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Cretaceous coccoliths in the middle Eocene of the western and southern margins of Australia: evidence of a significant reworking episode

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A reworking episode is indicated by occurrences of upper Cretaceous coccoliths among middle Eocene assemblages in four basins (Carnarvon, Perth, Eucla, and Otway Basins) along the Australian western and southern margins. The episode falls within the coccolith biostratigraphic interval from the lowest occurrence of *Cyclicargolithus reticulatus* to the highest occurrence of *Daktylethra punctulata*, which correlates with the foraminiferal zonal interval P.12–P.13. At the time of the episode (about 45–44 Ma) the sea advanced along the southern margin from the west, causing a transgression in the Eucla Basin and an ingression in the Otway Basin. Coincident with this sea-level rise, and probably the cause of it, was a major acceleration in the spreading rate south of Australia. In the absence of known in-situ occurrences of upper Cretaceous coccoliths on the southern margin or offshore to the south, the Naturaliste Plateau is thought to have been the most likely provenance for the reworked taxa in the Eocene of the Eucla and Otway Basins — short-lived strong currents stripped off coccolith-rich upper Cretaceous sediments on the plateau and transported them eastward. In the Perth Basin a local source, the upper Cretaceous coccolith-rich Gingin Chalk/Lancelin Beds, is suggested for the reworked taxa, whereas in the Carnarvon Basin a distant source is more likely.

Introduction

My studies of the biostratigraphy of the early Tertiary calcareous nannofossils of the Australian region (Shafik, 1973, 1978a, 1983) indentified occurrences of upper Cretaceous coccolith taxa among Eocene assemblages in four basins situated along the western and southern margins of Australia, from northwest to southeast, the Carnarvon, Perth, Eucla, and Otway Basins (Fig. 1). The occurrences in the Eucla and Otway Basins are anomalous, because in-situ upper Cretaceous coccoliths are not known there or in the offshore areas to the south.

Coccoliths are prone to reworking because of their very small size and their usual great abundance. Detection of reworking in an assemblage can be difficult if the stratigraphic gap between the indigenous and reworked taxa is short. However, in the present case this gap is not only great (late Cretaceous–Eocene) but also, because of the mass extinction of Cretaceous coccoliths at the Cretaceous/Tertiary boundary and appearance of new forms during the early Tertiary, differentiation of the reworked taxa is a simple matter.

This paper explores the significance of the reworked upper Cretaceous coccoliths in the middle Eocene of the Australian western and southern margins and attempts to locate their provenance, particularly for those in the Eucla and Otway Basins.

Carnarvon Basin

The lower Tertiary sequence of the Carnarvon Basin is best exposed along the flanks of the Giralia Anticline and nearby structures, where Paleocene greensand and calcarenites (containing coccoliths) underlie the Eocene Jubilee and Giralia Calcarenites. The facies of the Eocene calcarenites is unsuitable for coccoliths, but their subsurface equivalents further north include facies with abundant coccoliths. Four WAPET wells from these northern areas (Fig. 2A), Ningaloo-1, Rough Range South-1, Long Island-1, and Pasco-1, contain reworked upper Cretaceous coccolith taxa in association with middle Eocene assemblages.

The indigenous coccoliths are generally well preserved in most of the Eocene of the sections studied. However, within the relevant interval (middle Eocene levels with the reworked taxa), they are distinctly poorly preserved. It appears that the reworked taxa occur at more than one level within the middle Eocene biostratigraphic interval bracketed by the lowest occurrence of *Cyclicargolithus reticulatus* and the highest occurrence of *Daktylethra punctulata*, an interval within which a regional unconformity is suspected.

Perth Basin

Shafik (1978a) recorded a middle Eocene coccolith assemblage from the Rottnest Island Bore (Fig. 2B) in the Perth Basin. Before then, the known marine lower Tertiary of the Perth Basin was limited to the late Paleocene and earliest Eocene calcareous microfossils of the Kings Park Formation.

The Rottnest Island Bore assemblage (Shafik, 1978a) also contains reworked upper Cretaceous coccolith taxa of Campanian to early Maastrichtian age. These taxa include the cosmopolitan forms *Arkhangelskiella cymbiformis*, *Ahmuellerella octoradiata*, *Biscutum blackii*, *Broinsonia parca*, *Cretarhabdus crenulatus*, *Cribrosphaerella ehrenbergii*, *Cribrocorona gallica*, *Eiffellithus eximius*, *E. turriseiffeli*, *Gartnerago obliquum*, *Lithraphidites carniolensis*, *Micula staurophora*, *Prediscosphaera cretacea*, *P. spinosa*, *Vekshinella imbricata*, *Watznaueria barnesae*, and *Zygodiscus diplogrammus*, in addition to the nearshore forms *Kamptnerius magnificus*, *Lucianorhabdus cayeuxii*, *Calculites obscurus*, and *C. ovalis*. It is worth noting that nearshore species are usually the least resistant to destruction.

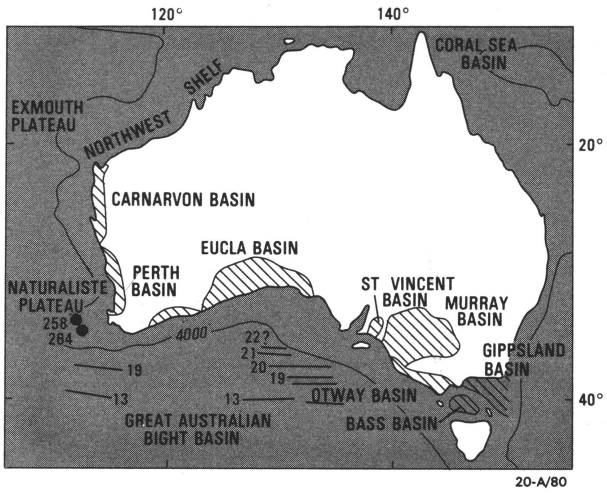

Figure 1. Sketch map of Australia and surroundings, showing the sedimentary basins of the Australian western and southern margins, and the Naturaliste Plateau.

Note that anomalies 19 to 22 south of Australia are remodelled as 20 to 34 by Cande & others (1981).

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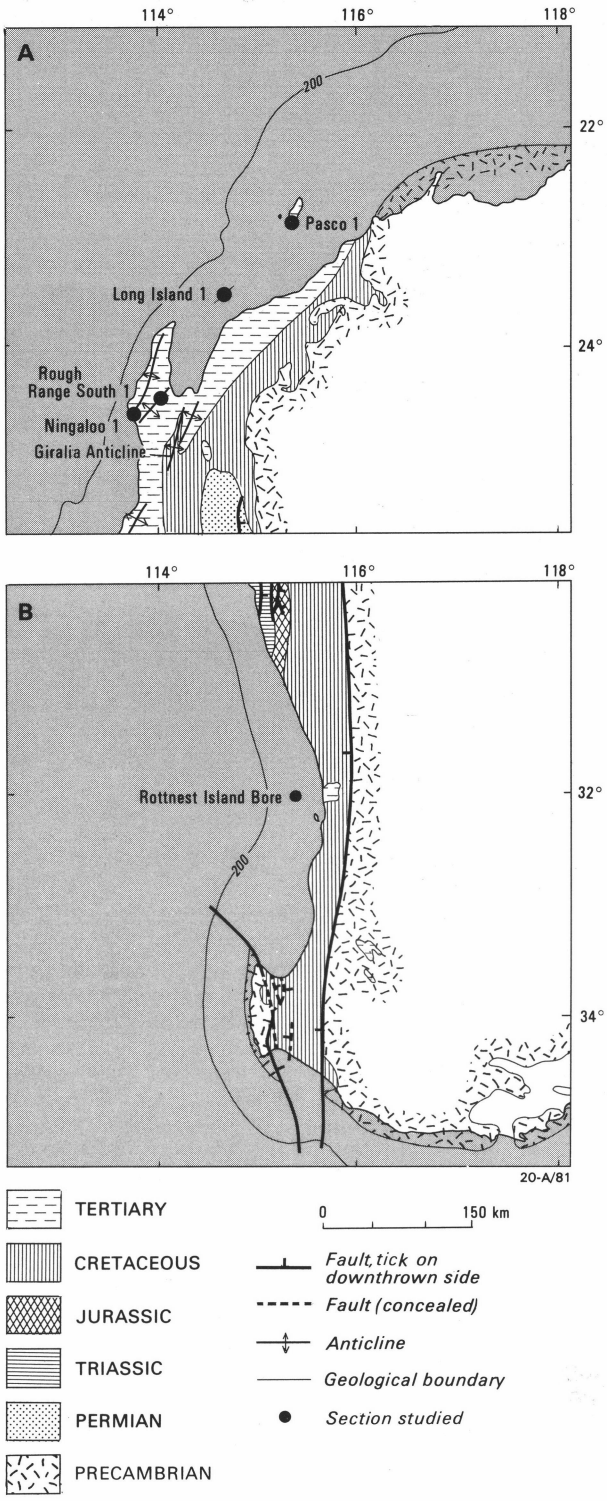

Figure 2. Location of material studied from the Australian western margin: (A) Carnarvon Basin, and (B) Perth Basin.
Note that the widely occurring Cretaceous sediments in both basins include upper Cretaceous units rich in coccoliths.

The key taxa of the Rottnest Island Bore indigenous assemblage include *Chiasmolithus grandis*, *C. solitus*, *Cyclicargolithus reticulatus*, *Cyclococcolithus formosus*, *Discoaster barbadiensis*, *D. tani nodifer*, *D. saipanensis*, *Helicosphaera compacta*, *H. reticulata*, *Reticulofenestra scrippsae*, *R. umbilica*, *Daktylethra punctulata*, and *Pemma papillatum* (Shafik, 1978a). The evidence, discussed by Shafik (1978a), seems to suggest that this middle Eocene assemblage represents a short-lived transgression or a major ingression in the basin.

Eucla Basin

The lower Tertiary sequence of the Eucla Basin is composed of the Hampton Sandstone (or its probable correlative, the Pidinga Formation) and the overlying Wilson Bluff Limestone. It rests disconformably on the Cretaceous Madura Formation or on Permian and Proterozoic rocks. The contact is not exposed and the lowest part of the Tertiary sequence is known only from bore holes. Material studied, representing the Hampton Sandstone and the basal Wilson Bluff Limestone, came from four sections (Fig.3): Guinewarra and Albala Karoo Bores (in South Australia) and Eyre-1 and Gambanga-1 wells (in Western Australia). In all these sections, reworked upper Cretaceous taxa were encountered consistently at the base of the marine Tertiary sequence, immediately above the disconformity with the older rocks. The indigenous assemblages, containing the reworked taxa are middle Eocene and similar in the four sections. Their main elements include *Chiasmolithus grandis*, *Cyclicargolithus reticulatus*, *Helicosphaera compacta*, *H. reticulata*, *Reticulofenestra umbilica*, *R. scrippsae*, and *Neococcolithes dubius*. *Chiasmolithus solitus* is either very rare or absent, and a form similar to *Reticulofenestra scissura* is present. The reworked taxa include *Arkhangelskiella cymbiformis*, *Eiffellithus eximius*, *E. turriseiffeli*, *Gartnerago obliquum*, *Lithastrinus floralis*, *Micula staurophora*, *Prediscosphaera cretacea*, and *Watznaueria barnesae*. Although these reworked taxa are rare, they are undoubtedly more abundant and more diversified than those reworked in the middle Eocene of the Otway Basin to the east (see below). The reverse is true when compared with the reworked taxa in the middle Eocene of the Perth Basin to the west.

Otway Basin

The lower Tertiary sequence in the western portion of the Otway Basin (Gambier Embayment) comprises a clastic section of sand grit, silt, clay, and a little marl (Knight Formation, Kongorong Sand, and Lacepede Formation, in ascending order), and an overlying carbonate unit (Gambier Limestone). Coccoliths are absent from the lower part of the clastic section (Knight Formation) and their record higher in the section (lower part of the combined Kongorong Sand/Lacepede Formation) is noticeably discontinuous before becoming continuous. The counterpart clastic section in the eastern part of the basin at Browns Creek is composed of sand, clay, and marl (Johanna River Sand and Browns Creek Clays), and its lower part (Johanna Sand) is devoid of coccoliths.

In a study of the coccolith biostratigraphy of the Eocene of several Otway Basin sections (Fig. 4), I concluded (Shafik, 1983) that middle Eocene marine ingressions, represented by isolated assemblages, occurred in the Gambier Embayment, but did not reach the eastern parts of the basin. Reworked upper Cretaceous taxa were encountered in a single section in the Gambier Embayment (Beachport-1) among an assemblage containing the key species *Chiasmolithus expansus*, *C. grandis*, *C. solitus*, *Cyclicargolithus reticulatus*, and *Daktylethra punctulata*. A coeval assemblage, described as representing the first middle Eocene marine ingression in the Gambier Embayment, was also identified (Shafik, 1983) in Kingston Construction Camp Bore (Fig. 4).

The reworked upper Cretaceous taxa in the Beachport-1 middle Eocene amount only to a few specimens of a very

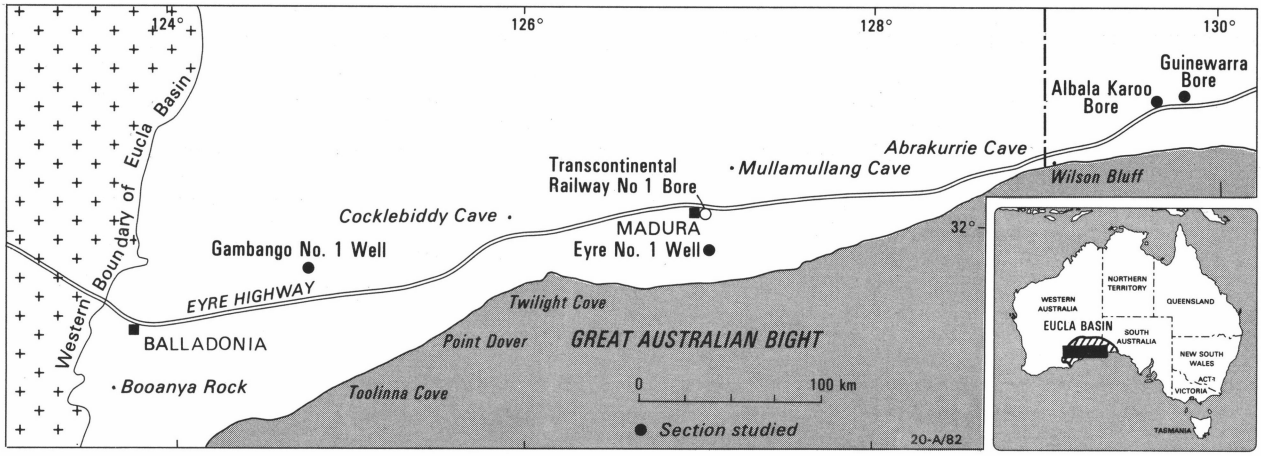

Figure 3. Location of material studied from the Eucla Basin.

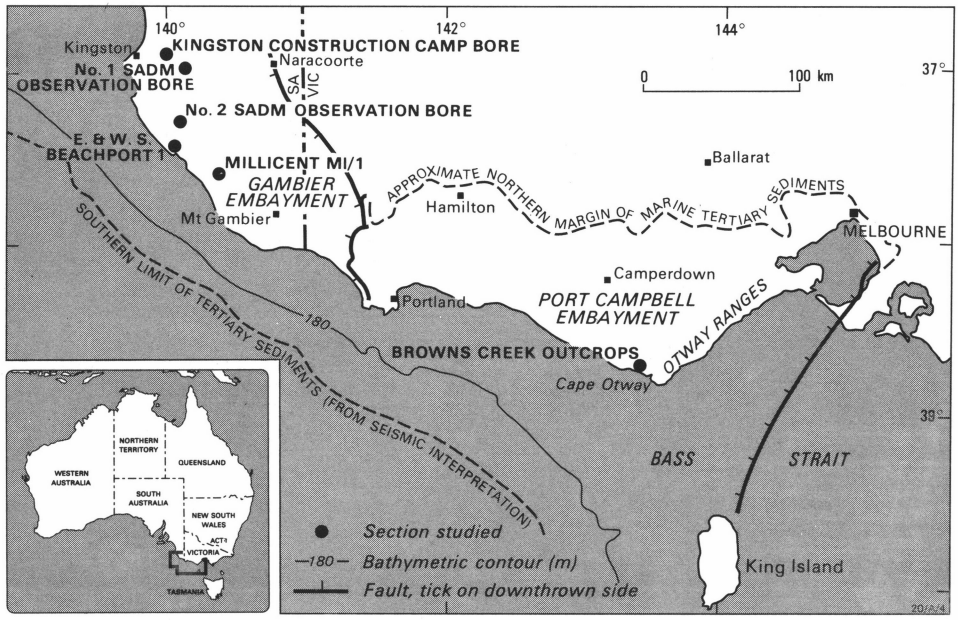

Figure 4. Location of material studied from the Otway Basin.

few species. They include *Watznaueria barnesae* and *Prediscosphaera cretacea*, species highly resistant to destruction, and usually among the more common taxa in indigenous Cretaceous assemblages.

Discussion

The Otway Basin assemblage (Beachport-1) and the Rottnest Island Bore assemblage from the Perth Basin share the same indigenous key species, *Chiasmolithus grandis*, *C. solitus*, *Cyclicargolithus reticulatus*, and *Daktylethra punctulata*. The presence of *Chiasmolithus solitus* in association with *Cyclicargolithus reticulatus* suggests a correlation within the low-latitude foraminiferal zone P.12, at about the 45–44 Ma (Shafik, 1978a, 1983). Except for *Chiasmolithus solitus*, which is either very rare or absent from the relevant assemblages in the Carnarvon and Eucla Basins sections, other key taxa, including *Cyclicargolithus reticulatus* and *Daktylethra punctulata*, are the same as those in the Beachport-1 and Rottnest Island Bore assemblages. A correlation with a level near the foraminiferal zonal boundary P.12/P.13 is suggested. This is consistent with the occurrence only of forms similar to *Reticulofenestra scissura*, and not the typical form, in the Eucla Basin assemblages; typical *R. scissura* in association with *Daktylethra punctulata* indicates a younger correlation within the foraminiferal zone P.13.

In the four basins studied, the coccolith assemblages containing the reworked upper Cretaceous taxa are contemporaneous, being assignable to the middle Eocene biostratigraphic interval from the lowest occurrence of *Cyclicargolithus reticulatus* to the highest occurrence of *Daktylethra punctulata*. The implication is that the occurrences of the reworked upper Cretaceous taxa in the middle Eocene of the four basins are coeval and can, therefore, be considered as a single reworking episode. That the reworked taxa are restricted to the basal part of the Tertiary sections studied from the Eucla Basin and to a single horizon in the Beachport-1 in the western Otway Basin suggests that the agents responsible for the reworking episode along the southern margin were short-lived.

At the time of the reworking episode and immediately after, i.e. during the interval post-dating the lowest occurrence of *Cyclicargolithus reticulatus*, but before the extinction of *Daktylethra punctulata* (foraminiferal zonal interval P.12–P.13) the depositional scenarios in the four basins (Shafik, 1984) were different in detail, though apparently

related: a normal pre-existing shelf setting in the Carnarvon Basin, which apparently was interrupted briefly sometime before the end of the interval; a short-lived transgression (or a pronounced ingression) in the Perth Basin, which started and ended in the mid middle Eocene; initial stages of a transgression in the Eucla Basin, which persisted into the late Eocene; and marine ingressions in the Gambier Embayment of the Otway Basin, which did not reach the east of the basin and which, subsequently, were followed by a transgression at the end of the middle Eocene (Shafik, 1983).

Western margin

The reworked upper Cretaceous coccolith taxa in the middle Eocene of the Perth Basin (Rottnest Island Bore) are unlikely to have been transported far, because they include species prone to destruction (particularly those indicative of nearshore deposition). Coccolith-rich upper Cretaceous sediments in the Perth Basin (Gingin Chalk and Lancelin Beds) also contain these relatively fragile taxa (including those indicative of nearshore deposition) (Shafik, 1978b, and

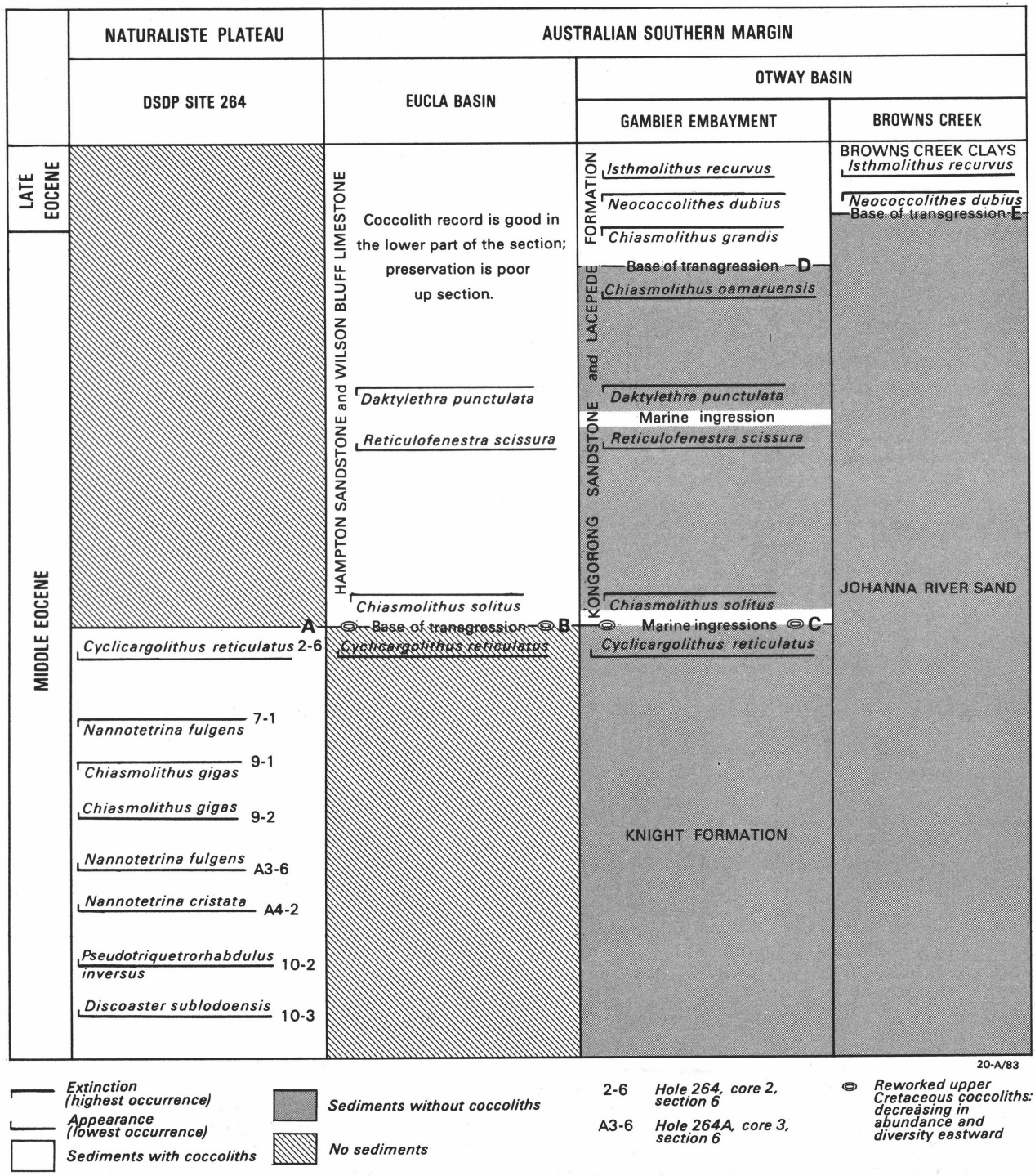

Figure 5. Eocene events at DSDP site 264 (Naturaliste Plateau) and along the Australian southern margin (Eucla and Otway Basins). A, B, & C are virtually isochronous. *Chiasmolithus grandis* occurs with *C. oamaruensis* at D. E is younger than the extinction of *Chiasmolithus grandis*.

unpublished data). Shafik (1978a) suggested the Lancelin Beds as the source of the reworked upper Cretaceous taxa in the middle Eocene of Rottnest Island Bore, because of agreement between the age of the Lancelin Beds (Campanian) and the Campanian or younger age of the reworked taxa. The age of the Gingin Chalk was thought then to be Santonian (Shafik, 1978b, and references therein). However, new data (Shafik, unpublished) indicate that the Gingin Chalk is as young as the latest Maastrichtian, so this unit, too, is a possible source for the reworked taxa in the Rottnest Island Bore.

In the Carnarvon Basin and adjacent offshore areas, upper Cretaceous sediments with abundant coccoliths are widely distributed. The reworked upper Cretaceous coccoliths in the middle Eocene occur at more than one level, mostly without nearshore taxa, suggesting contributions from distant provenances or some oceanic source.

Southern margin

According to Cande & others (1981), a major acceleration in the seafloor spreading rate occurred south of Australia at 45 Ma, i.e. at about or slightly before the time of the reworking episode in the Eucla and Otway Basins. This acceleration in the spreading rate is consistent with the rise in sea level that resulted in the middle Eocene transgression in the Eucla Basin and the coeval ingressions in the Otway Basin. Along the southern margin, the base of the marine lower Tertiary sediments — as detected by the lowest occurrence of coccoliths — is progressively younger eastward (Shafik, 1973), suggesting that the sea advanced from the west. Accordingly, it is not unreasonable to suggest that the middle Eocene ingressions in the Otway Basin, and its subsequent transgression (Shafik, 1983; Fig. 5) were the distal expression of the coeval transgression in the Eucla Basin. That these ingressions were confined to the Gambier Embayment in the western Otway Basin is consistent with the above argument. The argument is strengthened further by the coeval reworking episode: the reworked taxa are restricted to the very base of the Eucla Basin transgression and the coeval first middle Eocene ingression in the Otway Basin.

In-situ upper Cretaceous coccoliths are not known along the Australian southern margin or in the offshore areas to the south. Although the break up of Australia and Antartica may have occurred during the mid late Cretaceous (Cande & others, 1981), it is unlikely that during the late Cretaceous the proto-Southern Ocean was deep enough, with good connections to the open sea, to give water conditions favourable to coccoliths. In the Eucla and Great Australian Bight Basins, open marine conditions did not exist during the late Cretaceous (Deighton & others, 1976). Further to the east, in the Otway Basin, the same is also true, and even the accepted 'marine' upper Cretaceous unit (the Belfast Mudstone) 'would have been deposited in intertidal salt marshes to very shallow marine, delta front environments' (Deighton & others, 1976, p. 26).

On the other hand, upper Cretaceous sediments rich in coccoliths occur widely on the Naturaliste Plateau, off southwestern Australia, and they were eroded from time to time, including the Eocene — at the time of the reworking episode in the Eucla and Otway Basins. A widespread disconformity separating upper Cretaceous and younger sediments of the plateau has been reported by several investigators. Burkle & others (1967) recorded upper Cretaceous directly below Pleistocene (Core RC8-56) in the northeastern slope of the plateau. Davies, Lyendyk & others (1974) recorded a Santonian/Miocene unconformity at DSDP site 258 (northern part of the plateau). The sedimentary sequence at DSDP site 264 (southern edge of the plateau) contains two relevant unconformities: Campanian/Paleocene, and mid middle Eocene/upper Miocene (Shafik, unpublished data); these unconformities were reported by Hayes, Frakes & others (1975) as Cenomanian/Paleocene and upper Eocene/upper Miocene, respectively.

With the available biostratigraphic resolution, the top of the middle Eocene section at DSDP site 264 (which is

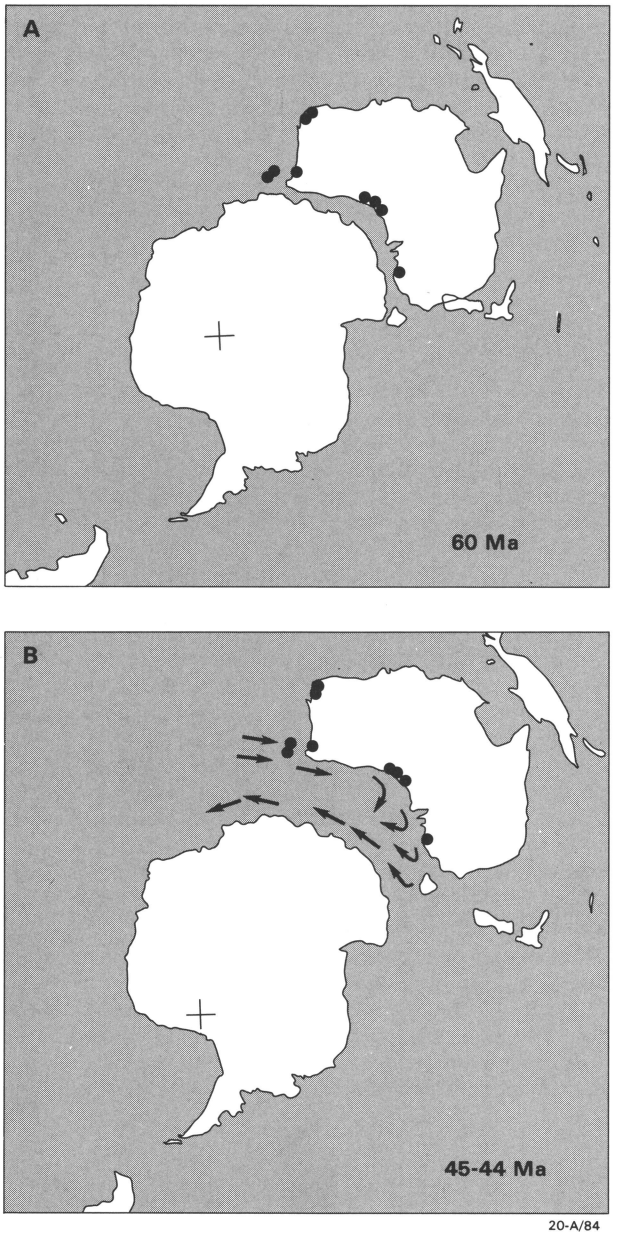

Figure 6. Reconstruction of the relative positions of Australia and Antarctica during the late Cretaceous (A) and mid Eocene (B). During the late Cretaceous and Paleocene, the proto-Southern Ocean was narrow and shallow, and generally unsuitable for coccoliths, but by the mid Eocene it was deep and wide enough for coccolith assemblages to flourish in the Eucla Basin; at about 45 to 44 Ma, strong currents, marking the advent of a transgression in the Eucla Basin, were apparently developed, but only for a short time. These currents would have circulated clockwise in the proto-Southern Ocean as the eastern end of this 'ocean' was not sufficiently deep to permit flow past the South Tasman Rise. The easterly flowing currents would have been responsible for erosion of upper Cretaceous sediments on the Naturaliste Plateau, of southwestern Australia, and eastward transportation of the claysized coccoliths derived from them.

immediately above the lowest occurrence of *Cyclicargolithus reticulatus*) can be equated with the time of the reworking episode in the Eucla and Otway Basins (Fig. 5). The records in the northern parts of the plateau too (Core RC8-56, and DSDP site 258) fit the scenario of erosion of upper Cretaceous sediments during the middle Eocene.

The Naturaliste Plateau is probably the best candidate for a source of the reworked upper Cretaceous coccolith taxa in the middle Eocene of the Eucla and Otway Basins. I envisage that the onset of the Eucla Basin transgression was marked by strong currents coming from the west and passing over the Naturaliste Plateau (Fig. 6). Upper Cretaceous sediments were stripped off and their constituents (mainly coccoliths) were transported and progressively redeposited eastward, along the currents' path. This would explain why the reworked taxa in the Eucla Basin samples are much more abundant and diversified than those in the Beachport-1 assemblage in the Otway Basin. Evidently, these strong currents were short-lived, being active only during the very beginning of the transgresssion in the Eucla Basin and the coeval first middle Eocene ingression in the Otway Basin.

Conclusions

As a result of a short-lived reworking episode, upper Cretaceous coccoliths were displaced and incorporated with middle Eocene assemblages in four basins (Carnarvon, Perth, Eucla, and Otway Basins) along the western and southern margins of Australia. The indigenous assemblages are coeval, belonging to the coccolith biostratigraphic interval from the lowest occurrence of *Cyclicargolithus reticulatus* to the highest occurrence of *Daktylethra punctulata*, which correlates with the low-latitude foraminiferal zonal interval P.12–P.13.

The reworking episode in the Carnarvon Basin is one in a long history of marine sedimentation that laid down widely distributed Paleocene and Eocene sediments. Evidence for the reworking episode occurs at levels where there is a noticeable drop in the quality of coccolith preservation, and also where a regional unconformity is suspected. Distant provenances or some oceanic source contributed to the reworked upper Cretaceous coccoliths in the middle Eocene of the Carnarvon Basin.

The reworking episode in the Perth Basin coincided with a short-lived middle Eocene transgression (or a pronounced ingression). The reworked taxa are more abundant and diversified than those recorded in the middle Eocene of the three other basins studied, and also are different in that they contain several species indicative of nearshore deposition. This indicates a nearshore source, probably the local upper Cretaceous Gingin Chalk/Lancelin Beds.

At the time of reworking, the sea advanced eastward along the Australian southern margin, causing a transgression in the Eucla Basin and an ingression in the western Otway Basin. The Naturaliste Plateau is thought of as the probable provenance area for the reworked upper Cretaceous coccoliths in the middle Eocene of these basins, in the absence of known in-situ upper Cretaceous coccoliths along the southern margin or offshore to the south. The reworking episode on the southern margin apparently was caused by short-lived strong currents stripping coccolith-rich upper Cretaceous sediments from the plateau and transporting them eastward. The coccoliths were progressively redeposited along the currents' path, only a few reaching the western Otway Basin.

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Appendix. List of coccoliths referred to in this paper

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