measurement. Specific energy loss and range straggling depend on the energy of the particle. The evenness of the sheet thickness has to be better than ± 0.2 μm. Under the conditions described here the contribution of the etching process and the microscopic measurement amounts to 40 keV for the ^{210}Po peak and 33 keV for the ThC major peak.

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Received October 31, 1973.

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Eocene echinoids and the Drake Passage

AUSTRALIA and Antarctica separated about 50 million years (Myr) ago[1]. Echinoid populations indicate a warmer climate at the time of separation than later. A model of oceanic circulation in the Southern Hemisphere, consistent with this observation, leads to a more precise dating of the opening of the Drake Passage between South America and Antarctica.

The oldest echinoid fauna known from the opening seaway between Australia and Antarctica has been preserved at several localities between Albany and Adelaide. The fauna is most abundant and best known in the Late Eocene Tortachilla Limestone, which outcrops along the eastern flank of the St Vincent Basin, south of Adelaide. Eighteen species of echinoids have been described from this formation of small lateral extent and a further five have yet to be described. The marsupiate echinoids, which are intermittently common in the Tertiary of southern Australia, are notably absent. Echinoids are also abundant a little further up the section at a Late Eocene horizon, low in the Port Willunga Beds. Less than 10 species are known at this level, and almost all are of genera different from those in the earlier Tortachilla. They include the earliest of the Australian marsupiate echinoids, the temnopleurid *Paradoxechinus stellatis* Philip and Foster.

A similar situation exists on the opposite flank of the basin. There is a complete change in the echinoid fauna between the Muloowurtie Formation and the overlying Rogue Formation in which *P. stellatis* appears.

By analogy with recent Antarctic brood-protecting echinoids, it has been inferred that the marsupium, developed in the female of several species of Australian Tertiary Temnopleuridae, Clypeasteroida and Spatangoida, confers an advantage in colder water[2]. An unsatisfactory aspect of correlating the presence of marsupiate echinoids with cold water is that the earliest fauna of the discussed region contains no marsupiate echinoids—despite the fact that this fauna probably lived more than 20° further south than its present position. Marsupiate echinoids are, in fact, a conspicuous component of the fauna during the journey of Australia towards the tropics.

Frakes and Kemp[3] proposed a model of early Tertiary climates which may provide the answer. In the Eocene there was no circumpolar cold current in the Southern Ocean because of the presence of a continuous Andean–West Antarctic mountain chain. As Australia was far to the south of South-east Asia, ample room existed for the southern equatorial current of the Pacific to continue into the Indian Ocean, sweep south and return, at least in part, through the new seaway which separated Australia from Antarctica. Because of the long time spent travelling through about 200° of longitude in the tropics, the equatorial current, which left the coast of South America at about 19° C, began its southerly sweep into the Indian Ocean at about 37° C. It was probably still above 20° C as it passed along the southern coast of Australia. A warm water echinoid fauna can therefore be expected. By the mid-Oligocene, the northward drift of Australia had restricted the flow of warm equatorial Pacific water into the Indian Ocean. More important, the breaching of the Andean–West Antarctic mountain barrier allowed a circumpolar cold current to replace the warm current in the widening seaway between Australia and Antarctica. The water temperature probably fell to well below 10° C. A changed echinoid fauna, including brood-protecting species, is consistent with this model.

Dalziel and Elliot[4] estimate the opening of Drake Passage, and thus the beginning of the circumpolar current, to have occurred between the latest Cretaceous (65 Myr) and about 25 Myr ago.

The Tortachilla Limestone was deposited at the beginning of the Late Eocene, probably high in P15 in the planktonic foraminiferal zonation[5]. The Port Willunga Beds have been sampled and dated[6] especially to provide a time framework for the sequence of echinoids, and the horizon containing *P. stellatis* has been placed high in the Late Eocene, corresponding to P17.

Using ages attributed to the planktonic foraminiferal datum planes[5] as a guide, the event which caused the replacement of a warm water by a cold water echinoid fauna in the seaway between Australia and Antarctica can be dated at about 40 Myr—probably 41–36 Myr. This event was probably the inception of the mighty Antarctic circumpolar current, which began with the breaching of the Andean–West Antarctic Cordillera and the concomitant creation of the Drake Passage. Thus, there is indirect evidence which enables the separation of South America from Antarctica to be more precisely dated than before.

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Received February 26, 1974.

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Closing of the Protocadic Ocean and intraplate basins

THE presence of several long-lived, deeply subsiding basins, autogeosynclines[1], such as those in Michigan, Illinois, North Kansas and Williston suggests that the North American craton or plate remained in a constant position relative to the underlying mantle during the Palaeozoic.

In the Michigan Basin the Precambrian basement surface subsided about 4,000 m between the late Cambrian and the Devonian[1-6]. Throughout this time, there was little deposition of terrigenous sediment and subsidence was largely independent of loading. With a few exceptions, the isopachs of many of the series and stages within the basin are centred to the west and north of Saginaw Bay, a little to the north-east of the centre of the structural basin[7]. However, during the mid-Ordo-