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ANTARCTIC PALYNOLOGY AND PALAEOCLIMATE – A REVIEW

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ABSTRACT

The first exciting clues that Antarctica had not always been ice-covered were the leaf fossils of *Glossopteris* plants that Scott's party brought back from the Beardmore Glacier region in 1912. Since dated at ~ 250 million years old, it has become evident that Antarctica has been vegetated longer than it has been ice-covered. These first plant fossils from the Beardmore have led to over 100 years of scientific investigation of the rich macro- (e.g. leaves and fossil wood) and micro- (terrestrial and marine palynomorph) fossil record of Antarctica. Palynomorphs from the sedimentary record of Antarctica continue to provide an exceptionally detailed interpretation of high latitude vegetation and climate from Devonian to Neogene times, complementing and extending the macrofossil record. They document the transition from the *Glossopteris*-dominated Gondwanan flora to more modern conifer and then beech-dominated polar forests, followed eventually by a less diverse and lower stature vegetation as climates cooled and ice sheets became large and relatively stable into the Neogene. Continued research into terrestrial and marine palynomorphs provides essential insight into the environmental sensitivity of the polar regions in a future warmer world.

Keywords : Antarctica; palynology; palaeoclimate; vegetation

Introduction

During their ill-fated expedition to the South Pole in 1912 Captain Robert Falcon Scott and his party struggled to carry samples of leaf fossils back from the mountains of the Beardmore Glacier. These were the first exciting clues that the Antarctic continent had not always been covered with ice and proved that the continental interior had supported lush vegetation ~250 million years ago (Seward, 1914).The leaves were identified as *Glossopteris,* a now extinct but once prolific seed fern that was distributed across the southern super-continent Gondwana (McLoughlin, 2012). Since these early days of Antarctic exploration, plant fossils have been found in many sedimentary rocks across Antarctica in outcrop on ice-free nunataks, coastlines and islands, and from drill cores around the margin (e.g. Cantrill, 2001; Tosolini et al., 2013).

In addition to finds of plant macrofossils (including leaves and fossil wood), microscopic remains of plants and marine algae (palynomorphs) are now commonly found in the Antarctic sedimentary record (Figure 1). These provide a complementary and exceptionally detailed interpretation of southern high latitude vegetation and climate since the early Devonian (e.g. Kyle, 1977a; Bowman et al., 2014).

Devonian – Triassic

The earliest, poorly preserved, trilete spores from the Terra Cotta Siltstone in Victoria Land record the colonization of Antarctica during the Devonian by early vascular plants in relatively warm climates (Simon et al., 2007). Following the complex Carboniferous and Early Permian glaciation of Gondwana, climate warmed significantly by the end of the Permian (Isbell et al., 2003;

Figure 1, Bowman

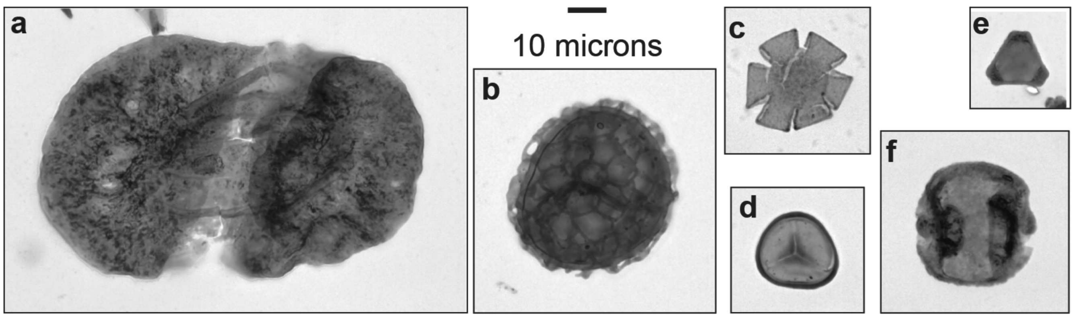

Figure 1– Examples of Antarctic terrestrial palynomorphs from Seymour Island, Antarctic Peninsula (after Bowman et al., 2014). Transmitted light photographs. a, *Protohaploxypinus ?amplus* (Permian, reworked); b, *Retitriletes austroclavatidites* (Maastrichtian); c, *Nothofagidites dorotensis* (Maastrichtian); d, *Stereisporites antiquasporites* (Maastrichtian); e, *Proteacidites* sp. cf. *P. scaboratus* (Maastrichtian); f, *Phyllocladidites mawsonii* (Maastrichtian).

Shi and Waterhouse, 2010). From Permian sediments, there is palynomorph evidence for a much more diverse vegetation across Antarctica at that time from localities in Victoria Land, the TransAntarctic Mountains, the Pensacola Mountains and Droning Maud Land (Cantrill and Poole, 2012). These palynomorphs record vegetation that included mosses (Bryophyta, Lycophyta), horsetails (Sphenophyta), ferns (Pteridophyta) and seed plants (Spermatophyta) (e.g. Kyle, 1977b; Lindström, 2005).

The transition from the Permian into the Triassic is marked by a dramatic change in the Antarctic vegetation from one dominated by *Glossopteris* to one more modern in character (e.g. Lindström and McLoughlin, 2007). The palynofloral record at this time from Antarctica indicates that the woody swamp-forest vegetation died back across the continent and was replaced by the seed plants Peltaspermaceae and Corystospermaceae (Looy et al., 1999; Cantrill and Poole, 2012). The Early Triassic was a time of extreme warmth and seasonality, after which global climate was variable, then cooled and was humid to the end of the Triassic. Ferns and lycophytes became abundant, and *in situ* fossil forest horizons were discovered in the Transantarctic Mountains (del Fueyo et al., 1995; McLoughlin et al., 1997).

Jurassic

The Triassic–Jurassic transition marks a biotic crisis, both on land and at sea and precedes the prevailing warm, wet greenhouse climates of the Jurassic period (e.g. Frakes et al., 1992). Gondwana was breaking up and the palynomorph record from the Early Jurassic of Antarctica is limited, but includes a *Classopollis*-dominated (Cheirolepidaceae) assemblage at Section Peak, northern Victoria Land (Norris, 1965). At this time, the palynofloras suggest vegetation dominated by Cheirolepidaceae and Araucariaceae conifers with bryophytes, ferns and other seed plants (Cantrill and Poole, 2012). *Classopollis* and *Araucariacites* pollen continue to dominate assemblages into the Middle Jurassic (Truswell et al., 1999). Generally, the vegetation of West Antarctica is poorly known for the Late Jurassic into earliest Cretaceous, although the palynomorph record records a significant decline in *Classopollis* pollen during this time (Duane, 1996).

Cretaceous

Greenhouse climates continued into the Cretaceous, with global temperatures peaking during the Turonian (Huber et al., 2002). Despite intense seasonality at the high southern latitudes, vegetation in southern Gondwana spread to 85° South (Spicer and Parrish, 1986). Conifers and ferns became prevalent in highly productive polar forests. The first primitive angiosperm pollen in Antarctica, *Clavatipollenites*, was recorded from the early to mid Albian Kotick Point Formation on James Ross Island (Dettmann and Thomson, 1987; Riding and Crame, 2002). These pollen grains have been compared with modern Chloranthaceae; their arrival in Antarctica apparently post-dating the arrival of angiosperms in the neighbouring landmasses of southern South America and Australia (Cantrill and Poole, 2012).

The mid to Late Cretaceous was a time interval of generally equable global climates (Frakes et al., 1992). Changes in atmospheric carbon dioxide levels (*p*CO2), and ocean heat transport as a result of Gondwana break-up contributed to the climate state (Cantrill and Poole, 2012).By Maastrichtian times, *p*CO2 levels had decreased significantly (Royer, 2006). Although generally temperate at the high southern palaeolatitudes at this time, marine and terrestrial palynological evidence from Seymour Island, northeast Antarctic Peninsula suggests there were cold climatic spells. Temperatures at these times may have been cold enough for seasonal sea ice around Antarctica implying the presence of ephemeral high altitude ice caps in the Antarctic interior (Bowman et al., 2013, 2014). By the very latest Cretaceous it is possible that temperatures warmed globally due to the vast volcanic outpouring of the Indian Deccan Traps (e.g. Keller et al., 2011; Bowman et al., 2013).

By the latest Cretaceous, terrestrial palynomorph data from Seymour Island suggests that *Nothofagus* and podocarp trees were prominent components of the lowland vegetation of the eastern Antarctic Peninsula (Bowman et al., 2014). These riparian forests had an understory of bryophytes, lycopods, ferns and Proteaceae, in a humid temperate climate, with *Araucaria* and subalpine shrubs occupying the higher mountain slopes (Bowman et al., 2014).

Cretaceous–Paleogene transition

Latest Cretaceous vegetation communities on the eastern slopes of the Antarctic Peninsula were relatively stable, responding slightly in composition to changing temperatures and humidity, and persisted throughout the Paleocene (Bowman, et al. 2014; unpublished data). Preliminary studies across the Cretaceous–Paleogene (KPg) boundary exposed on Seymour Island suggest that Antarctic Peninsula vegetation suffered little at this time of global biotic disturbance (Bowman et al., 2014). This is in common with K–Pg boundary studies elsewhere in the Southern Hemisphere (e.g. Vajda et al., 2001). Detailed study of the terrestrial palynomorph record across this critical interval is the subject of ongoing work.

Paleogene – Neogene

A short-lived cold spell during the mid-Paleocene (Leckie et al., 1995) was followed by gradual warming to the Paleocene-Eocene Thermal Maximum, peaking at the Early Eocene Climatic Optimum ~ 50 Ma (Zachos et al., 2001). Mixed *Nothofagus*/podocarp/protea forests, comparable to the modern Valdivian rainforests of South America, continue to prevail on the east side of the Antarctic Peninsula, at least until the latest Paleocene (Askin, 1992). Climate began to cool in the late Eocene and *Nothofagus* became more dominant in these high southern latitude forests (Cantrill and Poole, 2012).

From the late Eocene global climate began to cool related to declining *p*CO2 levels. Close to the Eocene-Oligocene boundary at ~34 Ma previously ephemeral ice sheets in the Antarctic interior coalesced, becoming relatively stable and permanent, influenced by the final opening of Drake Passage and the initiation of a deep circumpolar current (Deconto and Pollard, 2003). Palynology and macrofossil data from the high southern latitudes indicate that vegetation across the south polar region was in transition from a mainly evergreen forest to tundra vegetation (Thorn and DeConto, 2006). The modeled sensitivity of continental temperatures to vegetation-climate feedbacks at this time indicated that Antarctic vegetation change might have played a vital role in the rapid glaciation of the continent at this time (Thorn and DeConto, 2006).

From this time, the plant fossil and palynomorph record is restricted to drill cores around the Antarctic margin (Askin and Raine, 2000; Warny et al., 2006). By the Miocene, the palynomorph record indicates that tundra vegetation had reached low altitudes in the generally cool climate, although there is evidence that this was punctuated by at least one short-lived warm interval (Warny et al., 2009). Overall, this tundra vegetation had a much lower diversity and stature than during the Paleogene. The timing of the final demise of significant woody vegetation is still a subject of ongoing study (Anderson et al., 2011).

Summary

Continuing to study the terrestrial and marine palynomorph record from the high southern latitudes provides detailed information about past vegetation and climate that is globally relevant. It is critical for improving our knowledge of the climatic history of the polar regions, which informs our understanding of the environmental sensitivity and stability of ice caps. This information from the geological past directly contributes to the study of biotic responses to globally warm climates and is relevant to mitigating the effects of future climate and sea level change in a world altered by human industrial activities.

REFERENCES

Anderson, J., Warny, S., Askin, R.A., Wellner, J., Bohaty, S.M., Kirschner, A.E. (2011). Progressive Cenozoic cooling and the demise of Antarctica's last refugium. Proceedings of the National Academy of Sciences, **108:** 11356–11360.

Askin, R.A. (1992). Late Cretaceous–early Tertiary Antarctic outcrop evidence for past vegetation and climates. In: Kennett, J.P., Warnke, D.A. (eds.), The Antarctic Paleoenvironment: a Perspective on Global Change. American Geophysical Union, Antarctic Research Series, **56:** 61–73.

Askin, R.A., Raine, J.I. (2000). Oligocene and Early Miocene terrestrial palynology of the Cape Roberts Drillhole CRP-2/2A, Victoria Land Basin, Antarctica. Terra Antartica, **7:** 493–501.

Bowman, V.C., Francis, J.E., Riding, J.B. (2013). Late Cretaceous winter sea ice in Antarctica? Geology, **41:** 1227–1230.

Bowman, V.C., Francis, J.E., Askin, R.A., Riding, J.B., Swindles, G.T. (2014). Latest Cretaceous–earliest Paleogene vegetation and climate change at the high southern latitudes: palynological evidence from Seymour Island, Antarctic Peninsula. Palaeogeography Palaeoclimatology Palaeoecology, **408:** 26–47.

Cantrill, D.J. (2001). Early Oligocene *Nothofagus* from CRP-3, Antarctica: implications for the vegetation history. Terra Antartica, **8:** 401–406.

Cantrill, D.J., Poole, I. (2012). The Vegetation of Antarctica through Geological Time. Cambridge University Press, Cambridge. 480 p.

Deconto, R., Pollard, D. (2003). Rapid Cenozoic glaciation of Antarctica induced by declining atmospheric CO_2. Nature, **421:** 245–249.

del Fueyo, G.M., Taylor, E.L., Taylor, T.N., Cúneo, N.R. (1995). Triassic wood from the Gordon Valley, central Transantarctic Mountains, Antarctica. International Association of Wood Anatomists Journal, **16:** 111–126.

Dettmann, M.E., Thomson, M.R.A.(1987). Cretaceous palynomorphs from the James Ross Island area, Antarctica – a pilot study. British Antarctic Survey Bulletin, **77:** 13–59.

Duane, A. (1996). Palynology of the Byers Group (Late Jurassic–Early Cretaceous) of Livingston and Snow islands, Antarctic Peninsula: its biostratigraphical and palaeoenvironmental significance. Review of Palaeobotany and Palynology, **91:** 241–281.

Frakes, L.A., Francis, J.E., Syktus, J.I. (1992). Climate Modes of the Phanerozoic. Cambridge University Press, Cambridge.

Huber, B.T., Norris, R.D., Macleod, K.G. (2002). Deep-sea paleotemperature record of extreme warmth during the Cretaceous. Geology, **30:** 123–126.

Isbell, J.L., Leneaker, P.A., Askin, R.A., Miller, M.F., Babcock, L.E.,(2003). Reevaluation of the timing and extent of the late Paleozoic glaciation in Gondwana: role of the Transantarctic Mountains. Geology, **31:** 977–980.

Keller, G., Bhowmick, P.K., Uphadhyay, H., Dave, A., Reddy, A.N., Jaiprakash, B.C., Adatte, T., (2011). Deccan volcanism linked to the Cretaceous–Tertiary boundary mass extinction: new evidence from ONGC wells in the Krishna-Godavari Basin. Journal Geological Society India, **78:** 399–428.

Kyle, R.A. (1977a). Devonian palynomorphs from the basal Beacon Supergroup of South Victoria Land, Antarctica. New Zealand Journal of Geology and Geophysics, **20:** 1147–1150.

Kyle, R.A. (1977b). Palynostratigraphy of the Victoria Group, south Victoria Land, Antarctica. New Zealand Journal of Geology and Geophysics, **20:** 1081–1102.

Leckie, D.A., Morgans, H., Wilson, G.J., Edwards, A.R. (1995). Mid-Paleocene dropstones in the Whangai Formation, New Zealand evidence of mid-Paleocene cold climate? Sedimentary Geology, **97:** 119–129.

Lindström, S. (2005). Palynology of Permian shale, clay and sandstone clasts from the Basen till in northern Vestfjella, Dronning Maud Land. Antarctic Science, **17:** 87–96.

Lindström, S., McLoughlin, S.(2007). Synchronous palynofloristic extinction and recovery after the end-Permian event in the Prince Charles Mountains, Antarctica: implications for the palynofloristic turnover across Gondwana. Review of Palaeobotany and Palynology, **145:** 89–122.

Looy, C.V., Brugman, W.A., Dilcher, D.L., Visscher, H. (1999). The delayed resurgence of equatorial forests after the Permian–Triassic ecologic crisis. Proceedings of the National Academy of Sciences of the United States of America, **96:** 13857–13862.

McLoughlin, S. (2012). *Glossopteris* – insights into the architecture and relationships of an iconic Permian Gondwanan plant. Journal of the Botanical Society of Bengal, **65:** 1–14.

McLoughlin, S., Lindström, S., Drinnan, A.N. (1997). Gondwanan floristic and sedimentological trends during the Permian–Triassic transition: new evidence from the Amery Group, northern Prince Charles Mountains, East Antarctica. Antarctic Science, **9:** 281–298.

Norris, G. (1965). Triassic and Jurassic miospores and acritarchs from the Beacon and Ferrar Groups, Victoria Land, Antarctica. New Zealand Journal of Geology and Geophysics,**8:** 236–277.

Riding, J.B., Crame, J.A. (2002). Aptian to Coniacian (Early – Late Cretaceous) palynostratigraphy of the Gustav Group, James Ross Basin, Antarctica. Cretaceous Research, **23:** 739–760.

Royer, D.L. (2006). CO_2-forced climate thresholds during the Phanerozoic. Geochimica et Cosmochimica Acta, **70:** 5665–5675.

Seward, A.C. (1914). Antarctic plant fossils. In: British Antarctic ("Terra Nova") Expedition 1910. Natural History Reports. Geology. No. 1 London: British Museum (Natural History), 1–49.

Shi, G.T., Waterhouse, J.B. (2010). Late Paleozoic global changes affecting high-latitude environments and biotas: an introduction. Palaeogeography, Palaeoclimatology, Palaeoecology, **298:** 1–16.

Simon, L., Godderis, Y., Buggisch, W., Strauss, H., Joachimski, M. (2007). Modelling the carbon and sulfur isotope composition of marine sediments: climate evolution during the Devonian. Chemical Geology, **146:** 19–38.

Spicer, R.A., Parrish, I.T. (1986). Paleobotanical evidence for cool north polar climates in middle Cretaceous (Albian Cenomanian) time. Geology, **14:** 703706

Thorn, V.C. DeConto, R. (2006). Antrarctic climate at the Eocene/Oligocene boundary climate model sensitivity to high latitude vegetation type and comparisons with the palaeobotanical record. Palaeogeography Palaeoclimatology Palaeoecology, **231:** 134157

Tosolini, A-M. P., Cantrill, D., Francis, J.E. (2013). Paleocene flora from Seymour Island, Antarctica: revision of Dusén's (1908) angiosperm taxa. Alcheringa, **37:** 1–26.

Truswell, E.M., Dettmann, M.E., O'Brien, P.E. (1999). Mesozoic palynofloras from Mac. Robertson Shelf, East Antarctica: geological and phytogeographical implications. Antarctic Science, **11:** 239–255.

Vajda, V., Raine, J.I., Hollis, C.J. (2001). Indication of global deforestation at the Cretaceous–Tertiary boundary by New Zealand fern spike. Science, **294:** 1700–1702.

Warny, S., Wrenn, J.H., Bart, P.J., Askin, R.A.(2006). Palynology of the NBP03–01A transect in the Northern Basin, western Ross Sea, Antarctica: a late Pliocene record. Palynology, **30:** 151–182.

Warny, S., Askin, R.A., Hannah, M.J., et al. (2009). Palynomorphs from a sediment core reveal a sudden remarkably warm Antarctica during the middle Miocene. Geology, **37:** 955–958.

Zachos, J., Pagani, M., Sloan, L., Thomas, E., Billups, K. (2001). Trends, rhythms and aberrations in global climate 65 Ma to present. Science, **292:** 686–693.