THE SUMBA FRACTURE: A MAJOR DISCONTINUITY BETWEEN EASTERN AND WESTERN INDONESIA

M.G. AUDLEY-CHARLES

Geology Department, Imperial College of Science and Technology, London (U.K.)

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ABSTRACT


Recent tectonic interpretations of the Sunda Arcs have claimed that a continuous subduction system extends from the trench southwest of Sumatra and south of Java, through the Timor trough, south of Tanimbar then swinging in strike to continue north of Seram. This article challenges this view. It proposes instead that a major tectonic discontinuity separates eastern Indonesia, consisting of Sumba and the Banda Arcs (including eastern Sulawesi), from western Indonesia, composed of western Sulawesi and the islands west of Sumba. The evidence for this Sumba fracture is discussed and its tectonic function interpreted as initially a late Jurassic wrench fault that became a Cretaceous and Cainozoic transform.

The evidence is discussed for Sumba having been detached from northern Australia, and for Timor and the other islands of the Outer Banda Arc representing the deformed margin of the Australian continent. Emphasis is placed on the need to distinguish the overthrust Asian elements present in these islands from the Permian and Mesozoic Australian facies also present. The basis for considering these Australian facies in the Banda Arcs as autochthonous is set out. The conclusion is reached that the Outer Banda Arc islands are underlain by Australian continental basement and that no subduction has taken place between these islands and Australia since the Early Permian. The plate boundary of Australia in eastern Indonesia is identified between the Inner and Outer Banda Arcs.

INTRODUCTION

Most tectonic maps of Indonesia show the Sunda Arcs as a continuous system of a double arc extending from Sumatra in the west, through Timor and Seram in the east, then by a sinuous link through eastern Sulawesi northwards (Murphy, 1973) into the Philippine island arcs. According to Katili (1971, fig. 5, and 1973, fig. 2) and Hamilton (1972 and 1973) the Indonesian Archipelago of a double island arc represents a continuous subduction system now bounding the Indonesian region against the Indian Ocean—Australian plate (Fig. 1). One purpose of the present paper is to challenge this interpretation. A major tectonic discontinuity is identified separating
western Indonesia, as part of Asia, from eastern Indonesia, as part of northern Australia.

The importance of distinguishing the autochthonous from the allochthonous elements in the Banda Arcs will be emphasized as the critical factor to be considered in any palinspastic reconstruction. The basis for the interpretation that Sumba, Timor and the islands of the Outer Banda Arc are underlain by Australian continental basement is discussed. It will be argued that this together with geological and geophysical observations imply that no subduction has occurred between the Outer Banda Arc islands and Australia since the beginning of the Permian.

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The linear zone of strongly negative gravity anomalies, the pattern of earthquake behaviour, the submarine morphological features and the occurrence of volcanoes all show a sharp discontinuity located close to the island of Sumba. The various lines of evidence for this break and its interpretation are outlined below.

Discontinuity in the linear zone of negative gravity anomalies

Vening Meinesz (in Kuenen et al., 1934) showed the sharp break in the linear belt of negative gravity anomalies between the east end of the submarine Java ridge and the region southeast of Sumba (Fig. 2). His isostatic
gravity anomaly map (Van Bemmelen, 1949, fig. 105) shows this feature amounting to a change from −108 mGal to +39 mGal.

Sumba is anomalous in its NW—SE strike which is continued as a submarine ridge 2 km deep connecting with the Ashmore—Sahul Block forming the 200 m deep margin of NW Australia (Fig. 3). The positive gravity anomaly of Sumba (+39 mGal) may be compared with that of the Australian shelf (+32 mGal), and contrasted with the strongly negative gravity anomaly zone, which continue from Timor into Roti and Sawu. The isostatic gravity anomalies of the Sumba region are consistent with Sumba being a detached block of the Australian continent. Further support for this interpretation is provided by the geological history of the island as discussed later.

Changes in the pattern of earthquakes in the Sumba region

The earthquake behaviour shows two distinct changes in the Sumba region. These are: (1) east of 115°E no dip-slip motions have been recorded for the earthquakes (Fitch, 1970); and (2) the density of shallow-focus earthquakes diminishes sharply east of the western region of Sumba. Fitch (1970, p. 578) summarized the seismic evidence for tectonic behaviour in this region as, “There is no evidence from focal mechanisms supporting the existence of underthrusting along the eastern end of the Sunda Arc (east of 115°E) even though a well-developed inclined seismic zone exists beneath...
the arc in this region". He went on to draw attention to "the lack of an oceanic trench" in this region as a further indication for the absence of underthrusting.

East of Java the only part of the Sunda Arcs that displays shallow-focus earthquake activity comparable in density and magnitude (although not in focal mechanism) to that in the Java trench (7 km deep) is the Weber deep (7 km deep) at the easternmost end of the arc. Fitch (1972) drew attention to "the only shallow-focus earthquakes of large magnitude recorded in the eastern Sunda region are two events located near the inner wall of the Weber deep".

**Discontinuities in submarine morphology south of Sumba**

Immediately south of Sumba there is a sharp break in three well defined
submarine linear morphological features that do not continue east of Sumba: (1) The Java trench (here 6 km deep); (2) the Java ridge; and (3) the Bali trough (4 km deep) separating the Java ridge from the volcanic islands of Bali, Lombok and Sumbawa (Fig. 3).

In addition there is a linear discontinuity marking the eastern boundary of the Wharton Basin of the Indian Ocean (5 km deep). The 3–5 km isobathymetric contours strike almost NE—SW and separate the Indian Ocean from the continental margin of Australia.

East of Sumba there is no trench south of the Sunda Arcs separating them from Australia and West Irian. The Outer Banda Arc islands east of Sumba are separated from the Australian shelf by the Timor trough and its eastward extensions that only locally descend to 3 km. This forms a major contrast with western Indonesia, where from west Sumba to west of central Sumatra the Java trench varying from 6–7 km deep is present south of the arcs.

Another submarine morphological feature to which attention should be drawn is the inter-arc zone in eastern Indonesia. The Sawu Sea (3 km deep) separates Timor and Roti of the Outer Banda Arc from the volcanic islands of the Inner Arc. At the easternmost end of the Banda Arcs, where they swing in strike through 180°, the Weber deep (7 km deep) occurs separating the Outer Banda Arc islands of Tanimbar and Kai from the Inner Banda Arc volcanoes of Nila, Sarua, Manuk and Banda. Audley-Charles et al. (1972) interpreted these inter-arc deeps as relics of the northward dipping subduction zone developed in association with the northward drift of Australia.

**Discontinuity of strike of the active volcanic zone north of Sumba**

There is a pronounced displacement of the strike of the linear zone of volcanoes in the islands north of Sumba (Fig. 4). This break may be an extension of the strike-slip fault in southwest Sulawesi plotted by Katili (1970) and Hamilton (1972). The Late Cainozoic age of the volcanoes suggests that these dextral movements were Quaternary.

**TECTONIC FUNCTION OF THE SUMBA FRACTURE**

The various lines of evidence adduced above for the presence of a discontinuity between eastern and western Indonesia are interpreted as indicating an important fracture (Fig. 5). Essentially the Sumba fracture separates the Indian Ocean from the continental margin of Australia. The Outer Banda Arc islands have been interpreted (Audley-Charles et al., 1972) as representing the deformed margin of Australia involved in a series of collisions with a succession of northward-dipping subduction zones during the Cainozoic northward drift of Australia (Fig. 6). The results of these repeated Cainozoic collisions have been the imbrication of the pre-Tertiary autochthonous strata and the emplacement of overthrust sheets and olistostromes towards the Australian continent. The apparent absence of the imbricate zone of pre-
Fig. 4. Distribution of volcanoes (large dots) in the islands of the Inner Sunda Arc near Sumba. A southwesterly extension of the dextral wrench fault in SW Sulawesi (Katili, 1970; Hamilton, 1972) has been postulated to account for the apparent displacement of the strike of volcanic zone. The position of the parallel Sumba fracture is shown.

Tertiary strata, and the absence of piles of thrust sheets and olistostromes from the island of Sumba (Van Bemmelen, 1949) imply that it was not involved in these collisions with a succession of subduction zones on its northern (Asian) side. The western termination of this deformed margin of the Australian continent corresponds with the Sumba fracture. It appears therefore (Fig. 6) that the Sumba fracture acted as a transform fault associated with the western termination of a series of subduction trenches developed at the margin of northwest Australia during the Cainozoic. The Sumba fracture must also have acted as a transform associated with the Cretaceous development of the eastern Indian Ocean in the Wharton Basin, as indicated by the results of oil exploration (Warris, 1973). In an earlier interpretation Audley-Charles et al. (1972) suggested a transform, separating the Indian Ocean from northwest Australia during the Early Cainozoic. They called this the Song Ma and Sarasina transform, thinking to correlate it with the discontinuity between eastern and western Sulawesi. That speculation now seems unjustified as there is no evidence to suggest how far north the Sumba fracture extended during the Early Cainozoic. More recently, Katili (1973)
Fig. 5. Summary of evidence for the Sumba fracture. Note that western Sulawesi is shown adjacent to eastern Kalimantan before the opening of the Makassar Strait. E.S. = eastern Sulawesi; W.S. = western Sulawesi; S = Sumba; T = Timor; V = Vogelkop.

speculated that the “break near Sumba could perhaps be ascribed to the presence of a small transform fault”, but he did not attempt to analyse the evidence or the function of this feature.

SUMBA: A PART OF THE AUSTRALIAN CONTINENTAL MARGIN

In his recent review of theories of Indonesian tectonics Katili (1971) remarked that “another of Brouwer’s (1925) ideas which has had to be abandoned was the connection between Sumba and Timor. Geological and marine geophysical data collected afterwards proved that there exists a very big difference in the geology and geophysics between these two islands”. Katili’s emphasis on the large differences between the geology and geophysical features of Timor and Sumba is valid but, despite this, the present writer considers the evidence of the geological history and geophysical data support Brouwer’s hypothesis. The isostatic gravity anomalies (Fig. 2) suggest that there are fundamental structural differences between Sumba and the islands of the Outer Banda Arc such as Timor, which are characterised by a linear zone of negative anomalies. These strongly negative gravity anomalies may be correlated with the very thick sedimentary imbricate zone and an over-
lying pile of thrust sheets, while the positive gravity anomalies of Sumba may be correlated with the absence of such a thick pile of low-density rocks, and suggest comparison with the Australian shelf. It was suggested by Brouwer (1925) that Sumba represents the western continuation of the Outer Banda Arc islands. The present writer suggests that Brouwer's interpretation requires some modification to take account of Katili's (1971) objections. The interpretation put forward below is that Sumba formed part of the Australian margin, and so a continuation of the Outer Banda Arc, until it became detached from Australia by the Sumba fracture in the Jurassic. This meant that Sumba was not involved in the series of Cainozoic collisions with subduction zones causing orogenic phases that characterise the islands of the Outer Banda Arc.

The presence of Jurassic shallow marine and non-marine strata not only suggests that Sumba is underlain by continental crystalline basement but it corresponds with the Late Jurassic emergence of the adjacent region of Timor and Ashmore (Waris, 1973). The presence of granites and granite
Fig. 7. Summary of the Early Permian to Late Jurassic palaeogeography of the Timor—northern Australia region (after Warris, 1973). The locations of various oil company drilling sites are indicated by large dots. WLM = western landmass; I = shelf and fluvio-deltaic deposits; 2 = shelf, slope and rise deposits.

porphyry with muscovite and tourmaline in Sumba (Van Bemmelen, 1949) together with syenite also strongly suggest an underlying continental basement.

Palaeogeographic reconstruction (Fig. 7) of the northern Australian shelf region for the Permian and Mesozoic, based on extensive oil company drilling and seismic exploration, led Warris (1973) to interpret the presence of a landmass southwest of Roti during the Permian, Triassic and Jurassic. He called this the “Western Landmass” and claimed that evidence indicated that during the Late Jurassic and Early Cretaceous this Western Landmass moved northwards along a right lateral wrench fault. The Jurassic position of this landmass corresponds well with the anticlockwise rotated position of Sumba along the strike of the Outer Banda Arc at the northern margin of the Australian continent (Fig. 8). The right lateral fault also corresponds well with the position and movement of the proposed Sumba fracture. Warris (1973) pointed out that “as the western landmass moved further northward, the Indian Ocean Basin appeared for the first time as a distinct morphological unit”. This can be used to explain the origin and early history of Sumba. The dextral wrench fault developed in the Late Jurassic splitting Sumba from the continental margin in response to the initiation of the Wharton Basin of the Indian Ocean. In the process Sumba and its southeast extension, now a submarine ridge, were rotated clockwise by the newly spreading eastern Indian Ocean (Fig. 8).
Fig. 8. Late Jurassic palinspastic interpretation of the early evolution of Sumba as a detached block from northern Australia. The wrench faults represent the initiation of the Sumba fracture as a response to the early spreading of the eastern Indian Ocean. The "western landmass" refers to the recognition of a Late Jurassic—Early Cretaceous palaeogeographic landmass by Warris (1973). Note that all submarine bathymetric contours, 200 m, 2000 m and 5000 m show present positions except that the Sumba 2000-m ridge has been rotated anticlockwise to bring it adjacent to the 2000-m contour at the margin of Australia. All islands have been drawn in their present positions relative to Australia except Sumba and Sawu that have been moved anticlockwise (cf. Fig. 3).

THE BASEMENT OF THE OUTER BANDA ARC

The recognition of typical Australian facies of Permian and Mesozoic age in the islands of the Outer Banda Arc led Teichert (1939) to propose that the Westralian Geosyncline continued into Timor—Seram and eastern Sulawesi during the Late Palaeozoic and Mesozoic (Fig. 9). The present writer (Audley-Charles, 1965) presented evidence for the Permian flysch of Timor having been deposited in a basin close to the continental margin of Australia. More recently Warris (1973) on the basis of drilling and seismic data came to very similar conclusions although he regarded the Timor Permian and Mesozoic as mainly slope and rise sediments (Fig. 7). It now seems to be widely agreed that the Australian-like facies of Permian, Triassic and Jurassic age in Timor were originally deposited at the Australian continental margin (Fairbridge, 1953; Veevers et al., 1971; Griffiths and Burrett, 1973; Veevers and
Evans, 1973). Following Teichert (1939) it was argued by Audley-Charles et al. (1972) that, as these same facies are present in the other islands of the Outer Banda Arc including eastern Sulawesi, these islands also formed the margin of the Australian continent during the Permian, Mesozoic and Cainozoic (Figs. 6 and 8).

From this it can be argued that if these strata have been correctly identified as having been deposited on the shelf, slope and rise of northern Australia then by definition they were originally deposited above the Australian continental basement. Furthermore this implies that ocean crust could not have separated their site of deposition from the continent during the period from Early Permian to Late Jurassic. As subsequent deformation of these strata involved their folding and some thrusting (imbrication) towards the present Australian shelf, then it follows that the islands in which these strata occur, must be underlain by Australian continental basement. It has
been suggested elsewhere (Barber and Audley-Charles, in preparation) that some tectonic slices of this basement may be present as overthrust sheets containing granulite facies rocks that were emplaced by movements towards Australia.

These Australian Mesozoic and Permian rocks have been referred to as autochthonous in Timor (Audley-Charles, 1968) on the basis that they must be underlain by Australian continental basement.

TECTONIC SUTURE BETWEEN ASIA AND AUSTRALIA: DEFINITION OF THE AUSTRALIAN PLATE BOUNDARY IN INDONESIA

The presence in Timor of two very different Permian facies has been emphasized by the writer (Audley-Charles, 1968) who drew attention to the juxtaposition of the Maubisse Formation of reef limestones and eruptive rocks in overthrust sheets adjacent to apparently autochthonous flysch of the Cribas and Atahoc Formations. In an earlier paper (Audley-Charles, 1965) it was suggested that this anomalous situation could be the result of "the continental drifting together of southeast Asia and Australia". The Maubisse reefs accumulated in the Permian tropics while Timor lay some 3000 km to the south near the Permian pole. This distance was closed during the Cainozoic northward drift of Australia. There must therefore be a tectonic suture in eastern Indonesia between Asia and Australia. However, Hamilton (1973) seems unwilling to separate the Asian elements from the Australian elements as different structural units in the Outer Banda Arc which he interprets as a tectonic mélange without an autochthon. The exact location of the suture between these Asian and Australian elements is not easy to determine because the large thrust sheets of Asian rocks probably moved towards Australia by gravity sliding over the autochthon. This means that the crustal suture representing the southern margin of Asia is north (i.e. on the Asian side) of the leading edge of the thrust sheets, that now rest on the Australian plate (Fig. 10).

In western Indonesia the plate boundary is well defined by the Java trench with its shallow-focus earthquakes indicating underthrust movements of the Indian Ocean—Australian plate below the Sunda Arc of Asia (Fig. 10).

It is clear now that in trying to define the plate boundary in eastern Indonesia, where, as Fitch (1970) pointed out, there is no evidence from earthquakes of any underthrusting, that those who have interpreted the Timor trough (3 km deep) and its eastern extensions as the plate boundary (Fitch, 1972; Hamilton, 1972; Katili, 1971 and 1973; Warris, 1973) have placed it within Australian continental crust and south of the geological suture of Asia and Australia (Fig. 1). All the available geological evidence seems to indicate that the plate boundary in eastern Indonesia is between the Inner and Outer Banda Arcs (Fig. 10). This boundary does not at present appear to be an active zone of underthrusting because most of the ocean crust between the arcs has already been consumed (Audley-Charles et al., 1972). It is well
known that both these arcs have been elevated during the Quaternary (Umbgrove, 1938) and it was argued recently by Audley-Charles and Hooijer (1973) that this inter-arc trough is a very young feature, probably initiated as a downfaulted keystone in the rising arch of the two arcs since the Middle Pleistocene.

RELATION OF WESTERN INDONESIA TO ASIA AND SIGNIFICANCE OF THE CRETACEOUS MAGMATIC ARC

The Sunda Arcs of western Indonesia are marginal to Sundaland with its continental core and Sunda shelf (Van Bemmelen, 1949). The well defined Benioff zone with active underthrusting towards the Asian continent (Fitch, 1970) suggests comparison with the Andean mountain system with its volcanoes and granites. The structure of southeast Asia and Sundaland, which was summarized by Hamilton (1973) as "an aggregate of small continental fragments", is complicated by the presence of the marginal China Sea (Ben-Avraham and Uyeda, 1973) between part of the continental core in Borneo and the Asian mainland.
Fig. 11. Cretaceous magmatic arc and subduction zone in western Indonesia (modified after Katili, 1971 and 1973; and Hutchison, 1973). An implication of this interpretation is that oceanic crust being consumed at the subduction zone must have occupied the region south and east of the subduction zone. This means that East Java, Bali and the islands east to Sumbawa did not exist. In Cretaceous time Australia and eastern Indonesia were in high southern latitudes separated from western Indonesia by the Tethys Ocean.

Ridd (1971) suggested that western Indonesia was formerly adjacent to northwest Australia as part of Gondwanaland but Stauffer and Gobbett (1972) and Griffiths and Burret (1973) have argued strongly on palaeontological grounds that western Indonesia is distinctly Asian and could not have been part of Gondwanaland. On the basis of quite different evidence Hutchison (1973) showed how Sumatra, West Java, Borneo and Malaya were linked together by related igneous and tectonic activity from at least the Palaeozoic. There is a most important implication in this work of Hutchison (1973) and Katili (1973), who both interpreted a Late Cretaceous magmatic arc with a subduction zone linking Sumatra, northwest Java and the Meratus mountains of southwest Kalimantan (Fig. 11). If their interpretation is correct it implies that the ocean crust being consumed at the subduction zone lay to the south and east of the subduction trench; it means as Ridd (1971) pointed out that in the Cretaceous and Early Cainozoic East Java, Bali, Lombok and Sumbawa islands did not exist, furthermore it implies that an ocean separated the western Sunda Arcs from eastern Indonesia, which was then at the margin of Australia about 3000 km south of its present position.
CONCLUSIONS

Several different lines of evidence have been adduced to show that during the Mesozoic and Early Cainozoic eastern and western Indonesia were widely separated by the Tethys Ocean. The opening of the eastern Indian Ocean in the Wharton Basin was associated with the splitting of Sumba away from the northern continental margin of Australia. This Sumba fracture developed during the Late Jurassic and, with the Cretaceous spreading of the Indian Ocean, Sumba moved northwards away from the continental margin rotating clockwise. This separated it from Sawu, Roti and Timor which, together with the other islands of the Outer Banda Arc (including eastern Sulawesi), formed the northern margin of the Australian continent. As Australia drifted northwards during the Cainozoic the Outer Banda Arc suffered a series of collisions with a succession of subduction trenches. These collisions resulted in the imbrication of the autochthonous Australian strata at the continental margin and the emplacement of a series of thrust slices of Asian rocks. A consequence was the development at the leading edge of the Australian continent of a very thick deformed pile of mainly low-density sedimentary rocks. This is interpreted as being partly responsible for the strongly negative gravity anomaly zone coincident with the Outer Banda Arc. Sumba was protected from these collisions by the Sumba fracture and so did not acquire the thick pile of low-density rocks. Instead Sumba is composed of Australian Mesozoic shelf deposits with some calcalkaline eruptive rocks produced by subduction of the Indian Ocean to the south. Consequently its gravity anomaly is similar to that of the Australian shelf.

Other conclusions reached here are that the Outer Banda Arc is underlain by Australian continental crust on which the Permian and Mesozoic autochthonous facies accumulated. Evidence was given to refute the suggestion that the plate boundary in eastern Indonesia is present between the Outer Banda Arc and Australia. It is shown that this plate boundary must be between the Inner and Outer Banda Arcs although slices of the Asian plate have detached and slid under gravity onto the Australian plate in Timor and other islands of the Outer Banda Arc.

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