage of certain taxa, such as *Brassospora*, over several million years that are usually found in more favourable climates (except for these short term events).

Summary

Sporomorphs from the Antarctic Peninsula area and the Tasman Sea indicate Nothofagus-Podocarpaceae forests for the Eocene/Oligocene boundary time interval. Relative abundances of pollen and spores suggest, beyond a more steady climate deterioration, noticeable from ca. 34.4 Ma on, climatic cycles of about 0.8 Ma duration. In addition, effects of the northward movement of Australia/Tasmania may be visible in the pollen record.

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