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OUTLINE OF QUATERNARY TECTONICS OF INDONESIA

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ABSTRACT

Quaternary tectonics in Indonesia is conveniently grouped into four types comprising (1) uplift and subsidence, (2) warping and folding, (3) horizontal displacements, and (4) volcanotectonic deformations. Quaternary age of the various deformations is mostly inferred from horizontal to subhorizontal attitudes of strata or erosion surfaces, percentage of living mollusc and/or coral species in fossil assemblages, mammalian fauna, implements, incomplete recrystallization or compaction of sediments, and incomplete devellopment of post Glacial "Daly levels". Radiometric dates for Indonesian Quaternary deposits are rare. Uplift is generally intermittent as is indicated by the presence of multiple coral reef terraces and other types of marine phenomena. The maximum uplift has exceeded 750 meter during the Quaternary. Subsidence implies similar rates of displacement but results in greater depths through absence of denudation. Quaternary folding has raised the land to about 300 meter elevation. Warping has even affected the "stable" regions like e.g. the Sunda Shelf. Horizontal displacements are important along transcurrent faults; e.g. the Lembang Fault near Bandung, Java, displays a mean horizontal shift of 140 m in the last 6,000 years or even shorter. Vertical displacement through volcanotectonic collapse of the volcanoes and resulting folding through gravity tectonics of the bases are common features and has continued into subhistorical time. Contemporary tectonic diastrophism such as uplift and faulting is especially apparent in the Moluccas.

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INTRODUCTION

Since the turn of this century many geologists familiar with the Indonesian Archipelago have compared the island arcs of the area to mountain ranges in **status nascendi.** They have been led to this assumption through numerous manifestations of active tectogenesis, especially in the eastern part of the Archipelago where elevated coral reefs of very young age have been found till hundreds of meters above sea level. Kuenen (1950) listed the following evidences for a youthful age of the East Indonesian configuration.

Many Neogene tectonic structures are cut off by coastlines, while offshore deep basins with steep slopes immediately border the islands. Upper Tertiary strata have been found to break off at the edges of troughs. Facies changes of Tertiary sediments on many islands point to the existence of vast areas of denudation where basins are located at present. In Ceram marine Pliocene sediments were raised till 3000 m above sea level. Upper Pliocene and Pleistocene faults have deformed numerous islands and Plio-Pleistocene coral reefs attain altitudes of several hundreds of meters above sea level. In Timor such reefs have been reported from a height of 1283 m. Furtheron, the positive gravity anomalies over the deep sea-basins imply further subsidence of the Sulawesi (Celebes), Banda, Makassar, Bone, and Tomini depressions.

The present report puts emphasis on Quaternary crustal movements. The older data up to 1949 have been mainly gleaned from publications by Verbeek (1908), Rutten (1927), Van Bemmelen (1949), and Pannekoek 1949). In the present paper specific reference to publications already mentioned in the reference works will only be given if the subject is treated in some detail.

Although our Quaternary tectonic map lists figures in units of meter, yet most values should be regarded as provisional. Determinations of altitudes in E. Indonesia are generally approximations for want of triangulation points (bench marks).

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2) With I plate.

Radiometric age determinations of Quaternary deposits in Indonesia are almost non-existent. Carbon isotopes and K-Ar techniques have been employed to date the alluvial tin placers in Bangka island (Cissarz & Baum, 1960; Gentner & Zähringer, 1960), the Toba ignimbrite and the tectites found at the top of Kabuh (Trinil) bed in Sangiran dome (Ninkovich, personal communication 1969). Paleontological age determinations have been used in the folded Quaternary sediments of the Kendeng and Rembang zones in East Java (Von Koeningswald, 1934). Living coral and/or mollusc percentages in fossil assemblages constitute an other method to date elevated coral reefs and beach sediments, like e.g. in the central zone of Timor (Umbgrove, 1946). Most age determinations are based on stratigraphy, and correlating tectonic events over large distances are not exceptional in Indonesia.

Among the geologists in Indonesia there has been a tendency to assign Quaternary ages to horizontal or slightly tilted reef terraces, erosion surfaces, and raised marine sediments.

A new approach to Recent age determinations uses as base an incomplete development of the so called "Daly levels" on limestone coasts. These "Daly levels" indicate post Glacial strandlines at 0.5 - 1 m, 1.5 - 2 m, and 5 m above the present sea level and respectively they indicate ages of 3,500 yr B.P., 5,000 yr B.P. and 6.000 yr B.P. The strandlines are easily formed on limestone coasts, while a missing "Daly level" very probably indicates tectonic disturbance preventing its formation (Tjia, 1968 a).

Table 1. Quaternary sea levels

S. Australia Tindale, 1947 *)		Bangka & Billiton Tjia, in prep.	
Günz/Mindel	53 – 67 m	50 m	U. Pleistocene
Mindel/Riss	35 – 37 m	30 m	Yarmouth
Riss/Würm	22 m	18 m	± 46,000 yr
Würm Intragl. I	10 m	8 – 10 m	22,000–24,000 yr
Würm Intragl. II	8 m		
Holocene	3.5 m	5, 2 & 1 m	Recent
Present	0 m	– 0 m	Present
		– 7 m	?
	– 20 m	– 18 m	7,500 yr
		– 20 – – 22 m	9,000 yr (?)
		– 29 m	10,000 yr (?)
	– 40 m	– 40 m	
	– 57 m		
	– 67 m		

*) Reported by Fairbridge (1948).

In determining the rates of Quaternary deformations, in particular their vertical components, we should also take into account the varying eustatic sea level stands during this period. Estimates of minimum and maximum Pleistocene sea levels range between 100 - 130 m below (Umbgrove, 1929; Fujii & Fuji, 1967) and 50 m above present sea level (Flint, 1958). Between these two extremes about a dozen Quaternary sea stands have left traces. Table I lists various strandlines from Australia and the tin islands on the Sunda Shelf. The altitude descrepancies between the shorelines in the two areas should be ascribed to their different tectonic histories. The Sunda Shelf area, upon which the Indonesian tin islands are located, has been subjected to some faulting and warping in Quaternary time. Below we will substantiate this statement with examples.

In our map only the ubiquitous "Daly strandlines" were left out. In other words figures indicating subsidence till − 130 m or uplift to + 50 m may very well represent Pleistocene eustatic strandlines rather than tectonically deformed abrasional or depositional surfaces. However, the authors suspect that the majority of these figures still represent the results of Quaternary diastrophisms, particularly for Sulawesi, the Moluccas, and the islands west of Sumatra, where active tectonic movements have been demonstrated to exist until historical time.

TYPES OF QUATERNARY DIASTROPHISMS

In this discussion four types of deformation are distinguished. The classification is based on the predominant tectonic movement.

1. Uplift and Subsidence

Elevated or depressed levels and those displaying slight tilting are included in Deformation Type 1.

Coral reefs and reef terraces are common representatives of young uplift in the Moluccas, north coast of West Irian (New Guinea), Sulawesi, the Lesser Sunda Islands, and the islands west of Sumatra. Plio-Pleistocene reefs were encountered on Mt. Dirun, Timor till 1283 m above sea level, and these rocks also show folding. Uplift in the above mentioned regions has been intermittent as is shown by the presence of multiple terraces. The maximum number of terrace levels is known from Dai Island, west of the Tanimbar islands, and amounts to 15 surfaces reaching a summit of 620 m. Tjia (1965) reported from Nuhuroa Island, Kai Minor archipelago, 10 flat levels in reef limestones with a maximum altitude of only 22 m above sea level. On most islands the higher terraces are generally slightly tilted. Table II compiles the altitudes of reef terraces on three islands where detailed field measurements have been executed.

Age determinations of these reef terraces have been mainly based upon morphologic appearance (horizontal or slightly warped attitudes), incomplete recrystallization of the limestones, and corals or molluscs. Reef

Table 2. Reef terraces in the Moluccas Heights in meters.

AMBON Verbeek (1908) [1]	BINONGKO, Tukang Besi Kuenen (1933) [2]	TOMEA, Tukang Besi Tjia (1965)
300 – 348	210	130 – 124
200 – 240	199	124
185	160	106
165	123	99
150	104	96
77	74	71
63	67	68
52	57	62
38	51	60
	37	53
	14	33
	4	30
		10
		0.5

limestone at 765 m altitude near Niki-Niki, Timor, is of lower Pleistocene age on account of its high percentage of living coral species (79 % according to Umbgrove, 1946). The rate of uplift thus indicated is in the order of 1 mm/yr.

The absence of one or two of the three possible "Daly levels" at elevations of 0.5 – 1 m, 1.5 – 2 m, and 5 m along the limestone coasts of the Tukangbesi islands, S. E. Sulawesi, implies tectonic diastrophism at their respective times of development. The rate of uplift in these islands have been determined in this way to amount to 1 – 2 mm annually during the last 6,000 years.

Raised Quaternary beach or marine deposits have been reported from a few localities. Fennema (1887) found horizontal conglomerate and loose sand banks along Sumatra's western shoreline till 200 m altitude. On the Sunda Shelf, terraces have been mapped at 18 m (Bangka) and at 25 m (S. E. Billiton) by Van Overeem (1960). Pannekoek (1949) described beachridges in southern West Java which have been raised 400 m since the Middle Pleistocene. In the Central Graben of Timor littoral sediments between the Pleistocene reefs are located at heights till 655 m above sea level (De Bruyne, 1941). Beach deposits associated with some young coral reefs have been mentioned from 32 m elevation northeast of Amurang, North Sulawesi. On Buru Island Plio-Pleistocene conglomerates of Fogi have been raised and tilted.

Farther inland high stream terraces represent important vertical movements. Verstappen (1961) reported that the Toba Lake terraces,

1) Altitudes read off geological map.
2) Altitudes read off correlation diagram, traverse 3.

North Sumatra, have been raised 110 meter after their formations. Marine Quaternary sediments in Deli, Sumatra's East Coast, reach 60 m above sea level (Fennema, 1887). Level stream terraces till 65 m above the present streams occur in the northern folded zone of West and Central Java, e.g. near Subang (Tjia, 1964/65). The Solo River gap through the Kendeng Hills in East Java, has terraces at 32 m above the river. Holocene terraces in the Kutei area, East Kalimantan (Borneo) are at 80 – 90 m, 40 – 50 m, 25 m, 10 – 12 m, and 1 m altitudes (De Sitter, 1948). Intermittent uplift is also suggested by three stream terraces at 250 m, 125 m, and 50 m above present streams in the Patjitan area, East Java and are dated to have started in Middle Pleistocene (Pannekoek, 1949).

Bathymetric contours indicate a number of faults or flexures with important vertical displacements. These faults are probably of Quarternary age, for their effects on land are recorded as such. Offshore faults are shown on the map for Java and Salajar and Sula Islands. On land the Central Graben of Timor and that through Ceram also indicate vertical movements through faulting. Further on the northern boundary of Java's Southern Mountains is probably marked by a normal fault depressing the northern block. A throw of at least 650 m crops out at the western end of this fault.

The eastern segment of the Lembang Fault, north of Bandung, has vertical components ranging between 130 to 450 m. According to van Bemmelen (1934) the Lembang Fault is Late Pleistocene – Holocene.

In the Bird's Head, West Irian, the Ransiki fault zone has caused vertical displacements of stream terraces (d'Audretsch, 1966).

Subsidence has attained its greatest depths in East Indonesia. In our introductory paragraph the young age of the East Indonesian sea basins and troughs has already been discussed. The subsidence has probably started in the Upper Neogene time, but continued downward movements are implied by active uplifts in the land areas bordering these depressions. On the map only those sea basins and troughs are depicted for which Pleistocene subsidences were mentioned in the older literature. Newer information comes from geomorphologic work by Verstappen (1960).

In the Ceram Sea drowned reefs were sampled from depths of 1304 – 1633 m over a distance of 3 miles (Umbgrove, 1947). The same author inferred that the Togian islands in the Bay of Gorontalo have very recently subsided 40 meters for want of "Daly terraces". Umbgrove (1947) also assumed the Tiger or Taka Garlarang atoll-group in the northern Flores Sea to have sunk in Pleistocene time and estimated a 2 mm/yr rate of subsidence.

Off Bengkulu, Sumatra, a submarine plateau at –54 m was interpreted as a result of subsidence in Quaternary time (Van Es, 1916). This supposition appears to be corroborated by the presence of coastal terraces till 45 m height onshore.

Local subsidence in the southern structural zone of Java caused the present Baturetno Basin. A prominent dry valley south of the basin and trending towards the Indian Ocean indicates a drainage reversal through the development of the basin during presumably upper Pleistocene or even younger time (Pannekoek, 1949). Fresh-looking lagoonal deposits in the Brantas Delta, East Java, are now at a depth of –108 m.

2. Warping and folding

In the Tertiary oil basins of eastern Sumatra, northern Java and Madura, East and Southeast Kalimantan, Pliocene and Pleistocene sediments have been folded and faulted since the Lower Pleistocene. Even on the Sunda Shelf proper, earlier considered to have been stable since the Tertiary, warping is indicated in the Kapuas Lake area and in Bangka. The latter island has lower to middle Pleistocene sediments at 18 m altitude at one locality while elsewhere they are not higher than 4 – 5 m above sea level (Osberger, 1965). Young, normal faults with throws up to 6 m have been recognized in a number of places on Bangka. These faults cut through bedrock as well as alluvial tin placers, which have been radiometrically dated to be at the most lower Pleistocene in age. Near Dobo town on the Aru islands, East Indonesia, a very recent reverse fault with a throw of 1 m was mapped in limestones (Tjia, 1968 a).

In South Sulawesi Quaternary sediments have been folded into an anticline and are now at elevations ranging from 60 m to 130 m (Sunartadirdja, 1959).

Erosion surfaces in the Kendeng and Rembang hills of East Java were warped during the Middle to Upper Pleistocene, respectively raised to 150 – 250 m and 150 – 300 m.

Plio-Pleistocene deposits in the Central Graben of Timor are folded and faulted (De Bruyne, 1941). In a comparable graben in eastern Ceram Plio-Pleistocene Tufa Beds are gently warped.

Warping of river terraces are reported from the Bird's Head in West Irian (d'Audretsch, 1966).

3. Horizontal displacements

The large Semangko fault zone through the entire length of Sumatra has been established to possess important horizontal displacements. Katili and Hehuwat (1967) deduced that the measurable horizontal, dextral shift amounting to 20 – 25 km could have very well started in the Lower Pleistocene if the deformation rate equals that of the San Andreas Fault (5 – 7 mm/yr). Recent horizontal displacements of about 1.25 m are known from triangulation measurements before and after the Tapanuli earthquake in 1892.

In the last 6000 – 3000 years (dated by van Bemmelen, 1934) the western segment of the Lembang Fault north of Bandung, Java, was displaced in sinistral sense at a rate exceeding 30 mm/yr (Tjia, 1968 b).

In the Bird's Head, Irian, the important Sorong fault is reported to have Quarternary transcurrent movements and it dislocates Plio-Pleistocene Befoor Formation (Visser and Hermes, 1962).

The Fossa Sarasina in Central Celebes and the Gorontalo faultzone in North Celebes are postulated by Katili (in press) to be respectively sinistral and dextral transcurrent faults. Their relatively young age is proved by the presence of stream-offsets, dislocations of alluvial fans and present earthquakes along the fault-zone.

4. Volcano-tectonic deformations

Quaternary tectono-volcanic collapses of gigantic dimentions were assumed by van Bemmelen (1949) for the famous Toba Lake depression in North Sumatra and some other lakes in the Barisan Range of Sumatra. These collapses are characteristically accompanied by ignimbrites. The volcano-tectonic collapse of the Tengger caldera, East Java, and those on Sumatra appear to have resulted in vertical displacements only.

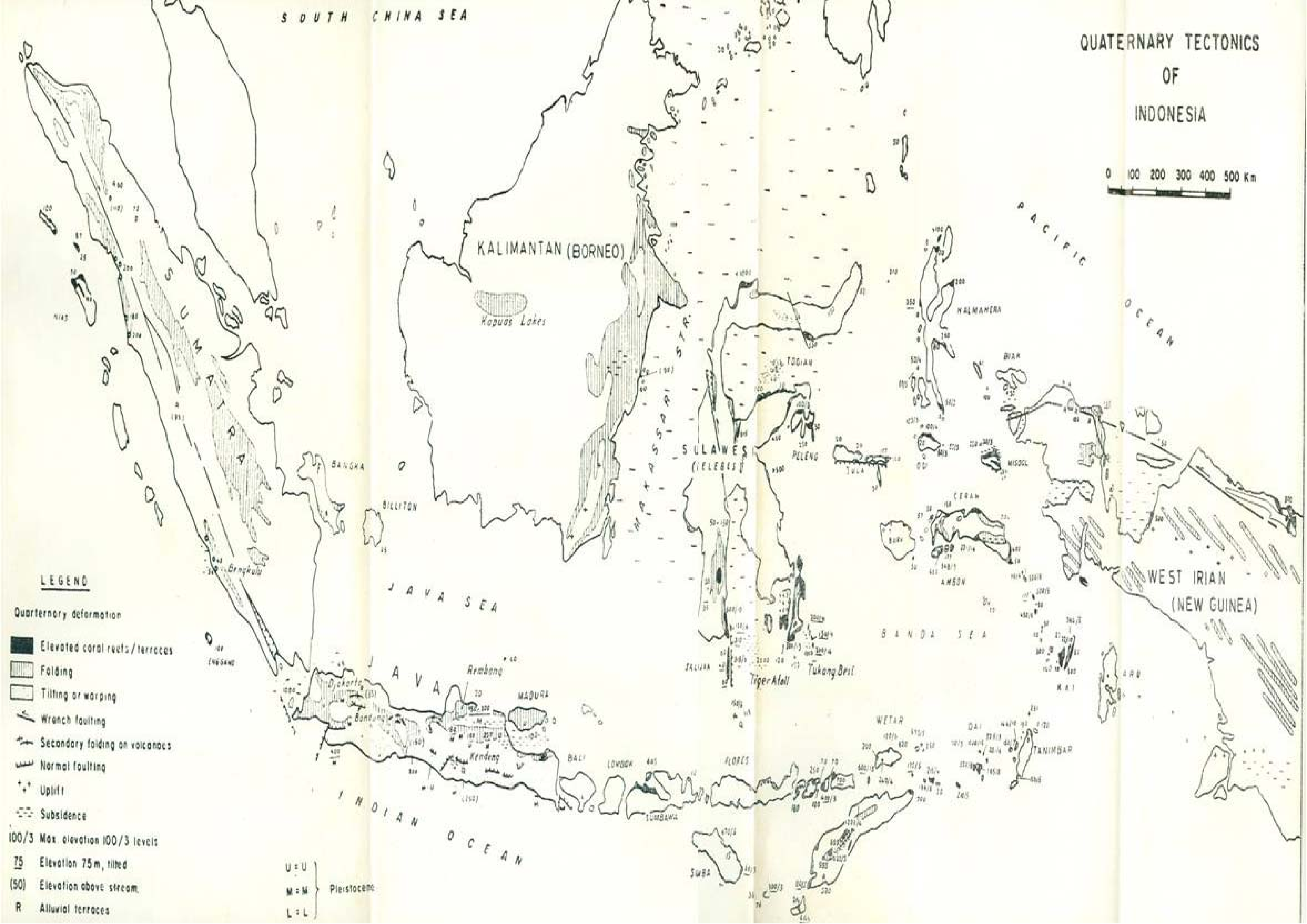
Recent uplift is demonstrated on some active volcanoes. Hartmann (1935) reported that the base of the Lewotolo volcano was raised 9 m; on the Labalekang volcano the elevation amounts to 7 – 12 m, while the base of the old Lerek volcano shows uplift of respectively 60 – 80 m and 5 – 7 m. The above mentioned volcanoes are located on Lomblen Island, Solor Archipelago.

Deep-reaching slumps on tall volcanic bodies result in warping or folding of the sediment at the volcanic foot. Many examples have been published by van Bemmelen from Java (1934, 1949). These folded volcanic bases have typically arcuate plans, bulging convexly away from the volcano. Pleistocene and younger fauna in the folded sediments indicate the youth of the deformations, like e.g. the Tambakan Anticline at the north foot of volcanic bodies near Bandung, Java.

Care should be exercised in considering all these structures to be caused by slumping of volcanic bodies. Most of the Quarternary structures interpreted as such show a pattern similar to the regional strike of the Quarternary folded zones.

DENUDATION VERSUS POSITIVE DIASTROPHIC DISPLACEMENTS

Rutten (1917, 1927, 1938) showed that denudation rates in an oro- or epirogenetically tropical landscape like Java generally exceed rates of downcutting in Western Europe or North America. Active uplift and fresh pyroclastics provide the relief while the volcanic material also contributes to the amount of easily transportable matter. In Java denudation rates of 1 mm/yr are common and in a number of cases the annual denudation amounts to 5 mm. Therefore, the sub-aerial relief in the Indonesian islands caused by Quarternary tectogenesis would be two to at least five times as pronounced without the high rates of down wearing.


QUATERNARY TECTONICS
OF
INDONESIA
0 100 200 300 400 500 Km
SOUTH CHINA SEA
PACIFIC OCEAN
KALIMANTAN (BORNEO)
Kapuas Lakes
SUMATRA
Bengkulu
NIAS
ENGGANO
BANGKA
BILLITON
JAVA SEA
JAVA
Djakarta
Bandung
Rembang
Kendeng
MADURA
BALI
LOMBOK
SUMBAWA
FLORES
SUMBA
INDIAN OCEAN
MAKASSAR STR.
SULAWESI (CELEBES)
SALIJAR
Tiger Atoll
Tukang Besi
TOGIAN
PELENG
SULA
BURU
CERAM
AMBON
BANDA SEA
WETAR
DAI
TANIMBAR
KAI
ARU
HALMAHERA
BIAK
MISOOL
WEST IRIAN
(NEW GUINEA)
LEGEND
Quarternary deformation
Elevated coral reefs / terraces
Folding
Tilting or warping
Wrench faulting
Secondary folding on volcanoes
Normal faulting
Uplift
Subsidence
100/3 Max. elevation 100/3 levels
75 Elevation 75 m, tilted
(50) Elevation above stream
R Alluvial terraces
U = U
M = M
L = L
Pleistocene

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