Rifting and Drift of Australia and the Migration of Mammals

Recently several investigators (1-5)have discussed the immigration of the primitive mammals (monotremes and marsupials) to Australia. The oldest fossils that have been found are probably Early Miocene in age (6). Interest in the subject has been stimulated by the profound changes in the thinking of geologists that have occurred during the past decade on the old problem of a postulated supercontinent, Gondwanaland, and on a possible timetable for its breakup and the dispersal of the fragments to their present geographical positions. Perhaps we have reached the stage where "it is therefore no longer profitable for biologists to speculate about the past arrangements of land masses" (2); at any rate, there is a widespread (although not unanimous) feeling on the part of geologists that we should now concentrate our attention on the problems-especially the timing -of a southern mammalian migration route, that is, via Antarctica, rather than from Asia via Indonesia (7), or even from North America across a postulated former landmass in the present Pacific Ocean (8). In this technical comment I discuss stratigraphic evidence from Australia bearing on the geographic relationship of Antarctica to Australia. I assume for the purpose that mammalian migration was by that route. My conclusion is that the geology of the Australia/Antarctica suture gives no evidence of any significant barrier to the passage of land animals during the time from the Early Permian (270 \times 10^6 years ago) to the Early Eocene $(49 \times 10^6 \text{ years ago})$. There is some evidence that incipient rifting already had occurred by the Early Permian, and strong evidence that active drifting (separation of the two continents) began in the Late Paleocene or Early Eocene. The distinction between rifting and drifting is important. It follows from this conclusion that geology's contribution to the historical biogeography of southern mammals (apart, of course, from the dating of fossil finds) will consist primarily of the examination of the history of other continental connections, especially the Scotia Arc between Antarctica and South America; those problems are outside the scope of this comment.

When Australia is fitted against Antarctica, there seems to be a continuity in a gross sense within the tectonic belts (geosynclines) of the Late Precambrian and the Paleozoic (9). The first evidence of incipient sutural rifting might be found in the first signs of geological trends cutting across those broadly north-south trends. One generally accepted piece of evidence is the presence of volcanic rocks in Tasmania and Antarctica of Jurassic age, which date from about 160×10^6 to $170\times$ 10^6 years ago (10). However, there are signs of cross-cutting geological trends which suggest that the formation of a continental suture in the position of the future Southern Ocean occurred in the Late Paleozoic. Wopfner (11, 12) has suggested that Permian sedimentation, including tills and other evidence for glaciation, was controlled significantly by tectonic trends which began in the Devonian, Early Permian ("Sakmarian") sediments with marine-type assemblages of microfossils occur widely in southern Australia, being known from the Denman, Arckaringa, and Troubridge basins and the Renmark Trough (Fig. 1) (13). These microfossils consist almost entirely of organicwalled phytoplankton and benthonic foraminifera with agglutinated tests (14). The stratigraphic sequence as presently



and the occurrence of shelly marine macrofossils at Bacchus Marsh (14). Marine assemblages are not recorded from other Permian basins shown, nor from Antarctica on the southern side of the suture. An essentially similar situation has been shown for the Late Cretaceous (21) and is held here to apply also for the Early Tertiary before the major Middle Eocene transgression (also from the southwest).

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known suggests that a time interval with a maximum extent of glaciation was succeeded by an interval during which a marine ingression penetrated deeply into this part of Gondwanaland, as a result of deglaciation and a consequent glacio-eustatic rise in sea level. This idea implies an approximately isochronous event, and available biostratigraphic evidence supports this notion. The microfossil assemblages indicate marine conditions; their essentially noncalcareous nature indicates water of less than normal marine salinity. The configuration of this marine ingression, inferred from its preserved record, further suggests that it came from a southwesterly direction, that is, around the present Australian margin along the route postulated (below) for the Cretaceous and Early Tertiary marine ingressions. This suggestion is at variance with the usual paleogeographic reconstruction showing a Permian seaway across what is now the Australian continent proper (15). The Permian ingression, which penetrated into India and southwestern Africa (16) probably at the same time, thus may be due primarily to glacioeustasy but perhaps reflects, in its direction and extent, early formation of the rifted Australia/Antarctica suture.

Stratigraphic relationships indicating sutural rifting become clearer in the Mesozoic with the development of the Otway Basin in southeastern Australia during the Late Jurassic (17, 18). There is evidence in the sutural zone of the worldwide Early Cretaceous transgression which culminated in Aptian-Albian times (18). However, the dominant pattern in the Otway Basin is that thick, essentially nonmarine sediments are succeeded by sediments of Late Cretaceous age with occasional ammonites (19) but with strong foraminiferal (20)for marine evidence conditions of a "restricted marine" kind, that is, rather weak oceanic influence. A paleotectonic reconstruction showing access of the sea from the west along a narrow if possibly widening rift (21) therefore is convincing. In the Late Cretaceous to Early Tertiary, the thick and mostly terrigenous sequences in the Otway Basin range environmentally from nonmarine, with lignites, through "restricted marine" with organic-walled phytoplankton (22) and benthonic foraminifera with agglutinated and essentially noncalcareous tests (23) to shortlived episodes of shallow-water marine conditions evidenced by shelly macrofaunas and microfaunas, low in diversity, and sometimes including planktonic foraminiferal assemblages but not calcareous phytoplankton (24). The sequence ends at about the boundary between the Early Eocene and the Middle Eocene, about 49×10^6 years ago.

In the Middle Eocene, beginning about 47×10^6 years ago, the full influence of marine and oceanic conditions can be seen in the stratigraphic record in southern Australia for the first time since the Early Paleozoic. In the marginal sedimentary basins, a major transgression is marked by glauconitic, limonitic, and especially calcareous sediments with marine fossils, including calcareous phytoplankton and zooplankton. Some of the Eocene calcareous sediments are very similar to the bryozoal carbonate facies of the modern continental shelf, but Middle Eocene chalks in the Eucla Basin contain cherts (25) which are similar to, and within the known age range of, the cherts which are partly responsible for the deep sea seismic reflector known as Horizon A (26-28), and they may indeed be an extension of these typically oceanic rocks across a continental margin. The transgression has a west-to-east trend in time; facies changes within the Otway Basin are similarly diachronous; and in the Late Eocene the sea transgressed into the St. Vincent and Murray basins, that is, out of the sutural zone onto the Australian continent proper. I judge that the greatest single change in the pattern of Tertiary sedimentation in southern Australia occurred between the Paleocene-Early Eocene and the Middle Eccene-Recent, that is, 47×10^6 to 49×10^6 years ago.

This stratigraphy on the trailing edge of Australia suggests the following conclusions. (i) There was a long period (perhaps 220×10^6 years) from the Early Permian to the Early Eocene during which the tectonic situation was relatively quiet. Rifting may have occurred by 270×10^6 years ago, but all evidence of sporadic marine conditions indicates restricted marine influence. Penetration by the sea into the sutural zone can be explained "externally," either by a glacio-eustatic rise in sea level, as in the Early Permian and perhaps in the Early Tertiary (see below), or by a tectono-eustatic rise in sea level, as, for example, sea-floor spreading and axial uplift beginning in the south Atlantic proto-ocean 150×10^6 to $130 \times$ 10⁶ years ago and controlling the extent of the Cretaceous seas. According to this

theory, local geological features and events would control only the configuration, not the timing, of a marine ingression. (ii) With the onset of seafloor spreading south of Australia, active drifting, as distinct from rifting, and perhaps slow widening of the rift began in the west by 52×10^6 to $54 \times$ 10⁶ years ago, and oceanic conditions subsequently entered from that direction. This is consistent with a comparison (29) at the level of tectonic origin with the Red Sea, Tasmania being analogous to the Sinai Peninsula (29). Sea-floor magnetic evidence from the ocean south of Australia is consistent with this timing (30), and so too is the preliminary assessment of evidence from recent drilling in the Indian Ocean (31).

If this interpretation is correct, then the only major barrier to the migration of Australia's primitive mammals on the southern route was the development of the Southern Ocean. Before about 49×10^6 years ago, and perhaps back into the Paleozoic, sporadic marine ingressions into the sutural region created minor water gaps which probably cannot be invoked even as filters of the migrating animals. Fooden (1)has noted that initial rifting on the continental scale is not necessarily final in its control on migration, but his rough estimate that "isolation of prototherians [monotremes] and metatherians [marsupials] in Australia-New Guinea dates from the Upper Jurassic or Lower Cretaceous" must be based then on negative faunal evidence, that is, on the absence of placentals (until the Late Tertiary or Pleistocene), not on geological or geophysical evidence. Jardine and McKenzie (2) suggest an Early Tertiary immigration. An upper time limit is imposed by a separation between Australia and Antarctica but a lower time limit (Late Cretaceous) is imposed by access between North America and South America, as inferred very tentatively on biogeographical and paleontological grounds [see (32)], and thus is outside the present context, as are the problems and possibilities discussed by Keast (3) and Clemens (4). Jardine and McKenzie have not considered oceanic-sedimentological evidence for a continental ice cap on Antarctica during the Early and Middle Eocene (33). Should the existence of that ice cap be confirmed (34), the time of most probable mammalian immigration is the Late Cretaceous or Paleocene. Fooden (1) rules out that time interval on the basis of the seem-

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ing absence of placentals from Australia (7), but this is a problem on which discussion is still at the speculative stage (2, 3, 32), where it will remain until relevant fossils are discovered. BRIAN MCGOWRAN

School of Geology, University of Adelaide, Adelaide, South Australia 5001

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(12), "the Jurassic-Cretaceous history of the Otway Basin is thus a classical example of transformation of an intracratonic basin into a pericratonic basin by progressive collapse (or removal) of the southern cratonic rim." Wopfner has also noted the contrast between Australian basins in which marine Early Cretaceous sedimentation is succeeded by nonmarine conditions and the marginal Otway Basin in which the reverse succession is observed.

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 34. There is no direct evidence that I know of in Australia for the Eocene ice con on
- in Australia for the Eocene ice cap on Antarctica. Berggren (27) has suggested that Antarctica. Berggren (27) has suggested that the cherts of Horizon A in the Atlantic Ocean reflect an influx of cold north polar water admitted by spreading on the Reykjanes Ridge. Ramsay (28) has pointed to a link in time between those cherts and the postulated Antarctic ice cap. Y. Herman [Nature 238, 392 (1972)] has suggested that the genesis of the chert of Horizon A and similar socks 392 (1972)] has suggested that the genesis of the cherts of Horizon A and similar rocks requires the coincidence of sea-floor spreading (continental breakup) and temperature zona-tion, that is, cooling. The cherts in Horizon A in the Middle Eccene carbonates of the Eucla Basin overlie a planktonic foraminiferal assemblage [B. McGowran and J. M. Lindsay, Quart. Geol. Notes Geol. Surv. S. Aust. 30, 2 (1969)] which are part of a short-lived

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35. I thank R. J. F. Jenkins and two anonymous referees for constructive comments on this technical comment.

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McGowran is to be congratulated for his clear and careful analysis of geological evidence concerning the date of separation of Australia and Antarctica. However, this date is not directly relevant to my interpretation (1) of the prototherian-metatherian fauna of Australia and New Guinea. According to my hypothesis, this fauna is a relict sample of the mammalian fauna that inhabited Pangaea before detachment of East Gondwana (Antarctica-India-Australia-New Guinea) [table 1 and figure 1, A and B, in (1)]. I attribute the survival of this relict fauna to isolation that dates from the separation of West Gondwana and East Gondwana (more specifically, South America and Antarctica), which McGowran excludes from his disussion, not from the subsequent separation of Antarctica and Australia [figure 1D in (1)].

JACK FOODEN Field Museum of Natural History and Chicago State University, Chicago, Illinois 60605

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Myeloid Leukemia: Does Blood Loss

Increase the Incidence in X-irradiated Rats?

Myeloid leukemia rarely occurs in the rat, and even after substantial irradiation the incidence is usually low (1). For example, Moloney et al. (2) found only six granulocytic leukemias among 161 Wistar rats x-irradiated with 450 r. Recently, however, Gong (3) reported a considerably greater incidence, with 44 myeloid leukemias among 199 Sprague-Dawley rats exposed to doses of 25 to 350 r. Significantly, the frequency rose to 100 percent when the animals were subjected to acute blood loss at either 1, 2, or 3 months after irradiation. It was suggested that x-irradiation, even with doses less than 25 r, induces a proneness to leukemia which tends to persist