Implications of recent geological investigations of the Mozambique Channel for the mammalian colonization of Madagascar

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SUMMARY

Madagascar separated from continental Africa during the break-up of Gondwanaland early in the Cretaceous. The presence of several terrestrial mammalian groups on Madagascar is paradoxical as (i) these groups postdate the departure of Madagascar from Africa; and (ii) terrestrial mammals are poor dispersers across wide water barriers. Recent geological studies focusing on the Davie Fracture Zone of the Mozambique Channel offer a resolution to this situation, by suggesting the presence of a land-bridge from the mid-Eocene to the early Miocene, an interval that matches the ages of Madagascar's mammalian groups.

The presence of mammals on Madagascar, despite its separation from Africa in the early Cretaceous (Rabinowitz *et al.* 1983), has been explained by two principal hypotheses: (i) island-hopping across the Mozambique Channel on landmasses revealed by a eustatic reduction in sea level (Eisenberg 1981; Jolly *et al.* 1984); and (ii) rafting across the channel on mats of flotsam (Jolly *et al.* 1984; Paulian 1984). The first hypothesis can be discounted as most of the Channel is over 2000 m deep, and the largest eustatic reduction in sea level since the Palaeocene has probably only amounted to a few hundred metres (Haq *et al.* 1987). A reduction of this amount would reveal few islands and narrow the Channel only slightly. The rafting hypothesis has two weaknesses. First, terrestrial mammals have colonized very few isolated islands (Lawlor 1986). If colonization of Madagascar was by rafting, there is little reason why other isolated islands would not have been similarly colonized by mammals. Second, the mammalian fauna of Madagascar is dominated by ancient groups and is almost completely lacking in more recent groups present on continental Africa, such as the old-world monkeys, felids and canids (hippopotami are the only representatives of a recent group). It is unlikely that primitive mammals were more suited to rafting than more recent groups. A change in oceanic currents in the Mozambique Channel has been suggested, reducing the frequency of rafting of mammals across the Channel (Cox & Moore 1993), but there is no documented evidence for such a change.

The geomorphology of the region resolves this situation by suggesting the existence of a Tertiary landmass in the Mozambique Channel. The southerly motion of Madagascar during its separation from Africa formed a transform (strike-slip) fault down the centre of the Mozambique Channel (Coffin &

Rabinowitz 1987). Geological studies of this area suggest that the Davie Fracture Zone (DFZ) is the relict remains of this fault (Heirtzler & Burroughs 1971; Segoufin & Patriat 1980). The DFZ forms a ridge rising from the floor of the Mozambique Channel (2500 m) to within 500 m of the surface in some places (figure 1). Core samples taken from the DFZ identify a metamorphosed continental basement, which is unconformably overlain by limestones, basalts and carbonate oozes, suggesting a marine sedimentary environment from about 26 Ma (lower Miocene). These cores indicate that prior to this, from approximately 45 Ma (mid-Eocene) to 26 Ma (lower Miocene), areas of the Mozambique Channel were above sea level and subject to erosion (Leclaire *et al.* 1989; Bassias 1992). The total area of land exposed at this time is difficult to estimate as core samples have been concentrated on the DFZ. However, a core to the east of the DFZ was sampled; this consisted of upper Eocene marine sediments, which probably lay unconformably on the continental basement (DSDP 242; Schlich 1974). This would indicate that even in some deeper areas of the Mozambique Channel marine conditions commenced only in the upper Eocene (40 Ma).

This uplift and later subsidence of the Mozambique Channel region was driven by larger-scale crustal movements occurring in the area. The separation of India and Madagascar approximately 83 Ma (Segoufin & Patriat 1981) resulted in basaltic eruptions along the crustal weakness of the DFZ (Bassias 1992). At this stage, in this tensional setting, the Mozambique Channel was probably marine, as evidenced by the presence of altered carbonate deposits from the upper Cretaceous in some sediment cores from the DFZ (Mougenot *et al.* 1986; Bassias 1992). Approximately 42 Ma, India collided with Asia. The result of this collision was to drastically slow down the rate of sea-

Figure 1. Map of the Mozambique Channel area, showing the position of the Davie Fracture Zone (DFZ) and the surrounding bathymetry. Filled circles indicate sediment cores taken along the DFZ which were analysed by Leclaire *et al.* (1989) and Bassias (1992). The open circle indicates the location of the Deep Sea Drilling Project core 242. (Map after Bassias 1992.)

floor spreading in the central Indian Ocean and to change the direction of spreading to a more east–west orientation (Patriat & Segoufin 1988), which is believed to have put Madagascar into a compressional setting. The old DFZ fault was reactivated as a normal fault and crustal blocks began to uplift along this fault-line in response to the compressional setting (Leclaire *et al.* 1989). This regional uplift was probably linked to the creation of the dry land detected in the core samples along the DFZ. In Miocene times the activation of the African rift valley system created a tensional setting in East Africa and the Mozambique Channel (Chorowitz *et al.* 1987). This led to normal faulting and subsidence again along the pre-existing crustal weakness that characterizes the DFZ, creating a series of grabens along the axis of the DFZ (Mougenot *et al.* 1986). Analysis of contemporary earthquake data demonstrates that this subsidence along normal faults in the Mozambique Channel is still in progress (Grimison & Chen 1988).

The Madagascan Lemuridae are estimated to have diverged from the ancestral prosimian lineage approxi-

mately 40 Ma (Martin 1993; Purvis 1995); the Tenrecidae from proto-insectivores at approximately 50 Ma (Eisenberg 1981); the Madagascan Viverridae from other viverrids between 27 Ma (Bininda-Emonds, personal communication) and 35 Ma (Wayne *et al.* 1989); nesomyine rodents between 16 Ma and 30 Ma (Eisenberg 1981; Catzefflis *et al.* 1993); the Madagascan armadillo from eutherian lineages more than 40 Ma (Macphee 1994); and the Madagascan hippopotamus from its continental allies probably less than 7 Ma (Faure & Guérin 1990). All of these dates, apart from that for the hippopotamus, fall broadly into the 45–26 Ma temporal window when the geological evidence cited above suggests that large areas of the Mozambique Channel were dry land. I therefore suggest that most of Madagascar's mammal fauna colonized the island during this period aided by the presence of these areas of dry land. With the subsidence of these areas in early Miocene times this fauna became isolated, and groups such as the old-world monkeys, canids and felids, diverging or arriving in Africa later in the Miocene (Wayne *et al.* 1989; Martin 1995; Purvis 1995), were unable to cross the resulting wide water barrier.

The proposition of vanished intercontinental land-bridges and island-arcs across ocean basins in order to explain the distribution of organisms has largely been discredited since the discovery of plate tectonics, but plate tectonics fails to explain the presence of mammals in Madagascar. However, it is likely that uplifted land in the Mozambique Channel in early Tertiary times significantly assisted the mammalian colonization of Madagascar. Geological investigations of other areas of the Mozambique Channel are required to ascertain the full extent and contiguity of this land, along with more detailed dated phylogenies of Madagascar's understudied biota, to further verify this hypothesis.

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