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# Active Faults in Indonesia

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**Abstract:** The recognition of active faults is of obvious importance to urban planning, engineering projects and earthquake studies.

A preliminary classification of faults according to their states of activity comprises four classes.

(1) Active faults occurring in Holocene deposits or associated with historical earthquakes, disturbances to man-made structures and to regular plant distribution patterns, deformation of alluvial deposits and live reef platforms.
(2) Potentially active faults in Quaternary deposits, earthquake-prone areas or active volcanoes.
(3) Faults of uncertain activity occurring in pre-Quaternary rocks in tectonically mobile regions and without information about their displacements.
(4) Inactive faults in pre-Quaternary, tectonically stable areas that are not underlain by limestone or exist far from steep slopes.

The known principal zones of active faulting in Indonesia comprise several strike-slip fault belts (Sumatra fault zone, 1600 km long; Palu-Koro fault zone, 700 km long; Irian fault zone that on land is 1300 km long); the central depression of Timor where normal faulting is associated with lateral displacements; the Banyumas depression of Java; active volcanoes (with records from Tangkubanperahu, Merapi, Kelut all in Java and Krakatau in Sunda Strait), where principally normal faulting takes place through tectono-gravity causes; extensive limestone terrains (Gunung Sewu, Java; Maros area, South Sulawesi; Ayamaru plateau, Irian Jaya) where normal faulting occurs through undermining.

Only few examples of active thrusting are known to the author.

Recorded single-event displacements by strike-slip motion amount to a few metres but are generally of shorter distances. Single displacements on active normal faults may create throws of up to 10 metres.

## INTRODUCTION

The majority of the Indonesian islands are located between the semi-cratons of the Southeast Asian or Sunda Platform in the northwest and the Sahul Platform in the southeast (Fig. 1). Quaternary tectonism is indicated by the occurrence of island arc structures and negative isostatic gravity, Vening Meinesz belts; active volcanism; frequent earthquakes; high relief on land and deep, marine depressions; successions of young reef terraces reaching altitudes hundreds of metres above sea level; transection of Quaternary geological structures; transection of geomorphological elements by coastlines or by scarps; consistent river offsets; presence of mudcones ("mud volcanoes") in Timor and Irian Jaya and other phenomena (see van Bemmelen, 1949; Umbgrove, 1949; Kuenen, 1950; Katili and Tjia, 1969; Katili and Soetadi, 1971). Recently determined, radiocarbon dates of raised shorelines on various islands of mobile eastern Indonesia indicate annual rates of uplift in the order of a few mm. to about 10 mm during the last 20,000 years or so (Tjia *et al.*, 1972, Tjia and Posavec, 1972). Table 1 summarizes our present state of knowledge on subsidence and uplift rates in Indonesia. Estimates of uplift rates in islands on the rim of the Sunda Platform appear to be two orders lower (Tjia, 1970).

A number of major and lesser fault zones with Quaternary activity are known from Indonesia (Katili, 1969; Tjia, 1973a). Many more will be added to a growing

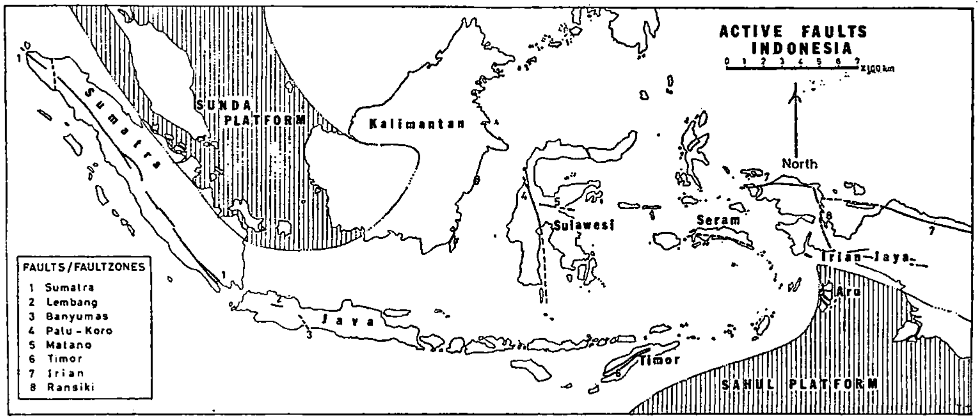

Fig. 1. Index map of active faults in Indonesia. Faults are dashed where time of activity or location are in doubt.

TABLE 1.

Average Uplift (+) Or Subsidence (—) Rates In Millimetres Per Year

| Locality | Based On Geology (since ....) | Based On C-14 ages (since .. yr BP) |
|---|---|---|
| *Tectonically Stable Areas* | | |
| Bangka island | +0.02 (Pleistocene) | — |
| Belitung island | +0.05 (Pleistocene) | — |
| Bawean island | +0.04 (L. Pleistocene) | — |
| *Tectonically Active Areas* | | |
| North Sumatra | +0.2 (L. Pleistocene?) | — |
| Strait Sunda | —1.0 (L. Pleistocene?) | — |
| West Java | +0.8 (M. Pleistocene) | — |
| Kendeng Hills, East Java | +0.5 (M. Pleistocene) | — |
| Rembang Hills, Central-East Java | +0.6 (M. Pleistocene) | — |
| Strait Madura | —0.5 (U. Pleistocene) | — |
| Saubi island, Kangean group | — | +8.0 (250?) |
| West Timor | +1.0 (M. Pleistocene) | +0.95 to 1.22 (30,000) |
| Selu island, Tanimbar | — | +10.0 (250?) |
| Kai Besar island | +0.6 (L. Pleistocene) | — |
| West Seram island | +1.2 (L. Pleistocene) | — |
| Ambon Island | +0.5 (L. Pleistocene) | — |
| Wangi-wangi island, Tukangbesi | +1.5 (6,000 yr) | — |
| Tomea island, Tukangbesi | +1.5 (6,000 yr) | +9.0 (3,320) |
| Tukangbesi islands (sea area) | —1.0 (Pleistocene) | — |
| Taka Garlarang Atoll | —2.0 (Pleistocene) | — |
| Southwest Sulawesi | +0.3 (L. Pleistocene) | — |
| Pangkajene, SW Sulawesi | — | +1.4 to 2.5 (4,000) |
| Palu Valley, Central Sulawesi | — | +4.5 (24,000) |
| Kutei, East Kalimantan | +4.0 (Holocene) | — |
| Tanjung Lipat, Sabah, Malaysia | — | +2.7 (180) |
| Miri, Sarawak, Malaysia | — | +5.5 to 6.2 (20,000) |
| Biak island, Irian Jaya | — | +0.8 (31,000 to 36,000) |

list, mainly through the efforts of the Geological Survey of Indonesia that has embarked on an extensive scale of systematic mapping. Holocene ages for geological phenomena in Indonesia have been determined by radiometric methods (mainly C-14), deformation of man-made structures and of alluvial deposits, the presence of shallow earthquake epicentres, and uncompacted character of sediments. In addition, Quaternary ages have been assumed on account of horizontal to subhorizontal attitudes of sediments, on account of depositional and of erosional surfaces, non-diagenetic nature of calcareous deposits, the presence of non-weathered fault surfaces, stream offsets, and the like.

## CLASSIFICATION OF FAULTS ACCORDING TO ACTIVITY

Active faulting, often accompanied by surface expressions, is indicated by certain features like shallow-focal earthquakes, displacement of man-made structures, disturbances to vegetation patterns in plantations, fractures in alluvium, and other deformations. According to fault activity I have employed the following preliminary classification.

(1) *Active fault.* Displacements should have occurred during the Holocene (11,000 years BP) or during historical time, or epicentres of shallow earthquakes occur within or close to the fault zone.

(2) *Potentially active fault.* Displacements have occurred in Quaternary (2 to 3 million years) rocks, or the fault occurs within an earthquake-prone area, or it occurs upon or close to an active volcano.

(3) *Fault of uncertain activity.* Those faults which occur in pre-Quaternary rocks and no displacements are known. This class embraces faults that occur in pre-Quaternary limestone or at the foot of steep slopes. Faulting may be gravity-induced, that is, in limestone terrains on account of subsurface solution followed by collapse, and by slumping in the other case.

(4) *Inactive fault.* Those faults which occur in a tectonically stable, pre-Quaternary area and not underlain by limestone and do not occur near or upon steep slopes. Inactive faults are to be found in the cratonic to semi-cratonic areas, such as West Kalimantan, Bangka, and Belitung (Fig. 1).

## DESCRIPTIONS OF ACTIVE FAULTS

The known principal, active faults of the Indonesian islands are located in the tectonically mobile areas between the Sunda and Sahul platforms. Smaller faults have also been recorded from areas at the edges of the platforms. Except for a small reverse fault near Dobo, Aru islands (see below), the faults in Quaternary deposits upon the platforms belong to the gravity type. Harsono (1975) records a few normal faults in the offshore areas of the tin islands of Bangka and Belitung. These faults possess throws of a few metres and show up clearly on sonograms. The gravity faults probably came into existence through compaction of loose Quaternary sediments or by undermining of calcareous basement, and the movements may have been triggered by earth tremors.

Active normal faults of a few kilometres length are also rather common on active stratovolcanoes in Sumatra and Java. Such faults which may or may not be accompanied by earthquakes may be caused by depletion of shallow magma chambers which initiate the deformation. Van Bemmelen (1949) proposed another cause and he related partial collapse of a volcanic body to a weak argillaceous substratum, so commonly found in Java, and overloading by the piling up of eruptive products.

Ch.E. Stehn (quoted by van Bemmelen, 1949, p.198 etc.) described fissuring at the surface accompanying a phreatic eruption in the Suoh basin of South Sumatra in 1933. Two examples of active faults upon or in the immediate neighbourhood of volcanoes occur in West Java and in Central Java (see van Bemmelen, 1949). East-west rents across the Tangkubanperahu volcanic complex, West Java, caused its north slope to slide down and crumpled its foot into an arcuate series of folds with accompanying tear faults that are radially arranged with respect to the centre of the complex. The volcano-tectonic event is thought to have occurred some 6000 years ago. In 1006 A.D., a paroxysmal eruption of the Merapi volcano in Central Java formed crescentic normal faults across the volcano. At 17-20 km distance towards WSW a series of folds was created by gravity sliding of the particular volcanic sector.

Still other, active normal faults may be expected to occur in extensive limestone areas like the Gunung Sewu in Java, the Maros region in South Sulawesi, and the Ayamaru Plateau in Irian Jaya. Such faults may be of tectonic origin or the fractures may be the result of solution without or together with earthquakes.

The following more detailed descriptions concern active faults of unequivocably tectonic origin. Their tectonic nature is indicated by the fact that fault motion has been essentially lateral or reverse. Besides, certain fault segments are loci of earthquake epicentres.

## Sumatra Fault Zone

The Sumatra fault zone consists of about 20 en echelon segments and strikes-N320-330E. The fault zone runs along the entire 1600-km long Bukit Barisan mountain range on the west side of the island (Fig. 2). At the junction of the segments are found topographic depressions, inactive and/or active volcanoes, and east-west aligned magnetic anomalies. (Tjia, 1977). The latter have been interpreted to represent occurrences of intrusive bodies by Posavec *et al.* (1973). Consistent stream offsets, subhorizontal to horizontal fault striations, and a few lithological offsets indicate

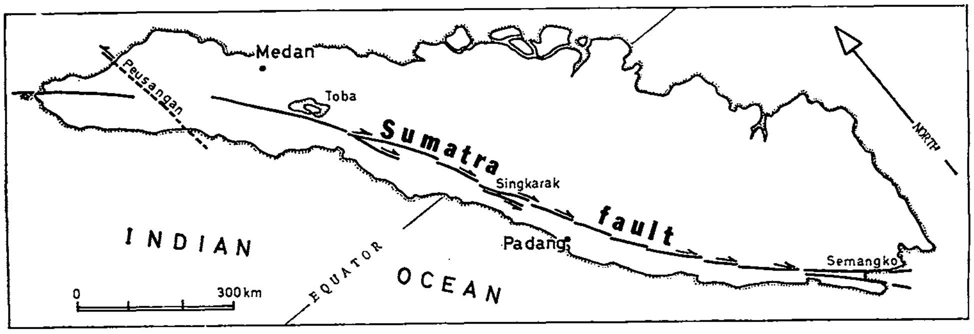

Fig. 2. Outline map of the dextral-slip fault zone in Sumatra. Note the *en echelon* arrangements of the fault segments.

right-lateral displacement in the order of 20 to 25km since the Middle Miocene. The river offsets are probably Quaternary events and indicate fault motion that range between 250 to 800 metres. Numerous earthquake epicentres are located within the fault zone. A few of the important earthquakes are: in the Tapanuli area (1892), in the Kerinci valley (1909), in the vicinity of Padangpanjang (1926), in Liwa (1932), of Tes (1952), and of Lubuksikaping in 1977. Katili and Hehuwat (1967) convincingly presented published evidence for the dextral-slip character of the fault zone, while earlier workers generally regarded the zone to represent normal faulting.

Muller (1895, cited by van Bemmelen, 1949, p.268) note that the Tapanuli earthquake shifted benchmarks in right-lateral fashion. Those on the west of the fault zone were displaced 1.2 to 1.3 metres towards NW relative to those on the east side. The displaced benchmarks on the west side are located along a line 50 km long which parallels the fault zone.

The Padangpanjang earthquake resulted in bent steel rails and displaced houses and a water tank on the west side of the fault zone relatively towards the northwest for distances up to 60 cm. The earth-quake shocks were reportedly felt to be directed parallel and normal to the fault zone. Within the zone, normal faulting created a 10-metre high throw at the rim of Lake Singkarak, (Visser, 1927).

Damage by the Liwa earthquake of 1932 was concentrated in a narrow zone parallel to the long axis of Sumatra. Berlage (1934) interpreted horizontally directed shocks within the zone. In the vicinity of Lake Ranau vertically-directed shocks were recorded. Relative displacements of houses occurred in NW-SE direction.

Kraeff (1953) reported that the Tes earthquake in 1952 resulted in relative lateral displacements of houses, respectively towards NW for those on the west side and towards southeast for those on the east side. Relative lateral displacements in the villages Turunlalang and Tes amounted to 0.5 metres. Similar amounts of lateral displacements occurred at Kotadonok and Talangratu villages.

In addition to fault motion parallel to the axis of Sumatra, earthquake-generated fault movements oblique to the Sumatra fault zone have also been noted. At Salayo village near Solok town, an earthquake in 1943 resulted in dextral displacement of parts of a bridge measuring 2.5 cm east-west. East-west motion is also exhibited by bent steel supports of a market shed close to the bridge (Tjia and Posavec, 1972). Other examples of faults striking across the trend of the Sumatra fault are indicated on the geological map of part of West Sumatra by Rosidi *el al.* (1976). East to northeast striking faults that traverse Quaternary deposits near Muaralabuh and at the north end of the Semurup depression possess dextral offsets of ca. 500 metres. An important transverse fault may be the Peusangan lineament in North Sumatra (Tjia, 1974). Its active character is implied by the occurrence of shallow earthquake epicentres.

In addition to dextral lateral displacements, the Sumatra fault zone also comprises normal faults and sinistral lateral slip faults. Normal faults show up as series of stepfaults that line the wider valleys and depressions within the fault zone. Left lateral stream offsets range up to 1200 m distance. Left lateral faulting is also exhibited by identifiable, small-scale markings on fault planes. Some of the sinistral motions were probably manifestations of elastic rebound, while the majority of these infrequent indications of left slip may be the result of *en bloc* oblique-slip

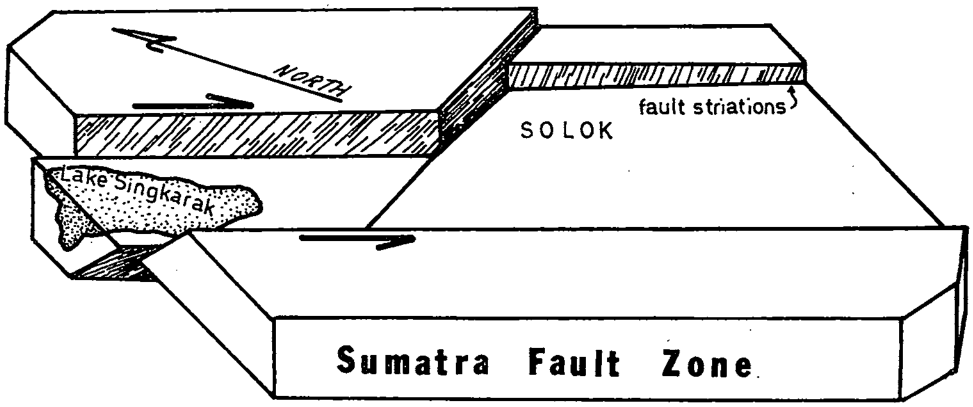

Fig. 3. Block diagram explaining the different senses of fault motion along parallel strands of the Sumatra fault zone. Oblique northward slip of the block containing Lake Singkarak is suggested as a possible cause.

faulting of portions of the fault zone. Figure 3 explains the formation of left oblique slips. The normal faults within the fault zone apparently represent the results of equilibrium-seeking forces after a particular area was disturbed by strike-slip faulting.

The general dextral slip character of the Sumatra fault zone is compatible with a regional compression that acts within the sector N002-008E (Tjia and Posavec, 1972).

### Lembang Fault, Java

A 22 km long, northward facing scarp that strikes parallel to the long axis of Java and which outcrops amidst young volcanic deposits about 10 km north of Bandung has been designated as the Lembang fault (Fig. 4). Twelve rivers and valleys that cross the fault from north to south indicate left lateral displacements that range between 75 and 250 metres, with an average displacement of 140 metres. One striated fault surface has markings that confirm sinistral motion (Tjia, 1968a). Anthropological data show that faulting must have occurred between 3000 and 6000 years ago (see van Bemmelen, 1934; 1949, p.643). Several of the transverse faults divide the Lembang fault into three sections, each of which indicating different amounts of uplift. Scarps that mark the eastern, central, and western sections are 130 to 450 m, approximately 100 m, and about 50 m high, respectively.

The left lateral slip component of the Lembang fault is compatible with a SSW-NNE regional compression. This direction is parallel to the relative spreading directions of the Asian and Indo-Australian lithospheric plates (Tjia, 1973a).

### Banyumas Fault Zone, Java

Many destructive earthquakes have had epicentres within a northwest striking zone that is located between West and Central Java (Fig. 5). Between 1961 and August 1971, two shallow earthquakes originated in the fault zone and are indicated on the earthquake map by Hamilton (1974). From gravity data of Java (density of measurements amount to one station in every six square kilometres) Untung and

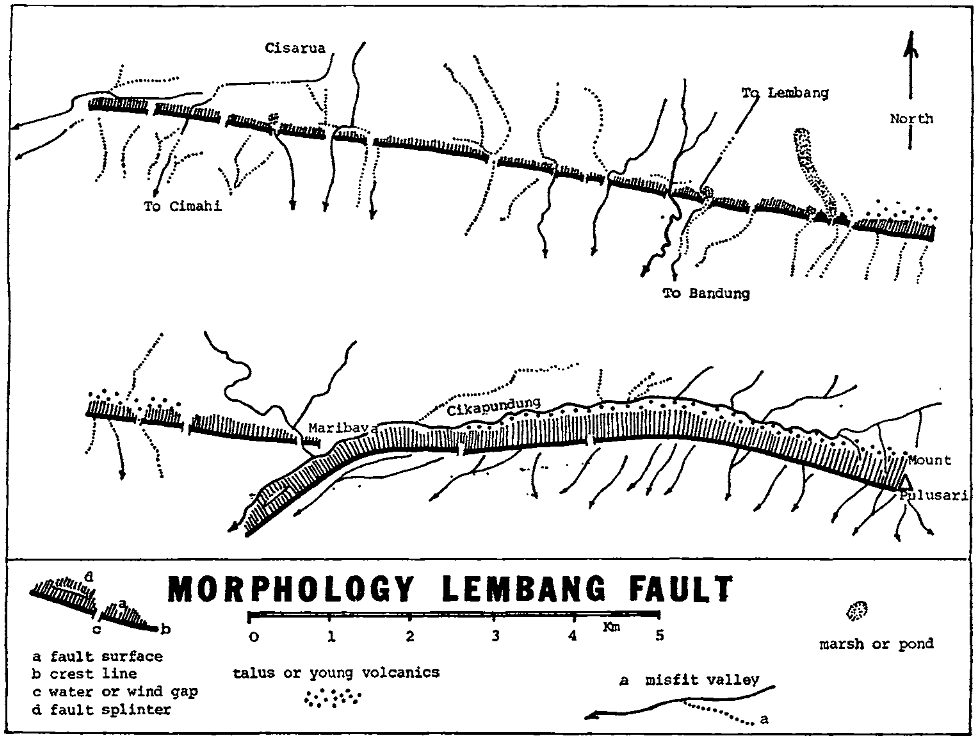

Fig. 4. The Lembang fault, north of Bandung, West Java. Note left lateral offsets of valleys. The right end of the top segment joins the left end of the bottom segment.

Hasegawa (1975) interpreted that the structure indicated by the Banyumas depression on Figure 5 represents normal faulting downthrowing to the east. Information from oil exploration that was available to Koesoemadinata and Pulunggono (1975) shows a NW-SE trending deep trough in the same region to contain tightly folded, Miocene flysch deposits.

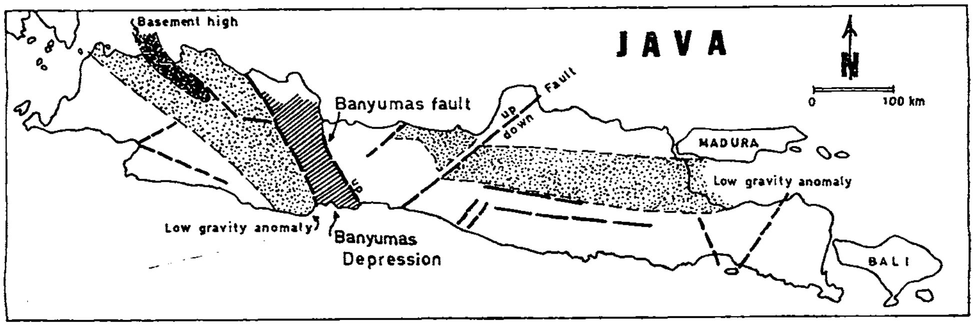

Fig. 5. Major structures of Java and zones of low gravity. The map is mainly after Untung and Hasegawa (1975) with small changes to the area between west and central Java. Most fault traces are tentative and have not been verified in the field. The Banyumas depression is equivalent to the Banyumas fault zone.

**Palu-Koro Fault Zone, Sulawesi**

The Palu-Koro fault zone was formerly known as the graben Fossa Sarasina. It strikes south-southeast and stretches from Palu Bay towards SSE for 300 km on land, while its 400-km long submarine extension in the Gulf of Bone appears to be indicated by bathymetry (Tjia and Zakaria, 1974). The Palu Bay and Palu Valley are bordered by stepfault topography, part of which consists of truncated alluvial fans, triangular to trapezoidal facetted scarps, and striated fault planes (Fig. 6). Farther towards the SSE the fault is indicated by straight narrow valleys that are interrupted by small basins. Within this narrow portion are found abundant indications of faulting: flasered rock, mylonite, and striated fault planes (Brouwer, 1947). Earthquake epicentres from within the fault zone prove the active nature of the fault zone. Three of the better known earthquakes occurred at Gimpu (1905), Kulawi (1907) and at Kantewu (1934). Katili (1969) also noted consistent left lateral stream offsets along the tributaries to the Koro river. Field studies by Tjia and Zakaria (1974) in the northern segment of the fault zone recorded the following features.

The Palu depression which includes Palu Bay and Palu Valley displays graben characteristics and stepfaults have throws reaching 60 metres or more. Young bioclastic limestone terraces reach to 75 metres above sea level. Material from one terrace suggests a rate of tectonic uplift of 4.5 mm per year during the past 24,000 years. Although the graben morphology is overwhelming, subhorizontal to horizontal fault striations and medium-sized NNE-striking drag folds in alluvial deposits indicate left lateral slip. Along the narrower southern part of the segmnet, sinistral stream offsets in the range of 100 to 600 metres are common features. Occasionally right lateral displacements occur and have been interpreted to represent lag faults or effects of elastic rebound. At several localities, other faults cross the Palu-Koro and cause lateral offsets (Fig. 6). On the whole, however, the transverse faults represent normal faulting.

A kinematic analysis of fault motions of the Palu-Koro fault shows that the fracture system corresponded to horizontal regional compression that has acted in ESE-WNW direction.

**Matano Fault Zone, Sulawesi**

The Matano fault zone is a 170 km long topographic lineament that extends between Losoni Bay and a point close to Lake Poso in Central Sulawesi (Fig. 7). The fault zone strikes WNW. Ahmad (1977) has studied a 45 km long stretch of its easternmost section. He recognized five, sinistral *en echelon* segments along the fault zone. Lake Matano occupies a 15 km long graben that is located at the junction of two *en echelon* segments. Lateral offsets of lithological contacts are distinctly shown by the distribution of crystalline metamorphic rocks, Mesozoic sediments and ultrabasic rocks. Parallel to the fault zone, offsets amount to 19 or 20 km in sinistral sense. Younger lateral shifts are represented by multiple sinistral stream displacements in the range of 200 to 600 metres. Probable fault scarps in Quaternary gravel deposits suggest Recent activity of the fault. Within the fault zone are located three shallow-earthquake epicentres that occurred between 1961 and August 1971 (see map by Hamilton, 1974; tables by Denham, 1977).

A few authors believe that the Matano fault zone may be the western end of a huge left lateral fault that includes the Sorong fault in Irian Jaya (Tjia, 1973b).

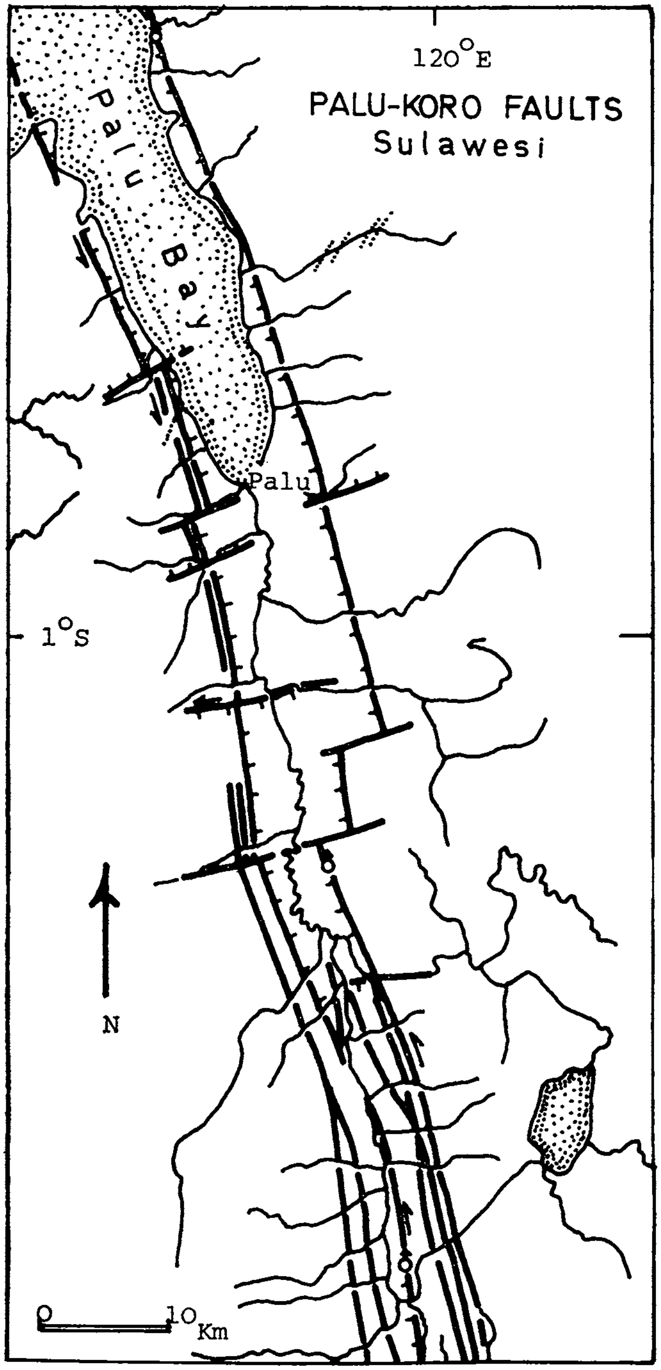

Fig. 6. Palu-Koro fault system, Central Sulawesi. Normal and lateral slip faults and hot springs are indicated with conventional symbols. Strikes of drag folds are indicated by dotted lines adjacent to faults.

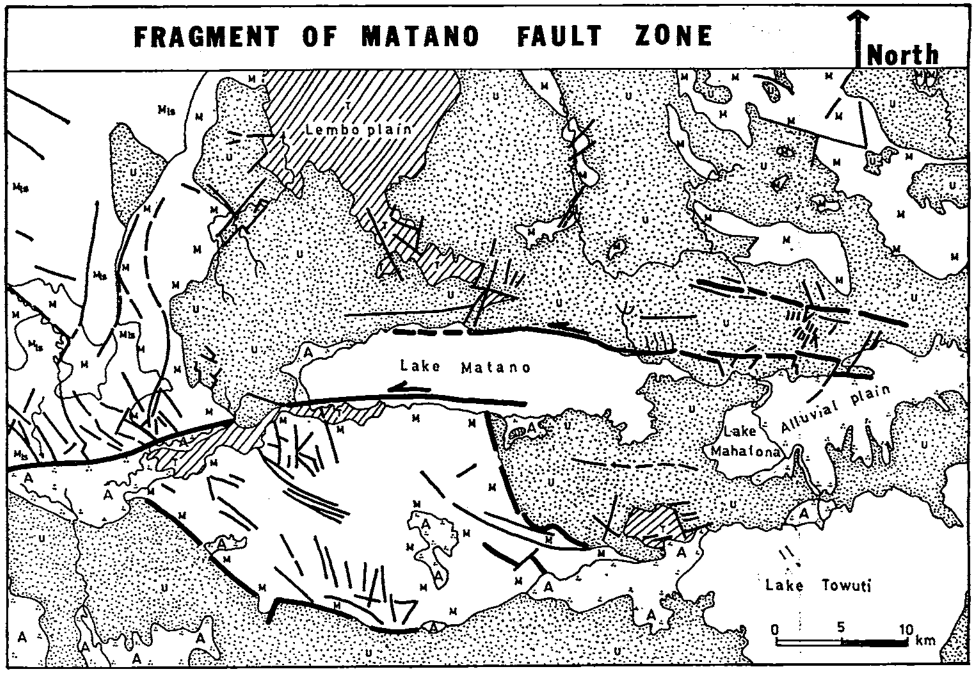

Fig. 7. Two *en echelon* segments of the Matano fault zone, Sulawesi. Lake Matano reaches depths exceeding 500 meters. U: mostly serpentinized ultrabasic rocks (Early Mesozoic/Late Mesozoic?); M: Mesozoic rocks; Mls: Mesozoic limestone; T: Tertiary sediments; A: Alluvium. Slightly simplified, after Ahmad.

## The central structural valley of Timor

The so called "central graben" (Umbgrove, 1949) of Timor extends for almost three quarters of its length along the axis of the island (Fig. 8). The central valley reaches widths of 15 km and its morphology agrees with its original designation. However, one central strand of the fault zone that is exposed where the Noil (=river) Mina begins at the confluence of Noil Besiam and Noil Leke, displays features of lateral displacements. Here, the author mapped the most conspicuous fault element to consist of a row of triangular facetted hill sides that reach up to 150 metres above the wide flood plain. The hills consist of upper Miocene to lower Pliocene calcareous tuff of the Batuputih formation (Hartono *et al.*, 1975) and may represent an allochtonous part of an overthrust sheet that occurred during middle Pleistocene time (Tjokrosapoetro, pers. commun.).

Along the base of the exposed fault plane and at distances of 20 to 25 metres are found zones of fault breccia that strike NO65-070E and form vertical individual fault planes. Each zone is about 4 metres wide and consists of flasered calcareous tuff. The flasers may be 30 cm long and are embedded in a brecciated groundmass (Fig. 9b). Still other but minor fault sets transect the flaser zones.

Figure 9c summarizes the interpretation of the fault system. The major fault is represented by the bundle of flaser zones that strikes NO65-070E for which the name

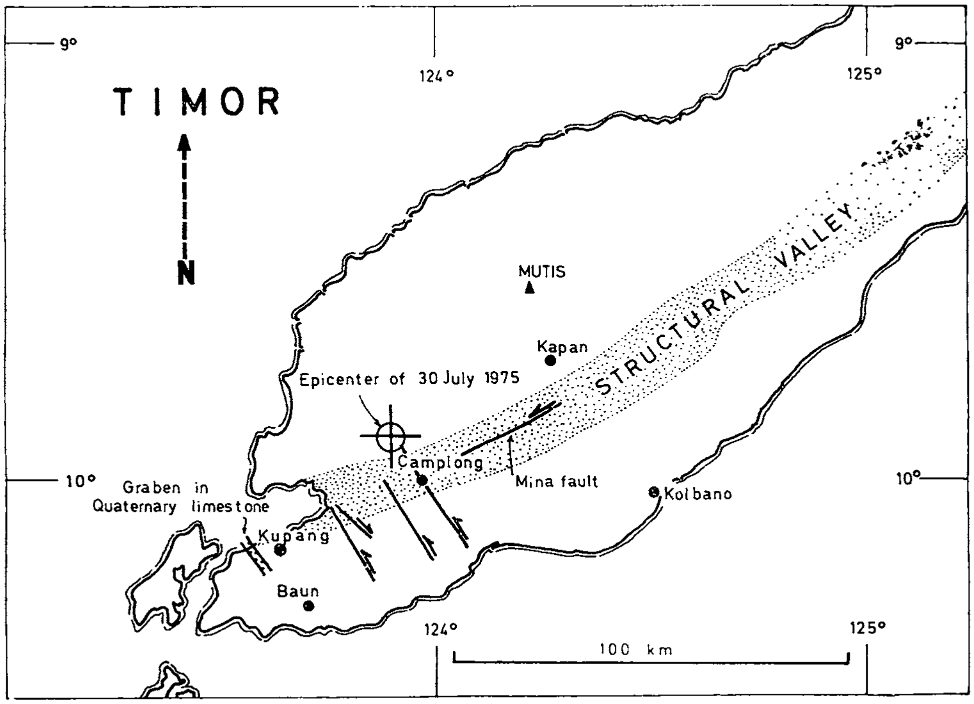

Fig. 8. Outline map of four active earthquake faults in Timor between Camplong and Kupang Bay, the Mina fault and a graben in Quaternary limestone near Kupang town. Step faults line the structural valley.

"Mina fault" has been proposed (Tjia, 1976) and is indicated as F1 on the figure. The Mina fault is transected and downthrown by F2 (fault set 2 with strike/dip =80/60). The other minor fault sets indicate lateral motions and are F3 =340/90 and F4 40/90. Set F3 displaced F1 and F2 right laterally by at least 2 metres, while the cumulative lateral displacement may amount to a considerable distance. Set F4 displaced individual flasers by a few centimetres left laterally. The vertical attitudes of fault sets F3 and F4 imply them to be subsidiary fractures of set F1. If the lateral displacements on F3 and F4 were caused by the same compression, and this subsidiary compression was generated by motion along the major strike-slip fault F1, fault motion on F1 should have been left lateral. Figure 1 in Tjia (1972) explains the above interpretation.

Gravity was the cause of motion on F2. The field relations suggest that F2 antedates F3, therefore, F2 also occurred before F1. All fault events should have taken place after overthrusting of the particular Batuputih rocks. According to Tjokrosapoetro (pers. commun.) the overthrusting took place during the later part of the Middle Pleistocene. Three or four shallow-earthquake epicentres depicted on Hamilton's map (1974) are located in or near the structural valley of Timor.

The left lateral slip along the Mina fault reflects the result of horizontal compression acting within the sector N155-245E.

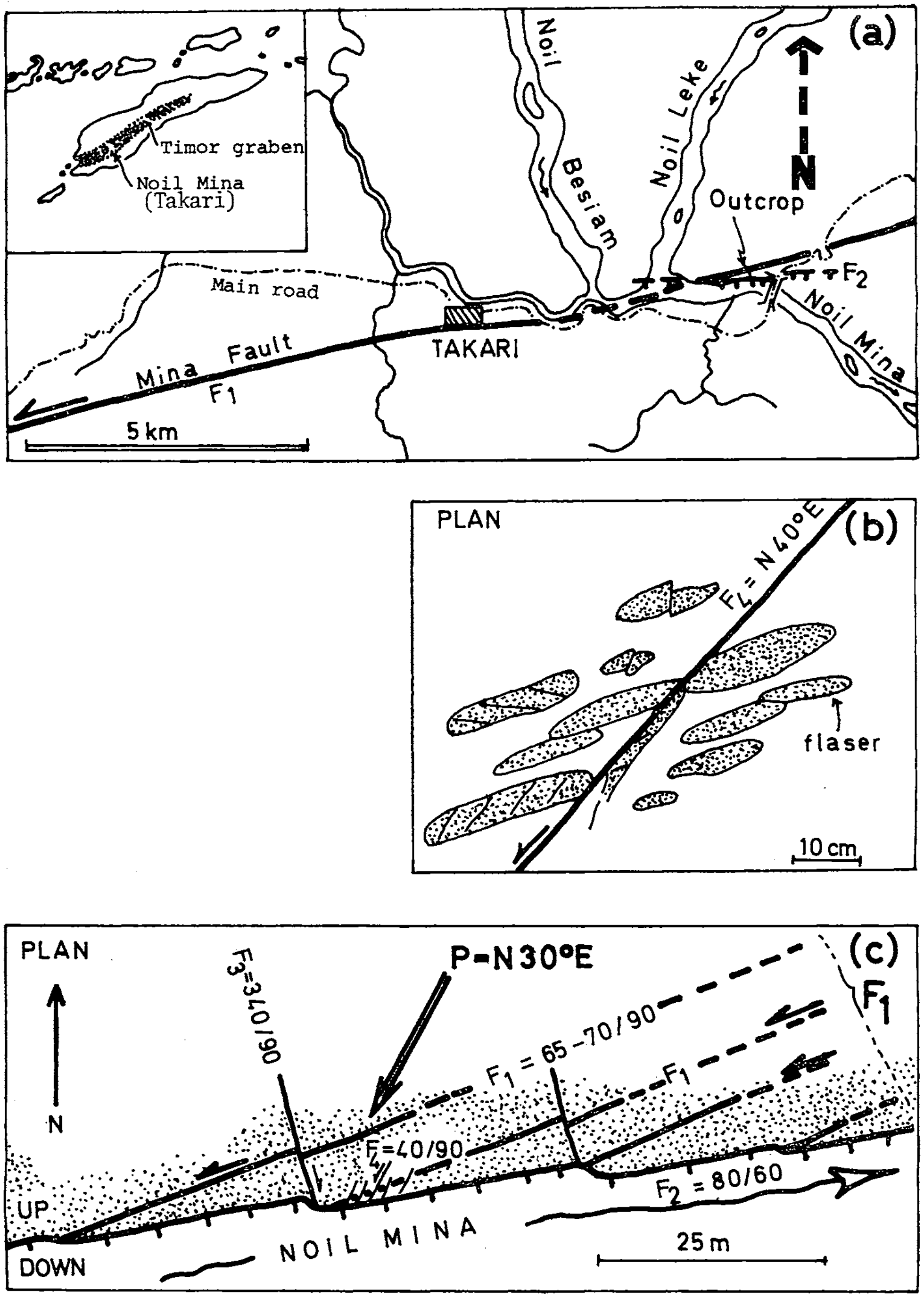

Fig. 9. a. Plan of the left-lateral Mina fault in western Timor.
b. Detail of fault flasers within a strand of the Mina fault.
c. The fault system exposed along Noil Mina near Takari village. P is the reoriented compression direction generated by left slip along the main fault Fl.

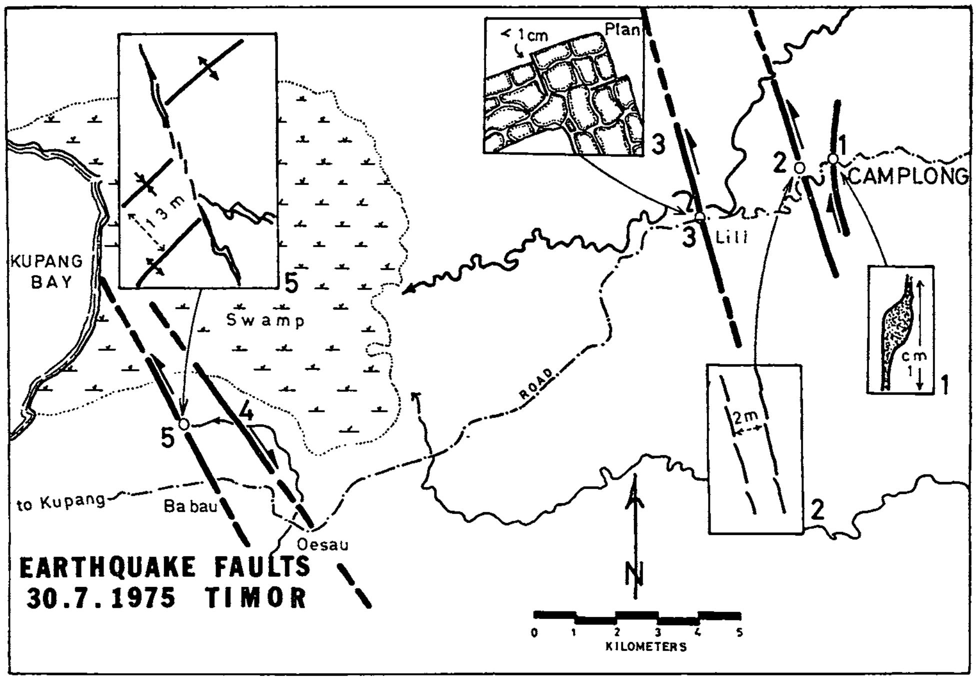

Fig. 10. Five major faults that moved laterally and were probably generated by the 30 July, 1975 earthquake in western Timor. Insets show details. Fault 1: dextral motion is shown by sigmoidal gashes in soil at Camplong market; fault 2: sinistral slip is suggested by *en echelon* arrays of gashes in soil; fault 3: left slip in NW direction is shown among many other phenomena by a deformed brick-and-mortar wall of the hospital at Lili (the ENE-trending fracture in this wall is a subsidiary phenomena); fault 5: left slip is indicated by *en echelon* and sigmoidal gashes and by drag folds in alluvium at the banks of the Oesau river. Fault 4: right slip is indicated by 5-cm offset of a weir and by markings on a fault plane cutting alluvium (no inset shown).

## Earthquake-generated cross faults in Timor

On 30 July 1975, an earthquake of magnitude 6.1 and of 30 to 50 km focal depth caused damage to man-made structures, activated or developed new mud-cones, and generated several sets of subparallel fracture zones across western Timor. Its epicentre was located on the island (Fig. 8; Sutardjo, 1975).

Often the fractures are arranged *en echelon* and form zones with typical widths of about one metre. Together the zones constitute belts consisting of fractured and non-fractured soil and rock spanning widths of up to 60 metres. Most fracture zones strike about N335E; at one locality a zone strikes NO1OE. More than two months after the event it was still possible to trace the fractures in the soil on account of the dry season. Five main fault belts cross a 20 km wide area consisting of rolling hills and coastal plain between Camplong and Kupang Bay (Fig. 10). One fault belt west of Camplong consists of *en echelon* segments in soil, occasionally of fractures in limestone and in the cement walls and floors of some houses. The *en echelon* arrays and small offsets of fractured walls suggest left lateral motion along the N340-350E trending fault strands.

The westernmost fault belt, caused by the earthquake, destroyed a church, traversed the main road and continued hundreds of metres into farmland. Its clearest manifestation occurs on the banks of the Oesau river. Here the fractures occupy a 60 metre wide zone that strikes N335E. The staggered arrangement of fractures and the attitude of tension gashes suggest left slip. Along one fault strand, broad warps and depressions with local relief of less than 50 cm are present. The longer axes of domes and depressions strike N040-050E (Fig. 11). The trend of these dragfolds are compatible with left lateral movement.

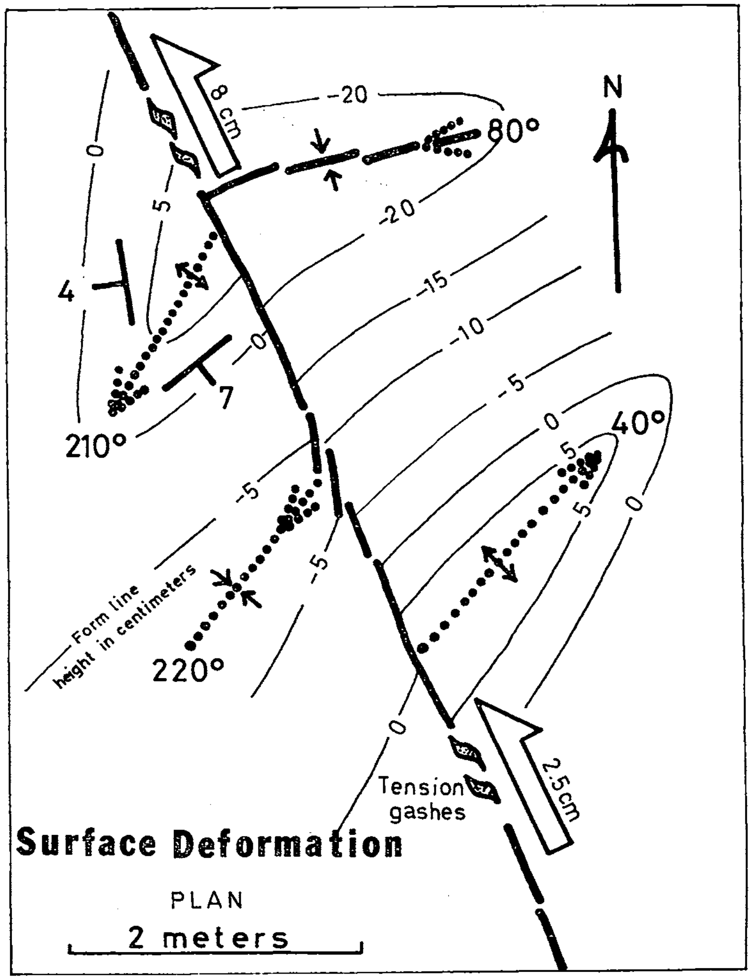

Fig. 11. Detail of 1975 earthquake fault in an alluvial terrace of the Oesau river near Babau, Timor. The terrace surface shows warping as indicated by formlines (two anticlines and two synclines). Tension gashes and fold axes agree in indicating left slip along the NW-striking fault. The large, half-tipped arrows indicate distances of left slip deduced from offsets in the field.
Note that the 80°-trending synclinal axis is also characterized by *en echelon* fractures suggesting left slip in this direction.

On Figure 10 are indicated the interpreted lateral motions along the five main faults. The northwest-striking faults are of left slip character, except fault belt Number 4. Fault zone Number 1 is also dextral, but it strikes N010E. The lateral motions of these faults, except fault Number 4, may have been the result of regional compression in east-west direction or correspond with regional tension in north-south direction. However, this interpretation does not explain left slip along the Mina fault.

### Reverse fault at Dobo, Aru Island group

The Aru islands are situated at the western edge of the Sahul Platform (Fig. 1). A terrace surface cut in reef limestone near Dobo town had been faulted along a plane striking N355E and dipping 80 degrees towards the east. Reverse faulting is indicated by the displacement and markings on the fault plane. In 1964, the exposed throw was approx. one metre. A 2 metre wide mylonite zone of the same material occurs on the downthrown side (Fig. 12). The entire fault plane is located within the intertidal zone, but the fault markings in the calcareous rock look fresh, suggesting the faulting to have taken place within the last 50 years (Tjia, 1968b).

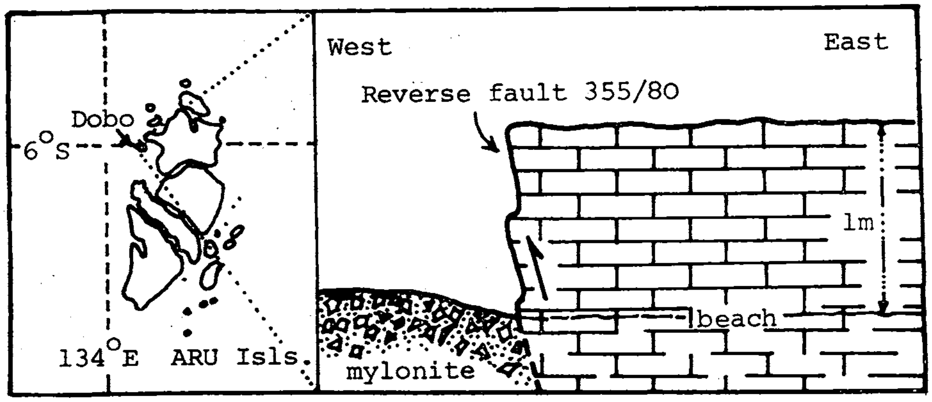

Fig. 12. Schematic section of the one-metre reef terrace and reverse fault scarp near Dobo town, Aru islands.

### Irian fault zone

Visser and Hermes (1962) described under the name Sorong fault zone a series of faults that strike almost east-west across the northern part of the Bird's Head of Irian Jaya (at that time known as West New Guinea). Sometimes the fault zone reaches widths of 10 km and is characterized by a range of rock types (miogeosynclinal as well as eugeosynclinal suites) of various geologic ages that occur as small to large, internally undeformed units embedded in a cataclastic to mylonitic groundmass. The chaotic general structure further suggests that the Sorong breccia represents a melange that developed at moving plate margins (Tjia, 1973b). Fault plane features and drag phenomena of the fault zone near Sorong town confirm the existence of left lateral components of movement. Stratigraphic and bathymetric considerations led Visser and Hermes (1962) to ascribe 350 km left lateral displacement along the fault zone since Miocene time.

Eastward the Sorong fault zone continues as the submarine Yapen fault, the Apauwar fault through a region characterized by active mudcones. the Tolateri-Gauttier fault, and the Nimboran fault. These fault zones, and provisionally also the Matano fault in Sulawesi, have been collected under the name Irian fault zone (Tjia, 1973b). The earthquake map covering the period 1961 to August 1971 (Hamilton, 1974) records more than a score of epicentres of shallow earthquakes along the Irian fault in Irian Jaya (Fig. 13). On the same figure, the eastern trace of the Irian fault zone is different from that interpreted by Hamilton (1974), but is based on descriptions by Visser and Hermes (1962).

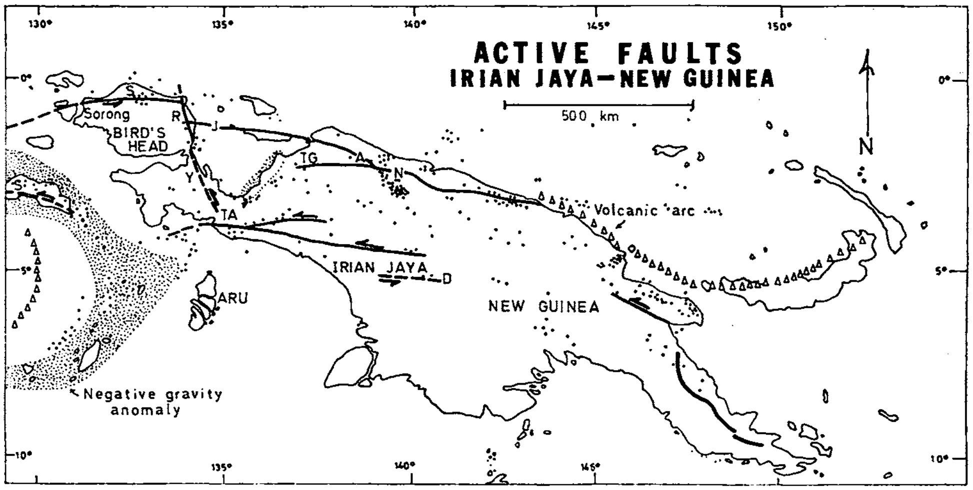

Fig. 13. Active faults in Irian Jaya—New Guinea. The Irian fault zone consists of the Sorong (S), Yapen (J), Apauwar (A), Tolateri-Gauttier (TG), and Nimboran (N) faults. Other active faults are the Ransiki (R), Tarera-Aiduna (TA), and the Papua-Solomon faults. Probably active faults are the Yakati-Yamur (Y) and Digul (D) faults in Irian Jaya and the Seram (S) fault in Seram. Active volcanism is indicated by triangles, shallow-earthquakes epicentres of the period 1961—August 1971 by dots, and Vening Meinesz zones of negative isostatic gravity anomalies by fine dots. The map is based upon Visser and Hermes (1962), Krause (1965), and Tjia (1973b) with newer additions.

## Ransiki fault, Bird's Head of Irian Jaya

d'Audretsch *et al.* (1966) recorded that the 3 to 4 magnitude earthquake of 29 June 1961 had its epicentre in the Ransiki valley. They also believed that the earthquake probably represented movement along the fault. The Ransiki fault strikes northwest and may be traced on land for a distance of about 70 km. It separates the Arfak block consisting of basic and intermediate effusive and intrusive rocks in the east from silicic, high, grade metamorphics and granite to its west. The fault zone is further indicated by the presence of elongated intrusions that vary in exposed widths between 100 and 600 metres and are traceable for an aggregate distance of 45 km. The igneous bodies are bordered by subvertical fault planes.

The absence of volcanic material on the west side of the fault zone led d'Audretsch *et al.* (1966) to interpret substantial lateral movement along the Ransiki fault. Normal faulting in Recent time is indicated by disturbed and warped terraces of the Prafi river at the north end of the fault zone (personal field observation in November

1977) and three epicentres of shallow earthquakes between 1961 and August 1971 (on the map by Hamilton, 1974).

**Other active faults in Irian Jaya**

The *Yakati-Yamur fault zone* (Visser and Hermes, 1962, p.149) occurs at the neck of the Bird's Head and runs almost north-south (Fig. 13). The fault extends from the Yakati valley to the Yamur lake. East of the fault are eastward hading imbrications; asymmetrical folds and reverse faults are found to its west. Two shallow-earthquake epicentres (on Hamilton's map, 1974) are located in this fault zone. The general structure of the adjacent area suggests that the fault zone may represent an important reverse fault with tectonic transport towards the west.

The *Tarera-Aiduna fault zone* trends east-west and separates predominantly pre-Tertiary sediments in the north from Tertiary deposits in the south (Visser and Hermes, 1962, p.152 etc.). Immediately to the south of the fault left lateral motion is implied by the disposition of WNW-striking fold axes in Tertiary sediments. The upthrown block possesses reverse faults that dip towards the north. Again Hamilton's map (1974) shows a close relationship between the fault zone and about ten shallow-earthquake epicentres (Fig. 13).

On the south limb of the Central Range near the international border runs a WNW-striking lineament that has been provisionally named the *Digul fault* by the present author. The structure was observed during a mapping flight with side-looking radar in 1972. To the south of the fault are a series of large, *en echelon* open folds trending NW. The fold directions suggest drag by left lateral motion on the fault. To the north of the lineament are tight folds striking more or less parallel to the fault. A few shallow earthquakes (see Hamilton, 1974) occur near the estimated location of the Digul fault (Fig. 13).

## POTENTIALLY ACTIVE FAULTS

(1) All existing faults that occur within the mobile region between the Sunda and Sahul platforms and traverse Quaternary deposits are potentially active faults.

(2) I presume that the majority of faults within the same mobile region and that occur in limestone areas (like Gunung Sewu in Java; in Maros, South Sulawesi; the Ayamaru Plateau in Irian Jaya) are potentially active faults. Faulting is likely of normal character and takes place on account of partial solution of calcium carbonate causing undermining and may be triggered by earthquakes.

(3) Van Bemmelen (1949) has presented many examples from Java where normal faults on active volcanoes resulted in deforming young sediments at the foot of the volcanoes. In view of the high seismicity of almost the entire island (see maps by Soetadi, 1965), the faults on these volcanoes should be classified as potentially active faults.

Among the many potentially active faults in Indonesia, short descriptions of two medium-sized structures serve as examples.

On the southwest foot of the Careme volcano, West Java, a WNW-trending fault can be traced for more than 10 km in Quaternary volcanic material. The Careme is an active volcano. A recent geological map showing this fault has been published (Djuri, 1973).

A NE-striking, more than 10 km long fault, is located several kilometres south of Malunda on the west coast of Sulawesi. This fault right-laterally offsets Miocene beds by 3 km and appears to cut alluvium (see geological map by Djuri and Sudjatmiko, 1974).

## SUMMARY AND CONCLUSIONS

The established active faults are of strike-slip or normal character. The existence of regional horizontal compression that is exhibited by Recent strike-slip faulting and the presence of fault-structures more or less perpendicular to the regional compression directions imply that reverse faulting and thrusting should also have taken place during the Holocene. Their near-absence (except the single example near Dobo, Aru islands ) in the present discussion may be due to the fact that effects of strike-slip and normal faulting are more prominent than those of reverse faulting. Inclinations of reverse faulting are usually less than 45 degrees and the hanging wall may not remain intact if the surface material involved in the faulting is weathered material. Furthermore short-term displacements of reverse faults may be small (of centimetre to decimetre size?) and coupled with the soft nature of the surface material show up as bulges or warps. Other contributing factors to our extremely meagre knowledge of active reverse faults are the general dense vegetation and very little detailed structural work in Quaternary deposits.

The majority of strike-slip faults in Indonesia have moved in directions similar to their pre-Holocene lateral movements (see Tjia, 1973a). Their senses of movement are compatible with the relative spreading directions of the adjacent Indo-Australian Plate (which influences faults in Sumatra and Java) and the western Pacific Plate (which governs lateral faults east of the Strait of Makassar). In other words the northward horizontal movement of the Indo-Australian Plate and the WNW-ward horizontal motion of the western Pacific Plate relative to the Asian Plate appear to have been transmitted to compatible lateral movements (and presumably also to reverse faulting and folding) along faults in the mobile regions of Indonesia. In Timor, left lateral slip along the Mina fault corresponds with relative movement between the Indo-Australian and Asian plates, but most lateral movements along the earthquake-generated faults reflect tensional stresses parallel to the above relative plate movements (or compression in directions normal to the general north-south motion between the plates).

For tectonically mobile areas, like most Indonesian islands, the recognition of active and potentially active faults is of obvious importance. The determination of the nature of an active fault enables planners of engineering projects to decide on the strength and the type of structures to be built. According to Sherard *et al.* (1974) for instance, earthquakes of the past hundred years in the western United States have yet to destroy earth-filled dams. One such dam near San Francisco withstood 3 metre lateral displacement by the 1906 earthquake (magnitude 8.3) and did not develop leaks. During the same earthquake movement along a fault that approached a concrete dam to a distance of 200 metres did not result in failure.

From the above review it is also clear that many more detailed structural and seismo-tectonic studies have to be carried out before a good working knowledge is collected on the location, size, past history, and behaviour of active faults.

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