J. geol. Soc. London, Vol. **136**, 1979, pp. 547–568, 9 figs., 2 tables. Printed in Northern Ireland.

Reinterpretation of the geology of Seram: implications for the Banda Arcs and northern Australia

M. G. Audley-Charles, D. J. Carter, A. J. Barber, M. S. Norvick & S. Tjokrosapoetro

SUMMARY: Reconnaissance field traverses in Seram have led to major revisions in the stratigraphy, structure, tectonic history and geological maps. The island is composed of 4 principal stratigraphical-structural elements: (1) metamorphic continental [illegible], of uncertain structural status and palaeogeographical affinity, (2) an entirely marine early Triassic–Miocene imbricate succession regarded as para-autochthonous, (3) an allochthon composed of several different thrust sheets, including metamorphic rocks, Triassic limestone and a late Miocene olistostrome, (4) a Plio-Pleistocene post-orogenic autochthon. The apparently overthrust slices of metamorphic basement complex can be interpreted as derived from either the Asian or Australian craton. The Australian shelf, slope and rise sediments, possibly including some oceanic sediment, are regarded as para-autochthonous. Remarkably close correlation is demonstrated between the stratigraphical breaks reported from the Mesozoic–Cenozoic succession of the NW Australian shelf, from Misool, and the para-autochthonous rocks of Seram and Timor. This emphasizes the presence of the Australian craton underlying these 3 islands. Close correlation is also found between the allochthonous rocks of Seram and Timor. Some of these thrust sheets are interpreted as having been derived from the Asian continental margin. The ultrabasic rocks of SW Seram and Ambon seem to form the highest thrust sheets. The main period of orogenesis, involving over-thrusting, olistostrome emplacement and imbrication of the underlying Australian cover-rock sequences occurred in the late Miocene–early Pliocene (N.18). The structural position of the volcanic rocks of Ambon is uncertain. A tentative interpretation is that they are *in situ*, having been extruded from deep-seated fractures that penetrate the 'Asian' thrust sheets and the underlying Australian continental basement.

In our continuing study of the Banda Arcs, Seram (Fig. 1) was considered the most important island to investigate after Timor, since it lies on the opposite side of the 180° curved Banda Arc, is the next largest island (being 400 × 75 km), and has geological sketch map coverage (with sample descriptions), which allow reinterpretation on the basis of airphotos, ERTS photos and field studies. The geology of Seram is a mirror image of the geology of Timor in many important respects, such as the supposed directions of overthrusting and the contrasting Mesozoic faunas and facies showing affinities with either Australian (basement) or 'Asian' (overthrust) elements. Published reports on the geology of Seram (Valk 1945; Germeraad 1946; van der Sluis 1950; Zillman & Paten 1975) suggested that lithologies and faunas were similar to those in Timor. Compared with Timor (Audley-Charles 1968; Carter *et al.* 1976; Barber *et al.* 1977), accounts of the pre-Neogene stratigraphy and structure of Seram seem confused, with apparently unrelated stratigraphical divisions and dissimilar structural elements lumped together unconvincingly. Furthermore, no unambiguous evidence of overthrusting had been found by earlier workers, although they suspected such structures were present.

Central Seram appeared to contain the widest range of stratigraphical divisions and was therefore selected as the primary target of our 1975–6 expeditions. The metamorphic rocks appeared likely to provide clues to the structure and geological history and to assist comparison with Timor. Additional traverses were planned around Nief in NE Seram which it was thought would prove to be similar in stratigraphy and structure to the Kolbano, Aliambata and Iliomar regions of southern Timor.

Our geological traverses in central, NE and S Seram are shown on Fig. 2. On the basis of field traverses and micropalaeontology, stratigraphical/structural sections have been drawn (Figs. 3, 4, 5). The new stratigraphical data for the pre-Neogene rocks has allowed the geological sketch maps, sections and sample descriptions of Central Seram (Germeraad 1946) to be considerably revised (Fig. 6), and those of western and eastern parts of Seram (Valk 1945; van der Sluis 1950) to be reinterpreted (Fig. 7). These interpretations were aided by vertical and oblique airphotos and the ERTS photos of Seram.

Outline of geology

The stratigraphical nomenclature used throughout is informal for all the pre-Pliocene rocks. Where stratigraphical divisions have been studied in the field, some new informal names have been proposed, but otherwise the published names are retained. The Plio-Pleistocene strata were formally described by Zillman

0016-7649/79/0900-0547$02.00

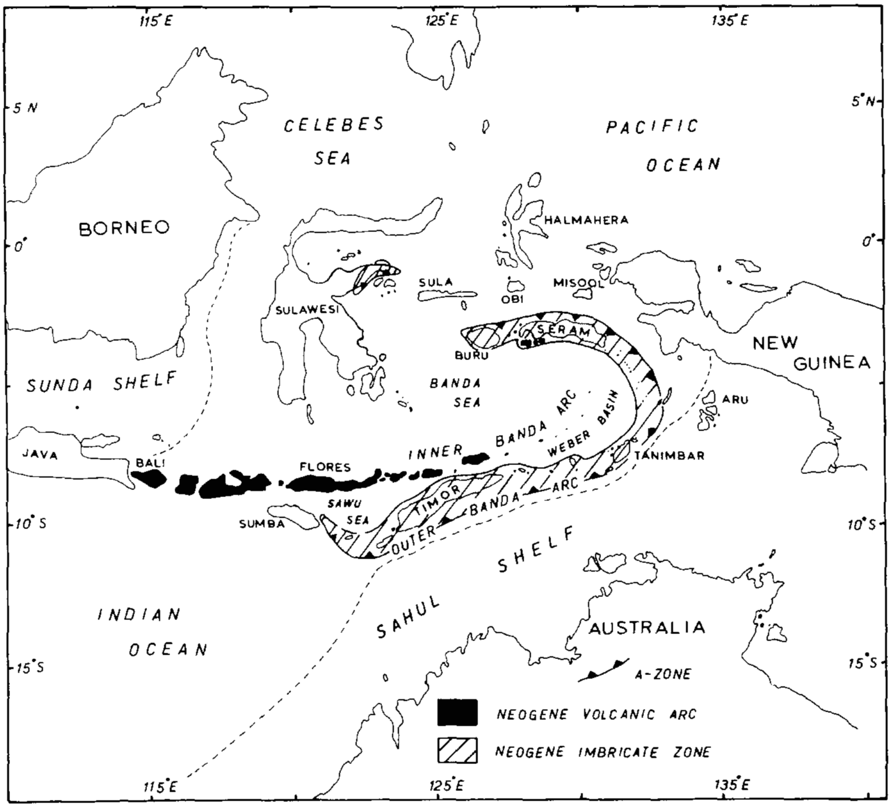

FIG. 1. Location map for the Banda Arcs, eastern Indonesia. The A-zone (northern margin of the imbricate zone) is plotted from Bally (1975) at the boundary of the imbricate zone with the gently deformed Australian craton and cover, except in the northern Banda Sea–E Sulawesi region, where young rifting may have separated it from Buru and the Sula islands. The position of the Benioff zone, not indicated, is controversial. The dotted line marks the edge of the Australian continental shelf.

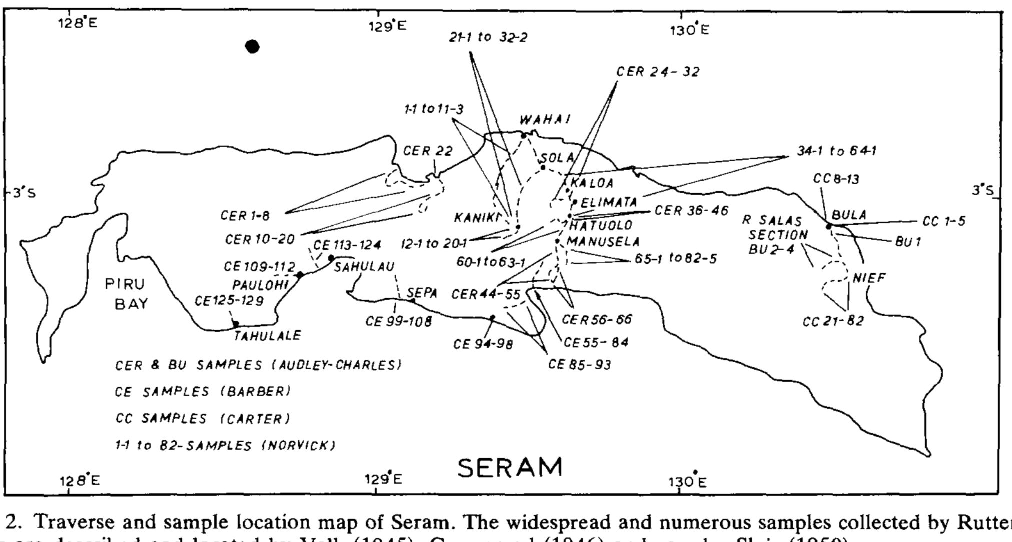

FIG. 2. Traverse and sample location map of Seram. The widespread and numerous samples collected by Rutten & Hotz are described and located by Valk (1945), Germeraad (1946) and van der Sluis (1950).

& Paten (1975) in terms of two divisions (Wahai Beds and Fufa Formation).

The repetition of stratigraphical divisions with some inverted ages (Figs. 3, 4, 5), involving rocks ranging from early Triassic to late Miocene, implies an imbricated para-autochthon, whose succession, facies, and faunas have a strong affinity with Australian continental margin deposits in Misool (van Bemmelen 1949; Froidevaux 1975), New Guinea (Visser & Hermes 1962; Harrison 1969; Davies & Norvick 1974), the NW Australian shelf (Powell 1976) and Timor (Audley-Charles 1968, 1978).

Some stratigraphical divisions are placed in allochthonous elements because there is evidence of their having been overthrust to their present position above the para-autochthon (Figs. 3, 4, 5) and because they have strikingly different facies and faunas from Mesozoic rocks of the same age in the para-autochthon. The conclusion that these allochthonous elements were derived, from a continental margin NW of Seram, before the Banda Arc acquired its sinuosity, together with their remarkable similarities with the allochthon of Timor leads to their being regarded as having been derived from the Asian continental margin possibly in the vicinity of easternmost Java or S Sulawesi (Audley-Charles 1978; Carter *et al.* 1976).

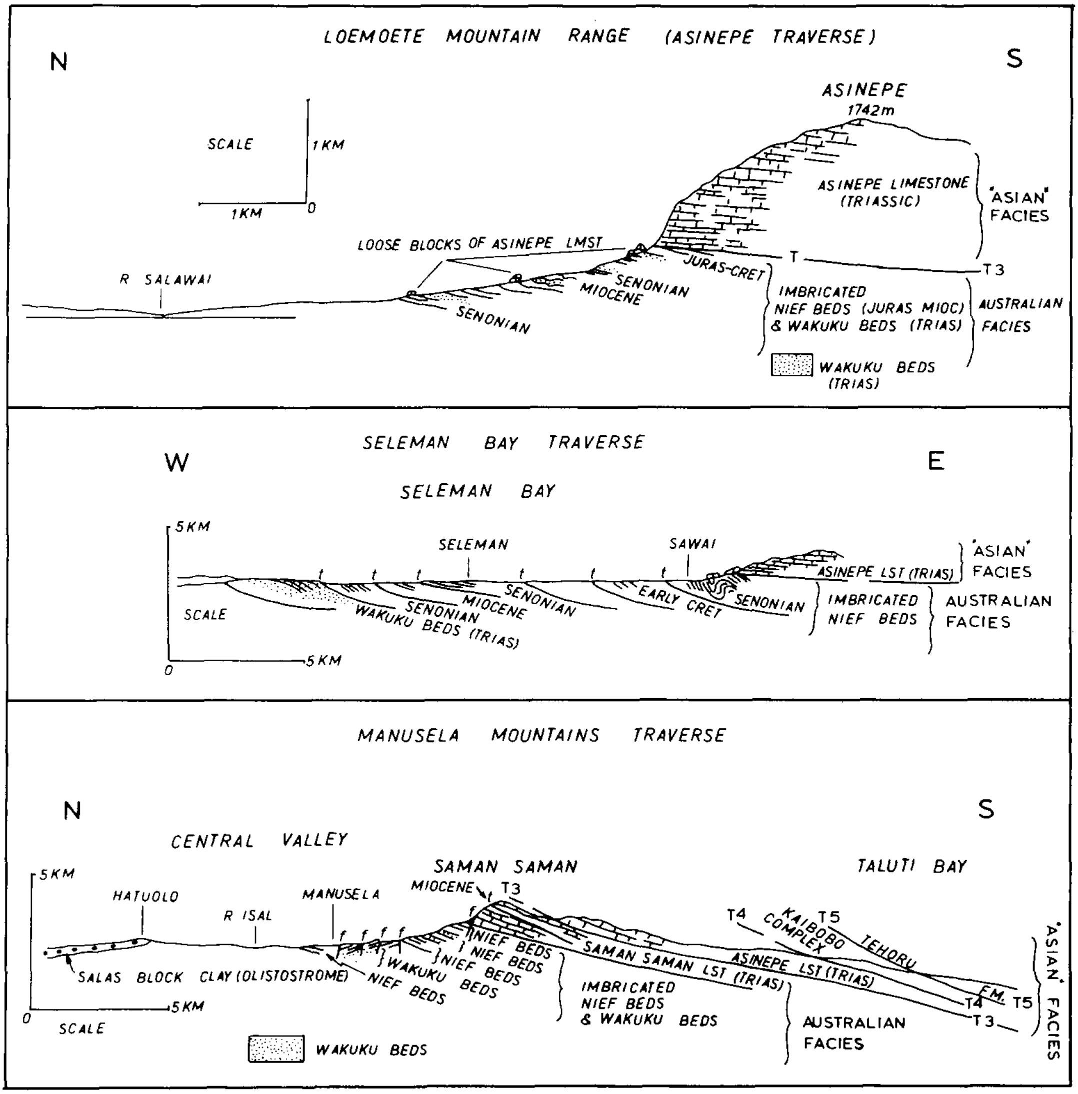

FIG. 3. Stratigraphical-structural sections in Mt. Asinepe, Seleman Bay, and Manusela mountains of central Seram.

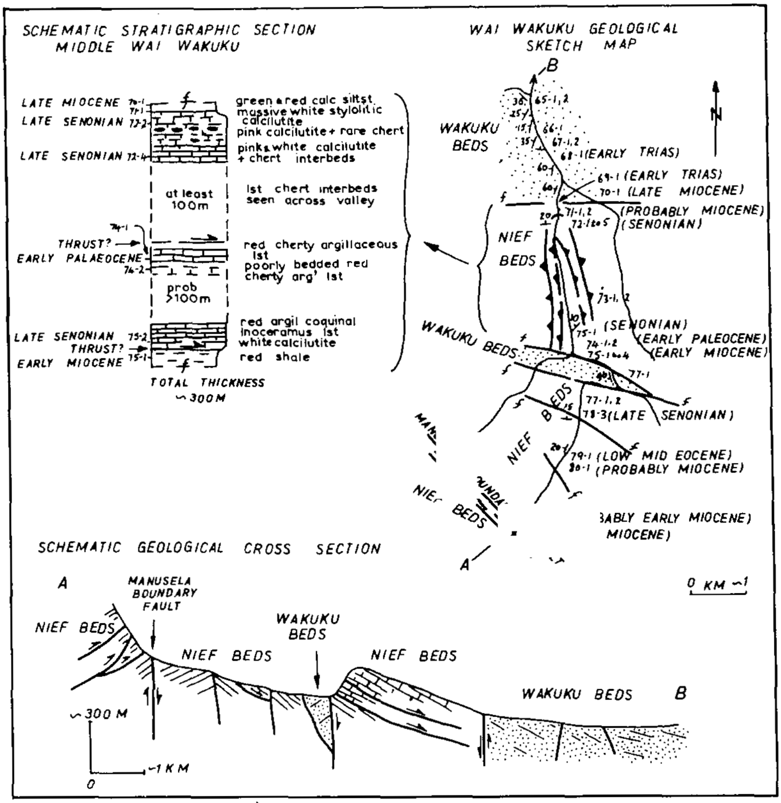

FIG. 4. Stratigraphical section and sketch map of the Wai Wakuku, central Seram.

In parts of central northern and E Seram, the Salas Block Clay formation above the overthrust elements and the para-autochthon appears to have been emplaced in its present position as an olistostrome during the late Miocene (N.18). It is best regarded as part of the allochthon, although most of its material, in the limited regions where it has been studied, has been derived from the para-autochthon and only a small proportion of the exotic blocks belong to the allochthonous 'Asian' elements. Elsewhere in Seram the proportion of 'Asian' exotics may be higher. The Salas Block Clay is overlain unconformably by the autochthonous, post-orogenic sediments of early Pliocene–Quaternary age (Zillman & Paten 1975).

The overall stratigraphic sequence and its 3 main elements, the late Cenozoic autochthon, Mesozoic and Cenozoic para-autochthon, and the apparently mainly Mesozoic allochthon, which may extend down into the Palaeozoic, are remarkably similar to the sequences reported from Timor and other islands of the Outer Banda Arc (Tables 1, 2).

Stratigraphy of the Australian shelf, slope and rise facies (para-autochthon)

3 main lithostratigraphical divisions of the para-autochthon are recognized: the Nief beds (late Jurassic–late Miocene), the Saman Saman Limestone (Triassic) and the Wakuku beds (early Triassic–Jurassic). These divisions are of formation status but are described here as informal divisions owing to the reconnaissance nature of our investigation. They are widespread throughout Seram, and are imbricated so that the Nief beds have been found in repetitive sequences with the Wakuku beds (Figs. 3, 4). The Saman Saman Limestone is well developed only in the Manusela Mountains of S central Seram, but appears locally to extend NW along the strike of these mountains into the northern part of W Seram (Valk 1945). The Saman Saman limestone facies is found in thin intercalations in the Wakuku beds, suggesting that their ages overlap. There is some indication of a

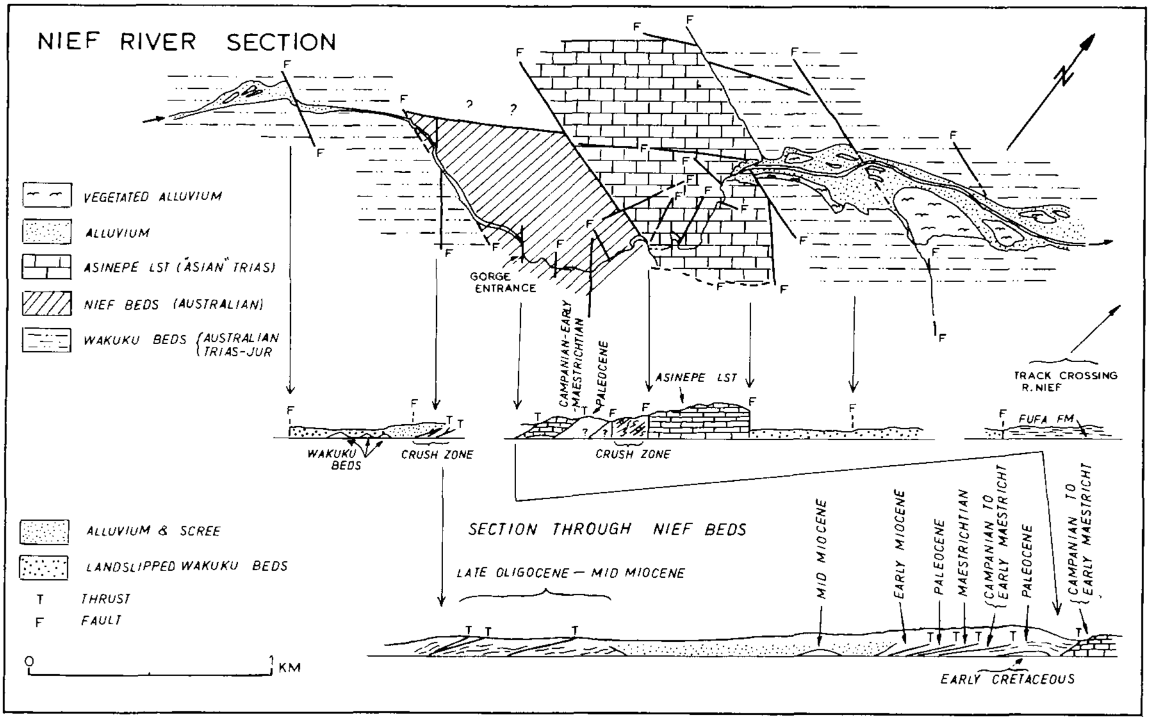

FIG. 5. Stratigraphical sections and sketch map of the Nief area of NE Seram.

stratigraphical gap between the top of the Saman Saman–Wakuku divisions and the base of the Nief beds, with the Middle and possibly some of the early Jurassic being unrepresented by any strata in the para-autochthon. This would not be a surprising gap in Australian continental margin deposits. The Middle and late Jurassic and locally the early Cretaceous are often missing from the basins around the NW Australia offshore region (Powell 1976). Part of the Middle and late Jurassic are missing from Timor (Carter *et al.* 1976) and from Misool (van Bemmelen 1949). This erosional phase in the Mesozoic of the Australian margin was ascribed by Powell (1976), following Falvey (1972), to the break-up unconformity associated with the rifting and block faulting related to the development of the Wharton Basin (eastern Indian Ocean) and to the disruption of Gondwanaland. The stratigraphy of the para-autochthon of Seram and Timor, and that of Misool and the NW Australian offshore area is summarized in Table 1.

Wakuku beds

The Wakuku beds take their informal name from the Wakuku River S of Manusela village (Figs. 2, 4). They comprise a series of dark grey siliciclastics. They probably extensively underlie the central valley, although exposure is poor, being largely masked by talus from the high mountain ranges to the S. Scattered exposures in creek beds suggest that the structure is complicated by numerous folds and faults. The most complete section is in the Wai (= river) Wakuku, SE of Manusela in central Seram. The base of the section is not exposed, but vertical shearing suggests that here it is steeply faulted against the Nief beds. The Wakuku beds consist of thinly bedded and laminated, hard, dark grey, carbonaceous and micaceous siltstones and mudstones, with small lenticles of fine, silty sandstones. These are interbedded with fine, quartzose, micaceous, carbonaceous sandstones, 10 cm–1 m thick. Sedimentary structures include indistinct ripple-drift lamination and extensive bioturbation. Deposition was probably under fully marine, low energy conditions in moderately deep water. Rare *Halobia*-type thin-shelled bivalves occur in the siltstones. Two samples have yielded early Triassic palynomorphs (Price 1976).

Elsewhere in the central valley region, the Wakuku beds were found in the Wai Lotu W of Kaniki and in the Wai Ai NE of Hatuolo (Fig. 2). Grey laminated siltstones are interbedded with thin micaceous sandstones. Float with *Halobia*-type bivalves suggests further similarities with the Wai Wakuku. In the Wai Lotu, turbidite structures (groove casts, prod marks and flute moulds) occur on the bases of the sandstone beds.

BIOSTRATIGRAPHIC DIVISIONS			PARA-AUTOCHTHON (distal facies)		AUTOCHTHON (proximal facies)	
			SERAM	**TIMOR**	**MISOOL**	**OFFSHORE CANNING BASIN**
NEOGENE	M. Plio.	N20				Shelf deposit:-
	E. Plio.	N18		Kolbano facies		limestone
	L. Mioc.	N17	Nief Beds		neritic lst.	dolomite limestone
	M. Mioc.	N12				
	E. Mioc.	N4	Nief Beds	Kolbano facies		basal sandstone
	L. Olig.	N3				
PALAEOGENE	E. Olig.					
	L.Eoc.		Nief Beds	Kolbano facies		shelf calcarenites
	M. Eoc.				neritic lst.	
	E. Eoc.		Nief Beds			deep water claystones and calcisiltites
	L. Pal.			Kolbano facies	? ?	
	M. Pal.		Nief Beds			
	E. Pal.					
CRETACEOUS	Maestr.					
	Campan.		Nief Beds	Kolbano facies	bathyal facies *Globotruncana* marls with shales	deep water claystones and siltstone
	Santon.					
	Coniac.					limestone and marl
	Turon.				? ?	
	Cenom.					
	Albian			Kolbano facies		claystone with sandstone
	Aptian					
	Barrem.					
	Hauter.		Nief Beds	Wai Bua facies	*Upper Fatjet Lst.* bathyal facies	major transgressive sequence
	Valang.					
	Ryaz.					
JURASSIC	Tithon.				Lower Fatjet Lst.	
	Kimmer.				neritic facies	transgressive sequence
	Oxford.		? ?	? ?	Lilinta Beds	
	Callov.					
	Bathon.			Wai Luli Fm.	neritic facies	
	Bajoc.		?			
	Toarc.		Wakuku Beds		*marls*	deltaic and epicontinental marine sequence
	Pleins.				limestones	
	Sinemur.				shale sandstones	
	Hettang.					
TRIASSIC	Rhaet		Saman Saman Lst.		? NORIAN BEDS ALLOCHTHONOUS ?	
	Norian			Aitutu Lst.		
	Carnian					
	Ladin.		Wakuku Beds	Babulu Member	Keskain Beds	deltaic and epicontinental
	Anisian		?			

TABLE 1: *Comparison of the stratigraphical divisions and biostratigraphical breaks in the para-autochthonous Mesozoic–Pliocene successions of Seram and Timor with the autochthonous Mesozoic–Pliocene successions of Misool and offshore Canning Basin. The data for the offshore Canning Basin is based on Powell (1976). The biostratigraphic data for Misool is based on re-evaluating the ages of the faunas described by van Bemmelen (1949) and on the many strong similarities in lithofacies between Misool and Timor–Seram deposits. The Norian limestones and marls of Misool are interpreted as possibly allochthonous and hence omitted from Table 1. In Table 2 these limestones and marls are included with the Misool autochthon.*

In the Loemoete mountains, near the N coast of central Seram, the Wakuku beds outcrop in similar turbidite facies, locally with calcareous nodules and cone-in-cone nodules. In the section just S of Seleman Bay, quartz arenites occur locally with small quartz pebble conglomerates. The relative stratigraphical position of these arenites with conglomerates within the Wakuku sequence is not known.

The Wakuku beds of the Nief region, NE Seram, are predominantly mudstones with subordinate arenites. They have been dated by palynomorphs as ranging from early Triassic to early Jurassic (Price 1976).

The sketch map and sample descriptions of Valk (1945) suggested that the Wakuku beds and Saman Saman Limestone outcrop widely in the NW part of Seram, where they have been strongly folded and faulted together.

On the oblique and vertical trimetrogon airphotos of the E end of the central valley, the Wakuku beds appear to be structurally overlain by early Cretaceous to Miocene Nief beds. On the ground, the contacts appear to be controlled by nearly vertical faults. Locally, as in the Wai Lotu, chevron folds are developed. However, on Gunung Asinepe (Fig. 3) and SW of the Manusela Boundary fault (Figs. 4, 9), there is clear evidence that the Wakuku beds are imbricated with Nief beds. It is likely that the Nief beds are locally thrust over the Wakuku beds in the central valley.

The age of the Wakuku beds throughout Seram appears to range from early Triassic to early Jurassic according to palynological evidence (Price 1976).

Triassic–Jurassic rocks, lithologically similar to the Wakuku beds, occur in Timor, western Papua New Guinea, Irian Jaya, Misool and on the NW Australian shelf (Table 1), and constitute an Australian siliciclastic shelf (basin) facies.

The true thickness of the imbricated, folded and faulted Wakuku beds, whose base has not been seen, is estimated as approximately 1000 m. In Misool a similar facies of Triassic age (the Keskain Beds) is said to be more than 2000 m thick and to overlie unconformably a slightly metamorphosed flysch-type facies (Froidevaux 1975).

Saman Saman Limestone

This formation takes its informal name from Mt. Saman Saman in the Manusela Range of central Seram. It consists of mushroom coloured, laminated marl, full of moulds of radiolaria and relict fragments of *Halobia*-type bivalves, interbedded with brittle, buff-grey finely recrystallized calcilutites, showing burrows infilled with darker material, violet-grey streaked calcilutites with radiolaria, and beds and nodules of black chert. These rocks are similar to the Aitutu Limestone of Timor, dated as Middle and late Triassic. Pale greenish-grey, calcite-veined, argillaceous calcilutite or indurated marl, full of thin-shelled planktonic *Halobia*-like bivalves and small spherical radiolaria are also present, dated as probably late Triassic or early Jurassic.

The thickness of the Saman Saman Limestone is estimated to be about 1000 m, but this is tentative owing to the possible presence of faulted repetitions. The Saman Saman Limestone behaved as the most competent member of the para-autochthon. It does not appear to have been involved in the complex imbrication characterizing the Nief and Wakuku beds. The main outcrop is in the Manusela mountains and its NW extension along strike in NW Seram. A similar facies is found as thin intercalations in the Wakuku beds.

The uniformly fine grain-size of the sediments, with their lack of terrigenous material except clay, and the predominantly planktonic fauna, the absence of a shelly benthos, and the fine lamination, suggest that the Saman Saman Limestone was deposited in very deep water beyond the shelf, probably on the continental rise of the northern Australian margin, as proposed for the equivalent Aitutu Limestone in Timor (Audley-Charles 1968).

Nief beds

(One of the authors regards the Nief beds as allochthonous, a view expressed in Table 2).

Wherever seen in Seram, the Nief beds are strongly imbricated and sheared. The unit takes its name from the River Nief in NE Seram and is dated late Jurassic–late Miocene. The Nief beds are deep water sediments, contain virtually no terrigenous detritus and carry rich planktonic faunas. They can be separated into 17 biostratigraphical-lithological subdivisions: breaks in deposition span most of the Oligocene, the Senonian/Palaeocene boundary and the late Cenomanian–early Senonian interval.

The 5 highest subdivisions are grey, argillaceous, occasionally procellaneous calcilutites, becoming violet-purple and fissile near the base where they are associated with silty, argillaceous limestone. These beds represent continuous deposition from latest Oligocene (N.3) to late Miocene (N.16 or N.17). Below the underlying stratigraphical break 5 further subdivisions are recognized: these consist of cream and white calcilutites, reddish or purple, usually fissile, argillaceous calcilutites and red and green marls. Their ages range from late Eocene to early Palaeocene and the basal bed contains derived, late Cretaceous material.

One late Senonian subdivision has been separated. This consists of dense, brittle, often porcellaneous and occasionally finely recrystallized calcilutite with or without cherts and carrying rich, Maestrichtian–Campanian *Globotruncana* assemblages. The calcilu-

TABLE 2 (Part A)

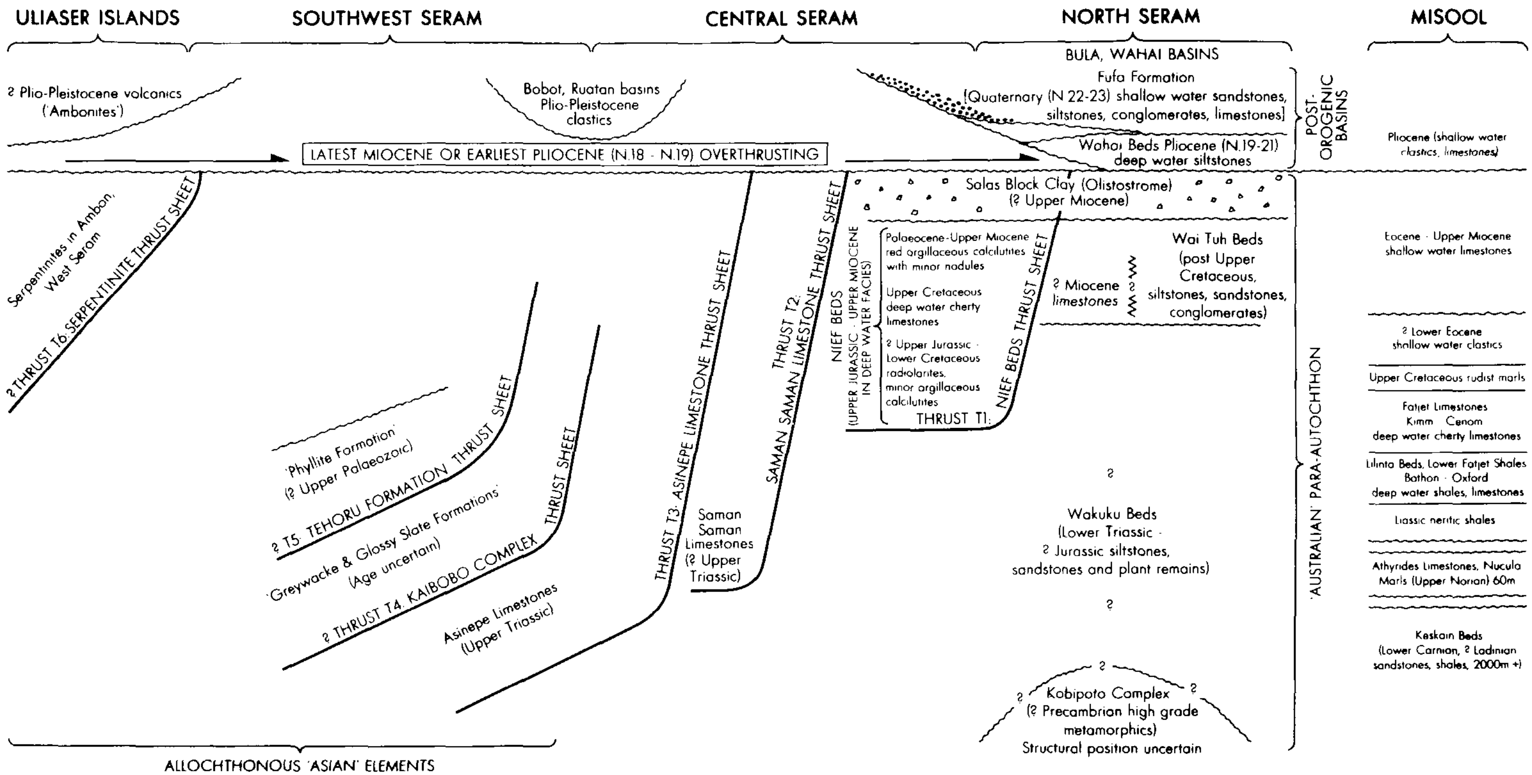

TABLE 2 (Part B)

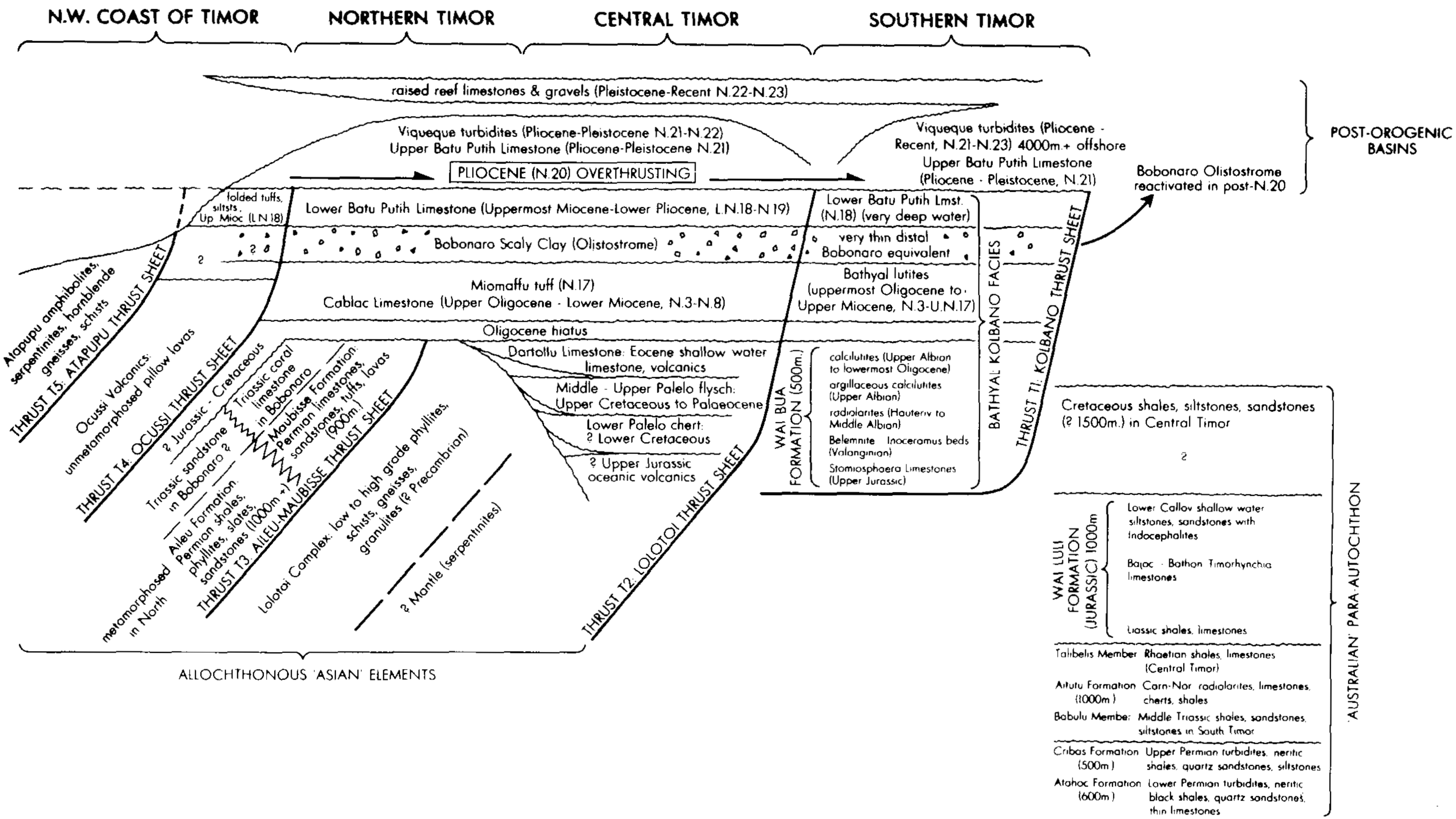

TABLE 2: *Comparison of the stratigraphic-structural elements of Seram and Timor showing the remarkable almost mirror image of the two islands now on opposite sides of the Banda Sea (Fig. 1), so that S Seram compares with N Timor. Note that the thrust sheets numbers T 1–5 in Seram do not correspond to the numbers used in Figs. 3, 8 and 9 because the Nief beds are classified as allochthonous in this Table (the alternative interpretation places them in the para-autochthon), and because the Kobipoto complex is classified as part of the Australian basement (not a thrust sheet) in this Table.*

tites, which often show slump structures, are white, cream, violet or pink and the cherts may be black, red or grey. The former always show strongly developed, parallel or sub-parallel stylolites which are sometimes filled with chocolate-coloured clay. As in Timor no beds of early Senonian or Turonian age have been encountered: in Seram the late Cenomanian also is missing.

6 pre-late Cenomanian subdivisions are recognized in the Nief beds. The youngest is a purple-brown, argillaceous, Albian–early Cenomanian calcilutite carrying abundant small *Hedbergella* and *Heterohelix moremanni.* Others consist of bioturbated, sometimes siliceous, grey and purple calcilutites with abundant radiolaria, *Inoceramus* prisms, ostracods and *Stomiosphaera,* etc. and low density, deep pink, manganese-filmed radiolarites. Probably the oldest is a reddish-brown to purple mudstone carrying thin-shelled, *Monotis*-like bivalves, *Inoceramus* prisms, ostracods, abundant radiolaria (including a species characteristically associated with *Stomiosphaera* and *Cadosina* in Timor and recently reported from the late Jurassic Franciscan of California) and slumped, shallow-water, late Jurassic material concentrated on manganese-filmed bedding laminae. Many of these calcilutites and radiolarites are faunally and lithologically indistinguishable from those of similar age found in the Kolbano thrust sheet of Timor (Audley-Charles 1968; Carter *et al.* 1976).

The base of the Nief beds has not been seen. The middle and early Jurassic may be missing, as in many parts of the offshore basins round NW Australia (Table 1).

The many repetitions of sequences indicates (Figs. 3, 4, 5) that the Nief beds have been strongly deformed and structurally thickened by imbrication. The late Cretaceous limestone may have acted as a competent bed, although subject to pressure solution and some internal deformation, as revealed by the stylolites and the stretching of cherts. However, the red and green argillaceous calcilutites, which resemble shales in the field, probably behaved as an incompetent envelope to the limestone and allowed extensive slippage.

The faunal and lithological characteristics of the Nief beds suggest that the unit was laid down under bathyal conditions, perhaps on the continental rise of the northern Australian margin and also on the deep ocean floor. This hypothesis is consistent with the condensed nature of the sequence, in which rocks of late Jurassic–late Miocene age occur within a very thin section.

Stratigraphy of the thrust sheets (allochthon)

5 major structural elements are interpreted as allochthonous in Seram: the Asinepe Limestone (Triassic), Kaibobo Complex (probably Triassic in part), Tehoru Formation (possibly Palaeozoic in part), the Kobipoto Complex (possibly Precambrian in part) and the Salas Block Clay (a Neogene olistostrome). The serpentinites and igneous rocks of W Seram and Ambon that are also interpreted as thrust sheets are discussed later with the igneous rocks.

Asinepe Limestone

This has been named after Mt. Asinepe in the Loemoete Mountain range of N central Seram (Fig. 3). It is composed of a grey, sometimes crystalline, oolitic and bioclastic grainstone, containing crinoid ossicles, calcareous algae, brachiopods, echinoids, sponges and corals. It represents a reef or sub-reef facies of early Mesozoic (probably Triassic) age. Van der Sluis (1950) regarded this fauna as Jurassic, largely on the basis of *Lovcenipora* sp. However, corals and associated fauna (such as *Montlivaltia, Thecosmilia, Isastrea, Astraeomorpha, Stylophyllopsis, Procyclolites, Myriophyllia* and *Spongiomorpha*), in an allochthonous limestone from Timor closely resembling the Asinepe Limestone in facies and fauna, have been dated as late Triassic (Yamagiwa 1963). A Triassic age for at least part of the Asinepe Limestone therefore seems likely.

The Asinepe Limestone, like its Triassic equivalent which forms *part* of the mainly Permian Maubisse Formation of Timor, is a shallow, warm water deposit and hence has close affinities with the Asian continental margin facies and faunas (Kanmera & Nakazawa 1973). It forms a striking contrast in facies with the Triassic Saman Saman Limestone, which it overlies tectonically in S Seram (Fig. 3).

The Asinepe Limestone outcrops in the main central ranges, extending from the Manusela mountains of S Seram to the Loemoete mountains in the N and NW (Figs. 3, 6, 7). On the airphotos it clearly forms one or more overthrust sheets. It rests tectonically on rocks of strikingly different facies, and on various imbricated strata ranging in age from Triassic to Miocene, some of which have steeper dips than the overlying Asinepe Limestone. In the Kabau range of central Seram, it appears to form a thrust sheet, resting on this same imbricated succession of Nief and Wakuku beds.

The Asinepe Limestone also occurs in parts of western and eastern Seram as much smaller outcrops. These appear to be small klippe in the NW (Valk 1945), where they have been much affected by post-thrusting steep faults. In the E, the Asinepe Limestone seems to form '*fatus*' (local name for isolated steep-sided limestone hills), which are probably large exotic blocks in the Salas Block Clay. It also occurs as boulder and pebble size exotics in the Salas Block Clay of N Seram.

The true thickness of the Asinepe Limestone is estimated to be about 1500 m.

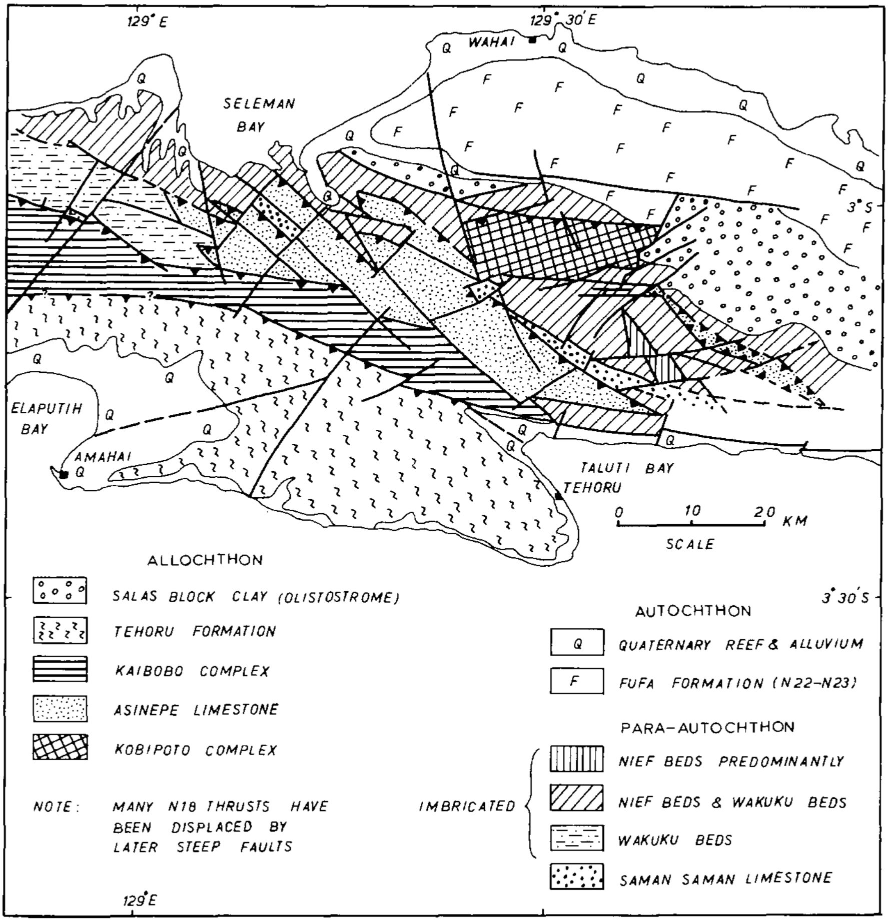

FIG. 6. Geological sketch map of Central Seram based on field traverses, interpretation of airphotos and ERTS photos, and revision of the geological sketch map by Germeraad (1946) from re-assessment of his sample descriptions.

Kaibobo Complex

This informal term, named after the Kaibobo peninsula of western Seram where these rocks are extensively exposed across their strike, is proposed to include rocks referred to by earlier workers from western and central Seram as Greywacke and Glossy (or Lustrous) Slate Formation and as the Crystalline Schists, Gneisses and Amphibolites of Valk (1945) and Germeraad (1946). The reclassification of these rocks is reflected in the geological sketch map of Seram (Figs. 6, 7).

'Greywacke and Glossy Slate Formation'

A traverse was made on the N side of Taluti Bay from Japutih to Piliana, across an area shown on the map prepared by Germeraad (1946) as 'Greywacke and Glossy Slate Formation'. The rocks are predominantly black glossy slates, broken up along lenticular shear surfaces coated with graphite, and interbedded with greenschists composed of albite, epidote, chlorite and actinolite. The greenschists are sometimes banded, probably derived from tuffs, or are more massive, representing lava flows. This assemblage of rocks closely resembles the low grade metamorphic rocks included in the Lolotoi Complex of Timor (Barber & Audley-Charles 1976).

The age of the 'Greywacke and Glossy Slate Formation' is uncertain but may be Triassic at least in part, because of the reported presence of limestones closely resembling the allochthonous Triassic Asinepe Limestone.

The overthrust position of the 'Greywacke and Glossy Slate Formation' is interpreted from Valk

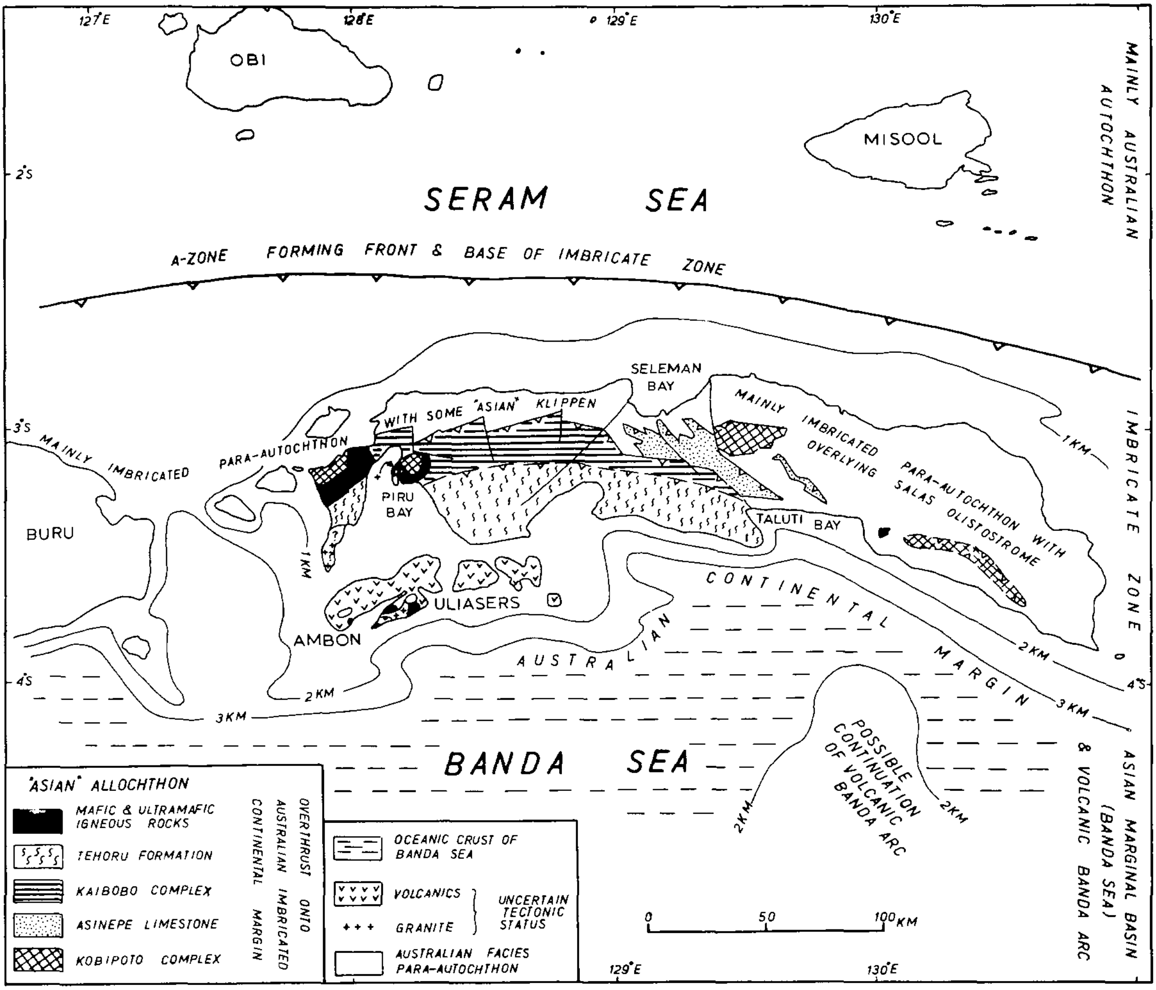

FIG. 7. Geological sketch map of Seram, Ambon and the Uliassers based on revisions of the maps by Valk (1945), Germeraad (1946) and van der Sluis (1950) from re-assessments of their sample descriptions, field traverses, and photogeological interpretation.

Identification of the A-zone follows Bally (1975). It represents the northern margin of the imbricate zone and is based on the reinterpretation of the Phillips Petroleum seismic reflection line 143 by Audley-Charles & Carter (1978).

Note: Some of the present authors regard Kobipoto Complex as more likely to represent upthrust horsts.

(1945), who remarked that it is everywhere 'pushed forward against or over the Upper Triassic'.

Possible equivalents of the Saman Saman Limestone

On the basis of our studies in central Seram, the hornstones and radiolarites, dark grey radiolarian limestones and argillaceous limestones with thin shelled lamellibranchs of uncertain age, which Valk (1945) included with his Triassic 'Greywacke and Lustrous Slate Formation', are here regarded as possible equivalents to the Saman Saman Limestone. In western Seram, these 'Triassic' radiolarian limestones and argillaceous limestones are described by Valk (1945) as 'interbeddings in the Upper Triassic flysch'. He distinguished them from the 'enormous limestone mountains' of NW Seram, which we interpret as part of the Asinepe Limestone on the basis of the airphotos (Figs. 6, 7). The reported 'interbeddings' of these rocks with 'Upper Triassic flysch' also suggests comparison with the Saman Saman Limestone. We suspect that these

rocks are slices of Saman Saman Limestone that have become tectonically associated with the Kaibobo Complex by faulting.

High grade metamorphic rocks N of Sahulau (i.e. Valk's 'Crystalline Schists')

Exposures of these rocks were not studied in the field. Their description is based on Valk (1945) and on float in rivers draining S from western Seram. Their presence on the sketch map (Fig. 7) is derived from Valk's map modified by our reconnaissance, the ERTS and airphotos.

During a traverse up the Wai Mala to the N of Sahulau through the 'Phyllite Formation' (Tehoru formation–see later) the metamorphic grade in the slates, grits and limestones was observed to be declining. However, the float coming downstream indicated that higher grade metamorphic rocks occur in the headwaters of this river. The higher grade rocks include hornblende schists and gneisses, serpentinites and one specimen of garnet-pyroxene granulite (metagabbro). This rock is at least of upper amphibolite metamorphic grade, but has been partially retrogressed under lower amphibolite facies conditions, forming reaction rims of hornblende around the garnet crystals.

The assemblage of high grade metamorphic rocks in the float of the Wai Mala is incompatible with the metamorphic grade of the 'Phyllite Formation' exposed in the banks of the river. A meta-anorthosite similar to the metagabbro collected in the Wai Mala has been described from the Lolotoi Complex of the Booi massif in W Timor.

In conclusion, the metamorphic rocks of the Kaibobo Complex appear to be similar to those in the Lolotoi Complex of Timor (Barber & Audley-Charles 1976) in their range of metamorphic grade and lithology, as well as in their structural history and present position with respect to both the oceanic Banda Sea and Australian continental margin.

Tehoru formation

This formation takes its name from Tehoru village on the western shore of Taluti Bay. Much of southern and SW Seram is occupied by an extensive series of metamorphosed grits and interbedded argillaceous deposits, previously described as 'Phyllite Formation' or 'Amphibolites' in the Wallace Mountains (Valk 1945; Germeraad 1946). The grits become more prevalent and thicker towards the S coast (e.g. grits up to 3 m at Paulohi). They are also coarser-grained and contain large mudflakes up to 30 cm in length. This sequence appears to be a turbidite one. N of Sepa some of the grits become calcareous. N of Sahulau, a massive limestone band up to 9 m thick was mapped, interbedded with slates and grits, and containing fragments of corals, algal limestone and crinoids. The organic debris is deformed and recrystallized, but still clearly recognizable. The crinoid ossicles are of Palaeozoic type.

The metamorphic grade also increases in a S or SW direction; argillaceous rocks are slates at Tehoru and mica schists at Sepa. A similar increase of metamorphic grade is also seen along the W shore of Elaputih Bay from Sahulau to Tahulale. In the areas of higher grade rocks, a dominant schistosity is defined by muscovite and biotite flakes, although these minerals have frequently been affected by later deformation, and biotite may be retrogressed to chlorite. Garnet occurs in both the grits and the schists; the crystals are frequently enclosed in augen and may include inclusion trails of quartz or graphite defining an earlier schistosity.

All the rocks have been affected by multiple phases of deformation, refolding earlier cleavage and foliation surfaces. The later folds may themselves develop secondary crenulation cleavages, often with a pressure solution component, especially in the grit beds. Later folds also affect earlier quartz veins and segregations. Slaty and schistose rocks are frequently affected by kink band folding. The higher grade psammitic rocks around Sepa and Tahulale are similar in lithology, structure and metamorphic state to much of the Moinian of the NW Highlands of Scotland, although the metamorphism in the Phyllite Formation never reached the temperatures at which partial melting takes place.

The Tehoru formation may be compared directly with rocks of the Aileu–Maubisse Overthrust Unit in E Timor (Barber *et al.* 1977). In Seram, however, the clastic rocks have the opposite polarity, having evidently been derived from the S, and being more highly metamorphosed in the same direction. In Timor, the clastic rocks are derived from the N and the highest grade metamorphic rocks occur along the N coast (Barber *et al.* 1977). In Seram, calcareous rocks containing Palaeozoic fossils are interbedded in the succession towards the N. Valk (1945) suggested that the phyllites pass northwards into the unmetamorphosed 'Greywacke and Glossy Slate Formation', which he described as interbedded with the massive Triassic limestone (Asinepe of this account). Similarly, in Timor, the silicilastic Aileu Formation passes southwards into the Permian crinoidal limestones of the Maubisse Formation around the village of Maubisse (Barber *et al.* 1977).

Kobipoto Complex of Central Seram

High grade metamorphic rocks of unknown age were examined in 2 areas: between Kaniki and Wai Tuh in the W, and in the Wai Isal gorge near Hatuolo in the E. Germeraad (1946) showed that metamorphic rocks occur extensively between these localities; they outcrop over a large area N of the central valley,

forming an upland region called here the Kobipoto massif after the mountain range of that name. However, in the Kobipoto massif the high grade metamorphic rocks are overlain unconformably by unmetamorphosed sedimentary rocks.

Metamorphic rocks of the Kobipoto Complex

The Kobipoto Complex in central Seram includes a variety of high grade metamorphic rock types. Near Kaniki, the southern margin of the complex is composed of pelitic and semi-pelitic schists, quartzites and rarer calc-silicate rocks. Pebbles of hornblende gneiss and schist, found by us in the Wai Sai, and by Rutten & Hotz (Germeraad 1946) in the Wai Ibi, may also have come from this complex. Further N, in the gorge of the Wai Tuh, the schists pass into migmatitic gneisses with quartzo-feldspathic segregations and complex folding (metatexites, Brown 1973). On the northern margin of the complex, the gneisses are associated with coarse-grained granitic rocks containing gneissose xenoliths (diatexites, Brown 1973).

Characteristic minerals in the schists and gneisses include garnet, staurolite, andalusite and cordierite. The latter is usually pseudomorphed by white mica (pinite). The biotite is a red-brown variety with intense pleochroic haloes around zircon inclusions. Some of the xenoliths within the diatexites are composed almost entirely of aluminium silicate minerals and include dense felts of sillimanite (fibrolite) with green spinel which appear to be pseudomorphing some earlier aluminium silicate mineral (possibly kyanite). Biotite is frequently retrogressed to chlorite, iron oxides and sagenite (needle-like crystals of rutile). Orthoclase feldspar and sillimanite may be retrogressed to sericitic white mica.

The metasediments of the Kobipoto Complex were metamorphosed at a very high grade, reaching temperatures at which a substantial proportion of the granitic material in the rock became molten, leaving behind a residuum of quartzose and aluminous material, now preserved as xenoliths in the granite. Such temperatures are generally reached in the upper part of the amphibolite facies. However, the granitic rocks show peculiarities which suggest that they have been metamorphosed at an even higher grade; e.g. the granites commonly contain garnets and cordierite, neither of which are constituents of normal granitic rocks, and although the granites are pale in colour on weathered surfaces, they are very dark when freshly broken. These features are characteristic of rocks which have been metamorphosed in the granulite facies. The diagnostic mineral of this facies, hypersthene, had not been identified in any of the thin sections studied. However, Germeraad (1946) reported cloudy 'enstatite' from one of his specimens from this area and unspecified 'pyroxenes' in several others.

In the gorge of the Wai Tuh, granitic rocks are intimately associated with serpentinite breccias. Unfortunately, the relationships between these 2 rock types was not clear, but the contacts could be tectonic.

Similar cordierite gneisses to those in the Kobipoto Complex were recorded by Rutten & Hotz from other parts of Seram, e.g. the northern part of the Hoamoal peninsula near Salah, the Wai Kawa N of Piru, and the Kaibobo peninsula (Valk 1945). They continue westwards into the neighbouring island of Buru (van Bemmelen 1949). An extensive outcrop of cordierite gneisses is shown by van der Sluis (1950) in the SE part of Seram. These rocks are also migmatitic. Van Bemmelen (1949) recorded cordierite-bearing granitic rocks from the islands of the Outer Banda Arc lying to the SE of Seram, including Manawoka, Kasiui and Tioor, and similar rocks were collected during the '1976 Banda Sea Program' from Kur and Fadol in the Kai Islands. In many of these occurrences, serpentinite accompanied the gneisses and granitic rocks.

A discontinuous belt of cordierite gneiss, granite and serpentinite extends from Buru, through Seram and around the Outer Banda Arc. The association of granites and serpentinites is unusual, and together with the high grade of the metamorphic rocks, suggests that the assemblage was derived from the base of the continental crust. Rapid uplift while high temperatures were maintained is indicated by the replacement of earlier aluminium-silicate minerals by sillimanite and spinel, and by the development of an andalusite-cordierite, high temperature/low pressure assemblage. There are 3 possible interpretations for the origin and emplacement of these continental rocks: they may have been overthrust from the outer margin of the Australian continental plate, overthrust from the leading edge of the Asiatic plate (Figs. 8, 9), or upthrust as horsts through the overlying sediments from the Australian basement beneath. From the available evidence the last explanation seems least likely to some of the authors.

Unmetamorphosed sedimentary rocks associated with the Kobipoto Complex

Wakuku beds. Although no contacts have been observed, the metamorphics are believed to be faulted against Wakuku beds in the S. Outcrops of Wakuku beds adjacent to the metamorphics in the Kaniki area are heavily sheared. Fault lenses of metamorphics are present in some shear zones. The shear zones are steeply dipping or vertical, and parallel to a major photogeological lineament at the edge of the Kobipoto massif.

Wai Tuh beds. At the western end of the Kobipoto massif, a series of grey siltstones, sandstones and conglomerates are steeply faulted in with high grade

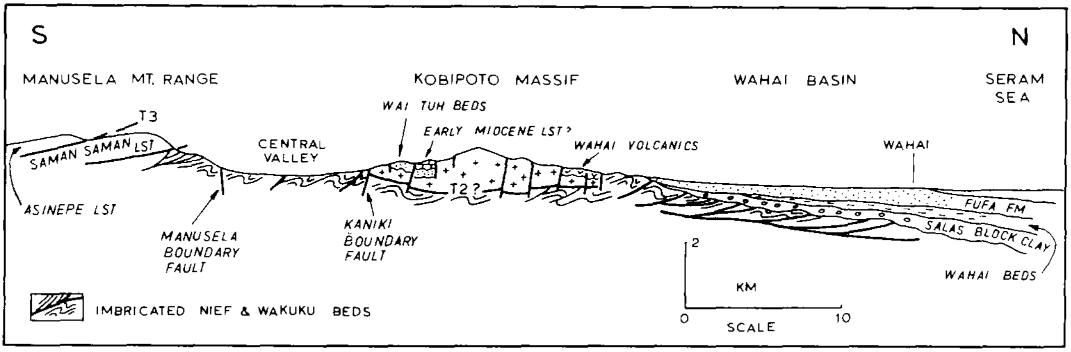

FIG. 8. Sketch cross section through central Seram interpreting the Kobipoto Complex as an 'Asian' thrust sheet, much broken by steep faults in the Plio-Pleistocene. The position of the Wai Tuh beds and the early Miocene limestone are schematic only.

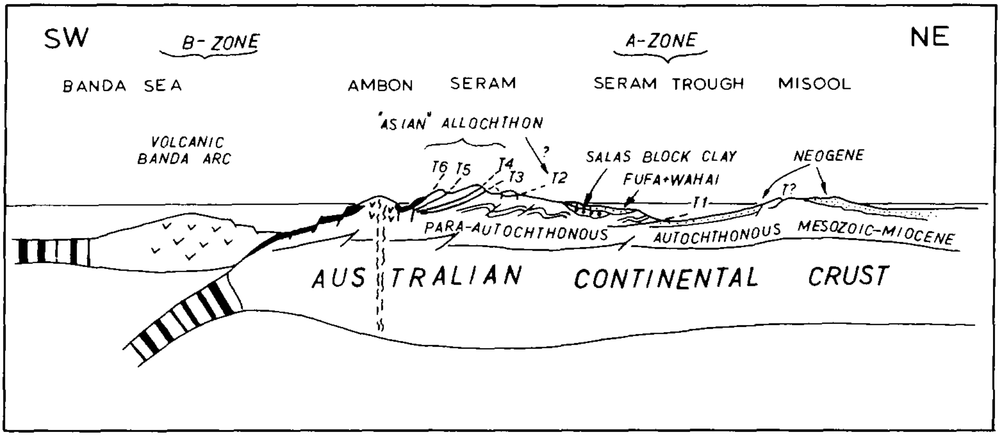

FIG. 9. Schematic cross section through the volcanic Banda Arc, Ambon, Seram to Misool. The main thrust sheets T 1–6 may be identified from Table 2 although the numbering system is different in the Table. For simplicity and clarity most of the effects of the Plio-Pleistocene strong phase of steep angled faulting have been omitted.

The Benioff zone (B-zone) and the A-zone (Bally 1975) were active during the late Miocene to late Pliocene but now appear to be relatively inactive (see Hamilton 1974, earthquake map).

metamorphics. Similar clastic rocks were described by Germeraad (1946) in streams draining into the Wai Isal further E. The clastics are similar to the Wakuku beds, but the presence of late Senonian limestone clasts in the conglomerates of the Wai Tuh indicate that they are considerably younger than the Wakuku in age. Further palaeontological work is needed to date the clastics.

Exposures in the Wai Tuh include poorly consolidated, dark grey, laminated siltstones, with thin stringers of fine sandstone. The sandstones contain large bronze mica flakes, abundant plant remains, load casting and flame structures. Also present are thicker, pale green, medium to coarse-grained, sometimes quartzose sandstones and unsorted beds of angular polymict conglomerate. The conglomerate contains clasts of high grade metamorphics, ultramafics and volcanics, as well as the Senonian limestone mentioned above. Volcanics of this type have yet to be recorded from outcrop in central Seram. No estimate of thickness can be made for the Wai Tuh section. The Wai Tuh beds are believed to rest unconformably on the metamorphics.

It is tempting to compare in terms of both age and lithology the Wai Tuh beds with the upper part of the Palelo Group of western Timor (Audley-Charles *et al.* 1975). The key to this correlation lies in the age of associated siliciclastics. If these prove to be late Cretaceous–Palaeocene, then the Wai Tuh beds would correlate very closely with the Palelo Group of Timor.

Asinepe Limestone and early Miocene Limestone. In the Gunung Kobipoto area, near the Wai Isal gorge, white cliffs of limestones appear to structurally overlie the metamorphics. Float boulders suggest that both Triassic Asinepe Limestone and early Miocene calcarenites and calcirudites, similar to the Cablac Limestone of Timor, might be present above the metamorphics.

Salas Block Clay (olistostrome)

This takes its name from the Salas River near the N coast of E Seram between Bula and Nief (Fig. 2). It has a greyish, somewhat waxy clay matrix, only locally with a scaly texture, containing exotic blocks of various types and sizes ranging up to 6 m diameter. The larger blocks are angular or subangular, mainly quartz arenites and siltstones, often micaceous and carbonaceous, with interbedded shale and argillaceous limestones. The blocks can be identified with the Wakuku beds of early Triassic–early Jurassic age, and are mixed with blocks of probably Triassic oolitic and bioclastic limestones with a coral-brachiopod reefal fauna, which can be compared closely with the Asinepe Limestone. Other blocks in this river section include limestones of the Saman Saman type and red lutites of Albian age with a very deep water microfauna belonging to the Nief beds, as well as calcilutites of Palaeogene age containing an abundant derived microfauna and basic volcanic clasts.

In the lower course of the Wai Tuh river of central Seram enormous exotic blocks of limestone (closely reminiscent of the Timor 'fatus') occur. These blocks must have been carried across the Kobipoto massif because they have a similar lithology to the limestones of the mountain ranges S of the Kobipoto range and are clearly out of place in this valley, as no other rocks of this type from which they could have been derived are known. Other large exotics seen in this valley included a very large block of pillow lava, unknown in outcrop, which was upside-down.

The Salas Block Clay outcrop is marked by much landslipping, producing muddy exposures often covered by grass and bamboo. The fact that previous workers did not recognize this as a formation testifies to the difficulty of distinguishing this as a stratigraphical division or structural element, which may be partly explained by the predominant exotic block constituent being Wakuku beds, so that the frequent landslips give the impression that is an outcrop of Wakuku. The 2 main clues to its proper recognition are: (1) the presence of mixed exotic blocks of widely different ages, those of the same age being of widely different facies, and (2) the presence locally of the scaly, waxy clay matrix.

The Salas Block Clay probably unconformably overlies the Wakuku beds at Nief. It can be identified on the seismic reflection records (line 74-18 of AAR Ltd.), and appears to thicken offshore. It seems probable that much of the sub-Wahai 'basement' of Zillman & Paten (1975) in the Bula–Nief region of NE Seram is the Salas Block Clay olistostrome.

A low level air reconnaissance shows much of the northern half of eastern Seram to consist of large landslips, described by earlier workers as a 'soup of shales' (van der Sluis 1950), and the occurrence of many scattered large blocks (between *c.* 0.5 and 1.0 km diameter) which closely resemble the 'fatus' of Timor (Molengraaff 1915; Audley-Charles & Carter 1972). The 'fatus' in Timor are exotic blocks of the Bobonaro Scaly Clay olistostrome (Audley-Charles 1968). However, it must be emphasised that the Salas Block Clay, where studied in the field, differs from the Bobonaro Scaly Clay in being much thinner, in lacking the same high proportion of exotic blocks, and in lacking the predominantly scaly waxy clay matrix of the Bobonaro. The Salas Block Clay may therefore be only an erosional remnant of a once much thicker deposit.

The youngest member of the Nief beds below the Salas Block Clay is late Miocene N.17, and the oldest rocks above the Salas Block Clay are the Wahai beds of early Pliocene age, N.19. The age of the Salas Block Clay is thus either latest Miocene or earliest Pliocene, N.18.

Stratigraphy of the exotic manganese nodule-bearing red mudstones

On a hill at Bula is an isolated outcrop of clays with manganese nodules (reddish-brown, yellow, grey and white clays, some of which contain large numbers of small (up to 30 mm diameter) sub-rounded, concentrically banded, earthy manganese nodules). Other small clasts include siltstone, sandstone, calcilutite, chert, olive-green shale and grey mudstone, quartz silt and a little white mica. The fauna consists of corroded, spherical radiolaria (not replaced by calcite), white opaline sponge spicules, fragments of the deep-water foraminiferan *Bathysiphon*, a specimen of *Dorothia* sp. resembling the Albian–Cenomanian *D. gradata*, a fragment of *Nodosaria*, and a small corroded fragment of an echinoid spine. The unaltered nature of the clay and the intense corrosion of the radiolaria suggest that this deposit may have been laid down close to the compensation depth for silica at about 4000 m. The microfauna in the associated clays without manganese nodules suggests an early Cretaceous age.

The stratigraphical and structural relationships of these rocks are very uncertain. The lack of internal deformation distinguishes them from the Nief beds, with which in other respects they have close affinity. Perhaps their particular clay composition allowed them to escape deformation and that they are part of the Nief beds. Alternatively, they might represent a

large exotic block within the Salas Block Clay (olistostrome). It seems unlikely that such soft beds could be part of a separate thrust sheet.

These beds are the deepest water deposits in Seram and comparable with the manganese nodule-bearing red clays that occur as exotic blocks in the Bobonaro Scaly Clay olistostrome of Timor, and which formed on the floor of the Cretaceous Tethys ocean (Margolis *et al.* 1978).

Stratigraphy of the autochthon

Zillman & Paten (1975) described the autochthonous rocks of Seram in terms of 2 principal divisions:

Fufa Formation. This consists of sands, conglomerates, reefal and other carbonate sediments, marine mud and lignite representing neritic, paludal and fluviatile deposits. Its maximum recorded thickness in an onshore well was 600 m; it probably thickens offshore in the Seram Sea. The age of the Fufa Formation is Pleistocene, N.22 and N.23. It lies unconformably on the Wahai beds and locally oversteps onto the Salas Block Clay (olistostrome).

Wahai beds. These are mainly composed of mudstones and siltstones, with a maximum recorded thickness of 156 m, although they probably thicken offshore in the Seram Sea. Zillman & Paten (1975) considered the Wahai beds to have been deposited initially in bathyal conditions, which became shallower towards the upper part of the division. The Wahai beds are of Pliocene and Pleistocene age (N.19–N.21), and are unconformable on the Salas Block Clay (olistostrome). Locally, a facies of the Wahai beds, containing a significant proportion of tuffs and re-worked tuffs, unconformably overlies the high grade metamorphic rocks of the Kobipoto massif (Fig. 8).

Igneous rocks

The majority of igneous rocks occur in W Seram. The exposures in central and E Seram are mainly loose blocks, many of which may be interpreted as exotic blocks in the Salas Block Clay olistostrome. There are 2 exceptions: (1) minor andesite and dacite effusive rocks in the Wakuku Beds, and (2) tuffs and tuffaceous siltstones of Neogene age in the Kobipoto massif, regarded as a facies of the Pliocene Wahai Beds (Fig. 8).

5 main types of igneous rocks were reported from W Seram by Valk (1945): (1) granites, granite aplites and pegmatites and quartz diorites containing cordierite, (2) peridotites (harzburgites, lherzolites and dunites, some with numerous veins of hornblende gabbro), (3) gabbro and diabase, (4) ijolite dykes cutting the cherty limestone of the Triassic para-autochthon and the 'Greywacke and Glossy Slate Formation', which implies the dykes are post-thrusting (i.e. post-late Miocene, N.18), (5) widespread black vesicular lavas that are either post-Triassic because they locally bake the Triassic strata, or possibly Triassic and related to the volcanics in the Wakuku beds of central Seram.

Apart from the black vesicular lavas, all the W Seram igneous rock types are found around the northern end of Piru Bay, where they are associated with a large positive Bouguer gravity anomaly (Milsom 1977), which implies that they extend deep into the crust (c. 3 km). Basic igneous rocks are also reported from the Hoamoal peninsula (Fig. 8).

All the igneous rocks, except the ijolite dykes, lack metamorphic aureoles and clear intrusive contacts against non-igneous rocks. Reported contacts are described as tectonic. The available sketchy evidence suggests that they form part of a thrust sheet, or more likely, several thrust sheets broken up by later steep faults (Figs. 7, 9).

There is much uncertainty about the relative structural positions of the basic and ultrabasic igneous rocks of W Seram, where some may form the highest thrust sheet, considerably affected by post-Miocene steep faulting. The granites and cordierite gneiss of the Kobipoto Complex are associated with serpentinites. This suggests comparison with the granulite, amphibolite and greenschist rocks of the Lolotoi complex of W Timor, which in Mollo and Mutis rest on a platform of a serpentinite (G.S.I., 1:250,000 Geological Map Atambua, in prep.). In Ambon, the ultrabasic igneous rocks appear to be overlain by the volcanics forming much of the islands of the Uliassers (van Bemmelen 1949).

The granites of W Seram and the volcanics of Ambon carry cordierite, suggesting an affinity between these rocks. The interpretation favoured here is that they are *in situ*. They may be related to deep fractures, which have penetrated the thrust sheets and the underlying Australian continental basement. Emplacement through continental basement could have led to the assimilation of country rocks, resulting in the acquisition of cordierite. The effusive rocks of Ambon are Plio-Pleistocene in age (van Bemmelen 1949), and a dacite at Liang, Ambon, of Pliocene age (M. Abbott, pers. comm.), indicates that they are post-thrusting, which would accord with their being *in situ* and related to the ijolite dykes of Seram. The available evidence suggests that these volcanics and dykes are associated with a fracture system that developed after the thrust tectonics, so that these igneous rocks do not appear to be related to subduction processes associated with the volcanic Banda Arc (Fig. 9). Pending more detailed field study of this complex region, interpretation of the igneous rocks can only be made in simplified and speculative terms.

Ambon and the Uliassers

The 'basement' of these islands is composed of unmetamorphosed Triassic sandstones. S of Ambon these occur together with serpentinite and granite of unknown age. Hutchison (1976) reported that at Tanjung Seri, serpentinite overlies granite and proposed that mantle material had been obducted over granitic continental crust. The critical locality was visited during the 'Banda Sea Program' by A. J. Barber and Mr Suharsono. They found that veins of granite were intruded into the serpentinite and that blocks of serpentinite were enclosed as xenoliths within the granite. If the serpentinite reached its present position by overthrusting, it was subsequently intruded by granite.

The 'basement' is overlain by volcanic rocks forming 2 major volcanic structures in the northern part of Ambon. Volcanic dacite from Liang has been dated by K-Ar methods at 4.5 Ma (M. Abbott, pers. comm. 1977). The volcanic structures are extensively eroded and are overlain by raised coral reefs. The volcanoes of Ambon were evidently active in Pliocene times, but are now no longer active.

The islands of Ambon, Ambelau and the Uliassers occupy the same position in relation to Seram that the islands of Alor, Atauro and Wetar bear to Timor on the opposite side of the Banda Arc. As at Ambon, these other islands were volcanically active during Pliocene times but subsequently became inactive. Present volcanic activity in the Banda Arcs is restricted to the segment between Damar and the Banda Islands.

The present spatial relationship between Ambon, Uliassers and Seram may not represent their original configuration. Major strike-slip faults appear to have been active during the late Neogene and Quaternary.

Structure

A geological sketch map of Seram was produced by Valk (1945) for W Seram, Germeraad (1946) for central Seram, and van der Sluis (1950) for E Seram, using the field notebooks and samples collected by Rutten & Hotz, who carried out the field work in 1917–19. Valk, Germeraad, and van der Sluis all inferred major overthrusting and structural vergence towards the N, although overthrusting was not proven. The principal contributions of our 1975 expedition have been (*a*) to provide sufficient stratigraphical and structural evidence to prove the presence of major overthrusts composed of allochthonous elements; (*b*) the recognition of intense imbrication in the underlying section of Triassic–Miocene strata forming the para-autochthon, and (*c*) the identification of a widespread Salas Block Clay olistostrome in central and eastern Seram. This previously unrecognized olistostrome was often described by earlier workers either as 'dreadful ground', meaning deep sticky mud with scattered boulders, or as a 'soup of shales'.

Imbrication in the para-autochthon

The stratigraphical and structural evidence for imbrication in the Nief beds and Wakuku beds is clear (Figs. 3–5). The imbricate sections in the Nief beds of E and central Seram are remarkably similar to sections exposed in southern Timor at Kolbano and Iliomar (Barber *et al.* 1977, fig. 3).

The para-autochthonous rocks are similar in lithology, facies and faunas to those reported from Misool (van Bemmelen 1949; Froidevaux 1975), New Guinea (Visser & Hermes 1962; Davies & Norvick 1974), NW Australian shelf (Lofting *et al.* 1975; Powell 1976). The term para-autochthonous is employed because these rocks, which are interpreted on the basis of their lithology, fauna and microflora as Australian slope and rise facies and which may be traced around the Outer Banda Arc, northern Australia, New Guinea and Misool (Table 1), have been structurally dislocated from their basement in the Outer Banda Arc islands but can be traced towards the Australian craton, where they are clearly autochthonous. A case can be made for interpreting the Nief beds as allochthonous (Table 2).

Some members of this imbricated para-autochthon have suffered penetrative deformation such as development of stylolitic cleavage and stretching of chert nodules.

The age of the imbrication in Seram can be dated as post-N.17 on the basis of the youngest member involved, and pre-N.19 because the basal unimbricated Wahai beds overlie the imbricated Nief beds unconformably. This dates the imbrication as late Miocene (N.18). The imbrication in Timor was dated as early Pliocene (N.19–N.20) because the youngest rocks involved in the imbricated thrust sheets are of N.18 age.

Overthrusting of the allochthonous elements

The stratigraphical and topographical evidence for major overthrusting is not clear (Figs. 3–5) partly because numerous later steep faults have displaced the thrust sheets (Figs. 6, 7). The intensity of these steep faults has obscured to some extent the basic overthrust sheet structure, just as in Timor (Carter *et al.* 1976; Barber *et al.* 1977).

One of the principal stratigraphical criteria confirming the presence of allochthonous elements in Seram is the distinction between 2 different limestone facies of late Triassic age occurring above each other in the Manusela mountains of S central Seram (Fig. 3). The higher structural element is the Asinepe Limestone, with a rich fauna of corals, brachiopods, sponges and crinoids in a bioclastic shallow, warm-water facies. Immediately underlying this allochthonous element is the Saman Saman Limestone, a calcilutite with radiolaria and an *Halobia*-type planktonic fauna probably deposited in a deep-water distal facies. The

Wakuku beds, a siliciclastic flysch facies, whose age overlaps the Saman Saman Limestone, also occurs beneath the thrust sheets.

This distinction between 2 Triassic limestone facies is important in interpreting the structure of Seram (Figs. 3, 9) and its palaeogeographical evolution. Earlier workers, who found these different but coeval types of limestone faulted together (Valk 1945), did not separate them into different structural elements, partly perhaps because they were unable to distinguish the important effects of the post-thrusting steep faults.

2 other examples of allochthonous elements having a similar age to different facies of the para-autochthon occur in Seram. The post-Senonian (possibly Palaeocene) Wai Tuh siliciclastics in the Kobipoto Complex contrast with the bathyal and distal facies of the para-autochthonous Nief beds that range from late Jurassic–Miocene. The shallow water grainstones and calcirudites of the Cablac-type limestone of early Miocene age, also found in the Kobipoto massif, contrast strongly with the early Miocene bathyal and distal facies of the para-autochthonous Nief beds.

The arguments for interpreting the allochthonous elements as having been derived from the Asian continental margin have already been set out.

Earthquake data for Seram–Ambon area

The earthquake map (Hamilton 1974) shows 2 prominent features in the Seram area: (1) there is a very wide scatter of shallow focus earthquakes extending *c.* 200 km from the N coast of Seram to the submarine ridges S of Ambon. No intermediate or deep focus shocks are recorded in this region and the Benioff zone cannot be recognized below 100 km; (2) earthquakes are concentrated throughout central Seram and along the N coast of E Seram, with very few in W, E and S Seram.

One possible explanation of this distribution is that most of the earthquakes are related to important strike-slip faults. ERTS imagery and airphotos show a distinctive trapezoidal pattern of complex large and small scale lineaments, which in other parts of the world is usually characteristic of transcurrent fault terrains. Such a transcurrent fault system could well be associated with the recent acquistion of curvature of this eastern part of the Banda Arc (Fitch 1972). Cardwell & Isacks (1978) described 2 underthrusting mechanisms for earthquakes in the region of Seram S of the Trough. They interpreted the earthquake data in the Aru region as indicating that the Tarera Aidoena fault zone of Irian extends westwards, separating the Banda Arc into 2 subducting slabs, one associated with the Seram Trough and the other with the Timor Trough. Such a tear in the hinge region of the Banda Arcs may be related to the curvature of the Banda Arcs that must be post-overthrusting and may be associated also with extensional tectonics reported in the Aru Trough (Bowin *et al.*, in press). It is also possible that this extensional regime led to the development of the Weber Deep after the collision between the volcanic arc and the Australian continent and is also associated with the post-collision acquistion of curvature by the arc.

Gravity data for Seram, Ambon and Uliassers

Milsom (1977) pointed out that the Bouguer anomaly map of Seram is similar to that of Timor (Chamalaun *et al.* 1976; Milsom & Richardson 1976). In both islands the gravity contours follow the long axes, with the Neogene–Quaternary basins apparently well defined on the Australian–New Guinea side and with high values and steep gradients along the Banda Sea coasts. More gentle gravity gradients are found on the Australian–New Guinea side of the Outer Banda Arc islands. The steep gradients of the Banda Sea side of these islands is interpreted as evidence of the Outer Banda Arc islands being underlain by Australian continental crust which extends to their Banda Sea coasts.

The Piru Bay local gravity high corresponds to the presence of ultrabasic igneous rocks, including harzburgites and lherzolites (Valk 1945), probably extending down to at least 3 km depth (Milsom 1977). These dense rocks may be associated with major strike-slip faulting which post-dates the overthrusting.

ACKNOWLEDGMENTS. Our expeditions (1975–76) were sponsored by the Indonesian Geological Survey, with Dr H. M. S. Hartono acting as coordinator. Financial support was provided by the Natural Environment Research Council and BP Petroleum Development Ltd. Local transport and base camp facilities in Seram, as well as general assistance in Ambon, were provided by AAR Ltd. We are particularly indebted to Mr G. Thomas and Dr T. D. Adams of BP Petroleum Development Ltd. and Mr R. Paten and Mr G. Evans of AAR Ltd.

References

AUDLEY-CHARLES, M. G. 1965. Permian palaeogeography of the northern Australia–Timor region. *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, **1**, 297–305.

—— 1968. The geology of Portuguese Timor. *Mem. geol. Soc. London*, **4**, 1–76.

—— 1978. Indonesian and Philippine Archipelagoes. *In*: *The*

Phanerozoic Geology of the World II: The Mesozoic A. MOULLADE, M. & NAIRN, A. E. M. (Eds). Elsevier, Amsterdam, 165–207.
—— & CARTER, D. J. 1972. Palaeogeographical significance of some aspects of Palaeogene and early Neogene stratigraphy and tectonics of the Timor Sea region. *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, **11,** 247–64.
—— & ——1978. Interpretations of a regional seismic line from Misool to Seram. Implications for regional structure and petroleum exploration. *Proc. Indones. Petrol. Assoc.*, 6th Ann. Convention, Jakarta, June 1977, **2,** 3–11.
——, —— & BARBER, A. J. 1975. Stratigraphic basis for tectonic interpretations of the Outer Banda Arc, Eastern Indonesia. *Proc. Indones. Petrol. Assoc.*, 3rd Ann. Convention, Jakarta, 1974, 25–34.
BALLY, A. E. 1975. A geodynamic scenario for hydrocarbon occurrences. *World Petrol. Congr.* Tokyo, PD–1, 33–44.
BARBER, A. J. & AUDLEY-CHARLES, M. G. 1976. The significance of the metamorphic rocks of Timor in the development of the Banda Arc. *Tectonophysics*, **30,** 119–28.
——, —— & CARTER, D. J. 1977. Thrust tectonics in Timor. *J. geol. Soc. Aust.* **24,** 51–62.
BEMMELEN, R. W. VAN. 1949. *The Geology of Indonesia.* Government Printing Office, The Hague.
BOWIN, C., PURDY, G. M., SHOR, G., LAWVER, L., HARTONO, H. M. S. & JEZEK, P. Arc–continent collision in the Banda Sea region. *Bull. Am. Assoc. Petrol. Geol.* (in press).
BROWN, M. 1973. The definition of metatexis, diatexis and migmatite. *Proc. geol. Assoc. London*, **84,** 371–82.
CARDWELL, R. K. & ISACKS, B. L. 1978. Geometry of the subducted lithosphere beneath the Banda Sea in eastern Indonesia from seismicity and fault plane solutions. *J. geophs. Res.*, **83,** 2825–38.
CARTER, D. J., AUDLEY-CHARLES, M. G. & BARBER, A. J. 1976*a*. Stratigraphical analysis of island arc–continental margin collision in eastern Indonesia. *J. geol. Soc. London*, **132,** 179–98.
CHAMALAUN, R. H., LOCKWOOD, K. & WHITE A. 1976. The Bouguer gravity field of eastern Timor. *Tectonophysics*, **30,** 241–59.
DAVIES, H. L. & NORVICK, M. 1974. Explanatory notes on the Blucher Range geological sheet. *Bur. Miner. Resour. Aust.* 1:250,000, Geol. Ser. Explan. Notes, SB/54–7, 1–29.
FALVEY, D. A. 1972. Sea floor spreading in the Wharton Basin (Northwest Indian Ocean) and the break-up of eastern Gondwanaland. *APEA J.* **12,** 86–8.
FITCH, T. J. 1972. Plate convergence, transcurrent faults, and internal deformation adjacent to southwest Asia and the western Pacific. *J. geophys. Res.* **77,** 4432–60.
FROIDEVAUX, C. M. 1975. Geology of Misool island (Irian Jaya). *Proc. Indones. Petrol. Assoc.* 3rd Ann. Convention, Jakarta, 1974, 189–96.
GERMERAAD, J. H. 1946. *Geology of Central Seram.* de Bussy, Amsterdam.
HAMILTON, W. 1974. Earthquake map of the Indonesian region. *U.S. geol. Surv.*, Map 1-875 C.
HARRISON, J. 1969. A review of the sedimentary history of the island of New Guinea. *APEA J.* **9,** 41–8.
HUTCHINSON, C. S. 1976. *In*: discussion of CARTER D. J. *et al.* 1976. *J. geol. Soc. London*, **132,** 358–61.
KANMERA, K. & NAKAZAWA, K. 1973. Permian–Triassic relationship and faunal changes in the eastern Tethys. *Mem. Can. Soc. Petrol. Geol.* **2,** 100–19.
LOFTING, M. J. W., CROSTELLA, A. A. & HALSE, J. W. 1975. Exploration results and future prospects in the northern Australasian region. *World Petrol. Congr.*, Tokyo. PD-7 (3).
MARGOLIS, S. V., KU, T. L., GLASBY, G. P., FEIN, C. D. & AUDLEY-CHARLES, M. G. 1978. Fossil manganese nodules from Timor: geochemical and radiochemical evidence for deep-sea origin. *Chem. Geol.* **21,** 185–98.
MILSOM, J. 1977. Preliminary gravity map of Seram, eastern Indonesia. *Geology*, **5,** 641–3.
—— & RICHARDSON, A. 1976. Implications of the occurrence of large gravity gradients in northern Timor. *Geol. Mijnbouw.* **55,** 175–8.
MOLENGRAAFF, G. A. F. 1915. Folded mountain chains, overthrust sheets and block faulted mountains in the East Indian Archipelago. *Int. Geol. Congr.* (Toronto, 1913), 689–702.
POWELL, D. E. 1976. The geological evolution of the continental margin off Northwest Australia. *APEA J.* **16,** 13–23.
PRICE, P. L. 1976. Miospore and phytoplankton assemblages from basement samples, Seram, Indonesia. AAR Ltd., Laboratory Report No. 200/1.
SLUIS, J. P. VAN DER. 1950. *Geology of East Seram.* de Bussy, Amsterdam.
U.S. GEOL. SURV. 1974. Bathymetric map of the Indonesian region. Map 1–875–A.
VALK, W. 1945. *Contributions to the geology of West Seram.* de Bussy, Amsterdam.
VISSER, S. W. & HERMES, J. J. 1962. Geological results of the explorations for oil in Netherlands New Guinea. *Verh. K. Ned. geol. mijnbouwkd. Genoot*, **20,** 1–265.
YAMAGIWA, N. 1963. Some Triassic corals from Portuguese Timor. Palaeontological study of Portuguese Timor. *Mem. Osaka Univ. Lib. Arts & Education. B. Nat. Sci.* **12,** 83–7.
ZILLMAN, N. J. & PATEN, R. J. 1975. Exploration and petroleum prospects, Bula Basin, Seram, Indonesia. *Proc. Indones. Petrol. Assoc.* 4th Ann. Convention, Jakarta, 1975, 129–48.

Read 6 December 1978; received 13 December 1978; revised typescript received 5 April 1979.

MICHAEL G. AUDLEY-CHARLES, Department of Geology, Queen Mary College, Mile End Road, London E1 4NS.
DAVID J. CARTER, Department of Geology, Royal School of Mines, Imperial College, Prince Consort Road, London SW7 2BP.
ANTHONY J. BARBER, Department of Geology, Chelsea College, 271 Kings Street, London W6 9LZ.
MARTIN S. NORVICK, BP Petroleum Development Ltd., Farburn Industrial Estate Dyce, Aberdeen AB2 0PB.
S. TJOKROSAPOETRO, Geological Survey of Indonesia, Jl. Diponegoro, Bandung, Indonesia.