Terminal Cretaceous climate change and biotic response in Antarctica

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Abstract Latest Cretaceous to early Palaeogene climates in Antarctica are being investigated from an exceptional sedimentary sequence on Seymour Island (James Ross Basin, Antarctic Peninsula) to determine the nature of climate change at the end of the Cretaceous. It has been suggested that, following peak mid Cretaceous warmth, cooling during the Maastrichtian (~71-65 Ma) may have been severe enough for short-term glaciations at high latitudes, challenging the current view of an ice-free, Cretaceous greenhouse world. High resolution records of palaeontological, sedimentological, and geochemical signals are being obtained to investigate the climate and environmental context at the Antarctic margin prior to the Cretaceous/Tertiary extinctions, the biotic response in the marine and terrestrial realm, and to test the hypothesis of the presence of ice in conjunction with climate/ice sheet model simulations.

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Introduction

Latest Cretaceous to early Palaeogene climates in Antarctica are being investigated from an exceptional sedimentary sequence on Seymour Island (James Ross Basin, Antarctic Peninsula) to determine the nature of climate change at the end of the Cretaceous (Figs. 1 and 2). Geological evidence suggests that after the peak Cretaceous greenhouse warmth climates cooled considerably during the Maastrichtian (~71-65 Ma). Controversially, it has been argued that cooling was at times so severe that high latitude regions suffered short-term glaciations, causing sea level changes worldwide (Miller et al., 2003, 2005). This challenges the current view that the Cretaceous greenhouse world was ice-free, implying instead that short-term glacial climates may have punctuated supposedly stable warm climates. Such dramatic environmental change would have stressed terrestrial and marine biota and made them particularly susceptible to early extinction related to the global environmental catastrophe at the end of the Cretaceous. The youngest part of the sequence at Seymour Island hosts the Cretaceous/Tertiary (K/T) boundary, however, interestingly, previous terrestrial palynomorph studies suggest that there is relatively little evidence of any major environmental change affecting this region due to this event (Askin and Jacobson, 1996).

Dating using strontium isotope stratigraphy has revealed that the Late Cretaceous sequence in the James Ross Basin, Antarctica is a good sequence in which to investigate Maastrichtian environments and climate change that led up to the Cretaceous/Tertiary (K/T) event

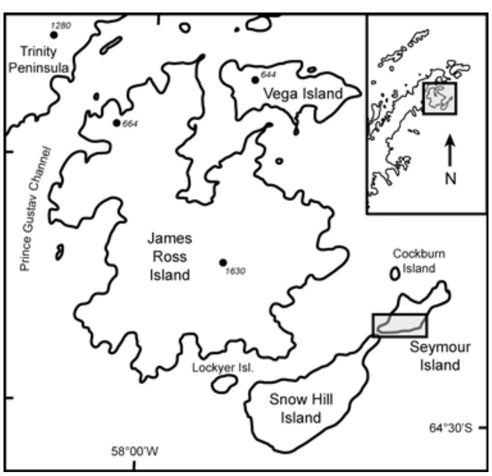

Figure 1. Location map of Seymour Island within the James Ross Basin, Antarctic Peninsula. Shaded box over Seymour Island refers to enlarged area in Figure 3.

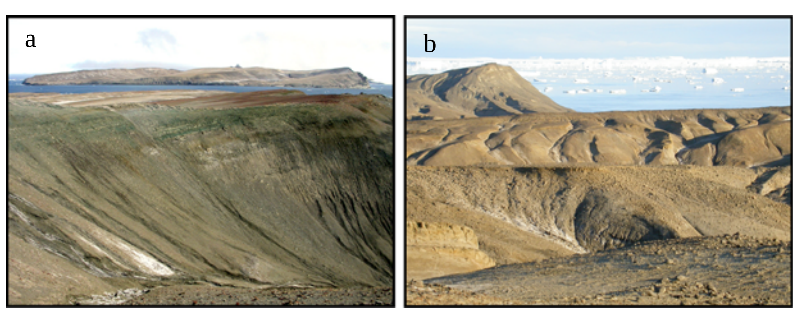

Figure 2. Seymour Island landscape, (a) the glauconite-rich beds of the uppermost Snow Hill Island Formation (Haslum Crag Member), and (b) the unconsolidated sediments of the López de Bertodano Formation.

(Crame et al., 2004). Further, the high latitude position of the basin (~65° palaeo-south, Lawver et al., 1992) makes it ideal for the determination of climatic trends and biotic response to climate shifts. This exceptional sequence is being exploited to obtain high resolution records of palaeontological, sedimentological, and geochemical signals to: a) investigate the nature of latest Cretaceous-early Palaeogene climate change at high latitudes, b) to test the hypothesis that ice was present at times and test climate/ice-sheet model simulations, c) to determine the biological response to this environmental change in both terrestrial and marine high latitude ecosystems, and d) to understand the environmental context in which the K/T extinctions occurred.

Sedimentology

Over 1200 metres of the López de Bertodano Formation, cropping out across south and central Seymour Island, has been measured, logged and sampled at stratigraphic intervals between 0.25 and 2 m (Figs. 3 and 4). With over 1200

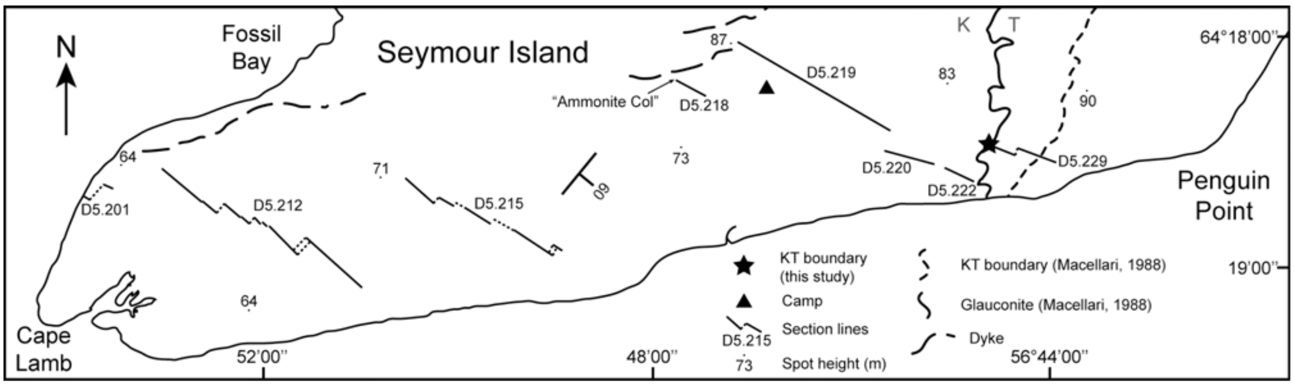

Figure 3. Map of southern Seymour Island to show measured section lines and the position of the K/T boundary as determined by marine palynology.

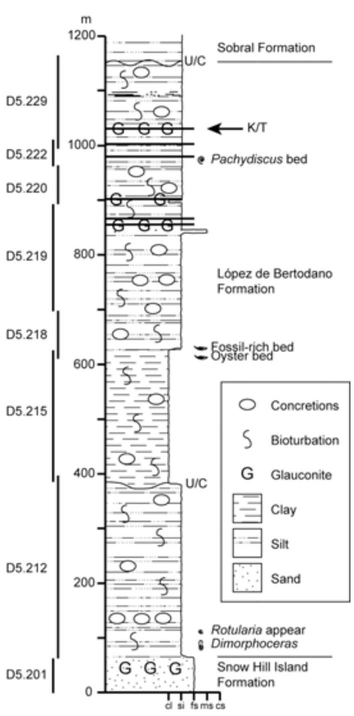

Figure 4. Summary sedimentological log. Geographic locations of the individual sections are plotted on Figure 3.

metres of sediment being deposited in approximately 3 million years, erosion and deposition rates must have been exceptionally high. The sedimentary sequence is shallowly dipping at approximately 09° to the southeast with a strike averaging 020° and consists mainly of superficially monotonous bioturbated muddy silts and silty muds containing varying amounts of both detrital and authigenic glauconite (Figs. 2 and 4). Glauconite requires very quiet conditions to form indicating that at times sedimentation on the sea floor stopped. The sediments are unconsolidated and commonly contain concretionary nodules, which allow insight into basin water chemistry during deposition. An unusual concretionary bed consisting of large pebbles and boulders of igneous rocks in a silt matrix was discovered within the early Danian sediments of the sequence. These quartz-rich sediments were originally eroded from the volcanic arc to the west (now the Trinity Peninsula region) and deposited in a rapidly subsiding marine basin (the James Ross basin) (Hathway, 2000). The likely depositional origin of this very poorly sorted deposit has yet to be confirmed, but it may represent a transgressive lag after a sea-level fall.

Previous authors have described the K/T boundary on Seymour Island as occurring at a significant glauconitic horizon in association with a fish mortality bed (Zinsmeister et al., 1989; Zinsmeister, 1998). During the mapping for this project, it was not possible to recognise the K/T boundary in the field solely on these criteria as several glauconitic and fish teeth/bone horizons were recorded throughout the relevant part of the sequence. Interestingly, Macellari (1988) had mapped a significant glauconite horizon at the *lowermost* boundary of his uppermost López de Bertodano unit, which coincides exactly with the position of the K/T defined by marine palynology in this study (Fig. 3).

Palynology

Late Maastrichtian and earliest Danian climate changes are being assessed by reconstructing vegetation composition on adjacent landmasses via the terrestrial palynomorph record (spores and pollen) in this succession. Dinoflagellate cysts are also present and provide biostratigraphic age control. The organic-walled

Figure 5. Example palynomorphs from the López de Bertodano Formation, sample D5.1258, slide 1 (latest Maastrichtian, Zone 4, Askin, 1988a), 0m above base of section D5.229. Scale bars = 10μm. (a) *Manumiella druggii* (Stover) Bujak and Davies (England Finder coordinates R35-4), (b) *Phyllocladidites mawsonii* Cookson *ex* Couper (J45-3).

microfossils are commonly exceptionally preserved having undergone minimal burial and oxidation (Fig. 5). To extract the organic material the sediment was treated with sodium hexametaphosphate (for deflocculation), sieved at 10μm and density-separated (using swirling and heavy liquid techniques) for quantitative analysis (after Riding and Kyffin-Hughes, 2004, 2006). The organic residues commonly contain abundant quantities of inertinite in addition to palynomorphs.

Samples from the upper part of the sequence have been studied first in order to locate the measured sections with respect to the K/T boundary. Preliminary biostratigraphic results from the marine palynology (dinoflagellate cysts and acritarchs), based on comparison with previous work by Askin (1988a,b), indicate a transitional K/T boundary located between 30 and 34 m in section D5.229 (Figs. 3 and 4). Stratigraphically below this level, *Manumiella* spp. and *Exosphaeridium bifidum* (Clarke and Verdier) Clarke et al. dominate the dinoflagellate flora and above an acme of *Senegalinium obscurum* (Drugg) Stover and Evitt and appearance of *Eisenackia circumtabulata* Drugg indicate the transition into the Danian. Marine palynomorphs across this interval are of relatively low diversity (between 11 and 21 taxa) and their abundance ranges between 33 and almost 37000 grains per gramme of sediment. The uppermost value is from an early Danian sample approximately 15m above the K/T boundary containing a virtually monospecific acme of *Spinidinium* sp. 1 Askin. A further acme of *Palaeoperidinium pyrophorum* (Ehrenberg) Sarjeant occurs at 60m above the K/T boundary. The *Senegalinium*, *Spinidinium* and *Palaeoperidinium* acmes occurring soon after the K/T boundary reflect perhaps a "settling down" period in ocean palaeoecology following the catastrophe.

Terrestrial palynomorphs across the K/T transition include spores (from land plants, fungi and freshwater aquatic ferns (*Azolla*-type and *Grapnelispora evansii* Stover and Partridge) and pollen (both angiosperm and gymnosperm). Miospore diversity ranges between 27 and 60 taxa across the K/T boundary with abundances between approximately 200 and 4000 grains per gramme of sediment. The predominant miospore taxa include *Stereisporites* spp. (affinity Bryophyta), *Laevigatosporites ovatus* Wilson and Webster and *Cyathidites minor* Couper (Filicopsida), *Phyllocladidites mawsonii* Cookson ex Couper and *Microcachrydites antarcticus* Cookson (Podocarpaceae), *Nothofagidites* spp. (mainly of the "*brassii*" group; Nothofagaceae) and *Peninsulapollis gillii* (Cookson) Dettmann and Jarzen (Proteaceae). Miospore composition does not change suddenly across the K/T boundary, but instead a gradual increase in angiosperm pollen is noted through into the Danian.

Macrofossils

Rich macrofossil beds are common in the upper parts of the sequence with the lower part dominated by calcareous worm tubes (*Rotularia* spp.). The remains of a diverse fauna of ammonites, bivalves, gastropods, echinoids, marine reptiles, corals, fish and sharks were documented at 5m intervals throughout the sequence allowing an assessment of changes in marine diversity through time (Fig. 6). Many of the macrofossils had retained their

Figure 6. Example macrofossils from the López de Bertodano Formation. Scale bars: (a) 1cm, (b)-(d) 5cm. (a) *Lahillia* sp. and gaudryceratid ammonites, (b) sharks teeth, (c) kossmaticeratid ammonite and (d) buccinoidean gastropod.

original aragonitic shell material and are exceptionally well preserved. Aside from sedimentological ambiguities, the K/T boundary was difficult to distinguish in the field from the disappearance of ammonites and marine reptiles due to the apparent surface drift of fossils up to approximately 40m, in a down-dip direction. Ammonites collected stratigraphically above the boundary, as subsquently defined by palynology, were notably weathered compared to those below. Further, the presence of fish teeth and bones at more than one horizon complicated the definition of the position of the K/T boundary as previously described by Zinsmeister (1998).

Summary

Over 1200 metres of mid to late Maastrichtian sediments of the López de Bertodano Formation are being studied in order to determine the nature of climate change through the latest Cretaceous and into the early Palaeogene. The unit consists of a fossiliferous sequence of clayey siltstone with intervals of glauconite-rich horizons, representing an environment of rapid deposition on a shallow shelf, interrupted with periods of non-deposition, possibly related to high sea levels. Initial palynomorph studies indicate that the K/T boundary is marked by a transition from a flora dominated by *Manumiella* spp. to virtually monospecific assemblages of different species (e.g. *Spinidinium* sp. 1 and *Palaeoperidinium pyrophorum*) reflecting unstable ocean palaeoecology after the K/T catastrophe. Conversely, there is little change in the terrestrial palynology across the K/T with only a gradual increase in angiosperm pollen noted into the Danian.

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