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# THE CASE FOR A STABLE EAST ANTARCTIC ICE SHEET: THE BACKGROUND

BY

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**ABSTRACT.** There are two primary views concerning the stability of the East Antarctic Ice Sheet. One view, relying critically on the interpretation of Sirius Group glacial deposits in the Transantarctic Mountains, is that the ice sheet has been fluctuating dramatically throughout its existence and that it last disappeared during the Pliocene ~3 Ma ago. By analogy with the warmer Pliocene, it is argued that the current ice sheet is susceptible to global warming. The other view, originating from marine and terrestrial work in the 1970s and 1980s is that the ice sheet has been stable for ~14 Ma and that the continent has been subjected to unbroken, cold polar conditions subsequently. After summarising the status of the two hypotheses, we explain the rationale for this volume. Building on the Vega Symposium of April 1993, it presents the case for the stability of the East Antarctic Ice Sheet and includes new work on terrestrial geomorphology and geology, marine cores and ice-sheet modelling.

In recent years it has been suggested that the East Antarctic Ice Sheet is intrinsically unstable and fluctuates dramatically in response to climate change. Indeed, Barrett *et al.* (1992) have suggested that it is sensitive to global warming and could largely disappear if global temperatures were to rise by a few degrees. This conclusion was reached by analogy with their interpretation of the behaviour of the ice sheet during the warmer climate of the Pliocene. If correct, then the implications are profound. The East Antarctic Ice Sheet, which is in excess of 4 km thick in places, is larger than the coterminous United States, and it locks up a mass of water equivalent to a 60 m rise in sea level (Drewry 1982). The proposed degree of ice sheet instability has major implications for our understanding of the global climate of today, its evolution over the past few million years, and possibly for projections of ice sheet changes and sea level rise in the future.

This view of inherent instability contradicts an earlier view that the East Antarctic Ice Sheet grew

step by step in response to changes in the distribution of land and sea accompanying the break up of Gondwana, and to positive feedback as the growth of the ice sheet led to progressive climatic cooling. This view was based on oxygen isotope measurements of carbonates in deep sea cores, which showed that the stepped cooling of Antarctica over the last 40 million years could be related to changes in ocean circulation around Antarctica. A coherent stable East Antarctic Ice Sheet first built up 14 million years ago (Shackleton and Kennett 1975; Kennett 1977). The marine story was also backed up by terrestrial studies in the Dry Valleys region which revealed evidence of large scale ice sheet overriding during the Miocene followed by ice sheet stability (Denton *et al.* 1984). The pros and cons of the debate were discussed by Clapperton and Sugden (1990), who favoured the stabilist view.

The case for the instability of the East Antarctic Ice Sheet is critically dependent on the interpretation of a glacial deposit, the Sirius Group, which occurs at high elevations throughout the Transantarctic Mountains. Webb *et al.* (1984) and Webb and Harwood (1987) have described occurrences of this deposit containing fragments of *Nothofagus* (southern beech) along with leaves and pollen. The plant remains indicate palaeoclimatic temperatures 20–25°C higher than at present and their incorporation into the Sirius Group suggests they have been overrun by glaciers advancing in a cool temperate environment, perhaps similar to that in Patagonia today. The Sirius deposits have been dated to ca 3 Ma BP on the basis of the marine diatoms that they contain. The dating was originally based on biostratigraphic correlation with southern ocean cores, and it has since been confirmed by dating volcanic ash in a core in front of the Ferrar Glacier immediately adjacent to the Dry Valleys (Barrett *et al.* 1992).

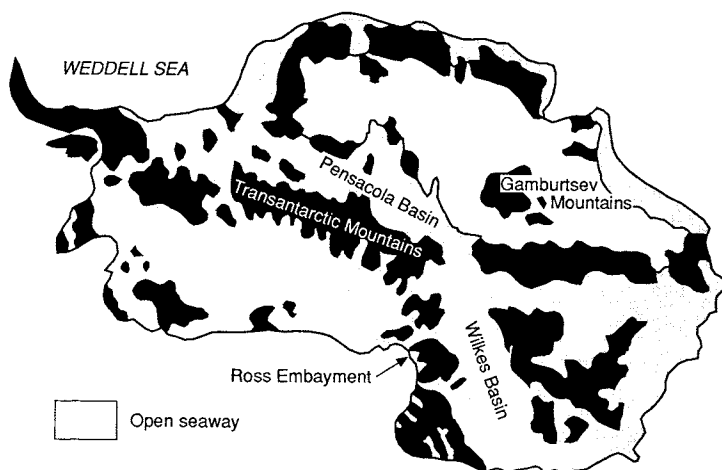


Fig. 1. Reconstruction of the hypothesized deglaciation of Antarctica during the Pliocene, showing the existence of open sea ways in the interior of East Antarctica. It is argued that marine diatoms from these interior basins were subsequently transported to the Transantarctic Mountains by an expanding ice sheet. The reconstruction assumes no isostatic recovery. After Webb *et al.* (1986).

The marine diatoms in the Sirius Group deposits have been interpreted as indicating that they were living in marine basins and that they were subsequently covered by an ice sheet which transported them to their present locations in the Transantarctic Mountains. The only feasible location for these marine basins is the interior of East Antarctica and this leads to the argument that the East Antarctic Ice Sheet must have been sufficiently small 2–3 Ma ago to expose much of East Antarctica to the sea (Fig. 1). Supporting evidence for warm Antarctic conditions during the Pliocene is discussed elsewhere in this volume (Denton *et al.*).

The hypothesis of Pliocene collapse of the East Antarctic Ice Sheet has apparently been strengthened by other discoveries in earth science. For example, high Pliocene sea levels in the eastern United States have been related to the melting of the the East Antarctic Ice Sheet (Krantz 1991; Dowsett and Cronin 1990). Secondly, fluctuations in the marine oxygen isotope record have been linked to the dynamic behaviour of the ice sheet (Abelman *et al.* 1990; Ishman and Rieck 1992). Finally, the presence of temperate vegetation at high elevations in the Transantarctic Mountains has been used to argue that significant tectonic uplift of the mountains has occurred since the Pliocene and that the cooling associated with uplift could have helped to trigger the growth of the polar Antarctic ice sheets (Behrendt and Cooper 1991).

The arrival of a challenging new hypothesis in any field of science is invigorating and welcome. It causes the scientific community to look more criti-

cally at past interpretations and in particular at the quality of the evidence and assumptions upon which such interpretations are based. More importantly, it acts as a spur to all interested parties and as a result there is a flurry of new work developing new techniques and approaches. This pattern of events has occurred in the case of the stability of the East Antarctic Ice Sheet. The last few years have seen work extending the data on which the instability hypothesis depends by studying new occurrences of the Sirius Group and improving the dating. But equally, the evidence in support of ice sheet stability has withstood additional scrutiny and moreover, new approaches have appeared to reinforce its credibility. The result is that at the time of writing both hypotheses stand. This was well illustrated by a LIRA Workshop on Landscape Evolution (interdisciplinary discussion of Antarctic Cenozoic climate change and tectonics in the Transantarctic Mountains, held at Haarlem, 28 September–2nd October, 1992) at which both research groups discussed their work. It emerged that there was no consensus as to which of the rival hypotheses best describes Pliocene palaeoclimate and ice sheet dynamics. Advocates of instability could not explain the evidence of prolonged cold desert conditions evidenced in ice free areas, while supporters of stability could not explain the presence of Pliocene diatoms in Sirius Group deposits.

Given this background it seemed that the Vega Symposium, held in Stockholm on 26th April 1993, could make a contribution to an important global problem. Rather than continue the debate

by asking for contributions from each side, we felt it would be more of a long term contribution if we could marshal the case for ice sheet stability, reappraising existing evidence, and introducing new evidence and arguments. Hence the title of this special issue *THE CASE FOR A STABLE EAST ANTARCTIC ICE SHEET*. We intend this to be a constructive step forwards in the attempt to understand the response of the ice sheet to climate change.

The papers in the volume are all free standing and independently refereed. They include discussions of detailed new stratigraphies in the Dry Valleys, underpinned by the critically important new dates on volcanic ash. These papers give detailed evidence of the long history of glaciation, volcanic activity and marine incursions and demonstrate that the landscape has been unmodified in the stable and hyper-arid climate for at least the last 13.6 Ma. They also include an overview of the problem and its relationship to the terrestrial evidence. A new geomorphological interpretation allows the dating evidence to be seen in the context of the long story of landscape evolution of the mountains since the final split with Gondwana some 55 Ma ago. The terrestrial evidence is coherent and internally consistent. Moreover, it strongly supports the view of ice sheet stability.

In another contribution new and existing marine evidence is examined and found to be consistent with a view of a stable East Antarctic Ice Sheet throughout the Pliocene. This is a particularly important conclusion since it shows that there is no sign of the massive environmental changes that would be expected were an ice sheet as big as that in East Antarctica to collapse. This evidence of stability is confirmed by a glaciological approach to the response of the ice sheet to change, which shows that a temperature rise of 17–20°C is necessary to cause significant melting of the ice sheet. Indeed, modest temperature rises such as might have occurred in the Pliocene would have led to a slight increase in ice volume.

Taken together, we believe that this volume contains a powerful body of evidence showing that the East Antarctic Ice Sheet is stable and has been so at least since middle Miocene time. This is the evidence that needs to be addressed by those arguing for an unstable ice sheet.

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