THE SIGNIFICANCE OF THE METAMORPHIC ROCKS OF TIMOR IN THE DEVELOPMENT OF THE BANDA ARC, EASTERN INDONESIA

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ABSTRACT


The metamorphic rocks of Timor are reinterpreted in the light of reconnaissance mapping of the whole island. All metamorphic rocks that crop out in Timor are allochthonous. Several metamorphic massifs are reported for the first time, the outline of others is revised. On the basis of their grade, three distinct groups can be mapped: lustrous slate, amphibolite—serpentinite, and a granulite—amphibolite—greenschist complex. Each group has distinctive structural relations to other allochthonous elements. The granulite facies meta-anorthosite in Timor must have originated near the boundary between the continental mantle and the crust. These and related high-grade metamorphic rocks may represent slices of an ancient Asian continental basement. These rocks imply that the history of the Mesozoic—Cainozoic fold belt of the Outer Banda Arc extends into the Precambrian Era. The metamorphic rocks of Seram appear to be remarkably similar to those of Timor in grade, distribution and structural relations. The overthrust directions of the metamorphic rocks in Timor is southwards, in Seram it is northwards. As the islands are separated by the 4—5 km deep Banda Sea, these directly opposite thrusts may be explained in terms of the Banda Arc acquiring its sinuosity after the emplacement of the metamorphic rocks.

INTRODUCTION

The island of Timor lies on the southern limb of the Banda Arc (Fig. 1), a double island arc which encloses the Banda Sea. The Banda Arc is generally regarded as a product of Mesozoic and Tertiary orogenic events which are still continuing. The Permian, Mesozoic and Tertiary stratigraphy of the region is known in outline, but its earlier geological history remains almost completely unknown. Recent geologic studies in Timor suggest that the
Fig. 1. Outcrop map of the metamorphic rocks (shown in black) in the islands of the Outer Banda Arc.

history of the metamorphic rocks probably extends from Precambrian to Mesozoic time.

This paper is not a detailed discussion of all the metamorphic rocks of Timor but attempts to show how reconnaissance mapping (on a scale of 1:100,000) of the whole island has revealed aspects of their composition, spatial distribution of three clearly distinguishable metamorphic elements and their different structural position that have important bearings on the history of the Banda Arc.

THE METAMORPHIC ROCKS OF TIMOR

Metamorphic rocks in Timor, called the Lolotoi Complex by Audley-Charles (1968), form a zone of massifs, with mountainous topography, rising to a height of nearly 3,000 m in Indonesian Timor and extending the whole length of the Island (Fig. 2). A general account and detailed descriptions of the metamorphic rocks of Timor are in reports of the University of Amsterdam's pre-war expedition to the area (De Roever, 1940; Tappendenbeck, 1940) and the work of De Waard (1954, 1956, 1957a, 1957b, 1959).

The metamorphic massifs of Portuguese Timor were delineated by
The highest grade metamorphic rocks are garnet meta-anorthosite obtained from the Booi massif in western Timor. These rocks contain pyropalmandine (Py$_{2.5}$Gr$_{1.4}$Alm$_{0.8}$) garnet and plagioclase of labradorite (An$_{4.8}$) composition. The presence of a high proportion of the pyrope molecule in the garnets indicates that these rocks were metamorphosed in the granulite facies. This is the first record of rocks of this grade occurring in the Banda Arc.

Rocks metamorphosed in the amphibolite facies occur in many of the massifs throughout Timor. The rock types include pyroxene amphibolite, garnet amphibolite, and garnet–hornblende–diopside gneiss (with brownish-green hornblende, plagioclase at least as calcic as oligoclase, and rutile). These rocks are commonly folded, foliated and lineated. Many specimens of garnet amphibolite in particular show a complex progressive metamorphic and structural history in inclusion trails within garnet crystals, many of which are sigmoidal (De Waard, 1957b). An equally complex history is in-
dedicated in the field where, for instance in the Mosu massif in the northwest, foliated and lineated hornblende gneiss is cut by unfoliated diorite and amphibolite dykes.

Amphibolite-facies metasedimentary rocks also occur in many of the massifs, for instance marble and calc-silicate rocks in Lalan Asu (De Waard, 1957b) and Lakaan. An extensive mass of cordierite gneiss occurs in the Mosu massif in northwestern Timor. Massifs lying farther to the south and east, Mollo, Mutis, Miomaffo and Lakaan, contain biotite gneiss and mica schist with kyanite, garnet and staurolite. A thin section studied by Tappenbeck (1940, p. 61, slide T127) and material collected by us from the Booi massif (Fig. 2), shows original garnet—kyanite assemblage in process of replacement by a cordierite—sillimanite—spinel assemblage. Garnet crystals are enclosed in rims of cordierite, whereas sillimanite occurs as aggregates of coarse crystals pseudomorphic after kyanite. Spinel forms a corona around the sillimanite pseudomorphs. The textural relations indicate that the high-pressure garnet—kyanite assemblage was formed early in the history of the complex and the low-pressure cordierite—sillimanite assemblage at a later stage.

GREENSCHIST FACIES METAMORPHIC ROCKS

Many of the amphibolite-facies basic and pelitic rocks show the effects of later deformation and retrograde metamorphism with the replacement of high-grade metamorphic minerals by aggregates of albite, epidote, chlorite and actinolite of the greenschist facies. Relict garnet, hornblende and plagioclase crystals enclosed in augen, and large rutile crystals enclosed in sphene rims, may be the only indication that the rock was formerly a high-grade mineral assemblage. Further complexity can be seen where greenschist facies foliation is itself refolded (De Roever, 1940, pl. V2). High-grade crystalline rocks on the southern side of the Usu massif have been reduced to fine-grained, banded, greenschist mylonite, resembling very closely mylonite found in major thrust belts such as the Moine thrust belt of the northwest Highlands of Scotland (Barber, 1965).

In addition to retrogressed high-grade rocks, many massifs, e.g. Mollo (Tappenbeck, 1940) and Mutis (De Roever, 1940), include metavolcanic and metasedimentary rocks which have been metamorphosed directly in the greenschist facies. Rock types represented are serpentine-schist, albite—epidote—chlorite—actinolite-schist, albite—epidote—chlorite-schist, spessartite—piedmontite—quartzite, quartz—graphite-schist and graphite-marble. These rock types appear to represent a volcano-sedimentary sequence of serpentine, pillow lava, tuff, manganese chert and black shale. These rock types are intimately associated in the field with retrogressed amphibolite-facies rocks (De Roever, 1940) suggesting that they were tectonically incorporated into pre-existing high-grade metamorphic com-
plexes before both rock groups were affected by greenschist facies metamorphism.

Tappenbeck (1940) observed the mineral glaucophane in the Mollo massif, indicative of very high-pressure metamorphism. This record has been used by others (e.g. Suwa, 1961) to make large-scale reconstructions of circum-Pacific orogenic belts. The thin sections in which the glaucophane was reported (T 193, T 288) were re-examined at the University of Amsterdam. The mineral from rocks collected in situ from the Mollo massif was found to be blue-green actinolite, typical of the greenschist facies, not glaucophane.

SLATE AND ASSOCIATED ROCKS

The third group of metamorphic rocks in Timor forms the Dili massif on the northern side of the island. The southern margin of this massif is composed of deformed crinoidal limestone and volcanic rocks of Permian age (Maubisse facies of Audley-Charles, 1968) associated with slate, which is by far the most important lithology of this massif. Towards the north coast coarse-grained arenite becomes more important, and the slates develop into mica schists intruded by occasional masses of gabbro. At the eastern end of the Dili massif, near Manatuto the rocks include hornblende gneiss and serpentine associated with marble in which crinoid ossicles may still be recognized. This complex assemblage of slates, arenites, schists and ophiolite suite were grouped as the Aileu facies by Audley-Charles (1968), who mapped their contact with the highly fossiliferous Permian Maubisse Formation as a thrust. Recent more detailed study of this contact has shown it to be a stratigraphical transition in the Maubisse region. The importance of this revision is that it proves the Permian age of at least part of the slate succession of the Aileu facies as suggested by Gageonnet and Lemoine (1958) on the basis of poorly preserved pelecypods in the slates. It is possible that the Aileu sequence of slates and arenites extends upwards into the Mesozoic and possibly downwards into the older Palaeozoic. In this massif both the complexity of the fold structures and the grade of metamorphism increase towards the north coast, where it reaches garnet grade in places.

The Permian limestones with volcanic rocks (Maubisse facies) also form several smaller isolated thrust massifs throughout the length of central Timor.

SIGNIFICANCE AND STRUCTURAL POSITION OF THE METAMORPHIC ROCKS OF TIMOR

The granulite and amphibolite facies rocks of Timor may represent fragments of ancient continental crust. The formation of pyrope garnet and kyanite requires pressures greater than 5 kbars, which can be generated
only at depths of 15–20 km. Garnet meta-anorthosite, such as that of the Booi massif, is known elsewhere only from continental Precambrian shields. An outstanding feature of the metamorphic rocks of Timor is the absence of rocks of granitic composition, especially migmatitic gneiss, which is a characteristic feature of most ancient continental shield terrains.

The metamorphic rocks of Timor are isolated massifs, on thrust planes above folded Permian to Jurassic sedimentary rocks of the Australian continental shelf (Audley-Charles, 1968). The metamorphic rocks are overlain unconformably by Cretaceous sedimentary rocks (Palelo Series of Tappenbeck, 1940) and unconformably by both Eocene limestone, tuff and agglomerate and Early Miocene limestone. These Tertiary rocks are overlain by the Bobonaro Scaly Clay, interpreted as an olistostrome (Audley-Charles, 1965a), which is composed of a great variety of rock fragments, some nearly 0.5 km across the outcrop, in a fine-grained matrix of scaly clay. The Bobonaro Scaly Clay generally surrounds the metamorphic massifs and covers their slopes. In many river sections this deposit can be seen resting on the metamorphic rocks.

North of the Lolotoi metamorphic massifs and clearly overriding them is a northward-dipping thrust sheet composed of Permian limestone with volcanic rocks (Maubisse facies) which passes stratigraphically into a much more extensive area of lustrous slate, arenite and a small ophiolite complex (Aileu facies).

OTHER ISLANDS OF THE OUTER BANDA ARC

Metamorphic rocks, similar to those described from Timor have been recognized in many of the smaller islands of the Outer Banda Arc (Fig. 1).

Fig. 3. Outcrop map of the metamorphic rocks of Seram (after Germeraad, 1946; Van der Sluis, 1950; and Valk, 1945).
and summarized by Van Bemmelen (1949). In Seram (Fig. 3) are extensive outcrops of amphibolite-facies gneiss, greenschist phyllite, and lustrous slate. Among the amphibolite facies gneiss, metapelite with kyanite (Valk, 1945) or cordierite (Germeraad, 1946) have been recorded, indicating that both high- and low-pressure metamorphic terrains are present.

INTERPRETATION

Of the two main divisions of the Lolotoi the higher-grade metamorphic rocks form the earliest unit, perhaps representing fragments of an ancient Precambrian continental shield. This would imply that the greenschist facies volcano-sedimentary sequence accreted to these older continental rocks during Late Precambrian or Palaeozoic time.

Two alternative hypotheses can be proposed to account for the high-grade continental metamorphic rocks in the Banda Arc. These rocks may represent the southeast margin of Sundaland of the Asiatic continent, detached from Western Indonesia and overthrust onto the northern margin of the Australian continent when the two continents collided during the Cenozoic (Fig. 4). The obvious obstacle to this hypothesis is that the Banda Arc is separated from Western Indonesia by the Banda Sea. This difficulty might be resolved if the Banda Sea could be shown to be a marginal basin of the Sea of Japan type (Matsuda and Uyeda, 1970), formed by the development of a spreading axis which has separated the Banda Arc from Western Indonesia.

Fig. 4. Sketch cross-section through the southern part of the Banda Arcs interpreting the allochthonous metamorphic rocks in Timor as detached thrust sheets from the continental margin of Western Indonesia. The absence of volcanism since the Pliocene in the islands opposite Timor may indicate subduction has ceased in this part of the Banda Arc.
Alternatively the Lolotoi metamorphic rocks may represent crystalline basement rocks which formed the northern edge of the Australian continent. According to this interpretation (Fig. 5) the leading edge was thrust back over continental-shelf deposits when it reached a subduction trench during the northerly drift of Australia (Audley-Charles et al., 1972). A variation of this interpretation has already been put forward by W. Hamilton (1973 and written communication, 1974). Hamilton also regards the Lolotoi metamorphic rocks as part of the Australian continent but considers that they have been driven over a wedge of melange and imbricated materials by the advance of an island arc migrating outwards from Sulawesi during the Cenozoic.

The overthrust succession of lustrous slates in the Outer Banda Arc, is closely associated in Timor and Leti with Permian limestone and volcanic rocks, which must have accumulated in tropical seas because they contain tropical faunas. During the Permian, Australia lay far to the south according to palaeomagnetic and palaeoclimatic data (Smith et al., 1973). Audley-Charles (1965b) suggested that the Maubisse facies of Permian limestone and volcanic rocks were derived from the northern margin of Tethys because of the presence of tropical faunas and similarity of the rocks in parts of Western Indonesia. Our recent observation that the Maubisse facies locally passes laterally into the Aileu facies of lustrous slate suggests that all the rocks of the Dili metamorphic massif originated at the Asian continental margin, perhaps forming part of southeast Sundaland from where the Lolotoi may have been derived. Certainly the stratigraphical association between the Aileu and Maubisse Permian facies seems to rule out the pos-
sibility that the Aileu flysch slate facies could be the deformed equivalents of the Permian Australian marginal facies, as suggested by Audley-Charles et al. (1972). The presence of quartz arenites in the Aileu facies along the north coast of Portuguese Timor implies a landmass source for the sand, north of Timor. This accords with the suggestion that the Aileu facies thrust sheet was derived from Sundaland.

The direction of overthrusting of the metamorphic rocks in Seram (Van Bemmelen, 1949) is towards the north, in Timor it is towards the south. Thus the present distribution of the metamorphic rocks in the Banda Arc (Fig. 1) suggests they have been thrust outwards away from the Banda Sea. As the Banda Sea is 4—5 km deep it seems a highly unlikely source for this variety of metamorphic rocks. These observations suggest that the sinuosity of the Banda Arc was acquired (cf. Visser and Hermes, 1962) after the metamorphic rocks had been overthrust onto Seram and Timor. This would produce an apparent divergence of thrust directions not representative of the original thrust movements. This hypothesis could be tested by palaeomagnetic studies of the unmetamorphosed intrusions into the overthrust metamorphic thrust sheets that field mapping indicates were emplaced before the thrusts were emplaced. Independent indications that the sinuosity of the Arc has been acquired are provided by the gross structure of the Arc. The gradual diminution of the volcanic arc eastwards suggests that subduction may have been progressively less important towards the eastern end of the arc where strike-slip movements may have predominated at the plate boundary. This would allow the arc to have developed its sinuosity while it evolved.

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