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POSSIBILITIES FOR URANIUM IN INDONESIA

By

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I. INTRODUCTION

Since the bibliographic report on the East Indies by W. G. Valentine, prepared during 1946, the published literature on geology and mineral resources of that region has expanded greatly. For Indonesia (formerly Netherlands East Indies) we have a monumental two-volume work by van Bremmelen (1949); for the British territories in Borneo, there is an excellent report (1951) by Reinhard and Wenk on North Borneo, followed by Annual Reports of the Geological Survey of the British Territories, including Sarawak and Brunei. Many other shorter but equally authoritative contributions to the subject, especially notably those by J. Westerveld, have also appeared.

In 1946, we had not yet become aware of the relative importance of metallic ore deposits (of particular types) as potential sources of uranium, nor of the comparative unimportance of thorium. Neither had we realized the significance of certain geological conditions or mineral associations as affecting the presence of uranium even in a deposit not profitably workable for some other metal. For these reasons, this present report will concentrate on favorable types of metallic lode mineralization, on the proximity of the acidic types of igneous intrusives, and on exposed areas of continentally deposited sedimentary rocks such as might conceivably carry uranium ores of the sandstone type.

To avoid voluminous data having little or no direct bearing on our problem, we shall confine attention to the six major land masses of the East Indies - Sumatra with adjacent Singkep, Bangka, and Billiton; Java with Madura; Borneo; Celebes; Timor; and New Guinea. Respecting ore deposits and features thought favorable for the possible occurrence of uranium, we shall further limit our observations exclusively to territories now belonging to Indonesia.

II. SUMMARY AND RECOMMENDATIONS

1. We have found no published, authenticated record of a deposit in Indonesia known to carry uranium. Monazite, a fairly abundant accessory in some of the productive tin gravels of Bangka, Billiton, and Singkep, offers possibilities, but we have found no data as to its uranium content.

2. Indonesian geology, however, displays several features which, elsewhere, have proved favorable for mineralization by uranium. These features include: (a) numerous and large intrusions by highly siliceous and radioactive granites; (b) many hydrothermally mineralized lodes or zones traceable to those granites or to other almost equally siliceous igneous intrusives; (c) lodes, often with propyllitized walls, carrying an assemblage of metallic and gangue minerals indicative of deposition at medium to low temperatures; (d) sulphides of copper and silver, together with pyrite, as among the most common ore minerals, and quartz as always present in the gangue of these hydrothermal lodes; (e) wide areas of continental and probably fluviatile sandstones, sometimes enclosing fossil vegetation; also of shallow marine sediments deposited under flysch conditions; (f) sedimentary series with interbeds of andesitic or rhyolitic tuffs. Both of these last two conditions of sedimentation have, elsewhere, proved conducive to the deposition of disseminated and other types of uranium minerals.

For convenience in exploration, the areas that seem most deserving a radiometric survey will be grouped on a geographical rather than a geological basis. Explanatory details appear in the text.

3. <u>Sumatra</u>.

(a) Lebong district (S. 3-02; E. 101-56) in northern Benkulen Residency. Several old mines, formerly large producers of gold-silver ores, of which the dumps should be examined. Also many veins partly explored but not exploited. Same conditions at Salida in the same general region.

(b) Mangani district (S. 0-09; E. 100-16), about 10 miles north of Lake Manindjau, southern Tapanuli Residency. Several fairly recent (since 1940) and some older large workings for gold-silver ores in veins. The Lower Tertiary "Brani conglomerate" exposed in this area (widely exposed elsewhere but differently named) is part of a typical terrestrial sequence.

(c) Gunung Arum mine, near Painan (S. 1-21; E. 100-35) on west coast, 30 miles south of Padang. Two main veins of gold-quartz with sulphides; one exhausted in 1940.

(d) Muara Sipongi, one of a compact group of copper-gold-silver mines centering at about N. 0-45, E. 99-45, in southern Tapanuli, near Panjabungan, which is on a main highway at 45 miles northeast of Natal on the west coast. Most of the deposits are tactites at contacts with granite or granodiorite, but the one at Muara Sipongi (like probably others) shows subsequent hydrothermal activity, affecting also the adjacent country rocks.

(e) Lake Singkarak (S. 0-40; E. 100-30) region of northern Benkulen, including the Sibumbun Mountains just east of the lake. Several deposits of copper ores derived from granites. Most of these are tactites, but strong veins occur in many places, especially in Piesala basin on the north edge of the field.

(f) Balung mines (approx. N. 0-10; E. 100-50), east of Baru town. Six deposits of lead-zinc-silver ores have been explored out of 11 known. Both tactites in sedimentaries and veins in pre-Tertiary schists are represented.

(g) Padang highlands, to east and northeast of that coastal city (S. 0-58; E. 100-22). Lower Tertiary formations exposed in this area, and on the east flanks of Barisan Mountains, include many sandstones and marls typical of fluviatile, lacustrine, and lagunal deposition. Similar deposits are well exposed to northeast of Pajakumbuh (S. 0-14; E. 100-38), in Limau Mountains (approx. S. 1-00; E. 102-30) of northwest Djambi district, around the Mangani mining district (as above noted), and, with special significance, in the drainage area of upper Kampar River (approx. N. 0-05; E. 100-30).

(h) Southern Barisan Mountains, in Benkulen, Palembang, and Lampong districts. Upper Tertiary formations in this region include measures characteristic of both terrestrial and shallow marine deposition. Their most significant feature is the abundance of interbedded andesitic, dacitic, and rhyolitic tuffs, breccias, and flows. A few definite localities are named: Baturadja (S. 4-07; E. 104-10); Gumai Mountains (S. 3-50; E. 103-00) 20 miles west of Lahat; small basins in headwater regions of Sekampung and Seputih Rivers (approx. S. 5-10; E. 104-30); Semangka Mountains (center at S. 5-30; E. 104-25); Muara Enim (approx. S. 4-20; E. 103-30).

4. Borneo.

(a) Bajang Mountains (N. 1-00; E. 109-50), 75 miles northeast of Pontianak seaport. A much mineralized area of quartz veins (some gold-bearing) and pegmatite dikes unusually rich in orthite.

(b) Matan district, southwest Borneo, eastward of seaport Matan (or Ketapang, S. 1-50; E. 109-59). Wide areas of granitic intrusives, some phases of which are highly radioactive. Two most notable localities: Mt. Loempoeng (possibly Mt. Raja) south of Mahawa village (S. 1-55; E. 110-40) which is on a road 30 miles south of Nangatajap; a point on Pawan River 10 miles below its confluence with Laoer River, or 12 miles WNW. of Nangatajap (S. 1-31; E. 110-36). This latter rock is a riebeckite-granite, exceptionally high in total radioactivity, some of which is probably due to thorium.

(c) Headwater region of Kapuas River (approx. N. 0-30; E. 113-30) on west slopes of Muller Mountains. Wide exposures of Upper Triassic formations, distinctly continental, include conglomerates, sandstones, and shales (but no limestone) with interbedded flows and tuffs acidic to medium in composition. Another long lenticular area of the same type lies along the Sarawak border, north of the Kapuas.

(d) "Lake district" of central Borneo. This region, lying to west and north of the Muller and Schwaner ranges, but also extending westward to the coast at Sambas, Singkawang, and Mampawah, exposes wide areas of Lower Tertiary formations in several facies. Among these, the "continental volcanic series" forms a belt extending westerly from Muller Mountains at headwaters of Kerijau River (approx. N. 0-30; E. 113-30) to the southern border of the lake district north of Semitau (N. 0-32; E. 111-58). Above a basal conglomerate, the series includes cross-bedded sandstones, shales, thin coals, and "combustible" shales. Uppermost measures are volcanic tuffs and flows ranging in acidity up to dacitic.

5. Java.

(a) Bajah area, within a radius of 12 miles northerly from this seaport (S. 6-55; E. 106-15) on the south coast near the extreme west end of the island. Several mines have worked quartz-carbonate veins in propyllitized wall rocks, carrying silver-gold with chalcopyrite and other sulphides.

(b) Tjikondang River basin, about 6 miles SSW. of Tjibeber (S. 6-57; E. 107-08). Many quartz veins (some productive) carrying gold-silver with chalcopyrite and other sulphides.

(c) Subang mountain (S. 6-35; E. 107-00), 15 miles east of Buitenzorg. Just north of the mountain, a propyllitized area has two intersecting systems of quartz veinlets, both carrying gold-silver; in one, the sulphide is mainly marcasite; the other has sphalerite, galena, pyrite, and tetrahedrite.

(d) Sawal mountain (S. 7-10; E. 108-20), 6 miles north of Tasikmalaja railway station. At a short distance to SSW. of this mountain, a small area of hydrothermally altered andesite is traversed by narrow quartz veins, between kaolinized walls, carrying argentiferous galena and other sulphides, including tennantite and polybasite.

(e) Sundry base-metal sulphide ore deposits. These are all much alike - quartz veins traversing propyllitized andesite or dacite, and carrying variable proportions of sulphides, along which chalcopyrite is almost always present. Named localities: Djampang, 9 miles south of Pasawahan (S. 7-08; E. 106-37). Dawuhan, just southeast of Tirtamaja (S. 7-57; E. 111-03). Kedungpring, west of Dawuhan and south of Tirtamaja. Mt. Domasan, just southeast of Slaung (S. 8-02; E. 111-25). South Bantam area, centering at about (S. 6-45; E. 106-20). An area northwest of Pasawahan, mentioned above. Tjikarang River area (approx. S. 7-15; E. 107-00). Karangnunggal area (approx. S. 7-30; E. 108-00). Mt. Parang area (S. 6-36; E. 107-21) 6 miles WSW. of Purwakarta. Tegalredjo (approx. S. 8-00; E. 111-25) 12 miles S. of Panaraga.

6. Celebes.

(a) Western Celebes (in strong contrast with eastern) is an intensely mineralized region, due to emanations from numerous intrusions of granite and granodiorite. The granites are of high-alkali and siliceous types, and orthite is a characteristic accessory.

(b) The long, narrow, northeast peninsula has the same structure as the western island. Typical late-Tertiary epithermal quartz-carbonate veins carrying the usual mixed sulphides (including chalcopyrite) have been worked for their gold-silver content at a few places:

Paleleh Bay (N. 1-00; E. 121-55) and vicinity, on north coast;
Cape Sumalata (N. 1-00; E. 122-30) and vicinity;
Totok (N. 0-50; E. 124-43) area, on south coast near outer end.

7. Bangka and Billiton.

(a) These two islands, identical in structure, are chiefly notable for their numerous and large intrusions of highly siliceous and radioactive granites. Their accessory minerals include cassiterite, monazite, zircon, apatite, titanite, fluorite, tourmaline, and a notable proportion of rare-earth minerals. In the Djebus district of northern Bangka (S. 1-45; E. 105-27) the granite is rich in orthite. These granites are further described (with localities) in Sec. VI.

(b) Monazite and xenotime are frequent (sometimes abundant) companions of cassiterite in the eluvial and alluvial deposits, derived from the granites, worked for tin on Bangka, Billiton, and especially nearby Singkep of Lingga Archipelago. Such deposits afford the only proved sources of fissionable materials now known in Indonesia.

8. Riouw-Lingga Archipelagoes.

A few small exposures of Lower-Tertiary formations occur along the southwest coast of Bintan (N. 1-00; E. 104-30). As these probably derived most of their substance from the highly radioactive Jurassic granites of the region, there is a possibility that they may contain uraniferous minerals of sandstone type.

III. POLITICAL GEOGRAPHY AND ECONOMICS

Of the East Indies as a whole, by far the largest and most thickly populated parts are now combined in the United States of Indonesia, an independent Republic (since Dec. 28, 1949). Indonesia has held membership in United Nations since Sept. 28, 1950. Jakarta (formerly Batavia) is the capital of the country.

Indonesia comprises ten Provinces (1); Plate I:

Djawa Timur - East Java and Madura;

Djawa Tengah - Central Java, including Jogjakarta, having the status of Province:

Djawa Barat - West Java, including Jakarta with status of a Province;

Sumatera Utara - North Sumatra;

Sumatera Tengah - Central Sumatra, including Riouw, and Lingga Archipelagoes;

Sumatera Selatan - South Sumatra, including Bangka and Billiton Islands;

Kalimantan - Borneo, excluding British territory;

Sulawesi - Celebes;

Maluku - the Moluccas (Halmahera, Ceram, Buru, etc.);

Nusa Tenggara (previously Sunda Ketjil) - the Lesser Sundas (Bali, Sumbawa, Flores, Sumba, Lombok, and the western half of Timor).

The East Indian Islands also include several important areas outside the United States of Indonesia, namely:

Western half of New Guinea, a colony of the Netherlands;

Eastern half of New Guinea, consisting of Australian Papua on the south side, and Northeast New Guinea on the north side, an Australian protectorate.

On Borneo, the whole north and northwest quarters are occupied by British colonies, North Borneo, Brunei, and Sarawak.

Eastern half of Timor, and the small Ocussi enclave on the northwest coast, remain colonies of Portugal.

Areas and densities of population of the larger islands (calculated from data in Ref. 2) follow:

	Sq. Miles	Pop. Sq. Mi.
Sumatra	163,557	73.4
Java	48,842	814.0
Borneo	286,969	10.7
Indonesian	208,285	10.4
British North Borneo	29,387	11.3
Sarawak	47,071	11.6
Brunei	2,226	18.3
Celebes	69,277	54.6
New Guinea (approx.)	343,000	5.2
Dutch (west of 141° E.)	159,375	2.2
Northeast Territory	93,000	11.6
Papua	90,540	4.1
Timor	13,148	61.2
Indonesian	5,765	60.7
Portuguese	7,383	59.3
Madura	1,762	1054.6
Bangka	4,611	44.5
Billiton	1,866	39.3
Bali and Lombok	-	454.0

Of a total (1952) estimated population of 78.9 million, about 145,000 (in 1952) were Dutch citizens (1).

Java has an excellent system of railways, totaling (in 1955) 3000 miles; it includes two main longitudinal lines, along north and south coasts, connecting by a network across the interior. Both lines connect, by ferry, with the southern point of Sumatra, whence a rail line runs north to Palembang. A separate line in northern Sumatra follows the east coast as far south as Rantauparapat. Madura has a railway line along the south coast for the whole length of the island.

Facilities for air transport are developing rapidly; Jakarta is a regular stop on routes between Europe and Australia. Local service to Singapore or Manila and elsewhere is provided by Garuda Indonesian Airways and the Pioneer Aviation Co.

Most of the larger islands are well provided with roads. In 1940, there were 16,850 miles on Java and Madura, 15,800 on Sumatra, 2,250 on Borneo, 5,090 on Celebes, 1,250 on Bali and Lombok, 2,100 on Timor, and 250 miles on the Molucca Islands (1). In 1954, the total for the country was 30,646 miles, of which 9,602 miles were on Java.

Tropical vegetable, fibre, and forest products are the mainstay of the islands. British, Dutch, and American oil companies produce petroleum on Sumatra, Java, and Borneo. The pre-war annual output of nearly 8,000,000 metric tons was seriously diminished during the war, but has now revived nearly to normal. The chief oilfields are Palembang on Sumatra, Surabaya on Java, Tarakan, Balikpapan, and Bandjermasin in Dutch Borneo, Miri in Sarawak, and Seria in Brunei. Bauxite is an important product in Sarawak. Tin ores similar to the Malayan are produced, at annual rate of 30,000 - 35,000 metric tons, by Government mines on Bangka, Government and private mines on Billiton, and private mines alone on Riouw and Sumatra.

Since 1948, Indonesia's exports have equalled or exceeded imports, in value.

Indonesia's monetary unit is the <u>rupiah</u> (Rp.) divided into 100 <u>sen</u>. Exchange rates established in 1952 were 31.92 Rp. to the Pound, 11.40 Rp. to U. S. Dollar, 3.00 Rp. to the Dutch Florin. Currency consists of banknotes for 1, 2½, 5, 10, 25, 50, 100 Rp., and aluminum coins of 1, 5, 10, 25, 50 sen. The former gold, silver, and nickel coins have not been legal tender since Nov. 2, 1951.

Metric system has been official since Jan. 1, 1938. Some of the old units still in use are:

Picul, 136.16 lb. Av.; 61.76 kg.
Katti, 1.36 lb. Av.; 0.617 kg.
Bouw, 1.7536 acre
Tjengkal, 4 yards
Paal (Java), 1506 meters
Paal (Sumatra), 1852 meters
Square paal (Java), 226.8 hectares; 560.93 acres.

IV. PHYSICAL GEOGRAPHY AND CLIMATE
(2, 3)

All of the larger East Indian islands are distinctly mountainous. The ranges, of various types and origins, form an interrupted chain from the northwest end of Sumatra to the southeast end of New Guinea, reaching their highest elevations - over 15,000 ft. - on the latter island. The most expansive areas of low lands are on east-central and southern Sumatra, southern and northwestern Borneo, and southern New Guinea, the three largest islands of the group. Most of the smaller islands are hilly, if not mountainous. Mountain slopes are usually forested with valuable and exotic varieties of timber.

Sumatra is 1110 miles long and averages 280 miles wide; the equator crosses near the middle and widest part. Close to its western ("outer") side, the Barisan Range, including 25 volcanic peaks, some of which rise to over 10,000 ft., traverses the whole length of the island. The north end of the island is a lava plateau, at 6000-7000 ft. Here, Lake Toba (Danau Toba on Plate I), largest on the island, occupies a graben. In the same region, several smaller lakes lie in calderas, or behind lava dams. Just off the southeast end of the island, the explosive volcano Krakatao stands at about the middle of Sunda Strait, which separates Sumatra from Java. Nearly the whole eastern ("inner") two-thirds of Sumatra forms a flat, often marshy plain, traversed easterly by the only large rivers on the island - Asahan, Rokan, Kampar, Indragiri, Hari, Musi, etc. - all of which rise in the Barisan Mountains, often within a few miles of the west coast. Several of these rivers are navigable for a long distance inland, and some of the principal commercial cities are situated at the heads of navigation instead of on the coast. The climate of Sumatra, except in the mountains, is hot and humid. Rains occur at all seasons, and are heaviest on the west coast. Much of the interior of the island is thick forest.

Bangka Island, just off the southeast coast of Sumatra, is about 140 miles long and 70 miles wide. It consists mostly of low granite hills, with some marshy land along its west coast, facing a great area of similar low ground on Sumatra. Billiton Island, nearly a square with 50-mile sides, lies 45 miles east of the south end of Bangka. It has some low granite hills on the western side, remainder flat.

Java, about 650 miles long by 40-130 miles wide, is conspicuously mountainous, with only a narrow strip of low land along its north coast, widest at the two ends. The mountain chain stretches from end to end of the island, with a few narrow defiles which permit transport communication between north and south sides. Of the more than 100 volcanic peaks (some still active), 20 rise above 8000 ft., and a few reach 10,000 ft. elevation. Due to recent uplifts, the south coast is rugged, contrasting with the low, shelving north coast. Java gets heavy rains during the November-March monsoon, but is comparatively dry the rest of the year.

Madura Island, about 100 by 25 miles, is actually an eastward extension of Java's northeast coastal plain, separated by Soerabaja (Surabaja on Plate I) by only 2 miles of salt water. It is mainly a level plain with a few hills in the middle. It is a thickly populated agricultural district, but some of its chalky soil lacks fertility, and rain is sometimes inadequate.

Borneo is divided by a range of mountains, which runs from the southwest to the northeast corner of the island, into two unequal parts which differ in most of their features. The northwest portion, about one-third of the island, occupied by British colonies - North Borneo, Brunei, and Sarawak - is mostly low plains; the southeastern, Indonesian, larger portion is more mountainous, especially in its western part where elevations rise to 13,000 ft., but it likewise includes large areas of low and marshy ground on the south where drowned rivers give access far inland. Interior Borneo is densely forested. Annual rainfall varies from 60-180 in. in the north, to 200 in. in the interior, heaviest during the long northeast monsoon, October to March.

Celebes is almost entirely mountainous in all of its gangling peninsulas. Narrow low coastal belts occur in some places, especially at the heads of some of the deeply indenting gulfs. The region is strongly and intricately fractured, giving rise to deep river gorges, and to vulcanism lasting to the present time. Interior of the island is densely wooded; fertile valleys and rich grazing areas also exist. The northeast monsoon brings 102-157 in. of rain.

Timor Island is 300 miles long, at a width varying from 10 to 60 miles. It is almost entirely mountainous, reaching 9,678 ft. on Mt. Ramelau in the interior, but has no volcanoes. Raised coral reefs are a prominent feature of Timor. Rainfall is only moderate, 58 in., mainly during January to March.

New Guinea, second only to Greenland in size, is largely unexplored tropical jungle. Its most prominent feature is an almost continuous broad belt of high mountain ranges, often over 15,000 ft. (16,400 ft. on Mt. Carstensz in the Nassau Range), which extends the full length of the island from northwest to extreme southeast; nearly 1,500 miles. Individual ranges are separated at many places by broad upland valleys, the sources of several large rivers. Foothill zones are usually present on both sides, but are almost lacking with some of the eastern ranges. The three largest rivers have sources close together in mountains near the center of the island. Two flow north - Idenburg, wholly within the Dutch area, and Sepik, mainly in Northeast Territory—while one - Fly, with its large Strickland tributary - flows south, almost all in Papua. A large area of lowland in south-central New Guinea consists mainly of swamps and lagoons along the coast, but inland it slopes gently upward towards the highlands to 300-500 ft., forming a dissected plateau. Rainfall is abundant throughout most of the island, heaviest during the northwest monsoon of October to March.

V. GENERAL GEOLOGY

Structure

This intensely disturbed part of the world owes its structure largely to its having been situated between two massive resistant bodies: Southeast Asia on the north, with its southerly spreading Sunda Shelf, and Australia on the southeast, with its northward Sahul Shelf. Some of the East Indian islands rest on one or the other of these shelves, others lie between them, and one--New Guinea--remains structurally a part of the Australian continent. Present shorelines of the islands result mainly from a general rise of ocean level during the melting of the polar ice caps. Some coasts are still in process of adjustment. Vulcanism, locally still active, contributed largely to the structure of many (but not all) of the islands.

Referring to Lobeck's map (3), Plate II, the inner belt (of massives) consists of detached pieces of the Asiatic continent; usually composed of old granite or complex blocks with rugged topography, as resistant masses either buried under alluvial plains, or entirely submerged.

On inner Sumatra, the low marshy plain is a part of a long trench of down-dropped resistant rocks, covered by Tertiary or Recent deposits, or submerged. Eastward, this unyielding block is represented by the Sunda shelf, under the shallow Java Sea, and by the plains of central Borneo.

Sunda shelf is the submerged part of a platform comprising inner Sumatra, northern Java, and eastern Borneo. Its depth varies only slightly between 120 and 140 feet. Before being inundated, it was a peneplane with occasional monadnocks, now islands such as Bangka and Billiton. These are a continuation of the Paleozoic formations on southern Malaya, with their granite intrusions.

Western Borneo is a stable massive traversed diagonally northeastward by a high mountain range, to south of which is a wide granite upland. Much of western and central Borneo is a high sandstone plateau. Northern Borneo has a narrow coastal plain, bounded on the south by an abruptly rising range of granite mountains.

Outer belt (of folding) contains mainly Tertiary beds and volcanic materials, much of the latter from submerged eruptions.

Outer Sunda folded belt swings an arc from Andaman Islands on northwest, through the Nicobar and Mentawei groups, thence eastward to include Soemba and Timor, then by a sharp bend to north to Ceram and Boeroe. There are no volcanoes in this belt of upwarped Tertiary beds, but some intrusive granites. Elevated coral reefs are characteristic.

Sumatra Volcanic chain, the Barisan Range, stretching from end to end of the island, includes 25 volcanic peaks. At its north end is a block-faulted lava plateau.

Java Volcanic chain, of more than 100 high peaks, surmounts an arch of Tertiary rocks. The southern coast is rugged, emerging from deep water, but the flat north shore slopes gently to merge with the Sunda shelf.

Lesser Sunda Volcanic chain forms the islands Bali, Lombok, Soembawa, and Flores, all strongly fractured; most of the coastlines of these islands are bounded by fractures.

Celebes-Halmahera volcanic chain. Most of the volcanoes in this region are situated at the end of the long northeastern arm of Celebes, and on small islands off the west coast of main Halmahera. On Celebes, each of the four prominent peninsulas has an anticlinal axis, radiating from a central nucleus. Its structure was intensely and intricately fissured (at two tectonic epochs), accounting for the narrow, often rectilinear, outline of its inlets.

Eastern Borneo is a broad plain of Tertiary formations, warped (especially along the eastern margin) into low anticlines and domes, yielding petroleum in several areas; also some coal. Major foldings occurred at three epochs--in the Mesozoic era, and in the Tertiary Miocene and Pliocene periods. Plate III, a map compiled from several sources by W. G. Valentine (4), traces the axes of the most prominent folds produced at each of these convulsions. Only the latest of these orogenies affected all of the larger islands. Thus, no evidence of Mesozoic folding has been found on Java, the Lesser Sundas, or New Guinea. Miocene folds appear to be absent on Sumatra, Borneo, and New Guinea, but are prominent on Madura, Lesser Sundas to as far east as Sumbawa, on Soemba and Timor, and especially on Celebes, where axes of Miocene folds interect those of the older ones at nearly right angles. Some volcanic activity accompanied both of the older foldings, but the recently active volcanoes are obviously related to the axes of the Pliocene folds; only on Borneo and New Guinea did this orogeny fail to develop vulcanism.

Crystalline Basement

In many (but not all) parts of the East Indies, the base of the sedimentary sequence rests on a metamorphic complex consisting mainly of crystalline schists with occasional gneisses. Such rocks occur usually as comparatively small patches or in narrow bodies, often forming the axes of high mountain ranges, but rarely in widely expanded masses such as would commonly be accepted as proof of antiquity or fundamental character. Their age has been much disputed, probably because it differs from place to place. According to van Bemmelen (5), they definitely do not belong to any distinct geological epoch, nor are they Archean, as previously supposed. They can not even be proved pre-Cambrian, since no Cambrian formation has yet been identified in the East Indies. In some areas, the schists show transitions into dateable fossiliferous strata; in others, only an upper limit can be fixed by reference to the proveable age of the oldest overlying measures. As to the probable ages of the schists in several regions, van Bemmelen offers the following conclusions.

On Sumatra, the schists are probably parts of a pre-Mesozoic basement complex; but even the overlying Mesozoic sediments often show phyllitic phases.

On the smaller islands of the Sunda Shelf, schists and phyllites are generally late Paleozoic or Upper Triassic.

In western and central Borneo, crystalline schists are older than Upper Triassic, some older than Permo-Carboniferous, but even Eocene, in some places, has phyllitic phases. Schists and gneisses in the Schwaner Mountains of central Borneo are considered older than Permo-Carboniferous. In the Meratus Mountains of southeast Borneo, schists are older than the Alino (probably Jurassic) formation.

On Celebes, schists are older than Mesozoic or late Paleozoic; but some phyllites are Mesozoic and Eocene.

Among the northern Moluccas, isolated outcrops of crystalline schists, possibly Paleozoic, occur on Obi and Batjan; on Sula Islands, the schists are pre-Jurassic.

Crystalline schists are well exposed among the southern Moluccas. On Ceram, two ages can be distinguished: pre-Upper Triassic (probably late Paleozoic) phyllites, and older crystalline schists.

On Timor, crystalline schists form part of an overthrust complex, and can be no younger than late Mesozoic; some are pre-Permian. They are widely exposed in the Lalan Asu mountain region.

On Java, crystalline schists in Loh Ulo region are partly Cretaceous, partly older; in Tjiletuh area they are pre-Eocene at latest. In New Guinea, and on islands off its north coast, crystalline schists and phyllites form part of the pre-Tertiary basement complex.

The oldest (prior to late Paleozoic) crystalline schists occur in west-central Borneo, and the Lampong districts of southern Sumatra.

Although the schists vary widely in composition, most of them are of types such as might be expected to result from dynamic regional metamorphism of originally highly aluminous sediments. In some cases, enough lime, magnesia, and iron were present to account for amphiboles, biotite, diopside, garnet, epidote, chlorite, etc. A few of the schists contain accessory granitic minerals, and certain gneissoid rocks appear to have resulted from intrusive contacts.

Reinhard and Wenk (6) describe the metamorphic rocks of British North Borneo as the oldest rocks in the region, and relics of an ancient (pre-late Paleozoic) basement. They are mostly hornblende- and chlorite-epidote schists, amphibolites, and gneisses with plagioclase, epidote, and hornblende; biotite is almost completely absent, and muscovite is scarce. Largest exposures are in the southeast, bordering Darvel Bay on north and west. They occur also along upper Telewas and middle Segama Rivers. Crystalline pebbles are common in the overlying Tertiary conglomerates.

In western and central Celebes, metamorphism occurred in two stages--first dynamic, later by contact with intrusive granites (7); in the east-central parts of the island, the latter form did not occur. Intrussions of granite and granodiorite "were accompanied by an intensive injectional activity", causing a close intermingling of igneous and thermally altered contact rocks.

On Australian New Guinea, according to Montgomery (8), central parts of the Owen Stanley Mountains consist of highly altered gneiss and graphitic or chloritic crystalline schists. In the Morobe area, the metamorphic rocks are slates, phyllites, schists, and marbles, resulting from regional alteration of sedimentaries. They are additionally altered and silicified by contact with granite and porphyry intrusions; due to their hardness, such rocks form high, rugged mountains. On the southwest slopes of the Owen Stanley's, between Nepa and Aibala (Alabule) Rivers, soft phyllites underlie Tertiary formations and grade into fossiliferous shales and sandy limestones, possibly Mesozoic.

To northwest, metamorphic rocks probably compose large parts of the Bismarck and Schrader Mountains, and northern slopes of Behrmann Mountains. They outcrop widely near the west end of Prince Alexander, and occasionally in the Torrecelli Mountains. They also form considerable parts of the frontier Serra Hills and Oenake Mountains, and of the Cyclops Mountains in Dutch territory. Plutonic rocks are closely associated with all of these metamorphics, but the alteration is regional rather than contact. Nothing is known as to the age of these altered rocks except that they and their intrusions were both well eroded before Tertiary deposition in the northern ranges, and probably prior to Mesozoic in the central highlands. It is not clear whether all of the metamorphics are older than part or all of the intrusives, but some of them certainly were folded before invasion.

Glaessner (9) describes the metamorphic rocks of the Cyclops Mountains, Dutch New Guinea, as regionally altered basic tuffaceous sediments. They include epidote-albite gneiss, and shists in great variety--epidote-albite, amphibole, epidote-chlorite, actinolite, sericite-albite, and glaucophane--also quartzite, and calcareous phyllites, with ancient intrusions of serpentine and harzburgite. More recent intrusives are gabbro and dolerite.

Paleozoic Sedimentary Formations

Cambrian strata have not been identified anywhere in the East Indies (10). Of later Paleozoics, Umbgrove's map (Fig. 1) locates their reported occurrences as known to him in 1938. Montgomery (8) states that no Paleozic fossils of any age have been proved in Australian New Guinea (many in adjoining Dutch territory), and Brouwer (7) says the same as to Celebes.

Silurian is the oldest age represented in the East Indies, based on somewhat dubious fossil evidence observed in certain limestone boulders in the Snow Mountains of Dutch New Guinea (5). Devonian sandstones are better authenticated in the same general region of New Guinea; also in eastern Borneo (7).

Permo-Carboniferous formations (usually not distinctly separable) occur on several islands--Sumatra, Borneo, east arm of Celebes, Timor (especially notably), the chain of small islands easterly from Timor, and in the Snow Mountains of Dutch New Guinea (5). In these regions most of the identifying marine fossils occur in neritic and littoral sediments; in Sarawak, and other western Borneo, are indications (radiolarian cherts) of deposition in deeper waters, and similar evidence appears in eastern Celebes (7).

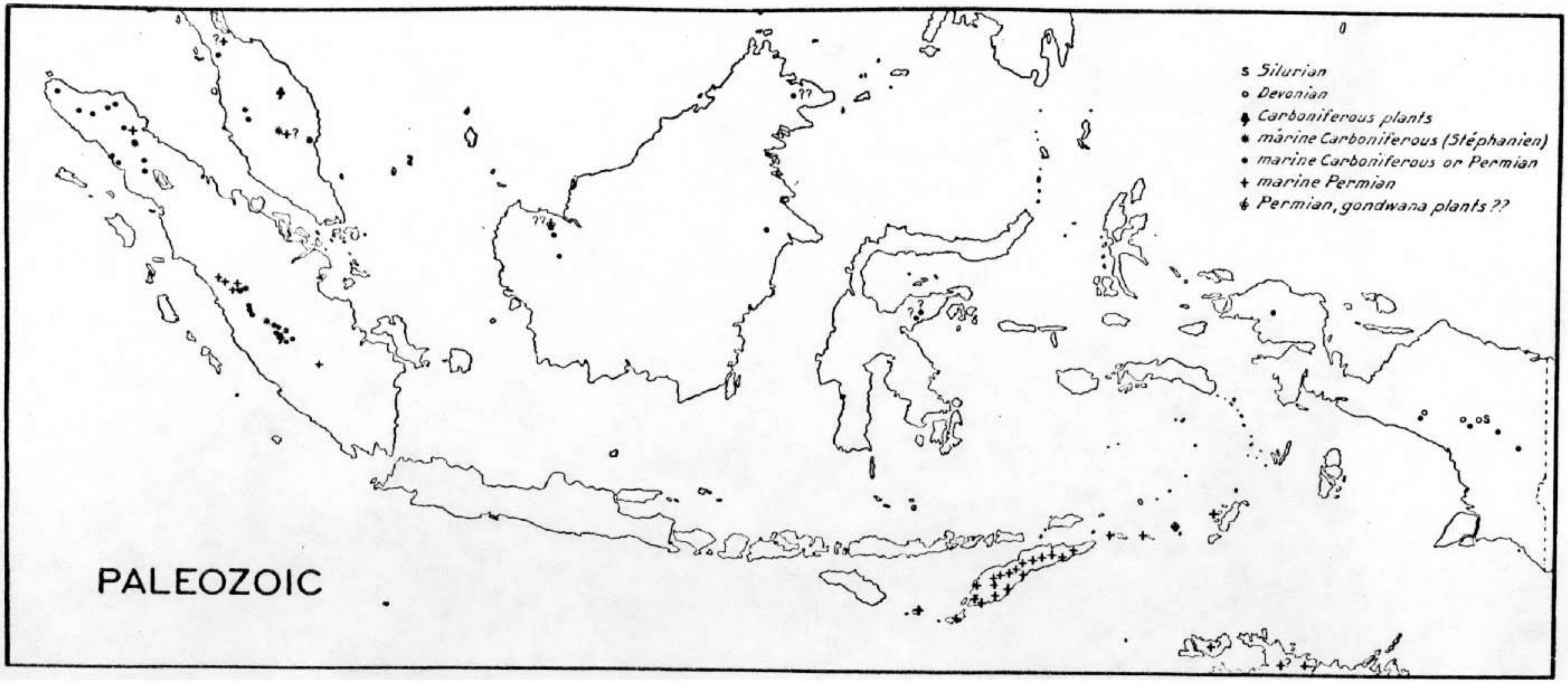

s Silurian
o Devonian
Carboniferous plants
marine Carboniferous (Stéphanien)
marine Carboniferous or Permian
+ marine Permian
Permian, gondwana plants ??
PALEOZOIC

Fig. 1

In Dutch New Guinea, Permo-Carboniferous formations are described (8) as slates, calcareous sandstones, and limestones. On the east peninsula of Celebes, certain bituminous limestones and shales may be Permo-Carboniferous (7). In Sarawak, the widely distributed Permo-Carboniferous formations are fine- to medium-grained massive sandstones with thin intercalations of indurated shales, and a basal conglomerate (11). On Sumatra, formations of this late Paleozoic age form a zone mainly along the west coast consisting largely of metamorphosed sediments, but including some unaltered beds with identifiable fossils. Lower-Carboniferous was recognized near Sungi Landak, Djambi district, and Upper-Carboniferous in Besitand River valley in northwest Sumatra (12). In central and western Sumatra, Permian merges gradually into the overlying Triassic measures.

Timor offers the widest display of Permian formations. Brouwer (13) describes them as strongly folded and faulted tuffs, tuffaceous and ordinary marls, and limestones, all richly fossiliferous; basic effusives also are present. Umbgrove (10) mentions 5,000 meters of Permian strata on Letti Island, 25 miles east of Timor.

Post-Paleozoic Stratigraphy

Mesozoic and Tertiary formations are so abundantly distributed in the East Indies, and cover such wide areas, that they can be described most conveniently on a geographical basis. Tertiary sediments and volcanics cover about three-quarters of the land area, occurring on all of the large islands and many (with a few exceptions) of the small ones. They are mostly marine but include some terrestrial and brackish sediments on the larger islands. "There are no known abyssal deposits of Tertiary age" (5). Vulcanism revived with great activity during this era; in many regions its products exceed the sedimentaries in area. Tertiary deposits reach great thicknesses, measured in kilometers; most notably on northern and southern Sumatra, and eastern and southeastern Borneo.

Considering, first, the region as a whole, Figs. 2, 3, 4 from Umbgrove (10, 14) map the principal exposures of sedimentary formations deposited, respectively, during Triassic, Jurassic, and Cretaceous times; and Fig. 5 correlates the data both geographically and chronologically, also showing the relations between the Mesozoic era and the last preceding and next following periods. Similarly, Figs. 6, 7, 8, 9 first distinguish and then correlate the Tertiary formations. For us, the most significant feature on these maps is the position of large paleogeographic land areas, the accessible remainders of which are likely to include terrestrial deposits, as suitable hosts for the sandstone type of uraniferous minerals. Among the following detailed data, those relating to such areas will receive special notice.

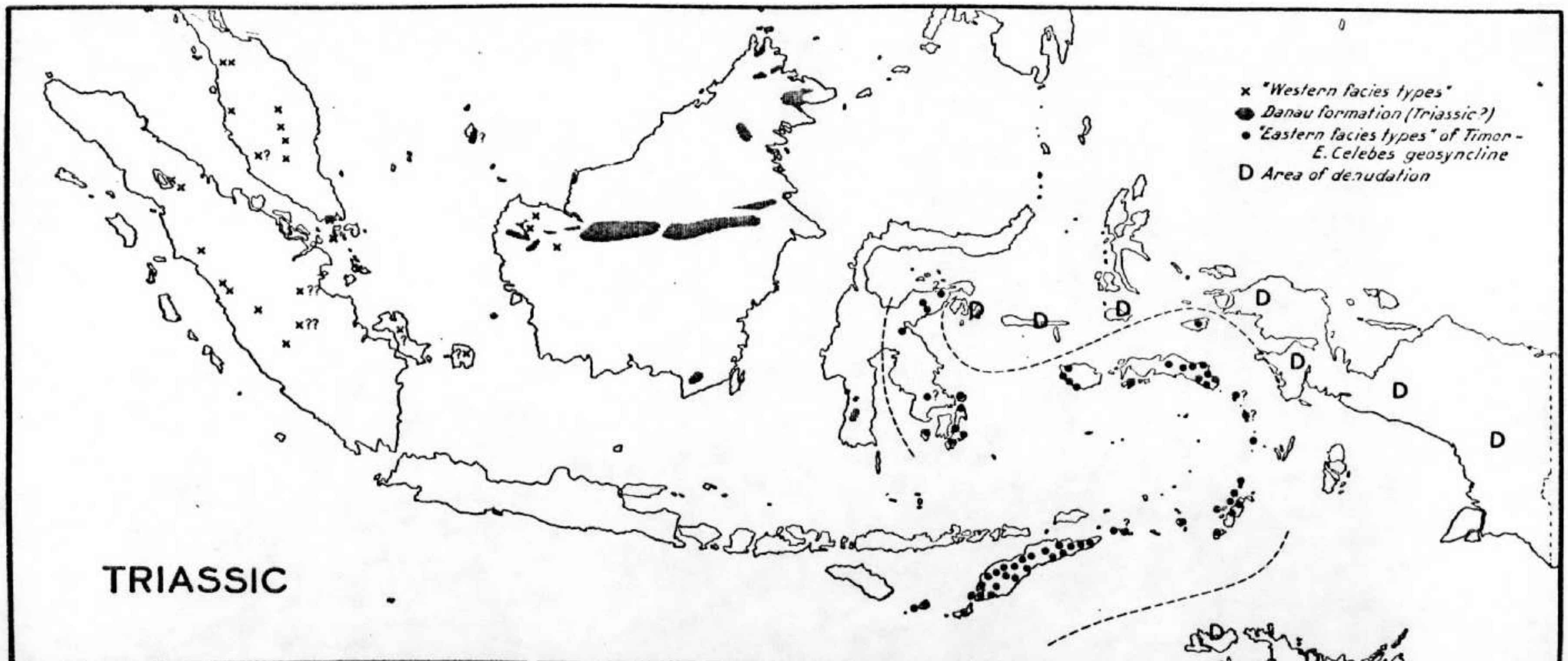
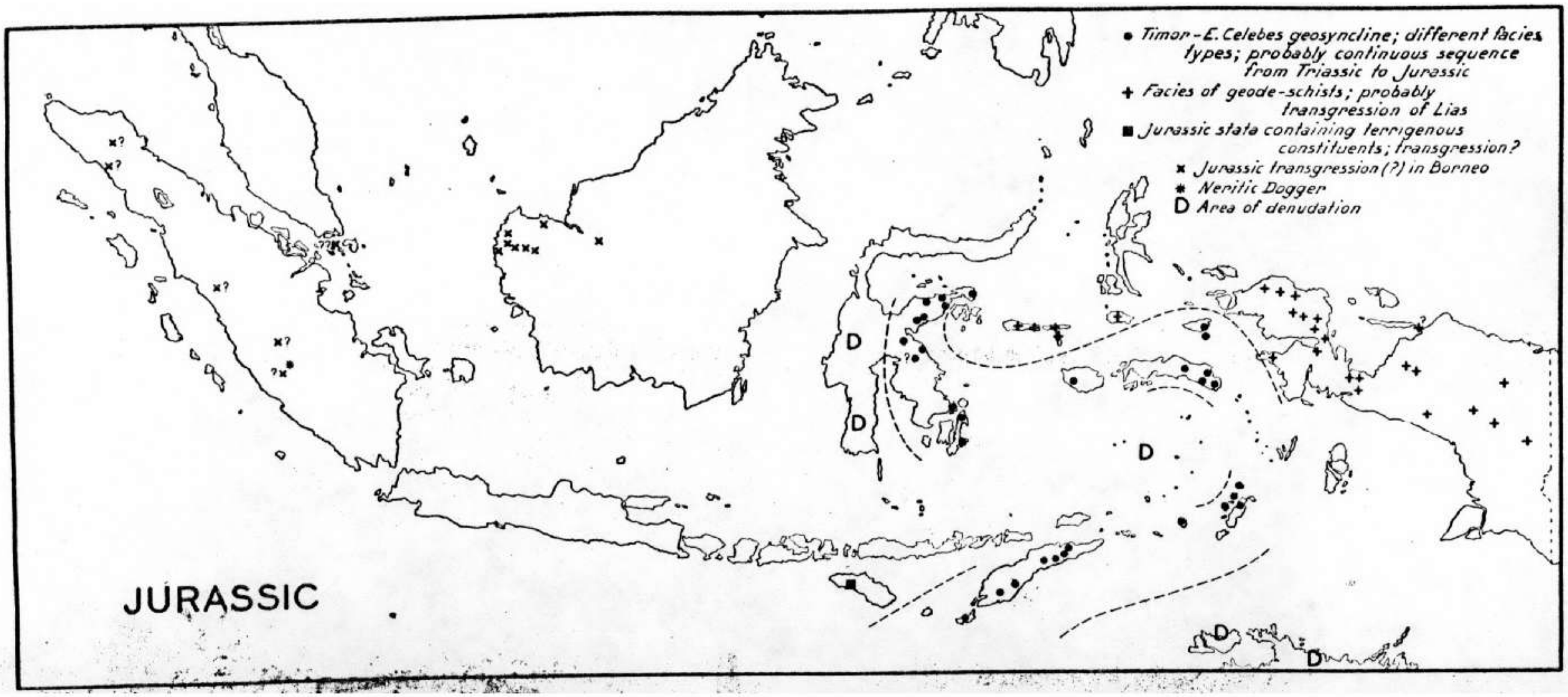

× "Western facies types"
Danau formation (Triassic?)
• "Eastern facies types" of Timor - E. Celebes geosyncline
D Area of denudation
TRIASSIC

Fig. 2


• Timor-E. Celebes geosyncline; different facies types; probably continuous sequence from Triassic to Jurassic
+ Facies of geode-schists; probably transgression of Lias
■ Jurassic stata containing terrigenous constituents; transgression?
× Jurassic transgression (?) in Borneo
✱ Neritic Dogger
D Area of denudation
JURASSIC

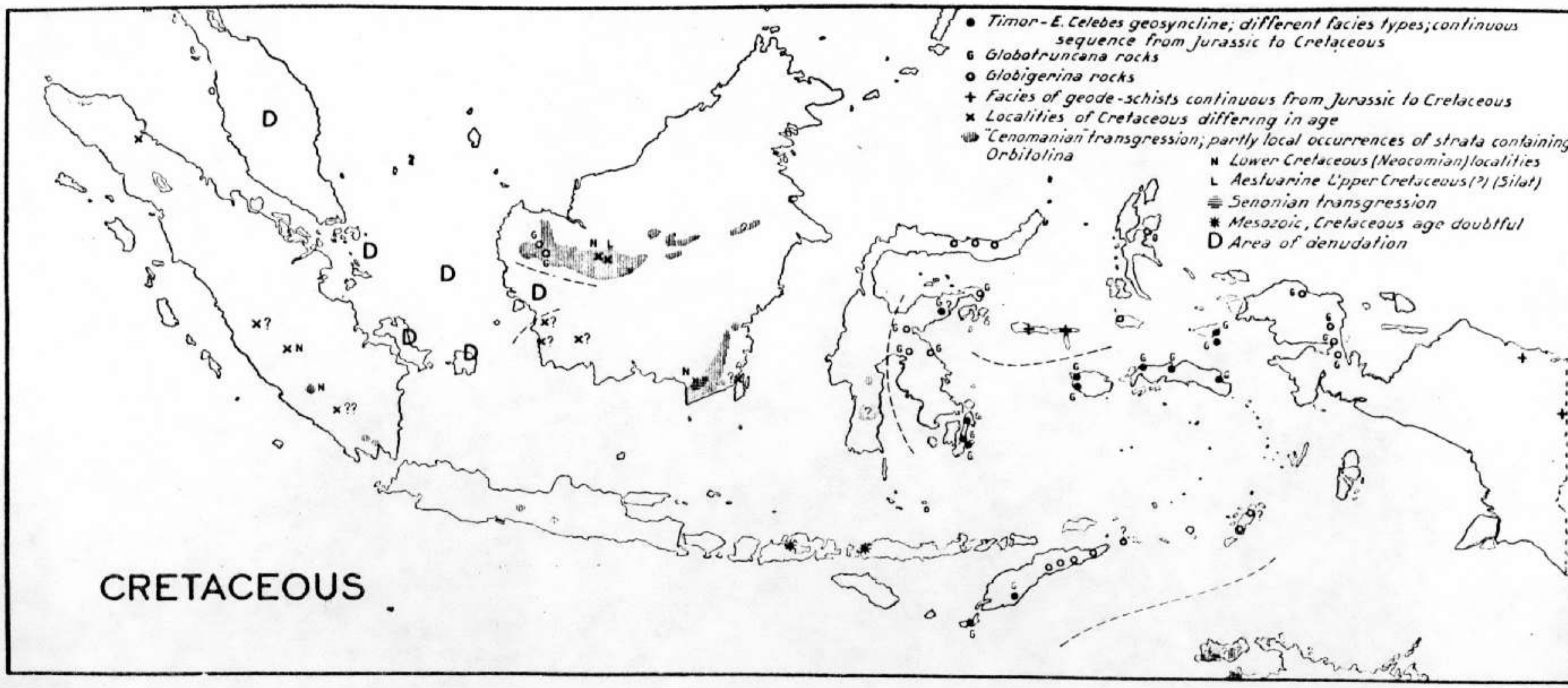
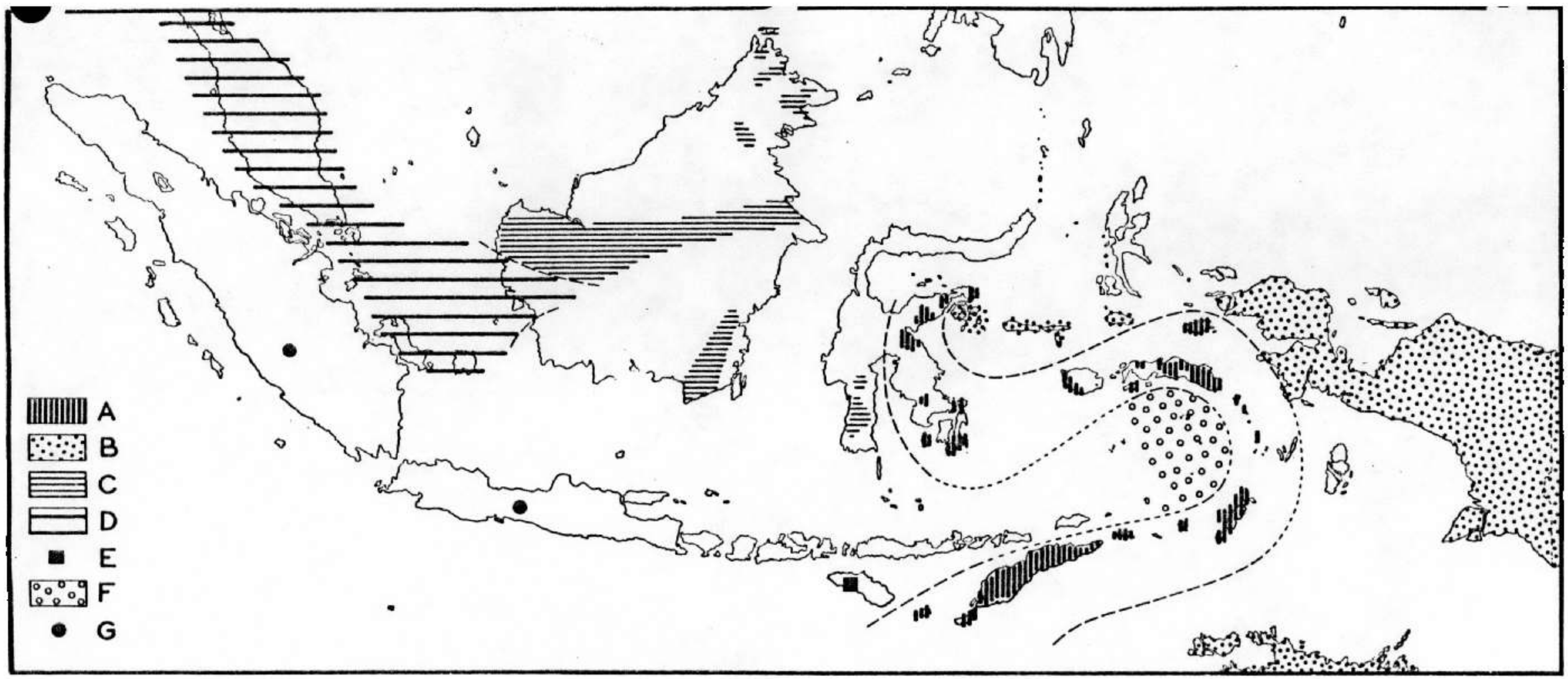
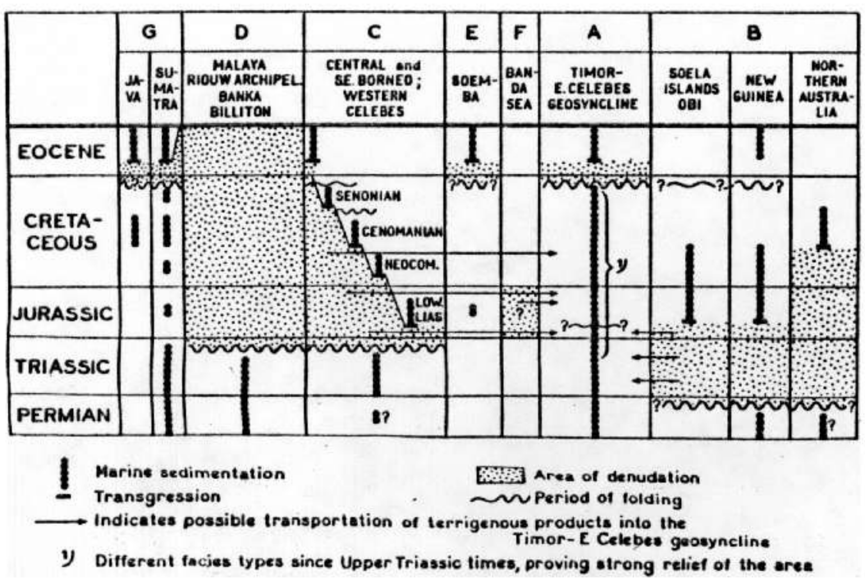

Timor - E. Celebes geosyncline; different facies types; continuous sequence from Jurassic to Cretaceous
G Globotruncana rocks
o Globigerina rocks
+ Facies of geode-schists continuous from Jurassic to Cretaceous
× Localities of Cretaceous differing in age
"Cenomanian" transgression; partly local occurrences of strata containing Orbitolina
N Lower Cretaceous (Neocomian) localities
L Aestuarine Upper Cretaceous (?) (Silat)
Senonian transgression
* Mesozoic, Cretaceous age doubtful
D Area of denudation
CRETACEOUS

Fig. 4





A. Mesozoic geosyncline

B. Area supplying sediments to geosyncline

C. Disturbed area; sometimes deep-sea (?); sometimes land; sometimes shallow

D. Region intruded by granite at end of Triassic or Jurassic

E. Neutral zone; little deposition

F. Probably land at times

G. Probably continuous sedimentation

Fig. 5

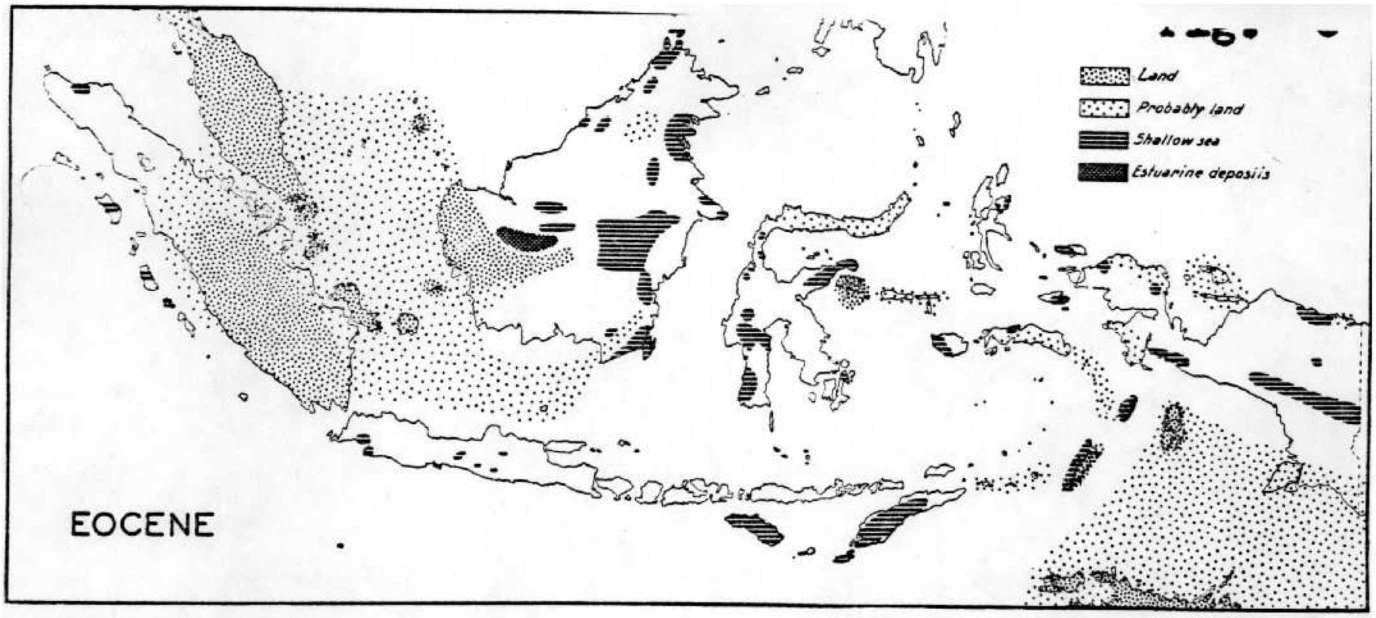

Land
Probably land
Shallow sea
Estuarine deposits
EOCENE

Fig. 7

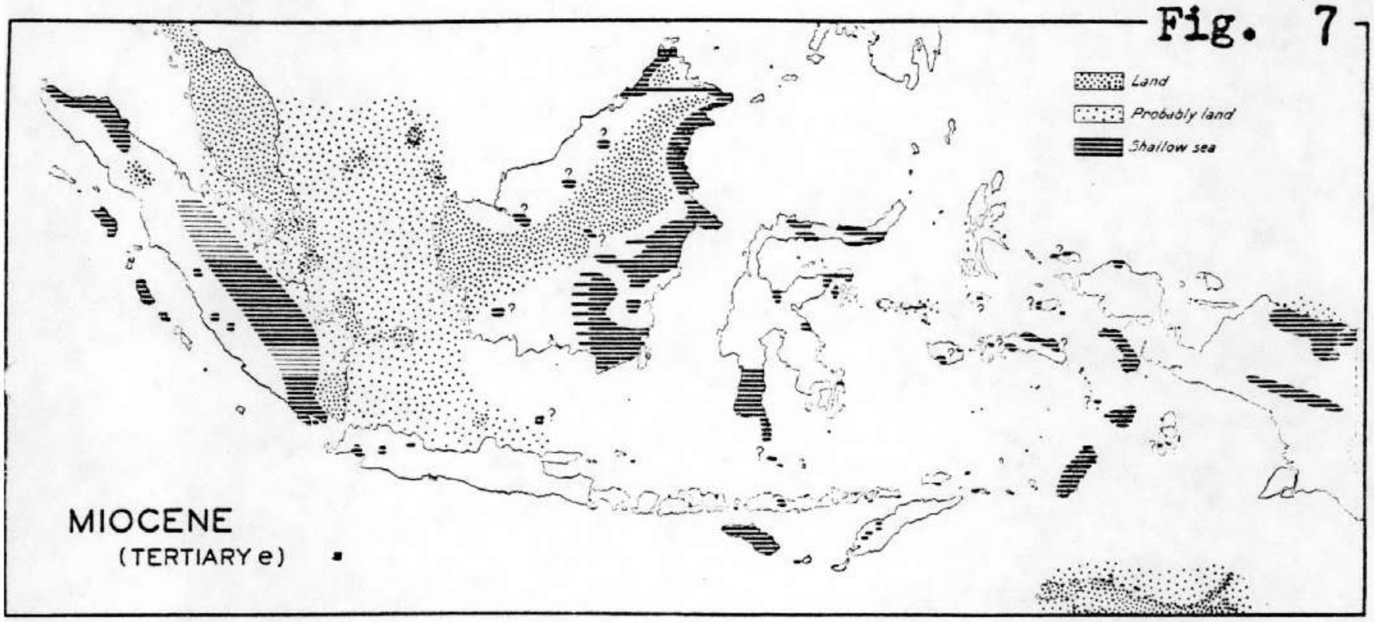
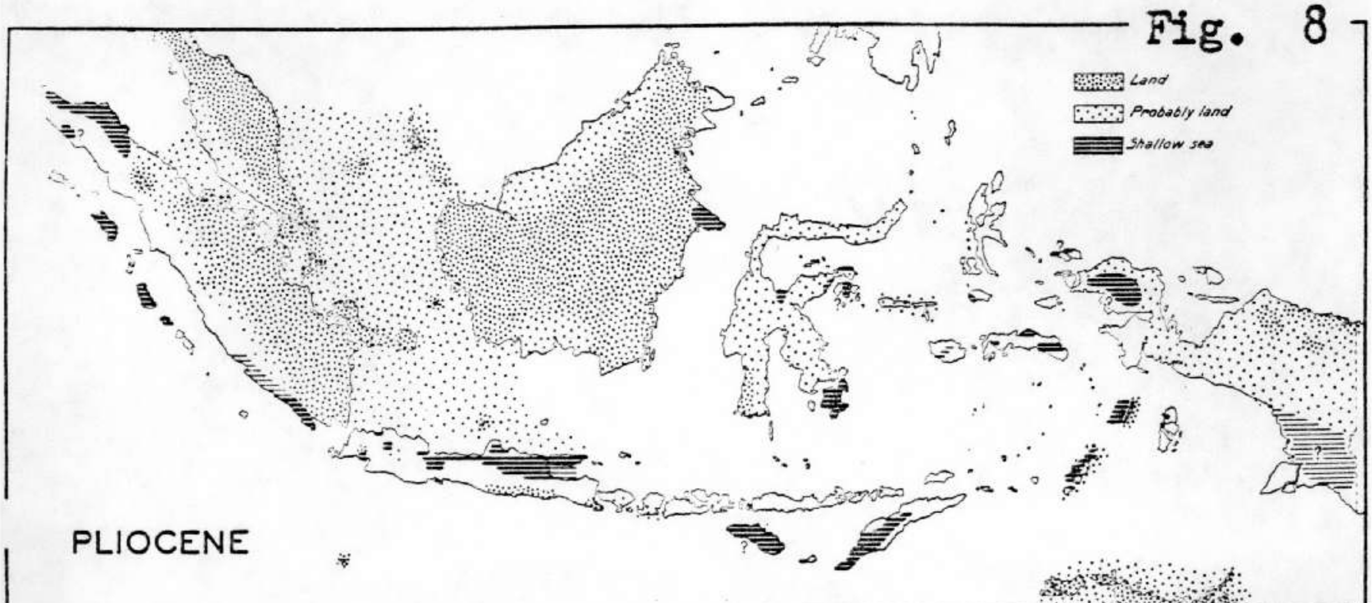

Land
Probably land
Shallow sea
MIOCENE
(TERTIARY e)

Fig. 8


Land
Probably land
Shallow sea
PLIOCENE

DIAGRAMMATIC SUMMARY OF TERTIARY STRATIGRAPHY

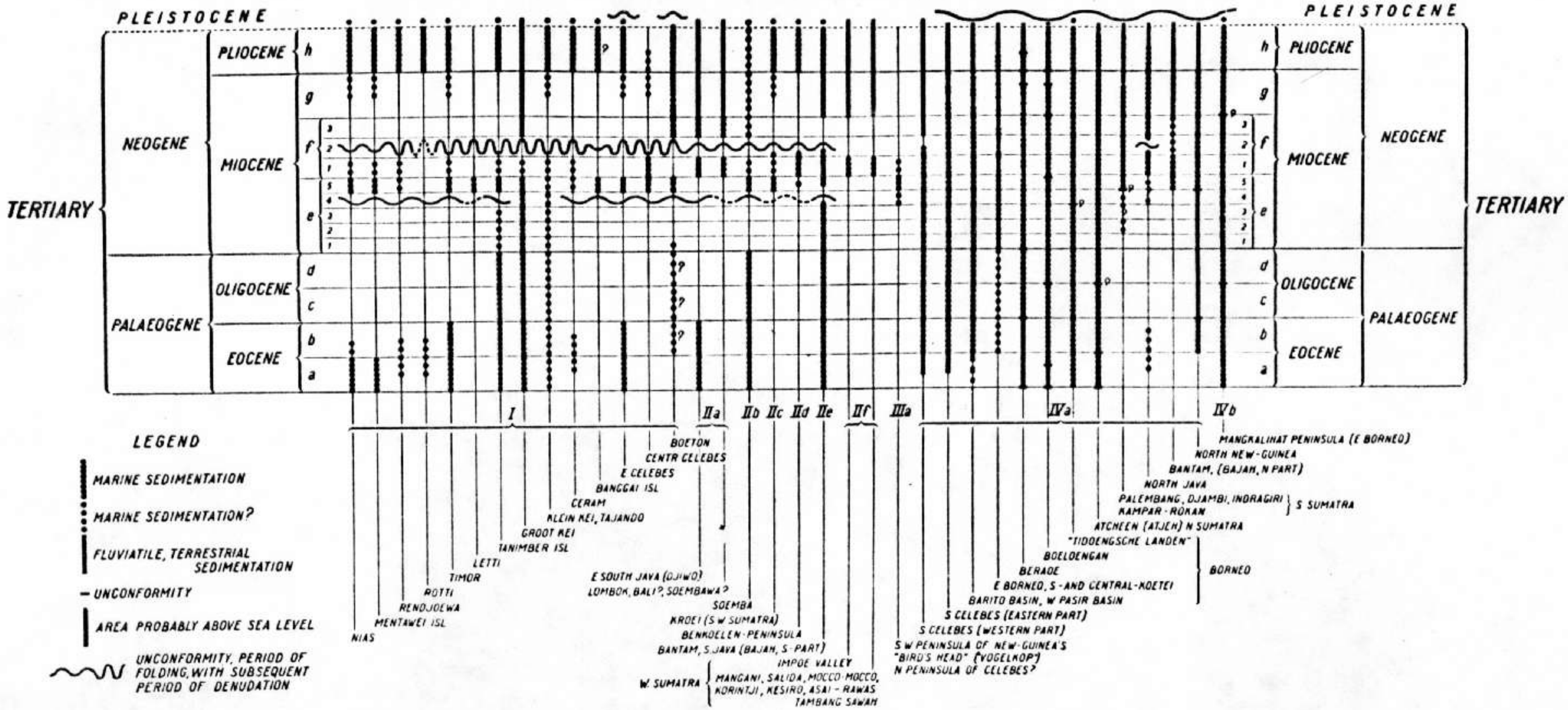


Fig. 9

Sumatra (Plate IV).

Mesozoic on this island is mainly represented by Triassic marine formations following Permian with no apparent break. Exposures are in small scattered areas, largest in a hill region (approx. S. 1-00; E. 102-30), and in the Barisan Mountains of central and southeastern Benkulen. Small exposures of Jurassic and Cretaceous measures, all marine, usually occur in vicinity of the Triassic.

Lower Tertiary formations, so provable by fossils, are rare. Southern Sumatra, at that time, was a part of an extensive land mass which included Malaya, west Borneo, and islands on the Sunda Shelf (Fig. 6). In northern Sumatra, Lower Tertiary is most widely exposed in the central mountain area, where it was deposited in a geosynclinal basin under an open sea. At transition to Upper Tertiary, volcanic materials appeared, and the sea transgressed continuously over wider areas (5).

In central Sumatra, the oldest Tertiary measures (either Eocene or Oligocene) are the "breccia and marl stage" in the Barisan highlands to east and northeast of Padang (S. 0-58; E. 100-22). This is a fresh-water lake deposit up to 1,500 feet thick, resting with sharp unconformity on the pre-Tertiary basal complex. It consists mainly of bituminous, fine, sandy, marly shales, with intercalations of coarse, arkose sandstones. Similar deposits, presumably of same age, occur to northeast of Pajakumbuh (S. 0-14; E. 100-38); in Limau Mountains (approx. S. 1-00; E. 102-30) in northwest Djambi district; and (called "Brani conglomerate") in the Mangani area (S. 0-09; E. 100-16), 10 miles north of Lake Manindjau (5).

Next above, with slight unconformity, the "quartz-sandstone formation" overlies the marls, and transgresses widely over north, central and south Sumatra. Where the marls are absent, the sandstones lie with distinct unconformity on the crystalline basal complex; their age is probably Oligo-Miocene, and there are no older Tertiary formations in southern Sumatra. They form a monotonous series, 3,000 to 5,000 feet thick, along the east border of the Barisan Mountains. "In region of the main Sumatra oil-basin, these terrestrial deposits are much thinner, reaching loo to 300 meters in the valleys and being thin or absent over the divides" (5).

With a basal conglomerate (sometimes a breccia), the rest of this series consists of micaceous quartz-sandstones alternating with arkoses, thin clay shales, and frequent coal seams; these coals are thickest (one of 30 feet) at Umbilin (S. 0-17; E. 100-20) near Fort-de-Kock, or about 15 miles east of Lake Manindjau. In the upper Kampar River area, (approx. N. 0-05; E. 100-30) north of Umbilin, the lower and middle stages show a somewhat different facies--dark, bituminous, marly shales passing into oil-bearing sapropelites and torbanites, with some coral limestones near the base; the higher stages contain only plant fossils, especially silicified wood. Deposition obviously occurred in shallow parts of a transgressing, quiet, shelf sea, with local lagunal, brackish, and fresh-water variations (5).

Upper Tertiary. A general transgression of the Aquitanian (lowest Miocene) sea was preceded by a stage of terrestrial, dominantly andesitic, vulcanism ("old andesites"), the frequently propyllitized products of which cover wide areas over the northwest section of the crystalline Lampong mass in most southeasterly Sumatra. These old volcanics are hosts to many mineralized hydrothermal lodes associated with later and more acidic intrusives. As developed in the Barisan mountain zone of Benkulen, Palembang, and Lampong districts of southern Sumatra, the successive Upper Tertiary formations were deposited in the following ascending order (5).

Baturadja basal stage (type locality, S. 4-07; E. 104-10) is well exposed also around the Gumai Mountains (S. 3-50; E. 103-00; 20 miles west of Lahat) and in small basins in the headwater regions of Sekampung and Seputih Rivers (approx. S. 5-10; E. 104-30). It consists "of some hundreds of meters" of quartz conglomerates and sandstones with a few coal beds. These are capped by Lower Miocene limestone. To southwest, this basal group passes laterally into the volcanics of Semangka Mountains (center at S. 5-30; E. 104-25).

Telisa beds are a monotonous series of globigerina marls and shales with intercalations of andesitic tuffs and breccias, glauconitic sandstones, platy or concretionary limestones, and occasional layers of plant remains.

Lower Palembang beds (late Miocene) are series of bluish-green or gray, frequently glauconitic marls and mudstones, interbedded with tuffaceous sandstones and glauconitic, concretionary, marly limestones. The formations contain molluscs and foraminifera, and correspond to the late Middle Miocene of western Java.

Middle Palembang beds (late Miocene to early Pliocene), as exposed near Muara Enim, consist of mudstones, tuffaceous sandstones, interbedded with marly or glauconitic sands and concretions, and several groups of lignites. The lower part of this formation, near the Gumai Mountains, has some marine horizons.

Upper Palembang beds (Pliocene) are mainly acidic pumice tuffs, tuffaceous sandstones, and bentonites, with almost no marine horizons and few coal streaks.

Upper Tertiary igneous activity, explosive, extrusive, and intrusive, occurred at two not widely separated epochs--Lower to Middle Miocene and again throughout Pliocene and into Pleistocene times. Both accompanied major tectonic disturbances in the Barisan mountain zone, and both started with basic types, graduating into types of medium and finally higher acidity--dacites and liparites (rhyolites). In northern Sumatra, where the pre-Tertiary basement complex reaches its highest elevation, vulcanism was less active than in the south, where the southward dipping basement is largely and deeply covered by igneous products (5).

Acidic intrusions of Middle Miocene age (post-Burdigalian) accompanied a Barisan uplift which occurred in the interval between the Telisa and lower Palembang stages of deposition. These intrusives will be described in Section VI.

Dacitic tuffs recur frequently as intercalations in the upper part of the middle Palembang, and are the main component of the upper Palembang beds. They represent a second phase of the earlier granodiorite-dacite intrusion, continued through Pliocene and into Pleistocene deposition.
Of these later eruptives, only the feeding channels (necks and dikes) are now visible.

Borneo (Plate V).

Mesozoic formations on Borneo, as elsewhere in the East Indies, occur characteristically in parallel belts widely differing in facies, due to extreme tectonic activity during that era, and continuing into Tertiary (5).

Triassic in central and western Borneo includes both volcanic and clastic facies. The normal sedimentary facies of Upper Triassic is of distinctly continental type--conglomerates, mixed sandstones, shales, and argillaceous sandstones, but no limestones. The conglomerates contain pebbles of acid plutonic rocks, Permo-Carboniferous sedimentaries, and basal schists. The igneous facies (Upper Trias) includes effusives and ejecta of acidic to medium-acid composition, grading into alkaline rocks such as quartz-keratophyre.

Widest exposures of Triassic formations in Indonesian Borneo are around the headwaters of Kapuas and Mahakam Rivers, both rising on the west slopes of the Schwaner and Muller Mountains of the central island, and a long lenticular area along the Sarawak border, extending northeasterly into British North Borneo. Another large area occupies central Sarawak.

Jurassic in southeast Borneo appears in two facies. The underlying (Alino) formation includes radiolarian cherts and basic high-magnesian effusives, and is probably a deep-water deposit; the upper (Paniungan) beds are more neritic calcareous sandstones, in age perhaps partly Lower Cretaceous.

Cretaceous, in western and southeast Borneo, is well exposed in the "lake district", drained by several of the upper tributaries--Seberuwang, Bojan, etc.--of Kapwas River (5). Semitau (N. 0-32; E. 111-58) is at the approximate center of this area. On the north side, these Lower Cretaceous sediments transgress the Bojan (mostly Upper Triassic) formation, and on the south they are overlain by the early Tertiary "plateau sandstones".

In Meratus Mountains (approx. S. 3-42; E. 115-00) of extreme southeast Borneo, some limestones are identifiably Middle and others Upper Cretaceous; both are definitely "younger than the peridotite massif in this area". The latter penetrates Paniungan (U. Jura) beds and is therefore Lower Cretaceous in age.

Other Mesozoic formations, not readily subdivisable as to ages, occupy large areas in Sarawak, extending southward into Indonesian and northward into British North Borneo. According to Allen (11), "Jura-Triassic" formations in the Lundu area of southwest Sarawak are almost certainly post-Permian and pre-Tertiary. Rapid alternations of quartzites and graphitic slates among the lower and middle measures indicate that these were deposited in a fluviatile and estuarine environment, while carbonaceous sands, silts, and muds, with coals, in upper measures suggest swampy conditions. Exposures of these formations in the Lundu area are on the east side of Datu Peninsula (N. 2-00; E. 109-30), some of them crossing southwesterly into Indonesian territory.

In British North Borneo, but corssing southward into Indonesia, are two dissimilar but closely related formations--the "Slate" and the "Danau" formations. As the Slate, which Reinhard and Wenk (6) believe to be the older, rests with distinct unconformity on deeply eroded basal schists, and as both formations, in some places underlie proved Eocene strata, their Mesozoic age seems fixed.

Slate formation, intensely folded and somewhat dynamically metamorphosed, consists predominantly of clay-slates, often foliated into roofing slates, and usually threaded by a fine network of quartz (less commonly calcite) veinlets. Sericitic and chloritic phyllites are less frequent, with intercalated quartzites, foliated arkoses, and graywackes. This formation forms a band extending southward from Mt. Kinabalu (N. 6-02; E. 116-30) to headwaters of Sembakong River (N. 4-55; E. 116-30) on west slopes of the Maitland Range, and thence into Indonesian North Borneo. It underlies Tertiary deposits through an interval of about 60 miles. There are no fossils in the slates, but in the Sembakong headwater region they underlie basal conglomerates of Eocene age, and show evidence of one more folding than the Tertiary beds (6).

Danau formation so named for its occurrence in the danau (lake) region of central Borneo--is better known in British North Borneo, where its most typical feature is an association of radiolarian cherts with high-magnesian basic effusives (6). Among the latter, high-soda types predominate. Overlying or bedded with the cherts are occasional variegated calcareous marls with microscopic Foraminifera. This typical assemblage forms part of a highly folded, often imbricated, sedimentary complex of alternating shales and sandstones, distinctly flysch in character. The Danau formation is prominent in Mt. Kinabalu area; also on Kudat and Bengkoka peninsulas of most northern Borneo, and on islands to north of them. Its age can not be determined from radioluria in the cherts, but Roe (15) states that a few identified other fossils indicate Upper Cretaceous deposition of the parts exposed in British North Borneo. He also suggests that the Danau formation of that region (which he prefers to call "chert-spilite association") is older than the Slate, and that the latter may be metamorphosed Lower Eocene.

Lower Tertiary is widely exposed in central and western Borneo, especially in the Indonesian region west of the Schwaner and Muller Mountains and south of the Sarawak boundary. This area includes the "lake district" and the headwater basins of Kapuas River and its numerous upper tributaries, but it also extends westward to the sea, at Sambas, Singkawang, and Mampawah. Little if any Upper Tertiary is known in this region. Lower Tertiary formations appear in several facies (5).

Melawi facies (type loc. approx. S. 0-20; E. 112-30) was deposited in an estuarine basin, about 220 miles long by 60 miles wide, which extended ESE. from the present headwaters of Landak River (N. 0-55; E. 110-00), past Sintang on the Kapuas, to the catchment basin of Melawi River (S. 0-15; E. 113-20).

A semi-marine facies lies to north of this Melawi belt, in the lake district north of Semitau (N. 0-32; E. 111-58). In its normal non-phyllitic type, its lower measures ("Kantu layers") 620 feet thick, it consists of clays and arkose sandstones with plant remains and thin coals, also a few marine fossils.

Plateau sandstone facies "is a series of cross-bedded, terrestrial quartz- or arkose-sandstone, sometimes conglomeratic, with occasional intercalations of coal seams. These sandstones are younger than the Melawi Series and the Kantu layers when occurring in the same area, but elsewhere they are contemporaneous and merge lateraly into the brackish and the marine facies" (5). They show two facies in different areas. The Silat facies (type loc. approx. N. 0-15; E. 112-00) is a large lens of clays, representing a long, narrow lagoon, ultimately filled. The Ketunggau facies (type loc. approx. N. 0-40; E. 110-45) develops gradually from the older sandstones but contains marine fossils.

"Continental volcanic series" forms a belt extending westerly from the Muller Mountains at headwaters of Keriau River (approx. N. 0-30; E. 113-30) to the southern border of the lake district north of Semitau. Its basal conglomerate rests with sharp unconformity on the Danau and Cretaceous formations. Its lower stage is 11,300 feet of sandstones alternating with shales and argillaceous sandstones. The lower measures include fossiliferous marls and limestones; higher parts include thin coals "and layers of combustible shales". The only intrusives in this series are sills of basalt, andesite, and dacite. The series was followed conformably by truly continental volcanic tuffs and flows ranging from basalt to dacite (5).

Source of the materials in the lower Tertiary of Borneo is not yet proved (5); they might have come partly from the central island, or partly or entirely from an Eocene land now under the South China Sea. (Fossils indicate the existence of a land bridge at this time between west Borneo and Asia). The lower Tertiary formations in western and central Borneo were deposited on the "more or less" consolidated pre-Tertiary basement complex, and were not later subjected to strong folding.

In British North Borneo, during Eocene time, the pre-Tertiary basement was locally and intermittently dry land, surrounded by a shallow, transgressing sea; this deposited red-brown sandstones and shales, with reef limestones (6). No geosynclinal basins were formed during the whole Tertiary era, and water in the several local basins was never deep. Considerable vertical movements, however, permitted accumulations to attain great thicknesses, up to 30,000 feet in some places. One thick series of Eocene shales and sandstones occurs around Cowie Harbor (N. 4-10; E. 117-55); and another of calcareous sandstone, marls, and clays, with plant remains, and one local limestone, is prominent around Darvel Bay (N. 4-50; E. 118-20).

Upper Tertiary formations in eastern and southeastern Borneo were deposited in several geosynclines developed by the early Miocene foldings, and during a general regression of the sea (5). Those basins were separated from one another by shallow thresholds, whence came two extreme facies--(a) relatively thin coral limestones on the thresholds; (b) a series, 21,000 to 45,000 feet thick, of sands, clays, marls, limestones, and lignite in the basins, all deposited in shallow sea or low bogland. Mixed facies also occur. The only reliable correlation between the several basins depends upon the larger Foraminifera; molluscs also are common. No deposits of this age in this part of Borneo are truly continental.

In western Borneo, middle and upper Tertiary formations, mainly Miocene, occupy a large coastal area extending NNE. form Rejang estuary in Sarawak to Kimanis Bay in North Borneo (15). They lie in a syncline and reach a maximum thickness of about 50,000 feet near the coast of Brunei.

Celebes (Plate VI).

Upper Triassic are the oldest Mesozoic formations yet identified on Celebes (5, largely quoting ref. 7). In the east peninsula, they overlie some bituminous limestones and shales which may be Permian, without proof. In the east-central part of the island, the formations are typical flysch deposits--alternating sandstones, shales, marly and other (including bituminous) types of limestones, and radiolarian cherts. Due to the complicated structure, "rocks of widely different age may occur together in the same complex". Grains of chromite in the calcareous sandstones of this series on the southeast peninsula prove that the deposits are younger than the ultrabasic intrusives of that region.

Lower and Upper Jurassic, so proved, are represented on the east and southeast peninsula and in central island; no characteristic Middle-Jurassic fossils have yet been found. On the east peninsula, Lower Jura is a dark-gray brecciated limestone. There, and at several other places in central and eastern Celebes, Upper Jura consists of red, gray, or white limestones (with Belemnites), and marls with radiolarian cherts. Jurassic as a whole includes both shallow and deep-water marine deposits.

Cretaceous formations are well exposed in the Biak-Poh-Pagimana area near the outer end of the east peninsula. They include soft to firm, light-buff to purplish-gray, micaceous siltstone and shale, with occasional harder interbeds of fine-grained calcareous sandstone; foraminifera are common. Their lower contact, wherever exposed, is either a fault or an intrusion of a basic igneous rock. Basal Tertiary formations overlie them discomforably, but with little or no angular unconformity. Paleontology indicates that these Cretaceous measures were deposited in shallow, warm sea-water, like those widely distributed throughout the Timor-East Celebes geosyncline.

Tertiary basal formations on the east peninsula and in southwestern central Celebes overlie pre-Tertiary without the sharp unconformity observed almost everywhere else in the East Indies. As elsewhere, lower Tertiary deposits on Celebes are almost exclusively littoral or neritic, indicating a gradual submergence of a land area until then existing between Asia and Australia (5).

Lower Tertiary is best known on the south peninsula. Here, the usual basal conglomerate of this period is sometimes displaced by a violet-red sandy clay. The next overlying formation is mainly terrestrial sandstones, clays, and coal, but includes some limestones and calcareous marls. Next above, and youngest of this period, are massive foraminiferal limestones with some andesitic tuffs. Other occurrences of lower-Tertiary formations on the east and southeast peninsulas are predominantly limestones and calcareous sandstones. Lower Tertiary formations are not known on the long northeast peninsula, presumably land at that time.

Upper Tertiary formations occur in central Celebes and on all peninsulas. Oldest measures, mainly limestones, form the highest parts of the island. The younger (Miocene-Pliocene) "Celebes Molasse" occurs in small areas all over the island. On the east peninsula, the lowest stage (of three) consists of conglomerate, breccia, and tuffaceous or marly sandstones; middle stage is marly sandstones, and limestones rich in small foraminifera; upper stage is conglomerate and sandstone. Total thickness of the Molasse reaches 7,740 feet at one locality. Marine limestones of the same age occur in the Koro-Paloe river basin of central Celebes.

Timor (Plate VII).

Mesozoic formations in Indonesian Timor are closely interfolded with Permian. "Several different facies representing simultaneous periods of deposition under widely different conditions are now found in superposition" (5). Triassic shows the widest divergence.

Oldest (Kekneno, early Permian to early Triassic) series, best exposed "in the middle part of the northern half" of Indonesian Timor, consists mainly of sterile shales, sandstones, and graywackes of alternating flysch facies; shales and sandstones are often micaceous and sometimes contain plant remains, as also siliceous and ferruginous concretions. Cherts, conglomerates, and calcareous rocks are subordinate; the series also includes some fragments of crystalline schists. Permian measures in southwestern Mutis region (S. 9-30; E. 124-10) contain detached blocks of "alkali-albitites". No fossils younger than Triassic have been found in this series (5).

Next younger (Sonnebait) series consists of shallow-water limestones, marls, and tuffs, with abundant marine fossils. The Permian measures have many intrusives, ranging from acidic trachytes and rhyolites (high-alkali) to basalts. The Mesozoic measures are deeper-water limestones, and radiolarian shales and cherts.

Next younger (Fatu) series is mainly massive limestones. The succeeding (Palelo) and youngest Mesozoic series has crystalline schists at bottom, but upper measures are graywackes, sandstones, marls, shales, and conglomerates, all containing some volcanic material, and interbedded with lava flows.

In Portugese Timor, the oldest sedimentaries, which rest on a basal complex of amphibolites and schists, and are probably Permian, are fossiliferous limestones and red calcareous shale. Mesozoic measures are flysch-type shales and sandstones, although no Triassic fossils have been found. Basic eruptives are absent in the Permian measures, but are clearly intrusive in the presumably Triassic members. Jurassic formations have not been proved, but Cretaceous shales and limestones are well distributed (5).

Lower Tertiary. In Indonesian Timor, Eocene formations lie transgressively on pre-Tertiary at several scattered localities; middle-Eocene is most widely distributed. Oligocene is absent or incomplete due to emergence resulting from the same forces that caused intense folding and overthrusting which began at this time but continued into middle-Miocene (5). The most complete section is exposed in Mollo Mountains (just west of Protugese Ocussi), where a basal conglomerate is unconformable on a large mass of crystalline complex and contains fragments of the latter. The conglomerate contains no fossils, but is conformably overlain by proved middle-Eocene limestones. Westward, in Booi Mountains, and Amfoan district (S. 9-35; E. 123-52), these Eocene limestones, shales, etc., interbed with increasing amounts of volcanic lavas, agglomerates, and tuffs; these are mostly of andesite and dacite compositions, and are often albitized.

Upper Tertiary. Early Miocene overlies older formations unconformably. Its rocks are rich in detritus, but they also include limestones and marls with globigerina and radiolaria, indicating deposition in a shallow sea with islands. Many of the early Miocene rocks are rich also in volcanic materials. Later Miocene, difficult to distinguish from the earlier, is mainly soft, white, fossiliferous limestones, with varying amounts of volcanic matter. Basalt and andesite flows, probably submarine, and covered by late Miocene calcareous measures, occur near the north coast; also rhyolites and dacites. Pliocene and younger deposits are almost all limestones and calcareous marls, rich in corals and foraminifera. Upper-Tertiary formations are only gently folded.

Java (Plate VIII).

Excepting one small lenticular area of pre-Tertiary complex at almost the exact center of the island, and two still smaller exposures of the same, one on Cape Karangtjapis on the west, other near Klaten (30km. E. by N. of Jogjakarta), the whole of Java consists of Tertiary and younger sediments, eruptives, and effusives. Among the Tertiary sediments, the upper greatly exceeds the lower half of the era. Of the igneous rocks, those of Tertiary age include both intrusive granodiorites and flows of basalt or adesite; eruptives, covering probably more than one-third of the island, were later in age.

Lower Tertiary formations, best exposed in small scattered areas in southern Bantan of westernmost Java, Eocene in age, are all shallow marine deposits, derived from a land mass on the south, now submerged, which consisted of schists and granites. The lowest measures, southern facies, include some quartz-sandstones, conglomerates, black shales, tuff, and coal seams. The northern facies has about the same, with addition of limestones (5).

Upper Tertiary occupies large exposed areas along the south coast and along the central axis for the full length of the island, and covers almost the whole of adjacent Madura. Where not exposed, it probably underlies the covering areas of volcanics and Quaternary deposits. The sediments are almost all marine. The granodiorite intrusives, of Miocene age, will be noted in Section VI.

Bangka and Billiton.

These two islands off the southeast coast of Sumatra are practically identical in constitution and structure, and represent the southernmost extension of a tin-bearing belt which occupies much of the Malay Peninsula and the whole of the intervening Riouw and Lingga archipelagoes. All of these areas have been dry land, subject to continuous denudation, since the close of Jurassic time.

On Bangka, the oldest formation is a Permo-Carboniferous limestone with Fusulina. Above this comes a thick sequence of Upper-Triassic typically flysch deposits consisting mainly of quartzites and phyllitic shales. Certain parts of these shales have been altered into crystalline schists by contact with the many massive granite intrusions on the island; these schists were first erroneously supposed to be part of a basal complex.

Triassic measures also include some radiolarian cherts, like those at the bottom of the Triassic sequence on Malay Peninsula. At Cape Lesum (S. 1-40; E. 105-21) on the extreme northwest coast of Bangka, such cherts "are cut by veinlets of quartz with some arsenopyrite and chalcopyrite", also hydrothermal quartz. The quartz veins carry a little silver (15 grains/ton), much less gold, some copper, but no tin. At Cape Penjabung (just west of Cape Lesum), the sedimentary series is transected by several wide dikes of dolerite or diabase; these are older than the nearby granites (5).

The granites of Bangka will be described in Sec. VI, and the tin-ore deposits of both islands in Sec. VII. Both features are illustrated on Plate IX.

Riouw-Lingga Archipelagoes (Plate X).

These islands form a connecting link between the structures of Malay Peninsula and Bangka and Billiton. No large exposures of sedimentaries younger than Triassic occur on any of the islands except as a narrow fringe along the southwest coast of Bintan, where a few small areas of lower Tertiary formations are exposed. The larger islands are chiefly notable for their bodies of late-Jurassic, highly siliceous and radioactive granites, to be described in Sec. VI. Alluvials from these granites are not rich in tin, but mowazite is unusually abundant in them, especially on Singkep.

VI. IGNEOUS ROCKS OF INDONESIA

General

According to Westerveld (16), each of the successive major tectonic disturbances to which the East Indies have been subjected gave rise to a suite of igneous rocks differing in many features from those of the other epochs. He makes the following distinctions.

1. Malayan orogeny (presumably late Jurassic), involving the Malay Peninsula, the "Tin Islands"--Riouw and Lingga archipelagoes, Bangka, and Billiton--and probably also parts of west, southwest, and central Borneo. Intrusives characterizing this period are highly acidic granites on the Tin Islands, and batholiths of more intermediate composition on parts of Borneo.

2. Sumatra orogeny (late Cretaceous or early Eocene) affecting all or important parts of the pre-Tertiary mountain system of Sumatra, the pre-Tertiary structures of Java (in south Seraju Mountains, Djiwo hills, and western Priangan), the Meratus-Bobaris Mountains of southeast Borneo, and the folded Cretaceous beds in Kapuas and Landak-Sekajam regions of central and west Borneo. On Sumatra, the related intrusives include peridotites, gabbros, diorites, granodiorites, and granites, the latter two most commonly. In southeast Borneo, by contrast, gabbros and peridotites form extensive masses, with some less basic types.

3. Sunda orogeny (approx. Middle-Miocene), active in the coast ranges of southwest Sumatra, the southern mountains of Java, on Flores and Wetar among the Lesser Sundas, and in central and north Celebes. Attendant plutonics are a "rather monotonous" group of diorites, granodiorites, and granites.

4. Moluccan orogeny (Lower-Tertiary, with after-effects lasting until Middle-Miocene, thus preceding the Sunda orogeny), particularly notable for the intensity of its foldings and overthrustings of Alpine type. It "harbours the longest chain of pre-orogenic gabbro-peridotitic or ophiolithic intrusions on earth". Such rocks are found on islands off the west coast of Sumatra, on Timor and islands of the Outer Banda arc, on Ceram and the Ambon group, and on eastern Celebes and islands further to the east.

Relics of older granites of uncertain but pre-Upper Carboniferous age occur in the Lampong and upper Djambi districts of southern and central Sumatra, and probably form parts of the crystalline basements on central Borneo, Celebes, Timor, and Ceram. Typical acidic granites on Sula and Banggai Islands, east of Celebes, are certainly pre-Mesozoic.

Lavas of the modern volcanoes are of two types--Pacific calc-alkaline, and Mediterranian potassic. The former, tending to follow the trend of the Sunda orogeny, are much more numerous than the latter, which are represented almost entirely by a few extinct volcanoes on southwest Celebes, north Sumbawa, and Java. On Sumatra and Celebes, andesitic volcanism was preceded by enormous outbursts of acidic pumice, now accumulated in wide beds of tuff.

Composition and radioactivity

To correlate their chemical composition with their radioactivity, Westerveld (16) caused to be analyzed and he radiometrically tested 137 specimens of Indonesian igneous rocks, which he segregated into the following groups according to their association with the several tectonic events mentioned above. Figs. 10, 11, 12 map the source of each specimen, and the scheme of segregation.

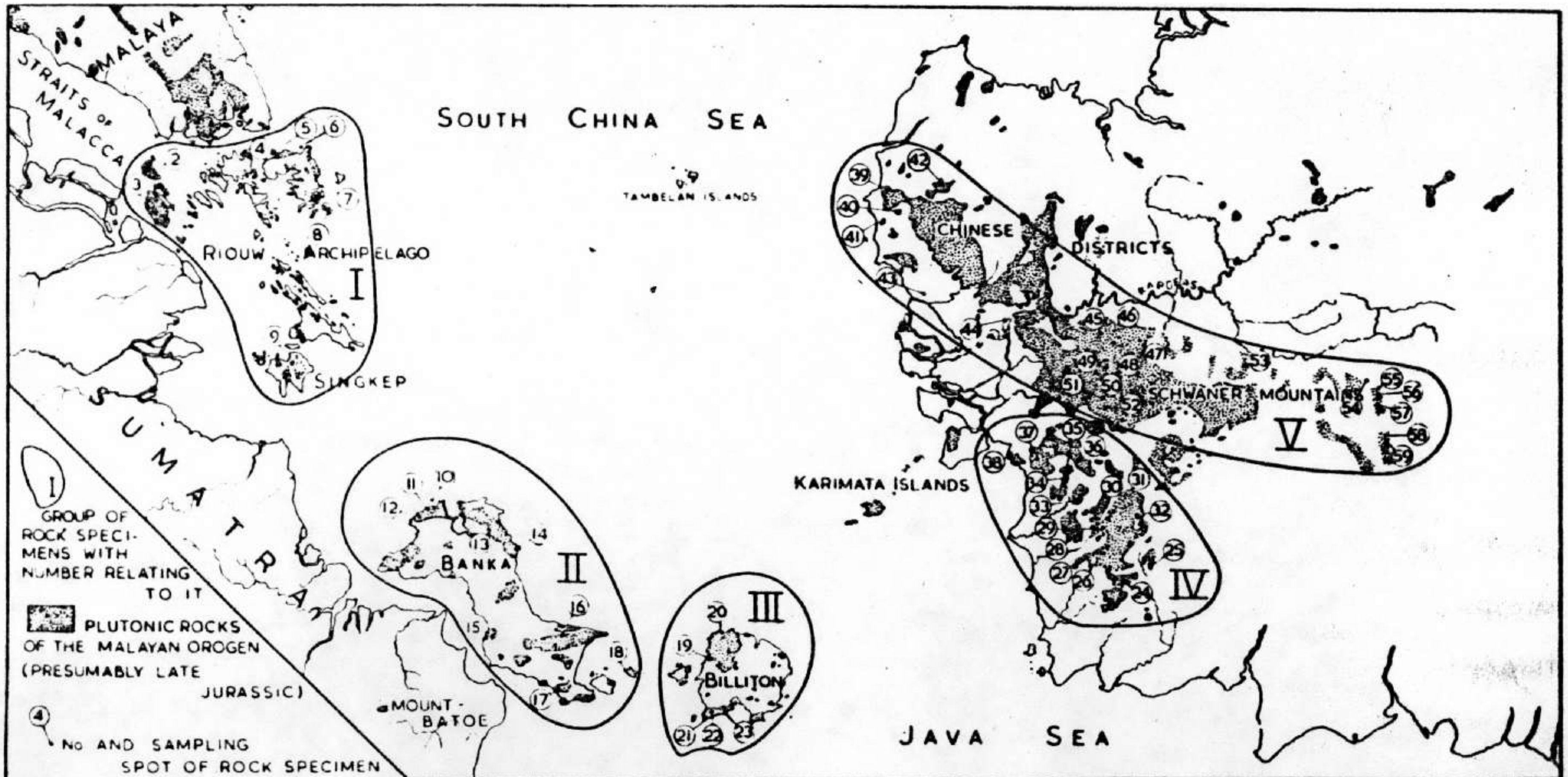
I. Granites of Riouw and Lingga Archipelagoes.
II. Granites of Bangka.
III. Granites of Billiton.
IV. Granites and allied intrusives in Sukadana and Matan districts of southwest Borneo.
V. Granites and allied rocks of Schwaner Mountains and Chinese Districts of central and west Borneo.

(These first five groups represent a large number of batholitic intrusions accompanying the presumably late Jurassic Malayan orogeny).

VI. Lavas of the andesitic and basaltic Quaternary volcanoes of Sumatra, Java, Lesser Sundas, and islands of the Inner Banda Arc; these fairly closely follow the course of the Sunda orogeny.
VII. Mesozoic granites and allied rocks from Sumatra. Those from the central and southern island are most probably of late Cretaceous age (Sumatra orogeny); there may be some doubt as to the same age of the northern intrusions.
VIII. Miocene granites and allied rocks from Sumatra, Java, Lesser Sundas, islands in Flores Sea, and Western Celebes; all related to the Sunda orogeny.
IX. Late Cretaceous (or early Tertiary) peridotitic intrusives on Timor, Moa, Leitimor, Ceram, Kabaena, and eastern Celebes; Moluccan orogeny.
X. Pre-Jurassic granites from Banggai and Sula Islands.

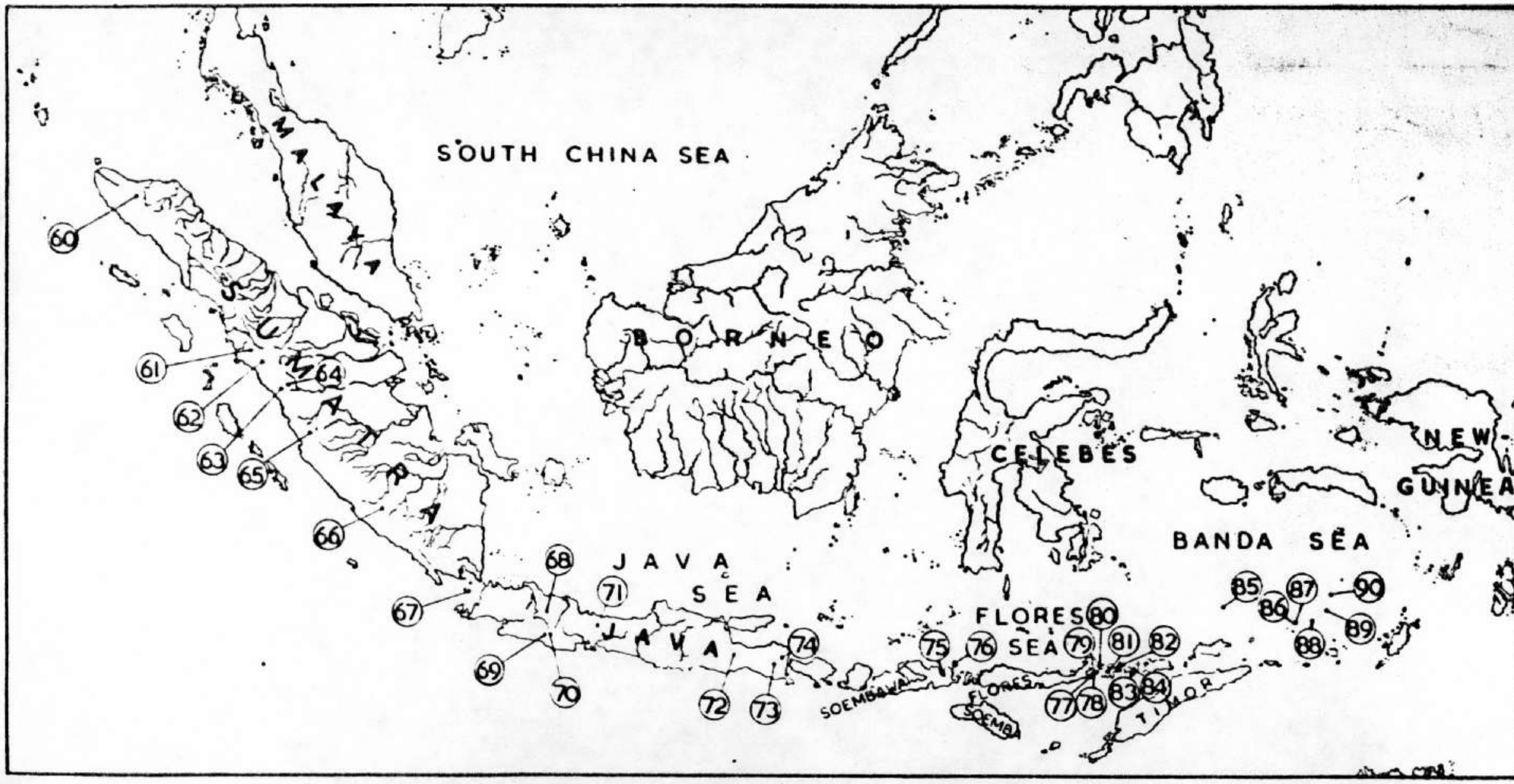
Table I records the analyses of powdered mixtures (thus averaged) of the specimens in each group, to which the Niggli parameters and nomenclature are added. The basic character of the basalts and peridotites of groups VI and IX is plainly evident, and renders these groups uninteresting to us.

Fig. 10



Locations of samples of granites and granodiorites from the late Jurassic Malayan orogen (Nos. 2–59; groups I–V).

Fig. 11



Locations of samples of andesitic (to basaltic) lavas from late Quaternary volcanoes on Sumatra, Java, the Lesser Soenda Islands, and in the Inner Banda Arc (Nos. 60–90; group VI)

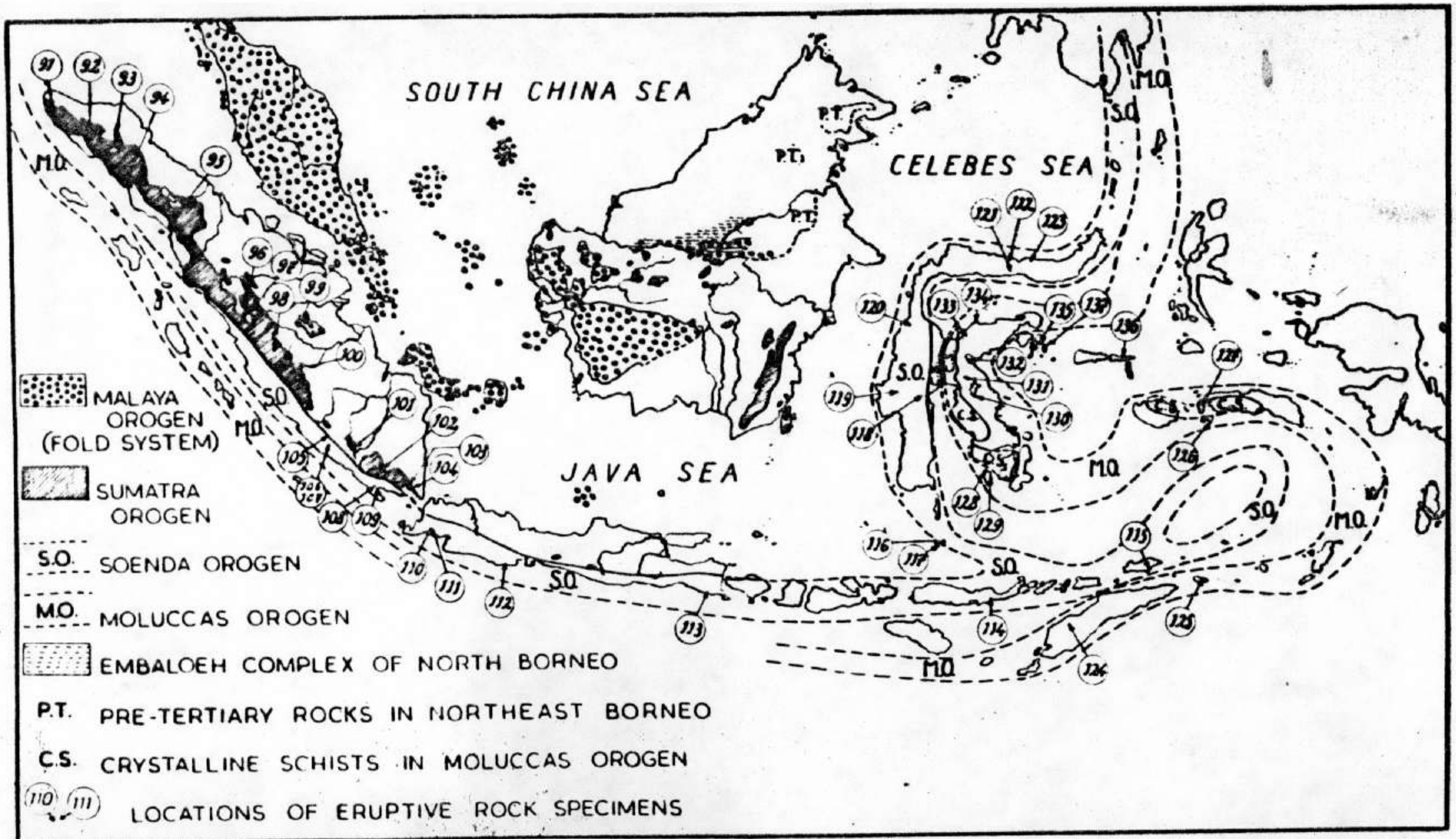


Fig. 12

Locations of samples of Mesozoic granites and granodiorites from Sumatra (Nos. 91–104; group VII); of Miocene granites and granodiorites from the Soenda orogen (Nos. 105–123; group VIII); of late Cretaceous (or Paleocene) peridotites from the Moluccan orogen (Nos. 124–134; group IX); and of pre-Jurassic granites from the Banggai and Soela archipelagoes (Nos. 135–137; group X).

TABLE I

Chemical analyses of average samples of groups of eruptive rocks belonging to a few outstanding Indonesian magmatic provinces

Average sample no.	I	II			III	IV	V	VI	VII	VIII	IX	X
		1	2	Average of 1 and 2								
SiO_2	75,11	71,94	71,61	71,78	71,60	67,12	65,81	56,18	67,00	67,56	42,71	71,90
Al_2O_3	13,05	14,01	13,49	13,75	13,49	14,56	15,72	17,90	16,11	15,26	1,88	13,73
Cr_2O_3											0,043	
Fe_2O_3	0,63	0,28	1,50	0,89	0,42	1,98	1,73	3,21	1.02	1,50	3,64	1,26
FeO	1,20	1,84	1,96	1,90	2,55	2,43	3,03	4,57	2,59	2,55	4,90	1,10
NiO											0,268	
MnO	0,03	0,049	0,03	0,04	0,04	0,084	0,089	0,15	0,217	0,103	0,141	0,057
MgO	0,20	0,65	0,66	0,66	0,74	1,49	2,21	3,24	1,37	1,42	40,32	0,82
CaO	1,17	1,82	2,02	1,92	2,39	2,75	4,46	7,27	3,40	3,89	1,75	2,01
Na_2O	3,14	3,18	2,94	3,06	2,74	4,67	3,01	3,38	3,61	3,44	0,01	3,52
K_2O	4,81	4,92	4,99	4,96	4,99	3,41	2,24	2,13	3,08	2,55	0,02	4,13
H_2O+	0,50	0,44	0,55	0,50	0,41	0,53	0,66	0,98	1,13	1,12	4,38	0,77
H_2O-	0,25	0,11	0,15	0,13	0,19	0,25	0,54	0,42	0,24	0,21	0,47	0,11
TiO_2	0,17	0,33	0,36	0,35	0,30	0,68	0,45	0,68	0,43	0,49	0,05	0,40
P_2O_5	0,15	0,093	0,07	0,08	0,09	0,26	0,18	0,19	0,171	0,142	0,00	0,24
Cl	0,014	0,03	0,012	0,02	0,03	0,048	0,04	0,035				0,00
S	0,003		0,003	0,003	0,003							
BaO	0,03		0,04	0,04	0,03			0,052				0,039
Sum	100,457	99,692	100,385	100,083	100,013	100,262	100,169	100,387	100,368	100,235	100,582	100,086
si	446			366	360	279	258	164	282	286	60½	368
al	45½			41½	40	36	36	31	40	38	1½	41½
fm	11			16½	18	24	28	32½	21½	23½	96	16
c	7½			11	13	12	19	23	15½	17½	2½	11½
alk	36			31	29	28	17	13½	23	21	0	31
ti	0,7			1,4	1,2	2,1	1,4	1,5	1,4	1,5	0,05	1,5
p	0,4			0,2	0,2	0,5	0,2	0,2	0,3	0,2	0	0,5
k	0,50			0,51	0,55	0,32	0,32	0,29	0,36	0,33	—	0,44
mg	0,17			0,30	0,31	0,38	0,46	0,43	0,40	0,39	0,90	0,39
L	38,1			40,3	39,1	42,8	37,7	42,8	41,1	39,7	3,0	40,0
M	3,1			4,8	5,7	9,7	10,8	18,7	7,9	8,0	89,6	4,7
Q	58,8			54,9	55,2	47,5	51,5	38,5	51,0	52,3	7,4	55,3
MAGMA-TYPE	engadinite granitic			yosemite granitic	yosemite granitic	± leuco-quartz dioritic	normal quartz dioritic	normal dioritic	normal grano-dioritic to farsunditic	farsun-ditic	perido-titic	yosemite granitic

Total radiation intensity (in percentage of a "standard") was determined by double ionization chamber on all individual specimens, and beta-emanation by Geiger counter on all but those of groups VII, VIII, IX. Table II gives the results; the maps show the location of each specimen. The results, with the exceptions just noted, are also plotted in Fig. 13, on which it should be observed that the two graphs are not to the same scale. As of most interest to us, we here give the author's (16) brief description of those specimens highest in beta-emission, arranged in order of increasing total radiation.

No. 23. Granite from northeast end of Mt. Parang Boeloe, Dendang distr., south coast of Billiton (S. 3-05; E. 108-00).

No. 137. Granite from Banggai Id., Banggai Archipelago (S. 1-40; E. 123-30).

No. 3. Two-mica granite from west coast of Kuenduer Id., Riouw Archipelago (N. 0-45; E. 103-25).

No. 15. Granite from Mt. Setrong, near road from Seboga to Goedang, Permis region, Soengei distr., Bangka (S. 2-35; E. 105-55).

No. 18. Granite from Telegan Id., of Lepor group, midway between Bangka and Billiton (S. 2-50; E. 107-05).

No. 4. Biotite granite from western Nongsa, Batam Id., Riouw Archipelago (N. 1-10; E. 104-00).

No. 21. Biotite granite from west coast of Blantu area, extreme southwest Billiton (S. 3-14; E. 107-35).

No. 17. Granite from Toboali distr., southernmost Bangka (S. 3-00; E. 106-28).

No. 19. Granite from Tandjungpandan, NW. Billiton (S. 2-45; E. 107-40).

No. 135. Granite from Bangkuelu Id., Banggai Archipelago (S. 1-50; E. 123-05).

No. 47. Granite from Riam Moeloeng, Menterap River, in Schwaner Mountains, central Borneo.

No. 9. Granite from center of Toemang hill, northern Singkep Id., Lingga Archipelago (S. 0-30; E. 104-25).

No. 26. Aplite granite from Mt. Lumpung, south of Mahawa village, Matan distr., southwest Borneo (S. 1-55; E. 110-40).

No. 10. Biotite granite from Malang Dojong Id., Djebus distr., northwest Bangka (S. 1-45; E. 105-25).

No. 16. Granite from Mt. Birah, Koba distr., southeast Bangka (S. 2-30; E. 106-25).

No. 14. Granite from Cape Raja, Sungeiliat distr., northeast Bangka (S. 1-53; E. 106-10).

No. 20. White granite with large feldspars, on road from Tikoes tin mine to Mt. Genteng, northwest Billiton (S. 2-40; E. 107-45).

No. 11. Granite from east of Penganaklaut village, Djebus distr., northwest Bangka (approx. S. 1-45; E. 105-25).

No. 2. Biotite-granite from Semampang, west Karimuen Id., Riouw Archipelago (N. 1-05; E. 103-23).

No. 34. Riebeckite-granite, on trail between Telokparak and Toelak villages, or 17 km. SW. of confluence of Laoer and Pawan Rivers, Matan distr., southwest Borneo (S. 1-27; E. 110-25).

All of these most highly radioactive rocks are granites, and nearly all are in the four groups related to the Malayan--late Jurassic orogeny. The still older, pre-Jurassic, granites of Banggai Archipelago (group X) are high in both acidity and radioactivity. That the maximum total radioactivity was found in a high-soda riebeckite-granite (No. 34) agrees with experience elsewhere in the world. A combination of high silica, high alkalies, and high radioactivity appears characteristic of these late Jurassic and pre-Jurassic granites. Table III consolidates the data on radioactivity, with which the analyses in Table I may be compared.

Our interest in acidic and radioactive granites is two-fold: (a) nearly all known deposits of primary uranium ores have been traced to their sources in highly siliceous magmatic intrusions, not exclusively granites; (b) a reasonable probability (not yet proved) that any hydrothermal metallic ore deposit, if traceable to the same magmatic source as an exceptionally radioactive intrusive, may be enriched in uranium. Such ore deposits often represent the closing phase of a nearby magmatic intrusion, of which the final products tend to retain and concentrate uranium, if any is present.

TABLE II

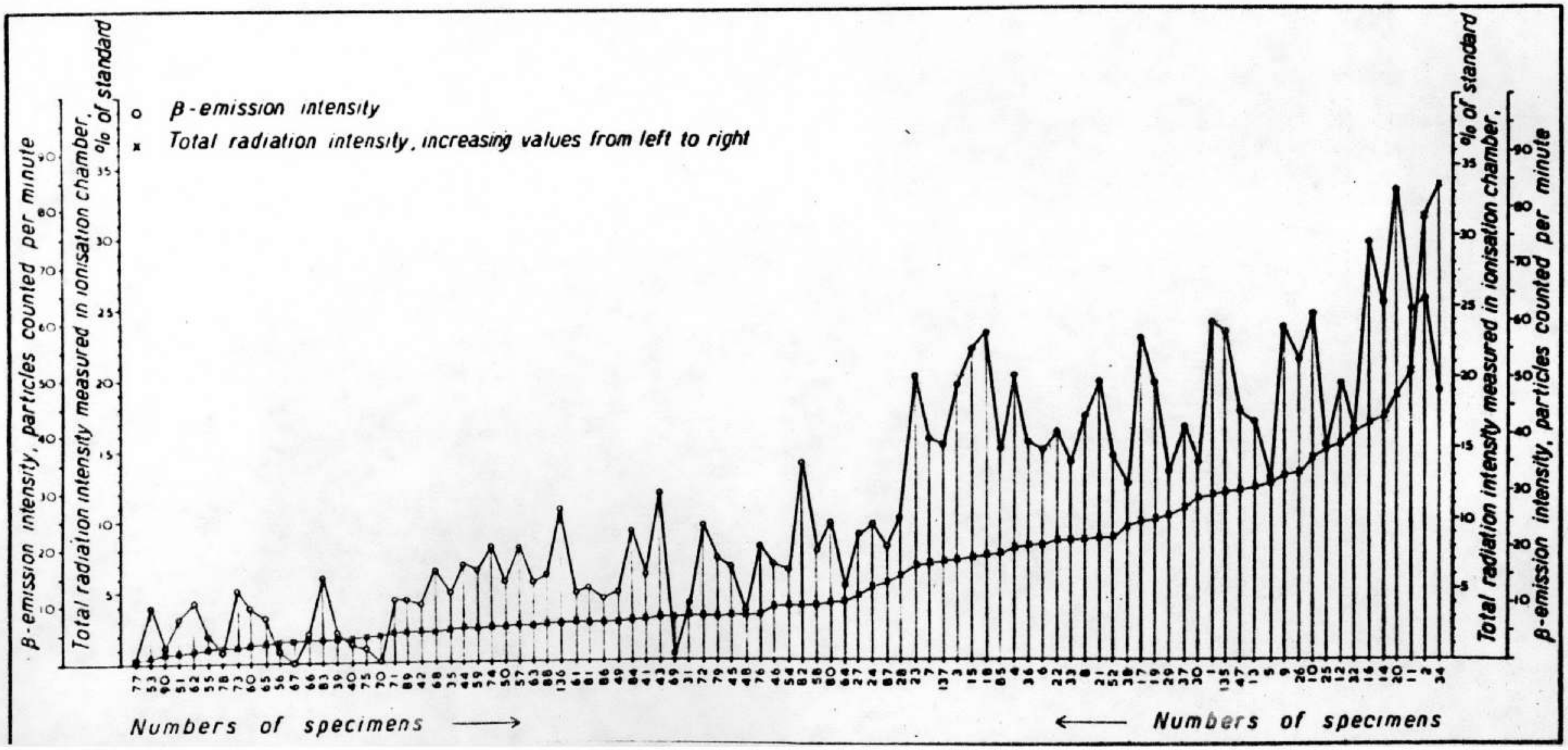
Total radiation and β-emission intensities of Indonesian eruptive rocks

Total radiations measured on 10, β-emission intensities on 15 grams of rock powder, A. Number of rock group. B. Number of specimen. C. Total radiation intensity, % of standard. D. β-emission intensity, particles per minute.

A	B	C	D
	1	11,6	60
I	2	31,6	64
	3	7,3	49
	4	8,0	50
	5	12,6	32
	6	8,1	37
	7	6,8	39
	8	8,5	43
	9	13,1	59
II	10	14,3	61
	11	20,6	62
	12	15,3	49
	13	12,3	42
	14	17,3	63
	15	7,3	55
	16	16,8	74
	17	9,7	59
	18	7,4	58
III	19	9,9	49
	20	18,9	83
	21	8,5	49
	22	8,4	40
	23	6,7	50
IV	24	5,1	24
	25	15,0	38
	26	13,3	53
	27	4,6	22
	28	6,0	25
	29	10,1	33
	30	11,5	35
	31	3,1	10
	32	16,3	41
	33	8,4	35
	34	33,6	48
	35	2,2	12
	36	8,0	38
	37	10,7	41
	38	9,4	31
V	39	1,7	5
	40	1,7	3
	41	2,9	15
	42	2,1	10
	43	3,0	30
	44	2,3	17
	45	3,2	17

A	B	C	D
	46	3,8	17
	47	11,9	44
	48	3,2	9
	49	2,8	12
	50	2,4	14
	51	0,8	8
	52	8,7	36
	53	0,5	10
	54	3,8	16
	55	1,1	5
	56	1,5	2
	57	2,5	20
	58	3,9	19
	59	2,3	16
VI	60	1,4	10
	61	2,7	12
	62	0,9	11
	63	2,5	14
	64	4,1	13
	65	1,4	8
	66	1,6	5
	67	1,5	0
	68	2,1	16
	69	3,0	1
	70	1,9	0
	71	2,0	11
	72	3,1	24
	73	1,3	13
	74	2,3	20
	75	1,8	2
	76	3,3	21
	77	0,4	1
	78	1,2	2
	79	3,1	18
	80	4,0	24
	81	2,7	13
	82	3,8	35
	83	1,6	15
	84	2,8	23
	85	7,4	37
	86	2,7	11
	87	5,5	20
	88	2,6	15
	89	2,0	11
	90	0,7	3
VII	91	1,8	

A	B	C	D
	92	2,8	
	93	23,0	
	94	3,4	
	95	11,2	
	96	2,3	
	97	2,3	
	98	4,7	
	99	5,0	
	100	4,1	
	101	2.6	
	102	2,0	
	103	4,7	
	104	4,2	
VIII	105	2,2	
	106	1,9	
	107	2,6	
	108	2,1	
	109	3,5	
	110	2,8	
	111	2,2	
	112	1,0	
	113	0,5	
	114	1,7	
	115	1,9	
	116	3,3	
	117	5,3	
	118	4,2	
	119	4,8	
	120	3,9	
	121	1,2	
	122	2,1	
	123	2,3	
IX	124	0,6	
	125	1,7	
	126	0,6	
	127	1,6	
	128	0,9	
	129	0,3	
	130	0,4	
	131	0,9	
	132	0,5	
	133	1,0	
	134	1,5	
X	135	11,8	58
	136	2,6	27
	137	6,9	38



β-emission intensity
Total radiation intensity, increasing values from left to right
β-emission intensity, particles counted per minute
Total radiation intensity measured in ionisation chamber, % of standard
Numbers of specimens →
← Numbers of specimens

Fig. 13

TABLE III

Total radiation intensity, β-emission intensity, and Ra and U content of powder mixtures representing eruptive rock groups, nos. I–X.

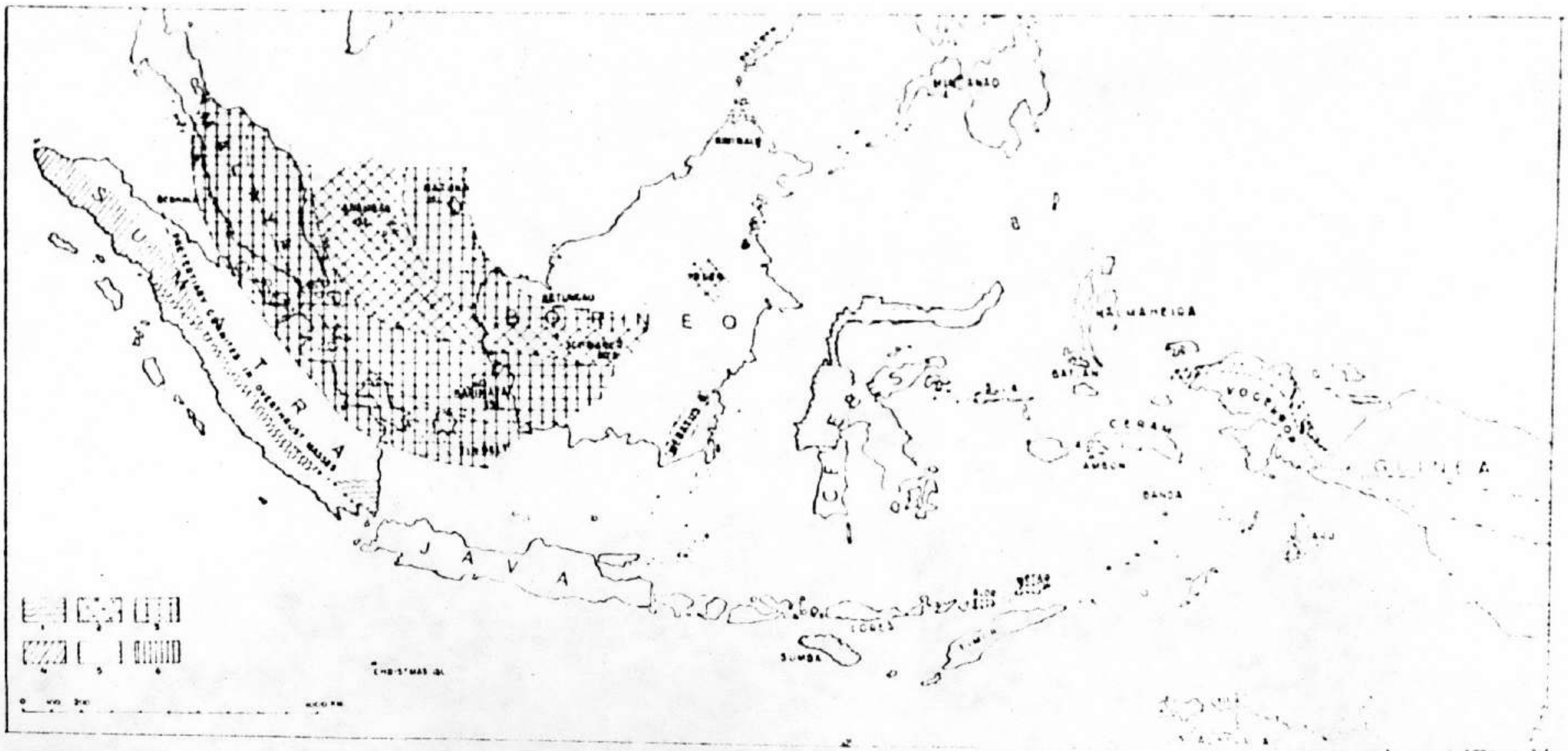
Eruptive rock group, No.	Total radiation intensity of 10 gr. of powder mixture, % of standard	Average of total radiation intensities of individual specimens	β-emission intensity of 15 gr. of powder mixture, particles per minute	Average of β-emission intensities of individual specimens	Ra content of powder mixture, gr./gr.	U content of powder mixture, gr./gr.
I. . .	11,8[1])	12,0	50	47	$3{,}1.10^{-12}$	$9{,}6.10^{-6}$
II. . .	13,1[2])	13,4	51	58	$3{,}2.10^{-12}$	$9{,}9.10^{-6}$
III. . .	10,2[3])	10,5	55	54	$2{,}5.10^{-12}$	$7{,}7.10^{-6}$
IV. . .	10,0	10,5	32	31	$1{,}3.10^{-12}$	$4{,}0.10^{-6}$
V. . .	2,8	2,9	16	15	$1{,}2.10^{-12}$	$3{,}7.10^{-6}$
VI. . .	2,9	2,5	14	13	$1{,}3.10^{-12}$	$4{,}0.10^{-6}$
VII. . .	4,0	5,3				
VIII. . .	2,2	2,6				
IX. . .	0,4	0,9				
X. . .	8,5[4])	7,1	39	41	$2{,}7.10^{-12}$	$8{,}4.10^{-6}$

[1]) Average of values 11,25 and 12,35. [2]) Average of values 13,85 and 12,40.
[3]) Average of values 9,85 and 10,55. [4]) Average of values 9, 8, 5, and 8.

Distribution of granites and related rocks.

In Fig. 14, van Bemmelen (5) maps the areas within which the acidic granitic rocks of six consecutive ages occur in East Indies. His groups 1 and 2 correspond to Westerveld's pre-Mesozoic (un-numbered) group above mentioned,- older than the latter's Malayan group. His remaining four groups--Jurassic, Cretaceous, Mid-Tertiary, and late Tertiary--respectively correspond roughly to Westerveld's Malayan, Sumatran, Moluccan, and Sunda orogenies. Van Bemmelen (5) gives the following descriptions of a few of the more prominent bodies of acidic intrusives.

On Sumatra, the Barisan uplift (Mid-Miocene) yielded many intrusions of acidic magmas. As now exposed, these form batholiths of granodiorite and dikes or bosses of dacite. Such intrusions are largest in southern Benkulen, and to east of Mana (S. 4-29; E. 102-55) and Bintuhan (S. 4-46; E. 103-20); they occur also in northern Benkulen and in the region southeast of Padang (S. 0-58; E. 100-22) central Sumatra. These intrusions caused extensive propyllitization and silicification over large areas of older andesites, and were the source of the gold-silver veins in Lebong district (S. 3-02; E. 101-56) northern Benkulen (to be described later), also those near Padang. The massive dacites are closely associated with the other bodies, but the dikes, in most cases, seem to be slightly older, as forerunners of a plutonic invasion.



Sketch map of the East Indies showing the distribution of granitic rocks in orogenic belts.
1. Crystalline basement complex granites, 2. Permotriassic granites. 3. Jurassic granites. 4. Cretaceous granites. 5. Mid-tertiary granites, 6. Late tertiary granites.

Fig. 14

At extreme south Sumatra, the Bengkunat batholith exposes an area of about 260 sq. km. extending northwesterly from the head of Semangko Bay (S. 5-35; E. 104-30) and forming a segment of the Barisan Range between the west coast and the Semangko River. Its core is a coarse biotite-granite (75% SiO_2); outward, quartz and orthoclase diminsh, while biotite, amphibole, sometimes pyroxene, increase to result in a medium- or fine-grained, sometimes porphyritic, granodiorite. More basic diorites occur along the margins, which are invaded by granodiorite dikes. Similar transitions occur also between the basic borders and the surrounding older andesites. These andesites have many dikes and irregular bosses of dacite related to the same intrusion. Granite seems fresh, but dacite is slightly altered hydrothermally, its large quartz crystals showing evidence of corrosion.

In the Schwaner Mountains of western Borneo, large batholitic intrusions invaded a series of Permo-Carboniferous sedimentaries which here rested on a crystalline complex. These Permo-Triassic intrusives include granite, quartz-diorite (tonalite), and locally diorite; pegmatites and other dikes of biotite-andalusite rocks also occur. Alteration of the invaded rocks, by contact or injection, is a prominent feature.

On Bintan Island (N. 1-00; E. 104-30) of Riouw Archipelago, granite batholiths are younger (probably Middle Jurassic) than the tonalites of west Borneo, also usually more siliceous. Invaded pre-Tertiary rocks include phyllitic and arenaceous shales, quartzites, diabases, and metamorphic volcanics, like the Pahang Series of Malaya. In contact aureoles, shales are altered to hornfels and other types resembling porphyries; the ultimate type has the composition (76-77% SiO_2) of an aplite-granite. Sandstones assume almost the appearance of a normal, abyssal igneous rock.

Jurassic granites of Bangka and Billiton are the same as those in the Malayan tin belt, and are probably from the same magma reservoir. They are porphyritic biotite-granites with unusually large (to 8 cm.) phenocrysts of orthoclase. Cheif other components are microcline, perthite, acid-plagioclase, biotite, and quartz, with accessory zircon, apatite, titanite, fluorite, and black tourmaline; locally also are cassiterite and amphibole. Monazite is a frequent minor accessory in many of these tin-bearing granites, most notably on Singkep and northern Bangka; this subject will be discussed in Sec. VII. Westerveld (16), besides proving that these granites of the "Tin Islands" are among most highly radioactive of all the Indonesian igneous rocks he examined (as recorded above), specially notes an unusual abundance of rare-earths—Y, La, Ce, Nd, Sm—in the granites of Bangka and Billiton. The average equivalent uranium content of Westerveld's nine representative specimens from Bangka is $9.9 \times 10^{-4}\%$; of five from Billiton, $7.7 \times 10^{-4}\%$; and of eight from Riouw-Lingga, $9.6 \times 10^{-4}\%$.

Granites along the northwest coast of Bangka sometimes contain dark streaks alternating with white bands; dark inclusions are also common. Both have the same, but finer-grained, components as the granite, with enrichment in biotite and addition of green amphibole and orthite; darkest ones may almost lack orthoclase and quartz. Fluorite and black tourmaline are sometimes abundant in the granite, the latter often occurring also in veins along with muscovite, sphene, late quartz, arsenopyrite, and fluorite. Cassiterite does not occur in such veins; where tin mineralization has occurred, it "was caused by the pneumatolytic phase of these granitic intrusions".

At Djebus (S. 1-45: E. 105-27; 3 km. E. of Kampa Bay) northern Bangka, an otherwise typical granite carries a notable proportion of orthite, evenly distributed throughout the mass. On nearby Cape Lesum, most northwesterly point of the island, certain radiolarian cherts are traversed by veinlets of hydrothermal quartz carrying arsenopyrite, chalcopyrite, a little silver, less gold, but no tin.

At Tendjolaoet, near the southwest coast of Java and 40 km. south of Tasikmalaja (S. 7-20; E. 108-15), a granodiorite intrusion is surrounded by a propyllitized aureole 1 km. wide, which is impregnated with alkali-feldspar. Quartz veins carrying pyrite, chalcopyrite, galena, sphalerite, and specularite occur at distances up to 9 km. from exposed granodiorite.

On the extreme southeast end of Java, the Merawan batholith (S. 8-15; E. 114-00) is exposed for a north-south distance of 30 km., between volcano Raoeng on north and Betiri Mt. on south. This granite, probably Middle Miocene, produced extensive hydrothermal alteration of the penetrated old andesite, introducing secondary quartz, sphene, and pyrite, and converting the original plagioclase phenocrysts of the andesite into aggregates of quartz, albite, epidote, and acicular hornblend.

On central Flores (S. 8-30; E. 121-00), a Miocene granite intruded a series of metamorphosed rhyolites, tuffs, arkosesandstones, hornfels, etc. The basic border of the batholith, also the immediately surrounding rocks, are penetrated by dikes of quartz-diorite composed of medium-grained plagioclase, amphibole, little biotite, quartz, and magnetite, with accessory ilmenite, pyrite, and scarce zircon.

Western Celebes (Plate VI) shows an abundance and wide variety of granites and granodiorites (7). Biotite is prominent in many of them, and is rarely lacking in any. Aggregates of re-crystallized quartz are common, and some rocks appear gneissic. Many of these intrusives have large (up to 6 cm.) crystals of potash-feldspar enclosing finer grains of the other components of the rocks. Enclosed plagioclase crystals often have a rim of albite. Accessories include magnetite, apatite, titanite, and pyrite. "One of the most characteristic accessory minerals is orthite. Euhedral crystals and more or less rounded grains of orthite are found in a large number of rocks". Garnet and tourmaline are present occasionally. Zeolites, pyrite, and clinozoisite fill veins in some of the rocks, showing that these were subjected to pressure after solidification. In some advanced stages of mylontization, only fragments of quartz and feldspar have resisted almost complete pulverization, followed by introduction of carbonates and chalcedony, with formation of chlorite and epidote. The age of these intrusions is uncertain, but there is some evidence for Tertiary age. Syenites, nepheline, and related rocks have not been found in west-central Celebes except as pebbles.

VII. SIGNIFICANT ORE DEPOSITS

General

We here disregard the lateritic deposits of bauxite and iron ores, the chrome ores because of their ultrabasic affinity, and the residual deposits of oxidized manganese and nickel ores, likewise derived from basic sources such as have not been known to carry uranium with its pronounced acidic preference. Gold, by itself, has little significance as an indicator of uranium, but in a large majority of known gold-ore deposits (and of all of those known in Indonesia) the ores also contain base-metal minerals, some of which often occur in uraniferous ores. Silver, a frequent associate of uranium, is alloyed (electrum) in large proportions with the gold of nearly all Indonesian deposits, and occurs also in several discrete minerals. Copper, especially in form of chalcopyrite, is one of the most consistent associates of uranium in primary ores. Cassiterite in primary deposits is sometimes accompanied by uraninite, and frequently in alluvials, by more complex and refractory uraniferous minerals; monazite is a common accessory in the tin placer deposits on the islands east of Sumatra.

Some of the features favoring an occurrence of uranium in a metallic lode deposit are: (a) Derivation from a magma of medium or higher acidity, such as granite, granodiorite, rhyolite, monzonite, etc.; the high-alkali granites have proved particularly favored sources of uranium. (b) A vein structure denoting successive mineralizations, due to reopening and refilling of a previously filled fracture or its intersection by a mineralized cross-fracture; in such case, pitchblende is most likely to occur in the latest vacancies to be filled. (c) A gangue in which quartz usually predominates, though sometimes accompanied or even surpassed by carbonates, barite, or fluorite; a dark coloration of the latter is a favorable sign, and some fluorites contain uranium. (d) An assemblage of metallic minerals commonly believed to have been deposited at medium to low temperature; these include the sulphides, arsenides, antimonides, tellurides, or selenides of iron, copper, cobalt, silver, antimony, bismuth, mercury, lead, and zinc; pyrite, chalcopyrite, and the silver compounds are the most frequent associates of pitchblende in lode deposits.

In general, it must be noted that the failure of a lode deposit to prove or continue to be profitably workable for its base or precious metals has no bearing on the possible presence of uranium; most of our present supply of uranium ore from lodes comes from mines which otherwise would not now be working. In bygone days, pitchblende is known to have been rejected because of its interference with amalgamation of gold ores, or with the smelting of copper ores. Indonesia possesses numerous old gold-silver and copper mines now recorded as abandoned or exhausted, in which it is still possible that pitchblende remains in prevously undeveloped narrow or low-grade veins. The waste dumps of such mines might repay examination.

Primary uranium minerals without sulphidic associates occur also in veins or sheeted zones mineralized from magmatic sources, and presumably at temperatures up to pneumatolytic. Pegmatites in several regions have yielded small and rarely profitable amounts of uraninite, thucholite, and uraniferous columbo-tantalites. The chief significance of a uranium-bearing pegmatite, however, is that it indicates some uraniferous magmatic source capable of enriching metallic mineralizations in the vicinity. Combinations of uranium with titanium, in davidite and brannerite, also belong in this higher-temperature group, and have yielded profitable amounts of uranium ore in a few places.

As to uranium ores of sandstone type, opinion is divided as to their source and manner of deposition. As seen on the Colorado Plateau of the United States, the obvious facts are that they favor terrestrial and fluviatile beds of medium- to fine-grained sandstone, with local lenses of still finer mudstones, and are richest in proximity of fossil vegetation. Several areas of terrestrial deposits in Indonesia were noted in Sec. V. Somewhate similar ores have been found also in shallow marine shore deposits, such as characterize flysch conditions of sedimentation. Several such areas in Indonesia have been noted. Selenium in small proportions has been found accompanying many of the secondary uranium ores on the Colorado Plateau; this may or may not bear upon the occurrence of selenium in notable amounts in the gold-silver-copper lodes of Lebong district, southwestern Sumatra. In some cases, an occurrence of uranium minerals in a stratified rock is believed to have been caused by percolation of ground-water through an overlying bed of siliceous tuff; such juxtapositions exist in several areas of Indonesia, as noted in Sec. V.

According to Westerveld (17), Indonesian ore deposits show evidence of segregation in accord with the natures of the intrusive rocks predominating in each of his four orogenic regions previously noted. We here extract only his general observations; details of individual deposits will follow.

<u>Malayan orogeny</u> (Late Jurassic), with its granite batholiths on the "tin islands" and in Western Borneo, yielded mainly cassiterite and gold, both residual and alluvial. Primary cassiterite occurs in three environments: (a) In greisen zones and in tin-tungsten-quartz pegmatites in granite; the latter, expecially in granites and Triassic sediments, reaching the form of stockworks. (c) Larger tin veins with both high- and lower-temperature minerals.

This last type of deposit is known only on Billiton, where it occurs exclusively in sediments. Such veins contain a wide assortment of pneumatolytic silicates and oxides along with hydrothermal pyrite, pyrrhotite, arsenopyrite, chalcopyrite, sphalerite, native bismuth, bismuthite, galena, pyrargyrite, and siderite. The parent granites for these (and other) deposits are porphyritic and highly potassic, and as primary accessories they contain cassiterite, monazite, fluorite, tourmaline, allanite (orthite), apatite, and zircon.

In western Borneo, around the great batholiths of Schwaner Mountains, tin ores are less abundant than those of gold, copper, molybdenum, zinc, and lead: this is probably due to a less advanced differentiation in the Borneo granites, which are more tonalitic, even gabbroic on their borders. Only alluvial gold has yet been produced in this region, but gold-quartz veins have been worked on a small scale in the Bajang Mountains (N. 1-00; E. 109-50; 125 km. northeast of Pontianak seaport), a strongly mineralized area of quartz veins and allanite-pegmatite dikes.

Sumatran orogeny (late Mesozoic) affected the whole west coast of Sumatra and a narrow belt along the southeast coast of Borneo. On Sumatra, the mainly intermediate to acidic intrusions yielded pyrometasomatic iron, copper, and other base-metal ores, sometimes carrying a little gold-silver. As yet undeveloped lead-silver ores of this orogeny exist in the Rewas River region (approx. S. 2-45; E. 102-15, and to east thereof) in northwest Palembang; also copper ores around Lake Singkarak (S. 0-40; E. 100-30) 40 km. northeast of Padang. On southeast Borneo, intrusives of this period were all basic or ultrabasic, largely peridotites, capped by lateritic iron and nickel ores; also providing alluvials which yield gold, platinum, and diamonds. (This is a most unlikely region in which to expect uranium).

Moluccan orogeny (Late Cretaceous to mid-Miocene), covering the islands off the west coast of Sumatra, the whole of Timor, eastern Celebes, and many of the intervening smaller islands, introduced basic and ultrabasic igneous rocks almost exclusively. Lateritic derivatives of these contain oxide ores of iron, manganese, nickel, cobalt, and chromium, with none of which might uranium be expected.

Sunda orogeny (mid-Miocene) touches the southwest coast of Sumatra, south coast of Java, the Lesser Sundas and Flores, and western Celebes. It is notable for its wide distribution of epithermal gold-silver quartz veins, all of which carry also a large assortment of low-temperature, base-metal and silver minerals. Such veins are most numerous in the west coast ranges of south Sumatra, the southern mountains of Java, and on western Celebes.

On Sumatra, the Lebong district (S. 3-02; E. 101-56) of northern Benkulen Residency, and "not remote" Salida district, during the 40 years after the start of European management, about 1900, yielded 82% of the total gold and silver from all East Indies. Most of the veins in Lebong district are related to diagonal fractures; as an exception, the Redjang Lebong vein occupies a fault related to the longitudinal rift zone of Sumatra. Many of the Lebong ores (while actively mined) were notably high in selenium; those from Salida contained tellurium also. These epithermal veins, as also those on Java, carry silver in sometimes large excess over gold; examples will be given later.

In western Java, the gold-silver ores related to the Sunda orogeny are all in Lower-Miocene volcanic breccias of the southern mountains; they were being mined, before the last war, in southern Bantam (approx. S. 6-45; E. 106-15) and Priangan Residencies. On Celebes, "swarms of epithermal lead-gold-silver veins" occur in the Sasak region of the southwest peninsula. On the long northeast peninsula, gold-silver ores occur in andesitic breccias and diorite-porphyrites near Cape Sumalata (N. 1-00; E. 122-30) and Paleleh Bay (N. 1-00; E. 121-55) both on the north coast; also in Miocene limestone around Totok Bay on the south coast near the east end of the peninsula. These north Celebes ores usually had more gold than silver.

Late Tertiary-Quaternary quartz veins carrying gold-silver occur in some of the dacite and rhyolite necks along the longitudinal fault-trough system of Sumatra, or in parallel fissures; none has yet been developed profitably. Westerveld (17) mentions deposits of this type in certain districts of western Lampong Residency (probably around S. 5-00; E. 104-15); valleys of Kerintje, Soempoer, and Angkola-Gadis rivers; headwater basin of Rewas River (approx. S. 2-45; E. 102-15); and Mangani (S. 0-09; E. 100-16), north of Lake Manindjau.

In western Java, young andesite pipes in Parang and Sanggabuwana Mountains, near Purwakarta (S. 6-34; E. 107-28), have silver-lead-zinc-mercury veins which are definitely younger than the epithermal veins of the southern mountains.

In Sambas district of west Borneo (N. 1-22; E. 109-15), occurrences of stibnite and cinnabar, also of placer gold, are probably related to Tertiary or Quaternary vulcanism, which was active in many parts of the island. In central Borneo, the same association of gold with antimony and mercury is found in the headwater region of Bojan and Tebaung rivers (approx. N. 0-15; E. 112-30).

Gold-silver Ore Deposits

Most of the gold-silver lode deposits in Indonesia originated by hydrothermal processes connected with intrusions of acidic magmas during the Sunda (mid-Miocene) orogeny, or even later effusions of similar types. They seldom reach more than moderate depths unless down-thrown by post-mineral faults (as in Sumatra's Redjang Lebong vein). Their almost uniform characteristic features are: (a) association of gold-silver with base metals, most commonly as sulphides of iron, copper, lead, and zinc; selenides are prominent in Lebong and Salida districts of southwestern Sumatra; (b) preponderance, sometimes large, of silver over gold, due either to their natural alloy or to the presence of discrete silver minerals; (c) quartz as the prevailing gangue. The following details come from van Bemmelen (18) and Edwards and Glaessuer (19).

Sumatra.

Sumatra's gold-silver belt follows the Barisan mountain ranges from end to end of the island, about 1600 km. Its maximum width is about 100 km., but in most parts the width is much less, and in some places the belt is interrupted. Its most productive areas have been in southern Tapanuli, northern and southern Benkulen, and adjoining parts of Lampong Residencies.

Lebong mining district (S. 3-02; E. 101-56) in northern Benkulen has been by far the leading gold-silver producer in Sumatra, or in all East Indies. Principal country rocks of the region are marls, sandstones, shales, etc., of the Miocene Telisa formation, unconformably overlying a complex of granite, diorite, and porphyries. The sedimentaries were penetrated successively by three bodies of dacite and by many andesite dikes or sheets, all now largely propyllitized. These intrusions accompanied intense faulting, in three directions, which faults became sites of the ore deposits. The four mines next described (18, 19) were the chief producers in that district.

1. Lebong Donok, an ancient mine, was reopened in 1899 and worked until exhausted in 1941. Its main vein occupied a fault in the N. 34° W. longitudinal system of Sumatra, and traversed andesites, dacite, and the Tertiary sediments. In width it ranged "from a few" to 66 feet, including horses of andesite. The vein was banded and gave other evidence of repetitious openings and fillings by quartz, chalcedony, calcite, and various minerals of manganese and selenium. Pyrite and chalcopyrite were sporadic, and galena was absent. Gold and silver (in ratio 1:6 or 7) occurred both native and in selenides, all in minute particles. Selenium amounted to 0.015% in mined ore, and to about 3.85% in the bullion.

2. Lebong Sulit mine, about 10 miles west of the Dunok, a relatively small producer, was active from 1903 to 1918. Its vein filled a fault at contact between pyroxene-andesite and an intruded trachyte, locally also within the andesite. The vein was traceable for 6600 feet, of which 2100 feet was workable; it was intersected and displaced horizontally by many cross-faults. Filling was quartz with about 3% of sulphides--pyrite, chalcopyrite, sphalerite, galena and probably argentite; native gold and some selenium minerals were present. Ag/Au, 1.6-3.0.

3. Simau mine, about 20 miles west of the Donok, or 2 miles northwest of Karang Soeloeh, was a large producer between 1910 and 1940. It worked the Lebong Tandai vein, which could be traced, to maximum width of 66 feet, for 2 miles; many cross-faults dislocate the vein in steps. In addition, the mine worked nine other separate veins differing in size, richness, and mineralization. Most of them were in brecciated zones (some local banding) at or near andesite-trachyte contacts. Vein fillings were mainly quartz, with some calcite and zeolites, carrying up to 4 or 5% of sulphides. Of these, the primary ones were pyrite, sphalerite, galena, chalcopyrite, pearceite,

polybasite, and argentite; gold-silver occurred in both electrum and selenides. Secondaries were native gold and silver and various copper and silver minerals. The Ag/Au ratio varied progressively from 1 at the western to 30 at the eastern end of the range; at one mine it also increased with depth, due to hypogene enrichment by silver minerals. For the whole group of workings, the Ag/Au ratio varied between 12 and 16.

4. Tambang Sawah mine was reported exhausted in 1931, after working only two of its six known veins. Oldest country rocks are marly shales penetrated by two large and a few small bodies of (probably) late Tertiary granites. Strong foldings and brecciation preceded a still later Tertiary intrusion of dacite and rhyolite dikes, the last phase of which was the probable source of mineralization in the area. The Gedang Ilir vein (one of the two worked) occupied a fault fracture in a coarse breccia mainly of andesite and granite, between walls well propyllitized and silicified. It was about a mile long and up to 45 feet wide; it had many branches, and associated parallel veins. Gangue, notably manganiferous, included quartz, chalcedony, opal, kaolin, calcite, rhodonite, rhodochrosite, inesite (Mn-zeolite), and adularia. Primary ore minerals were sphalerite, chalcopyrite, galena, argentite, pyrargyrite, and electrum; deep oxidation enriched some of the ore in native silver and an unidentified refractory silver compound. The Ag/Au ratios ranged 30 to 200; of all ore mined the ratio was about 90.

Salida area, in the coastal region of southern Benkulen, was the scene of extensive ancient workings, which were renewed at several times, most recently during 1914-1928 (18). Strongly propyllitized andesites and trachytes, locally quartz-porphyry, are in contact with slates and sandstones; the whole area is intensely and complexely faulted. The main vein, 3 to 4 meters wide, has acute splits ("leaders") on both sides, the widths of which vary irregularly "from a few cm. up to several meters"; these likewise have splits in foot- and hanging walls. Ore was richest at junctions.

The main vein was a normal late-Tertiary deposit, with sulphides and selenides, but no tellurides. In the leaders the gangue included quartz, rhodonite, calcite, dolomite, and orthoclase; ore minerals were native gold and silver, tellurides of both metals, and cerargyrite. Some of these leader ores ranged as high as 1% Te; the Te/Ag ratio ranged 1.7 to 2.5, increasing with depth. The Ag/Au ratio was between 20 and 40 in the main vein, averaged about 50 (but reaching 300-400) in leaders, and was 36 for the whole output of ore.

Mangani area, "Aequator" concession (S.0-09;E.100-16), is about 10 miles north of Lake Manindjau in the northwest highlands of Padang. It shows no evidence of ancient mining. Dutch companies worked two veins—Mangani and Rumput Pait— between 1913 and 1931; the concession passed to the Marsman interests in 1940, and two new veins—Rambutan and Silver—were developed and worked. Relationships of the several veins to one another are obscure, owing to the intense and intricate faulting of the area, both pre- and post-mineral (18, 19, 20, 21). Country rocks are late Tertiary basalt, andesite-tuffs, and folded Miocene sedimentaries, unconformably overlying intensely folded Permian formations. All veins are believed epithermal in deposition.

Mangani vein was worked for a length of 1000 feet and to 1500-foot depth; it is a composite vein with an important footwall split. Walls at the south end are andesite and basalt; at the north end (beyond a fault), dacite and rhyolite. Mineralization of the Mangani vein is highly complex. One authority (G. Schouten, quoted in ref. 21) believes that it progressed in at least seven stages. Filling is mainly quartz, with primary rhodonite, rhodochrosite, inesite, and dolomite; on upper levels, the manganese minerals are largely oxidized. Ore minerals (during operations) included pyrite, arsenopyrite, sphalerite, galena, chalcopyrite, tetrahedrite, alabandite, argentite, polybasite, stephanite, pyrargyrite, and electrum, but no tellurides; all were finely distributed through the gangue. Ag/Au ratio, 66. Recovery was by flotation; hence if pitchblende was present it would have tended to remain in the tailings.

Rumput Pait vein intersects conglomerate just below outcrop, but at deeper levels, the walls are eruptive rocks intruded between conglomerates and late-Tertiary shales. Most of the gold in this ore is free, but silver still greatly predominates in the ore as a whole.

Rambutan and Silver veins (18, 20) are both intimately related to rhyolite or dacite dikes in early-Tertiary conglomerates; the latter sometimes contain a little impregnated pyrite, but show no other evidence of contact alteration. Both veins are lenticular, with maximum width of 7 meters. Their fillings are mainly quartz carrying finely distributed sulphides, mostly pyrite, never a major component of a vein. Rhodochrosite is a fairly common gangue mineral, and the richest ore occurs in its vicinity. No free gold-silver is visible. Where the walls of a vein are rhyolite, these are usually much kaolinized; the rhyolite itself is slightly argentiferous, with traces of gold. The Ag/Au ratio was 29, on basis of the first year's production.

<u>Balimbing mine</u> (18, 19), 5 miles WSW. from Mangani, worked two veins between 1931 and 1934. They occupied strong faults cutting interbedded rhyolite, tuffs, and breccias, much altered and silicified where adjacent to a vein. A banded filling of manganiferous and ferruginous quartz carried pyrite, marcasite, adularia, zircon, and gold-silver; the latter was actually only 500-600 fine gold, but looked finer due to superficial

gilding. With depth, manganese and silver diminished while gold increased to equal or slightly exceed the proportion of silver in the ore.

Gunung Arum mine is near Painan (S. 1-21; E.100-35) on the west coast 30 miles south of Padang. Between 1935 and 1940, it worked out one of its two veins. A country of late-Tertiary clay-shales was invaded by rhyolite dikes. Other igneous rocks in the vicinity include biotite-granite, hornblende-andesite, diorite, and dacite, some of which show evidence of albitization. There is also a porphyritic and hydrothermally altered amphibole-biotite granite with acid plagioclase and accessory titanite, zircon, apatite, and orthite. (The author, Ref. 18, does not state which, if any, of these last-named intrusives might have supplied the ore-bearing veins).

Filling of the worked vein, averaging 1 meter wide, and intercepted by many diagonal faults, was quartz with only ½% of sulphides, of which pyrite was about 80% and the remainder sphalerite, galena, chalcopyrite, and pyrargyrite. Electrum (alloy of gold and silver) was minutely disseminated in quartz and pyrite. Wall rocks of the vein were rhyolite or dacite, or both.

Silver-gold ratios in Sumatran ores have been collated by de Haan (22); we here extract the data relating only to those mines or veins previously mentioned. Certain discrepancies with the text are probably due to differences in the bases or manner of calculation adopted by the two authors.

Source	Ag/Au	Description
Lebong Donok	~~6.0~~-6.8	Sulphide ore, 1926-1936
Lebong Sulit	1.6-3.0	Often strongly weathered
Lebong Simau	5 plus	- - - - -
Tambang Sawah	5.8	- - - - -
Gedang Ilir Vein	20 plus	Oxidized ore
" " "	150 plus	Sulphides and oxides
Salida, main vein	20 plus	Sulphide ore
" , leader	50 plus	" "
Mangani vein	32.4	Oxidized ore
" "	84.4	Sulphide ore
Rumput Pait vein	29.7	Sulphides and oxides
Rambutan vein	36.8-56.6	Oxidized ore
Silver vein	2300 plus	Rich sulphides
Balimbing	1.11-1.35	Oxidized ore
Gunung Arum	5-8	Oxidized ore

In respect to silver-gold ratios, deHann notes a resemblance of these Tertiary Sumatran ores to those of western United States—Tonopah, Comstock, Aurora, etc.—and the Mexican ores at Pachuca and El Oro. He attributes the variability of the ratios, even within the same orebody, to progressive alterations or tectonic interruptions of the differentiating process within a magma. In his opinion, silver tends to favor conditions of lower acidity than those favored by gold.

Java.

Primary gold-silver ores on Java occupy metallogenic areas of two ages (18). Those in the geanticline belt in southwest Bantam and eastward into the southern mountains are late mid-Miocene; those in the geosyncline belt of central and northern Java are Mio-Pliocene or younger. Deposits of the older group are much the more numerous. All occupy tension fractures, and in all cases gold-silver is only an adjunct, often a minor one, of copper, lead, or zinc sulphide ores. From the long list of localities supplied by vanBemmelen (18), we here select those few at which gold-silver appears to be of chief value.

Bajah region (S. 6-55; E. 106-15) on the south coast near the west end of the island. An area within a radius of 20 km. from Bajah, in the basins of Tjibareno and Tjihara Rivers, includes eight known deposits of gold-silver ores. Country rocks are propyllitized acidic andesite and trachyte, Lower-Miocene volcanics and tuffs, and some Eocene sedimentaries, which formations are continuations of those in south Sumatra.

Principal workings are at Tjikotok and Tjipitjung, respectively about 10 km. to north and northeast of Bajah. Vein fillings are quartz, calcite, rhodonite, and rhodochrosite; ore minerals include pyrite, sphalerite, galena, chalcopyrite, argentite, pyrargyrite, and electrum. The Ag/Au ratio at Tjikotok, working three veins, averaged 75; at Tjipitjung, it varied from 25 to 100 (19).

Tjikondang River basin, about 10 km. SSW. of Tjibeber (S. 6-57; E. 107-08). An area of "old andesite" has many quartz veins (some of which were productive) carrying pyrite, sphalerite, galena, chalcopyrite, arsenopyrite, bournonite, and electrum, probably also tetrahedrite and possibly petzite. Unlike the more usual East Indian ores, these veins yielded about four times more gold than silver.

Subang mountain (S. 6-35; E. 107-00) 25 km. east of Buitenzorg. Immediately north of this mountain, an area of propyllitized rock is traversed by two intersecting systems of quartz veinlets, both carrying gold-silver. In one, the sulphide is mainly marcasite; in the other the chief ore minerals are sphalerite, galena, pyrite, and tetrahedrite.

Sawal mountain (S. 7-10; E. 108-20) 10 km. north of Tasikmalaja Ry. Sta. At about 2½ km. SSW. of the top of this mountain, an area about ½ by 1¼ km. of hydrothermally altered andesite is traversed by narrow (10-50 cm.) quartz veins with kaolinized borders. Ore minerals are sphalerite, argentiferous galena, pyrite, chalcopyrite, and secondary covellite; accessories are tennantite and polybasite or pearcite.

Borneo.

In past years, a substantial output of alluvial gold came from the "Chinese districts" of westernmost Indonesian Borneo, which gold probably originated in the Bajang Mountains and other highlands between the basins of Sambas and Landak Rivers (centering around approx. N.1-00; E. 109-45). Bedrocks in this region are (presumed Devonian) schists, quartzites, sandstones, and conglomerates, intruded by granites and diorites (19).

According to van Bemmelen (18), lode mining for gold has been conducted at the following localities in this western region.

To southeast of Montrado (N.0-45; E. 109-10), 22 km. southeast of costal Singkawang. Here a NE.-SW. zone has short and shallow quartz lenses carrying free gold and auriferous pyrite. Similar deposits have been worked also at Serantak and at Sinturu, north of costal Pontianak (S. 0-02; E. 109-20).

At Sjiu Tsiet, near Bani, which is south of Bengkajan (N.0-50; E. 109-30). Here, gold was associated with copper.

Gold has been mined at several localities in Bandjermasin district of southeast Borneo, and auriferous lodes probably occur also in Lumut Mountains (S. 2-00; E. 115-45), since alluvials are found in several rivers rising in those highlands. This region, however, offers little if any hope for uranium, due to the predominantly basic character of its intrusives, which yield appreciable amounts of platinum in their derived alluvials.

Celebes.

Formerly productive gold mines on Celebes are near the outer end of the long northeastern peninsula—around Cape Sumalata and Paleleh Bay on the north, and Totok Bay on the south coast. Four European companies have operated in this district, one as late as 1941.

In Paleleh area (N. 1-00; E. 121-55), two mines worked quartz-calcite veins carrying much pyrrhotite, pyrite, chalcopyrite, sphalerite, galena, and free-milling electrum of about equal parts gold and silver. They were related to dike-like bodies of Miocene porphyry intruding slates. Similar deposits occur at Panguat, "a few miles" south of Paleleh Bay.

At Cape Sumalata (N. 1-00; E. 122-30), gold-quartz veins in andesite carry pyrite, pyrrhotite, arsenopyrite, and a little sphalerite, galena, and selenides.

In the Totok area (N. 0-50; E. 124-43), gold-quartz veins occur in a silicified limestone at contact with hornblende-andesite. Several mines southwest of Totok worked veins wholly within andesite (19).

Mixed-sulphide ore deposits.

Lodes carrying sulphides of iron, copper, lead, and zinc occur on all of the larger Indonesian islands. Copper is almost always present, predominating in most cases, but subordinate to lead or zinc in a few. Some of these, worked for their gold-silver values, have already been described. Only a few have temporarily proved profitably workable for their base-metal content alone, and only rarely have these metals been recovered as by-products of gold-silver mining. These facts, however, have no bearing on the possible presence of pitchblende. In the following paragraphs we try to select those occurrences that, on the basis of data recorded by van Bemmelen (18), seem to offer the better hopes for uranium.

Sumatra.

Copper is the predominant base metal in almost all Sumatran sulphide ores. These "generally occur in the neighborhood of igneous rocks or in the adjacent contact zones. Nowhere they form real veins, as far as known; the copper minerals occur either in contact deposits, or as impregnations of the igneous rocks, or only as irregular vugs". In the Sibumbun Mountains east of Lake Singkarak, the intrusive is late-Mesozoic granite-porphyry, (quartz-monzonite at one locality); elsewhere, the genesis of the copper minerals is not known.

(In emphasizing the supposed total absence of cupriferous lodes, van Bemmelen was perhaps thinking of the unprofitableness of such veins as were known to him. Several of the deposits he describes, though mainly metasomatic, do show some evidence of a deferred hydrothermal mineralization. This feature, we believe, favors the presence of pitchblende).

Aer Si Hajo (loc. 6, Plate XI; approx. N. 0-57; E. 99-25). This locality is on the right bank of Si Hajo, which is a left tributary to Gadis River, about 50 km. northeast of Natal on the coast of Tapanuli. The showing consists of quartz lenses (in shale) carrying copper and lead minerals.

Muara Sipongi deposit (approx. N. 0-45; E. 99-45) is in southern Tapanuli, about 90 km. northeast of Cape Biang. It was worked, 1936-1939, for copper and gold-silver. The productive orebody was a contact-metamorphic (tactite) deposit in a limestone member of the Mesozoic "old slates", which series includes also quartz-sandstone and dacitic tuffs and breccias. Granite and granodiorite were the most effective mineralizers, but other intrusives — quartz-hornblende diorite, andesite, dacite, occasional rhyolite, hornblende-diabase, and pegmatite — are also present in the area. Garnet is the most conspicuous mineral in the tactite; ore minerals include pyrite, magnetite, chalcopyrite, bornite, and minor sphalerite, glena, arsenopyrite, and electrum. Those parts of the tactite that are free of copper carry appreciable platinum; with copper, the ore is richer in gold-silver, with only traces of platinum.

Locally, some of the granites and andesites have undergone hydrothermal alteration. Numerous mineralized hydrothermal quartz veins, cutting at a sharp angle diagonally across the tactite orebody, penetrate also the andesites, granites, and sedimentaries. These veins were not considered workable for copper or gold-silver, chiefly because of their narrow widths.

Aer Sipongi (loc. 14, Plate XI) is just southeast of Muara Sipongi, and is one of a large group of former workings, in this small area of southern Tapanuli. Here a quartz vein 1½ meter wide is mineralized with copper, silver, and gold.

Mt. Marisi (loc. 15, Plate XI) is 1½ km. WSW. of Muara Sipongi. Many narrow veins, mineralized chiefly by arsenic, carry also minerals of zinc, lead, copper, gold and silver.

Sidingin (loc. 17, Plate XI) is the most northerly in this group of mineralized localities of southern Tapanuli, or just north of Kota Nopan Rao village, and about 25 km. north of Muara Sipongi. Many quartz veins here carry pyrite and various minerals of copper, arsenic, antimony, lead, zinc, silver, and gold. They were explored in 1938, but not developed.

Lake Singkarak region (loc. 20, Plate XI; S. 0-40; E. 100-30) of northern Benkulen, and 40 km. northeast of Padang, is well mineralized with copper from granitic sources. Most of the deposits are contact-metamorphic, but true hydrothermal veins occur at a few places. One of these is Timbulon (loc. 20-VI) in Piesala basin and surrounding hills, where many strong veins penetrate a contact zone between syenite and marls.

Mt. Rajah (loc. 32, Plate XI; S. 2-40; E. 102-33) about 25 km. WSW. of Surulangun, Palembang. Here stringers of quartz traverse granite and its contact zone, and carry pyrite, chalcopyrite, galena, and highly argentiferous sphalerite. All are coarsely intergrown, without prominent banding.

Mt. Batu Bertulis (loc. 33, Plate XI; S. 2-52; E. 102-00) on north side of Seblat River, 24 km. southeast of Mt. Pandan, Benkulen. Many thin quartz stringers, some in dacite and up to 40 cm. wide, carry manganese minerals and sulphides of iron, lead and copper.

Aer Penedjun (or Ulu Klumbuk, loc. 34, Plate XI) in the Lebong gold-mining district of Benkulen, 56 km. north of Costal Lais, and about midway between the Lebong Sulit and Simau mines previously described. Fine-grained quartz, occurring at a contact between dacite and sedimentaries, contains galena, sphalerite, pyrite, and chalcopyrite.

For the next four localities, at which lead and zinc predominate, refer to Plate XII, from van Bemmelen.

Balung (loc. 17, approx. N. 0-10; E. 100-50) just east of Baru town, 75 km. east of Lubuk Sikaping. Deposits here include both veins in pre-Tertiary schists and metasomatic bodies in limestones, sandstones, and shales near the base of a Lower Tertiary sequence. Six occurrences have been tested, and five others are known. Samples of vein ore ran 30-50% Pb, 11-17% Zn, and 300-400 gm./ton silver.

Lubuk Sulassih (loc. 20, approx. S. 1-00; E. 100-30) south of Solok town, or 20 km. southeast of Padang. Country rocks are breccia-like andesitic tuff with large xenoliths of limestone. Orebodies are lenses of quartz carrying mainly argentiferous galena, with some sphalerite and copper minerals, occurring in somewhat parallel planes. Hanging walls are well propyllitized, and footwalls are silicified.

Pagu River valley (loc. 22) at a point about 20 km. east of Muara Labuh (S. 1-30; E. 101-03) and on the north slope of Mt. Korintji. Country rocks are mainly schists locally overlain by limestone. Intrusives are granite and granodiorite. Ore deposits are both metasomatic and lodes (in different places) and contain minerals of manganese, iron, and lead, with not much gold-silver. One deposit (Pamanongan) of questionable type, 30 meters thick, is reported to be mineralized with pyrite and franklinite.

Tuboh River Valley (loc. 27) at a point about 2 km. south of Rawas River and 20 km. WSW. of Surulangun (S. 2-35; E. 102-46). Granodiorite here makes contact with schists and limestones, producing a lime-silicate hornfels mineralized with sulphides of iron, lead, zinc and copper, with high values in silver. Other mineralizations in limestone may be traced to certain thick dikes of hornblende-porphyry.

Java.

Mixed sulphides have been mentioned in connection with gold-silver ores at several localities already described. Deposits at the following localities, though deficient in the precious metals, are not, for that reason, less favorable for an occurrence of pitchblende.

Djampang, 15 km. south of Pasawahan (S. 7-08; E. 106-37). Many veins of quartz with some carbonates traverse propyllitized andesite and its breccia. Ore minerals are pyrite, sphalerite, galena, and chalcopyrite.

Dawuhan, close to southeast of Tirtamaja (S. 7-57; E. 111-03), southwestern Madiun district. A complex of quartz veins 0.6-2.1 meters wide carries sphalerite, galena, pyrite and chalcopyrite, with a little gold-silver.

Kedungpring, close to west of Dawuhan and south of Tirtamaja. Two intersecting veins have cupriferous pyrite, sphalerite, and galena. One sample ran 1% Cu, 19.6 Zn, 9.4% Pb, 27 gm./ton silver, no gold.

Mt. Domasan, close to southeast of Slaung (S. 8-02; E. 111-25). A young andesite dike cuts propyllitized "old andesite", forming a mineralized hanging-wall zone 1 meter wide. This contains quartz, pyrite, chalcopyrite, and occasional sphalerite.

Southern Bantam area of about 650 sq. km., centering at about S. 6-45; E. 106-20, or 30 km. northeast of coastal Bajah, has many veins traversing Miocene volcanic rocks—andesite and dacite flows, breccias, and tuffs—occasionally also sedimentaries. The veins are mostly of quartz, with pyrite and sulphides of lead, zinc, and copper, the last usually chalcopyrite locally altered to covellite. Gold and silver are rarely in profitable amounts; two gold-silver mines in this area—Tjikotok and Tjipitjung—have already been described. Copper is a minor constituent at both of these mines, and elsewhere in south Bantam it is always much subordinate to lead and zinc.

Pasawahan district (S. 7-08; E. 106-37) in southern Buitenzorg Residency. Country rocks are Lower-Miocene propyllitized andesites, dacites, tuffs, and breccias. The most important veins, of which about 30 have been explored by the Geological Survey, occur in a NNW. zone, 6 km. long by 800 meters wide, lying to northwest of Pasawahan. Besides predominant pyrite, the veins contain chalcopyrite, covellite, galena, and sphalerite, with little gold-silver.

Tjikarang River area (approx. S. 7-15; E. 107-00). Valleys of this and other tributaries to Tjibui River expose several small quartz veins in propyllitized Lower-Miocene volcanics. The veins carry the usual sulphides plus a little gold-silver.

Tjikondang district (approx. S. 7-00; E. 107-07) about 20 km. ESE. of Sukabumi (S. 6-55; E. 106-57), and 7 km. by good road from Lampegan railway station. Country rocks are hydrothermally altered late-Tertiary andesites, breccias and tuffs. There are several veins, one of which—Tjisudi—has been explored for 170 meters and to depth of 65 meters. This one, to maximum width of 1 meter, consits of kaolinized, propyllitized, and silicified rock traversed by veinlets and stringers of quartz, pyrite, arsenopyrite, galena, sphalerite, a little chalcopyrite, and some gold-silver.

Karangnunggal area (approx. S. 7-30; E. 108-00) in East Preanger Residency. A mineralized area south of this town exposes late-Tertiary andesitic breccias, tuffs, and tuffaceous sandstones. Three propyllitized zones occur near an outcrop of granodiorite. Each one carries quartz veins and stringers with lenses of pyrite, chalcopyrite, galena, and sphalerite, also hematite.

Mt. Parang area (S. 6-36; E. 107-21), about 10 km. WSW. of Purwakarta, has been considerably explored. Country rocks are shales and late-Tertiary propyllitized andesite. Quartz veins (one of which includes barite) and many irregular stringers and lenses carry mainly pyrite, sphalerite, and galena, with some copper, cinnabar, and stibnite.

Tegalredjo (approx. S. 8-00; E. 111-25), 20 km. by motor road south of Panaraga (S. 7-50; E. 111-28) in Madium district. Several veins ranging in width from 0.6 to 1.6 meter have been considerably developed. Zinc predominates in them, but they carry also lead and copper.

Antimony ore deposits

Although stibnite is not a usual associate of pitchblende in reported uraniferous lode deposits, its occurrence signifies an area within which mineralization at low temperature, favorable for pitchblende, has prevailed. Most of the Indonesian localities at which stibnite has been specially noted are in Borneo; van Bemmelen (18) names them as follows:

Mt. Silubat (approx. N. 1-10; E. 109-15), south of Sambas River and near the westernmost coast of Borneo.

Betung River drainage basin (approx. N. 0-20; E. 112-30), a right tributary to Bojan River, the latter a south tributary of the Kapuas in the "lake district" of central Borneo. Also on Mt. Undau, in the same region, about 10 km. east of Betung River.

Manungul village (approx. S. 3-30; E. 115-00), on Riam Kanan stream, in most southeasterly Borneo.

Mt. Nanta (very approx. S. 1-00; E. 116-00), southwest of Randampas in southern Kutei district of southeast Borneo.

No mining for antimony has occurred at any of these localities.

Lode tin deposits

Although almost all of the cassiterite heretofore actually produced on the "Tin Islands" has come from eluvial and alluvial deposits, worked by open-pit mines and off-shore dredges, primary lode deposits are known in many places, and have been actively productive at the Klappa Kampit and other mines on Billiton. Such lodes, with their often accompanying greisens, deserve attention as possible sources of uraniferous minerals, especially those that carry also sulphides or other hydrothermal accessories.

Country rocks are a uniform series of Triassic shales and feldspathic sandstones, the youngest sedimentaries in the tin-bearing areas (19, 23). In certainly pre-Neogene and probably pre-Cenomanian (Middle Cretaceous) time, these formations received many large and small intrusions of a granite, all of the same type—coarse-grained, strongly biotitic, and most commonly porphyritic with large feldspar phenocrysts. (Specimens of this granite form the high-silica, highly radioactive groups I, II, III of Westerveld's report, Ref. 16, described in Sec. VI).

Mineralization attending these intrusions affected both the upper parts of the granite bodies and their overlying or surrounding sedimentaries, taking the forms of stockworks, greisen, and veins. Westerveld (23) believes that it occurred at moderate, not shallow, depth. Thermal zoning is apparent. Ores in granite include cassiterite, tourmaline, and topaz. Those at or near a contact contain skarn minerals—magnetite, pyroxene, amphibole, garnet, and locally fayalite. More remote lodes in the sedimentaries, besides cassiterite, carry abundant pyrite and pyrrhotite, with smaller proportions of arsenopyrite, chalcopyrite, sphalerite, and galena; in these sulphide ores, carbonates, especially siderite, tend to displace some of the quartz in the gangue. At Seleomar, Billiton, a lode 8 km. from the nearest granite hill consists mainly of magnetite and hematite, with some quartz and a fluorine-mica. Magnetite also was a regular component of the Klappa Kampit tin ores.

(Any greisens adjacent to these granite masses, and more particularly any mineralized lodes radiating from them, deserve close scrutiny for concentrations of uranium. Even the sedimentaries remote from an intrusion might locally, be enriched in secondary minerals of carnotite type).

Referring to the map of Bangka, Plate IX, on which the numbers in rectangles relate to lode deposits, van Bemmelen (18) groups the occurrences as follows:

Djebus (S. 1-45; E. 105-27); many mineralized quartz veins in the area north of the town.

Muntok (S. 2-03; E. 105-10); mineralized "semi-greisen" at a point on the highway 30 km. northeast of the town.

Belinju (S. 1-38; E. 105-45), in old Sungei Pandji open-pit mine, 5 km. ENE. of the town; many mineralized stringers in granite bed-rock, also mineralized greisen.

Sungeiliat (S. 1-52; E. 106-07). A large body of granite to north, west, and south of this east-coast town exposes many variously mineralized quartz veins, some of which also penetrate sedimentaries. Among these, those at Pemali (No. 3), Balei Bandung (No. 4), and Sambonggiri (No. 5), all within 13 km. southwest of town, have been best explored. The outline of this granite body measures "more than 500 km.", and adjacent greisens are known to be mineralized at many places.

Pangkalpinang (S. 2-08; E. 106-07). Two localities within 10 km. south of this east-coast town. At Bengkuang (No. 6) a tin-topaz greisen has been prospected; at Salinta Hill (No. 19), quartz veins in granite carry cassiterite and wolframite.

Toboali (S. 3-00; E. 106-25). Irit Valley mine (No. 7), about 5 km. east of town, has veinlets and lenses of tin-bearing quartz in a tourmaline rock; also in bed-rock slate.

Koba (S. 2-30; E. 106-25). At a point (No. 21) 16 km. southwest of town, and on the northern contact of a large granite body, quartz veins carry cassiterite and sulphides of lead, zinc, and copper.

On Billiton (Plate IX), primary lode deposits, in past years (to 1941), have contributed substantially to the island's total tin production. The most developed (and only long productive) mines are in or adjacent to the Burungmandi granite batholith, which extends about 15 km. westward from Cape Burungmandi, the most northeasterly point of the island. Deposits take the forms of veins, stockworks, and greisen. In some veins, magnetite and hematite are large components of the gangue; in others, sulphides accompany cassiterite. Klappa Kampit mine (S. 2-43; E. 108-05), the largest producer of lode tin on Billiton, worked veins of the latter type, though magnetite was present. Cassiterite was irregularly distributed throughout the quartz ore gangue, closely intergrown with arsenopyrite, pyrite, and chalcopyrite; lead and zinc were absent.

Exploration in the larger Tandjungpadan granite mass in the northwest corner of Billiton disclosed many lode-tin deposits, one of which, at Badau (S. 2-50; E. 107-48), had a short productive life prior to 1938. Other deposits in the area were deemed unfavorable for development as tin producers (which may mean nothing as to uranium).

Monazite-bearing deposits.

Monazite, often accompanied by xenotime, is a frequent but irregular minor component of the eluvial and alluvial tin ores produced on the "tin islands"—most abundantly on Singkep, Bangka, and Billiton. Its source was those same granites, quartz veins, and greisens from which the cassiterite was derived. Other accessories in the placer deposits include ilmenite, pyrite, marcasite, hematite, rutile, zircon, and tourmaline. From 1936 to 1939, Singkep marketed 1554 tons of monazite, the whole Indonesian production of those years (18). We have found no published record of analyses stating the percentage of uranium or even of thorium in the monazites of the region.

Bodenhausen (24) reports his tests on certain eluvial tin deposits in

Muntok district (S. 2-03; E. 105-10) on the westernmost promontory of Bangka, notable for their large proportions of monazite and xenotime. Two granite intrusions occupy large parts of the area, and are surrounded by Triassic shales and sandstones; these form hydrothermally altered aureoles around the intrusives, but elsewhere show only slight regional metamorphism.

Both of the deposits examined were residuals resting on granite floors, and were mined by open pits—mine No. 2 at 10 km. northeast of Muntok, and No. 4 at 5 km. west of No. 2—both on the north slope of hill Menumbing. The samples investigated included concentrates from both mines, a magnetic fraction of No. 4 concentrate, and heavy-mineral residues from two strongly weathered tourmaline granites. No. 2 concentrate was washed on the spot, "after the mine had been closed on account of the large quantity of monazite in the ore". Examination was by grain-count only, disregarding volume or weight; cassiterite averaged somewhat coarser than the other minerals. Results in percentages follow; x means sporadic occurrence.

	Mine No. 4		Mine No. 2		
	Concentrate	Mag. frac.	Concentrate	Granite	residues
Cassiterite	36%	X	60%	13%	3%
Ilmenite	31	83%	11	30	5
Monazite	19	2	22	2	3
Xenotime	5	10	1	X	X
Tourmaline	4	5	2	52	89
Zircon	3	X	3	3	X
Anatase	1	-	X	X	-
Quartz	1	X	X	-	-
Brookite	X	-	1	-	-
Corundum	X	-	-	-	-
Rutile	X	-	X	-	-
Ankerite	X	-	X	-	-

Monazite was in fragments and tabular crystals; usually bright yellow, sometimes yellowish-brown. Xenotime was grayish to yellowish or greenish white, rarely in well developed crystals; commonly intergrown with tourmaline. Zircon was usually in well developed tetragonal prisms, pale or brownish yellow, violet, rarely pink or colorless. (The author gives no chemical analyses or radiometric data).

Favorable geological formations

Though not exactly "ore deposits", certain sedimentary rock formations in Indonesia so closely resemble others elsewhere in the world, which have proved uranium-bearers, that they deserve special notice. They have already been described (and located) at appropriate places in Section V, wherefore their significant features are here only briefly recapitulated.

Sumatra.

Nearly the whole of the Tertiary sequence on Sumatra consists of formations which might be expected to carry some uranium, whether as discrete particles of the more robust primary uraniferous minerals, or as segregations such as those now actively developed at deeper levels of the Colorado (U. S. A.) plateau; the latter are believed to have been introduced by percolating uraniferous solutions.

A probable source of the Tertiary deposits was the great land mass then existing to the east, and containing an abundance of highly radioactive granites of the late-Jurassic Malayan orogeny (Westerveld's groups I, II, III); the Tertiary formations might have derived some of their material also from the Cretaceous granites accompanying the Sumatran orogeny, and then exposed on the west. Important parts of the Tertiary sequence are plainly of terrestrial deposition; other conditions, existing at some times in some places, included lacustrine, lagunal, estuarine, and shallow marine; volcanic tuffs form interbeds among some of the measures. Each of these sedimentation conditions has somewhere been found conducive to some enrichment in uranium.

(a) "Breccia and marl stage", either Eocene or Oligocene, in Barisan highlands east and northeast of Padang. A fresh-water lake deposit consisting mainly of fine, sandy, marly, or bituminous shales, with interbeds of coarse, arkosic sandstones. Similarly, and probably of same age: northeast of Pajakumbuh; in Limau mountains of northwest Djambi district; in Mangani area ("Brani conglomerate") north of Lake Manindjau.

(b) "Quartz-sandstone formation", probably Oligo-Miocene, oldest Tertiary formation in southern Sumatra. A thick and uniform series along east margin of the Barisan ranges.

(c) Upward continuation of the preceding, starting with a basal conglomerate. Micaceous quartz-sandstones alternating with arkoses, thin clay shales, and coal seams. To north of Umbilin coal field, lower and middle stages are dark, bituminous, marly shales passing into sapropelites and torbanites; upper stages contain silicified wood.

(d) "Baturadja stage", Lower-Miocene. A thick series of quartz conglomerates and sandstones with a few coal beds.

(e) "Telisa beds", Middle-Miocene. A "monotonous" series of marls and shales, andesitic tuffs, glauconitic sandstones, thin or concretionary limestones, and occasional beds of plant remains.

(f) Lower, middle, and upper Palembang beds, late Miocene and Pliocene. A group of sandstones, marls, mudstones, tuffs, bentonite, etc., calcareous and glauconitic at bottom, but increasing upward in lignite, and especially in the proportion of tuffaceous matter; uppermost beds are almost entirely of tuffs and bentonite. A gradual transition from shallow marine, through lagunal, to fully terrestrial conditions is indicated.

Borneo.

Upper-Triassic in central and western Borneo was distinctly continental in origin. Components include conglomerates, various sandstones, and shales, but no limestones. Conglomerates contain pebbles of acid plutonic rocks, Permo-Carboniferous sedimentaries, and basal schists. An igneous facies of Upper-Trias includes flows and tuffs of acidic to intermediate composition. Triassic formations are most widely exposed in headwater regions of Kapuas and Mahakam Rivers, on west slopes of Schwaner and Muller Mountains; also along the Sarawak border.

Lower-Tetiary "plateau sandstone" consists of cross-bedded quartz- or arkose-sandstones, sometimes conglomeratic, and with occasional coal seams. Around Silat, the series includes a lagunal clay facies. The formation is well exposed in the area, including the "lake district", lying between the Schwaner and Muller ranges and the south boundary of Sarawak.

"Continental volcanic series" (Lower-Tertiary) has a basal conglomerate, followed by a thick sequence of alternating sandstones and shales, somewhat calcareous at bottom. Upper parts include thin coals and richly bituminous shales, followed by flows and tuffs ranging from basaltic to dacitic. This formation is exposed along the southern border of the lake district north of Semitau, and eastward to the Muller Mountains.

Celebes.

Upper-Tertiary "Celebes molasse" (Mio-Pliocene) formations occur in many small areas, especially numerous at the center and on the east arm of the island (Plate VI). In the latter region, an upper stage of conglomerate and sandstone is separated from a similar but more tuffaceous and calcareous lower stage by a middle group of marly sandstones and foraminiferal limestone. Similar shallow marine or shore deposits have been known to carry (usually secondary) uranium minerals.

Timor.

Early Triassic formation, as best exposed in north-central Indonesian Timor, consist mainly of alternating shales, sandstones, and graywackes, often micaceous and occasionally enclosing fossil plants, also siliceous or ferruginous concretions. Elsewhere, such typically flysch deposits have proved uraniferous. The evidence of an interstitial migration of mineralizing solutions, to consolidate the concretions, favors the occurrence of uranium minerals, especially in proximity of fossil vegetation.

Java.

Eocene formations, best exposed in southern Bantan Residency of westernmost Java, are all shallow marine deposits derived from an area (now submerged) of schists and granites. The lowest (most southern) measures include quartz-sandstones, conglomerates, black shales, tuffs, and coal seams. Further north, the series becomes more calcareous.

Bintan Island.

Along the southwest coast of this member of Riouw Archipelago, a few small, disconnected areas of Lower-Tertiary sediments are exposed (Plate X). Since these deposits were certainly derived from an area, exposed to denudation since the end of Jurassic time, and comprising large masses of highly radioactive granite (Westerveld's group I), their importance as possible sources of primary or secondary uranium minerals may be greater than is suggested by their diminutive size.

VIII. REFERENCES

1. Statesman's Year-Book, 1957. St. Martin's Press (New York, 1957).

2. Columbia Lippincott Gazetteer of the World. Col. Univ. Press. (New York, 1952).

3. Lobeck, A. K. Physiographic diagram of Asia (1945 small-scale edition, reprinted 1949). Geographical Press, Columbia University, New York.

4. Valentine, W. G. Bibliographic report on East Indies, January 1947 (private report).

5. Bemmelen, R. W. van. "Geology of Indonesia", vol. 1-A, General Geology, 732 pp., vol. 1-B, portfolio of 60 maps. Govt. Printer, The Hague, 1949.

6. Reinhard, M. and Wenk, E. Geology of the Colony of North Borneo. Geol. Surv., Brit. Terrs. in Borneo, Bull. 1 (H. M. Stat. Office, London, 1951) 160 pp., maps.

7. Brouwer, H. A. et al. Geological explorations on the Island of Celebes. North Holland Publishing Co. (Amsterdam, 1947) 346 pp. and maps. The section (pp. 177-346) on petrology of the metamorphic rocks is by C. G. Egeler.

8. Montgomery, J. N. et al. Outline of the geology of Australian New Guinea. Vol. I, chap. XIV (pp. 662-685), of "Geology of Australia" by T. W. E. David and W. R. Browne (1950).

9. Glaessner, M. F. Geotectonic position of New Guinea. Am. Assoc. Petrol. Geols., Bull., vol. 34, No. 5 (May 1950) 856-881.

10. Umbgrove, J. H. F. Geological history of the East Indies. Am. Assoc. Petrol. Geols., Bull., vol. 22, No. 1 (1938) 1-70; maps.

11. Allen, A. W. Geology of the Lundu District, West Sarawak. A chapter (pp. 41-85) in F. W. Roe's annual report for 1952 of the Geological Survey of British Territories in Borneo (Kuchang, 1954).

12. Brouwer, H. A. Geology of the Netherlands Indies. Univ. Michigan Studies, Sci. Ser., vol. 3. (Macmillan, New York, 1925) 160 pp.

13. Brouwer, H. A. Carboniferous and Permian of the Netherlands East Indies. Proc. 2d Pacific Sci. Cong., vol. 2 (1923) 1024-27.

14. Umbgrove, J. H. F. Structural history of the East Indies. Cambridge Univ. Press (1949) 62 pp.; maps.

15. Roe, F. W. Geol. Surv. Brit. Terrs. in Borneo, Ann. Rept. for 1953 (Kuchang, 1954) 127 pp. and maps.

16. Westerveld, J. Radioactivity and chemistry of some Indonesian eruptive rocks. Verhandelingen der Koninklijke Nederlandse Akademie van Wetenschappen, AFD. Natuurkunde, Erste Recks, Deel XX, No. 4. North Holland Pub. Co. (Amsterdam, 1954), 52 pp., maps, and bibliography. (English).

17. Westerveld, J. Phases of mountain building and mineral provinces in the East Indies. XVIII Internat. Geol. Congr. (1952), Reports, pt. 13, pp. 245-55; sketch map.

18. Bemmelen, R. W. van. "Geology of Indonesia", vol. II, Economic Geology. Govt. Printing Office (The Hague, 1949) 265 pp., and maps.

19. Edwards, A. B. and Glaessner, M. F. Mineral resources of the western Pacific islands. Austral. Inst. Min. & Met., Proceedings, n. s. No. 146-7 (1947) 75-227; maps.

20. Boomgart, L. Tectonics and ore deposits of Mangani. Geol. & Mijnbouw, vol. 10, No. 11 (Nov. 1948) 293-8; English.

21. Haan, W. de. The Mangani vein system. Geol. & Mijnbouw, vol. 10, No. 11 (Nov. 1948) 298-300; English.

22. Haan, W. de. Over de goud-zilverhouding in de jonge edelmetaalformatie op Sumatra. Geol. & Mijnbouw, vol. 5, No. 5-6 (May-June 1943) 33-47.

23. Westerveld, J. The tin ores of Banka, Billiton, and Singkep. Econ. Geol., vol. 32, No. 8 (Dec. 1937) 1019-41.

24. Bodenhausen,, J. W. A. The mineral assemblage of some residual monazite and zenotime-rich cassiterite deposits of Banka. Koninklijke Nederlandsche Akademie van Wetenschappen, Proc., vol. 57, No. 3 (Amsterdam, 1954) 322-28. English.

IX. GAZETTEER

	Latitude	Long. E.
Aer Si Hajo, Sumatra	N. 0° 57'	99° 25'
Amfoan, Timor	S. 9 35	123 52
Badau, Billiton Id.	S. 2 50	107 48
Bajah, Java	S. 6 55	106 15
Bajang Mts., Borneo	N. 1 00	109 50
Balikpapan, Borneo	S. 1 13	117 00
Balung mines, Sumatra	N. 0 10	100 50
Bandjermasin, Borneo	S. 3 20	114 35
Bangka Island, center	S. 2 30	106 00
Banggai Island	S. 1 40	123 30
Bangkulu Id., Banggai Arch.	S. 1 50	123 05
Batam Id., Riouw Arch.	N. 1 10	104 00
Batavia (Jakarta), Java	S. 6 12	106 50
Batu Bertulis, Mt., Sumatra	S. 2 52	102 00
Baturadja, Sumatra	S. 4 07	104 10
Belinju, Bangka Id.	S. 1 38	105 45
Bengkajan, Borneo	N. 0 50	109 30
Benkulen City, Sumatra	S. 3 48	102 15
Betung R., headwaters, Borneo	N. 0 20	112 30
Biak, Celebes	S. 0 55	122 52
Biang, Cape, Sumatra	N. 0 15	99 10
Billiton Island, center	S. 2 50	108 00
Bintan Id., Riouw Arch.	N. 1 00	104 30
Bintuhan, Sumatra	S. 4 46	103 20
Bismarck Mts., N. E. New Guinea	S. 5 30	145 00
Blantu, Billiton Id.	S. 3 14	107 35
Bojan R., headwaters, Borneo	N. 0 15	112 30
Buitenzorg, Java	S. 6 35	107 00
Burungmandi, Cape, Billiton Id.	S. 2 45	108 17
Carstensz, Mt., New Guinea	S. 4 05	137 10
Ceram (Serang) Island, Moluccas	S. 3 00	129 00
"Chinese Districts", Borneo, approx.	N. 0 30	110 00
Cowie Harbor, Brit. No. Borneo	N. 4 10	117 55
Cyclops Mts., New Guinea	S. 2 30	140 00
Darvel Bay, Brit. No. Borneo	N. 4 50	118 20
Datu peninsula, Sarawak	N. 2 00	109 30
Dendang, Billiton Id.	S. 3 05	108 00
Djambi distr., Sumatra, approx. center	S. 1 30	102 30
Djebus, Bangka Id.	S. 1 45	105 27

	Latitude	Long. E.
Flores Id.	S. 8° 30'	121° 00'
Gumai Mts., Sumatra	S. 3 50	103 00
Jakarta (Batavia), Java	S. 6 12	106 50
Jogjakarta, Java	S. 7 49	110 20
Kampar River, headwaters, Sumatra	N. 0 05	100 30
Kapuas River, headwaters, Borneo	N. 0 30	113 30
Kapuas River, mouth, Borneo	S. 0 15	109 10
Karangnunggal, Java	S. 7 30	108 00
Karangtjapis, Cape, Java	S. 7 12	106 24
Karimun Id., Riouw Arch.	N. 1 05	103 23
Kerijau River, headwaters, Borneo	N. 0 30	113 30
Ketapang (Matan), Borneo	S. 1 50	109 59
Ketunggau, Borneo	N. 0 40	110 45
Kimanis Bay, Brit. No. Borneo	N. 5 30	115 40
Kinabalu, Mt., Brit. No. Borneo	N. 6 02	116 30
Klappa Kampit mine, Billiton Id.	S. 2 43	108 05
Klaten, Java	S. 7 43	110 35
Koba, Bangka Id.	S. 2 30	106 25
Kudat peninsula, Brit. No. Borneo	N. 6 53	116 55
Kundur Id., Riouw Arch.	N. 0 45	103 25
Kutei distr., Borneo	N. 0 40	116 20
Lahat, Sumatra	S. 3 50	103 20
Lais, Sumatra	S. 3 32	102 03
Lalan Asu Mts., Timor	S. 9 55	123 50
Landak R., headwaters, Borneo	N. 0 55	110 00
Landak R., mouth, Borneo	S. 0 05	109 10
Lampong district, Sumatra	S. 4 50	105 00
Lebong, Sumatra	S. 3 02	101 56
Lesum, Cape, Bangka Id.	S. 1 40	105 21
Letti island	S. 8 10	127 40
Limau Mts., Sumatra	S. 1 00	102 30
Lubuk Sikaping, Sumatra	N. 0 08	100 10
Lubuk Sulassih, Sumatra	S. 1 00	100 30
Lumut Mts., Borneo	S. 2 00	115 45
Lundu, Sarawak	N. 1 41	109 51
Mahawa village, Borneo	S. 1 55	110 40
Malang Dojong Id., N. W. of Bangka	S. 1 45	105 25
Mampawah, Borneo	N. 0 20	108 55
Mana, Sumatra	S. 4 29	102 55
Mangani, Sumatra	S. 0 09	100 16
Manindjau, Lake, Sumatra	S. 0 20	100 10
Manungul village, Borneo	S. 3 30	115 00

	Latitude	Long. E.
Matan (Ketapang), Borneo	S. 1° 50'	109° 59'
Melawi, Borneo	S. 0 20	112 30
Melawi R., headwaters, Borneo	S. 0 15	113 20
Meratus Mts., Borneo	S. 3 42	115 00
Merawan, Java	S. 8 15	114 00
Miri, Sarawak	N. 4 22	114 07
Mollo Mts., Timor	S. 9 30	124 00
Montrado, Borneo	N. 0 45	109 10
Morobe, Austral. New Guinea	S. 7 45	147 40
Muller Mts., Borneo, approx. center	N. 0 30	113 45
Muntok, Bangka Id.	S. 2 03	105 10
Mutis, Timor	S. 9 30	124 10
Muara Enim, Sumatra	S. 4 20	103 30
Muara Labuh, Sumatra	S. 1 30	101 03
Muara Sipongi mine, Sumatra	N. 0 45	99 45
Nangatajap, Borneo	S. 1 31	110 36
Nassau Mts., Ned. New Guinea	S. 4 00	137 30
Natal, Sumatra	N. 0 33	99 12
Obi island, Moluccas	S. 1 30	127 30
Ocussi, Timor	S. 9 14	124 22
Owen Stanley Mts., Papua, New Guinea	S. 8 30	147 00
Padang, Sumatra	S. 0 58	100 22
Pagimana, Celebes	S. 0 48	122 39
Painan, Sumatra	S. 1 21	100 35
Pajahkumbu, Sumatra	S. 0 14	100 38
Paleleh Bay, Celebes	N. 1 00	121 55
Palembang City, Sumatra	S. 2 59	104 45
Panaraga, Java	S. 7 50	111 28
Pangkalpinang, Bangka Id.	S. 2 08	106 07
Parang Mt., Java	S. 6 36	107 21
Pasawahan, Java	S. 7 08	106 37
Poh, Celebes	S. 0 45	122 50
Pontianak, Borneo	S. 0 02	109 20
Prince Alexander Mts., N. E. New Guinea	S. 3 30	143 30
Purwakarta, Java	S. 6 34	107 28
Raja, Cape, Bangka Id.	S. 1 53	106 10
Raja, Mt., Sumatra	S. 2 40	102 33
Rejang R., mouth, Sarawak	N. 2 30	111 30
Rewas R., headwaters, Sumatra	S. 2 45	102 15
Sambas, Borneo	N. 1 22	109 15
Sawal Mt., Java	S. 7 10	108 20
Schrader Mts., N. E. New Guinea	S. 5 00	144 00
Schwaner Mts., Borneo, approx. center	S. 0 40	112 30

	Latitude		Long. E.	
Sekampung River, headwaters, Sumatra	S. 5°	10'	104°	30'
Semangka Mts., Sumatra	S. 5	30	104	25
Semangka Bay, Sumatra	S. 5	35	104	30
Sembakong R., headwaters, Brit. No. Borneo	N. 4	55	116	30
Semitau, Borneo	N. 0	32	111	58
Seputih River, headwaters, Sumatra	S. 5	10	104	30
Seria, Brunei	N. 4	36	114	22
Setrong Mt., Bangka	S. 2	35	105	55
Sibumbun Mts., Sumatra	S. 0	35	100	40
Silat, Borneo	N. 0	15	112	00
Silubat, Mt., Borneo	N. 0	20	112	30
Singkarak, Lake, Sumatra	S. 0	40	100	30
Singkawang, Borneo	N. 0	57	108	56
Singkep Island, center	S. 0	30	104	30
Sintang, Borneo	N. 0	09	111	35
Slāung, Java	S. 8	02	111	25
Snow Mts., New Guinea	S. 4	10	137	00
Subang Mt., Java	S. 6	35	107	00
Sukabumi, Java	S. 6	55	106	57
Sukadana distr., Borneo	S. 1	15	109	57
Sula islands, Moluccas	S. 2	00	125	00
Sumalata, Cape, Celebes	N. 1	00	122	30
Sumbawa Id.	S. 9	00	118	00
Sungeiliat, Bangka Id.	S. 1	52	106	07
Surabaya, Java	S. 7	18	112	46
Surulangun, Sumatra	S. 2	35	102	46
Tendjolaut, Java, approx.	S. 7	40	108	15
Tandjungpandan, Billiton Id.	S. 2	45	107	40
Tapanuli Residency, Sumatra	N. 1	00	99	00
Tarakan Island, Borneo	N. 3	20	117	45
Tasikmalaja, Java	S. 7	20	108	15
Tegalredjo, Java	S. 8	00	111	25
Telegan Id., Lepor group	S. 2	50	107	05
Tirtamaja, Java	S. 7	37	111	03
Tjibeber, Java	S. 6	57	107	08
Tjikarang River basin, Java	S. 7	15	107	00
Tjikondang, Java	S. 7	00	107	07
Tjilajuh, Java	S. 7	30	107	30
Toba, Lake, Sumatra	N. 2	30	98	45
Toboali, Bangka Id.	S. 3	00	106	25
Totok, Celebes	N. 0	50	124	43
Torrecelli Mts., NE. New Guinea	S. 3	25	142	30
Umbilin, Sumatra	S. 0	17	100	20
Wetar Id., Lesser Sundas	S. 7	45	126	15

Scale 1:4,000,000

BASE: *EAST INDIES* 1:4,000,000 G.S.G.S No. 3860, 1928-AMS 1, 1942; Sheets 1 and 2.

OTHER SOURCES: *ATLAS VAN TROPISCH NEDERLAND* Koninklijk Nederlandsch Aardrijkskundig Genootschap, Batavia; 1938.

INDEX TO PLATE SEPARATION

Plate No. 1	Border, neatline, grid, international boundaries, country names, scales, title, legend, cape names, island names, credits, glossary, and sources.
Plate No. 2	City symbols and names.
Plate No. 3	Coastline, rivers, lakes, swamps, and hydrographic names.
Plate No. 4	Water tone.
Plate No. 5	Provincial boundaries and provincial capitals.
Plate No. 6	Railroads, roads and physiographic names.
Plate No. 7	Study area boundary.

GENERAL BASIC INFORMATION

- International boundary
- Provincial boundary
- National capital
- Amboina — Provincial capital
- Railroad, selected
- Road, selected
- Trail, selected
- Swamp or marsh

11811.12 (East) 11-52

PLATE 1 EAST

Scale 1:4,000,000

BASE: *EAST INDIES* 1:4,000,000, G.S.G.S., No. 3860, 2nd edition 1928-AMS 1, 1942; Sheet 1.

OTHER SOURCES: *ATLAS VAN TROPISCH NEDERLAND* Koninklijk Nederlandsch Aardrijkskundig Genootschap, Batavia; 1938.

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Plate 5. Provincial boundaries and provincial capitals.
Plate 6. Railroads, roads and physiographic names.
Plate 7. Study area boundary.

GENERAL BASIC INFORMATION

- International boundary
- Provincial boundary
- National capital
- Medan — Provincial capital
- Railroad or tramline, selected
- Road, selected
- Swamp or marsh

11811.12 (West) 10-52

PLATE 1 WEST

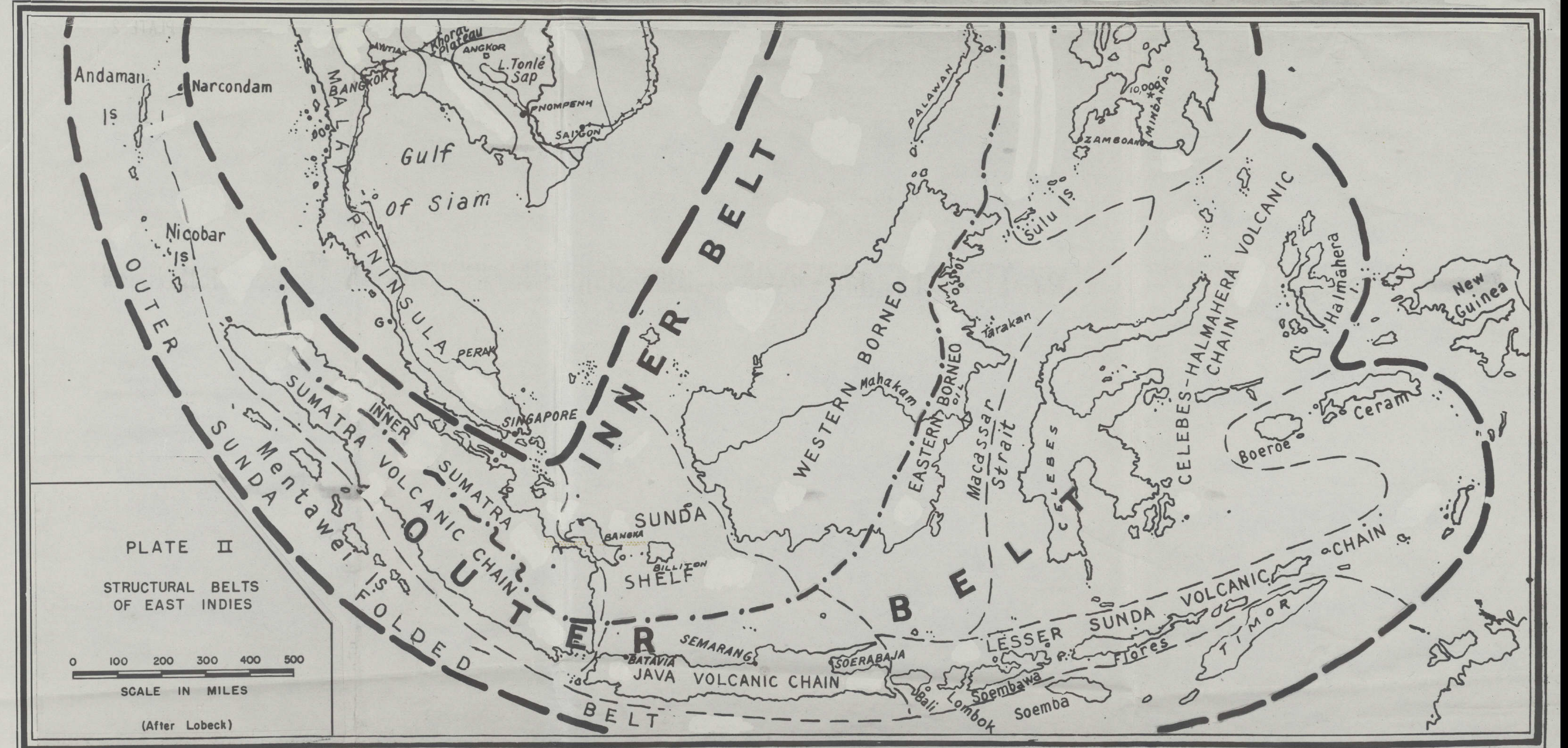


PLATE II

STRUCTURAL BELTS OF EAST INDIES

(After Lobeck)

PLATE 2

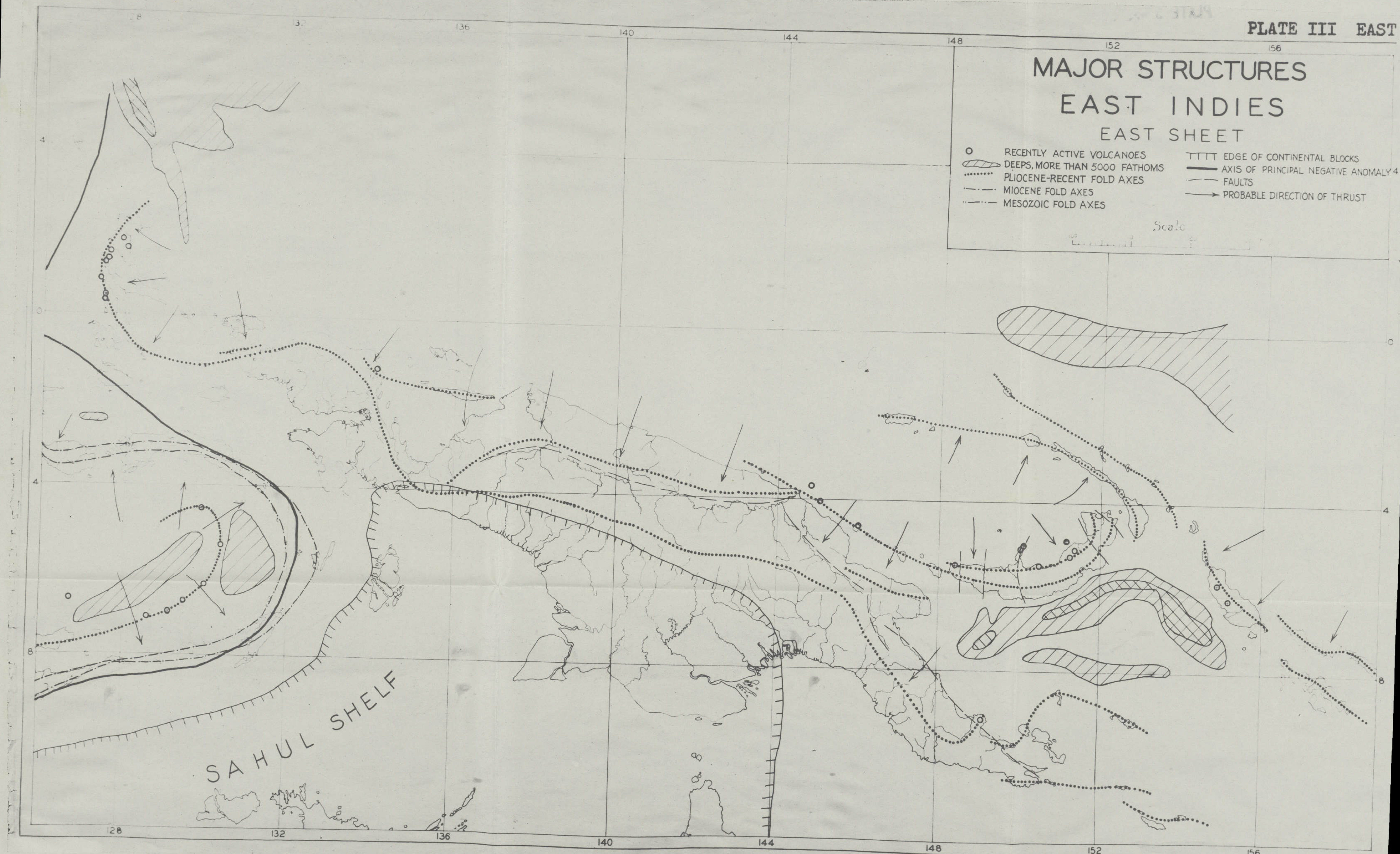

MAJOR STRUCTURES
EAST INDIES
EAST SHEET
RECENTLY ACTIVE VOLCANOES
DEEPS, MORE THAN 5000 FATHOMS
PLIOCENE-RECENT FOLD AXES
MIOCENE FOLD AXES
MESOZOIC FOLD AXES
EDGE OF CONTINENTAL BLOCKS
AXIS OF PRINCIPAL NEGATIVE ANOMALY
FAULTS
PROBABLE DIRECTION OF THRUST
Scale
SAHUL SHELF
128
132
136
140
144
148
152
156
4
0
4
8

PLATE 3 →EAST

PLATE III WEST

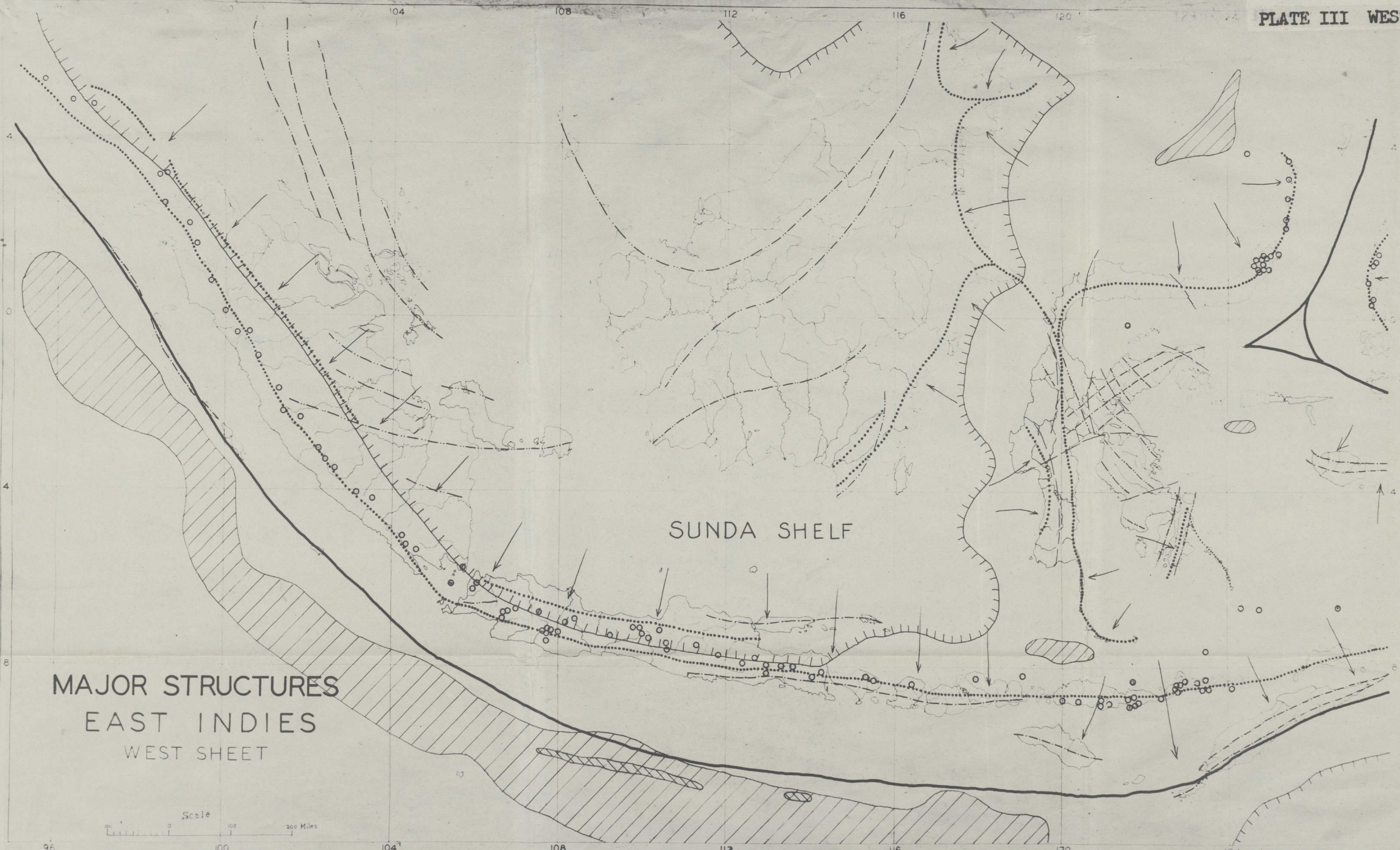


PLATE 3 →WEST

PLATE IV

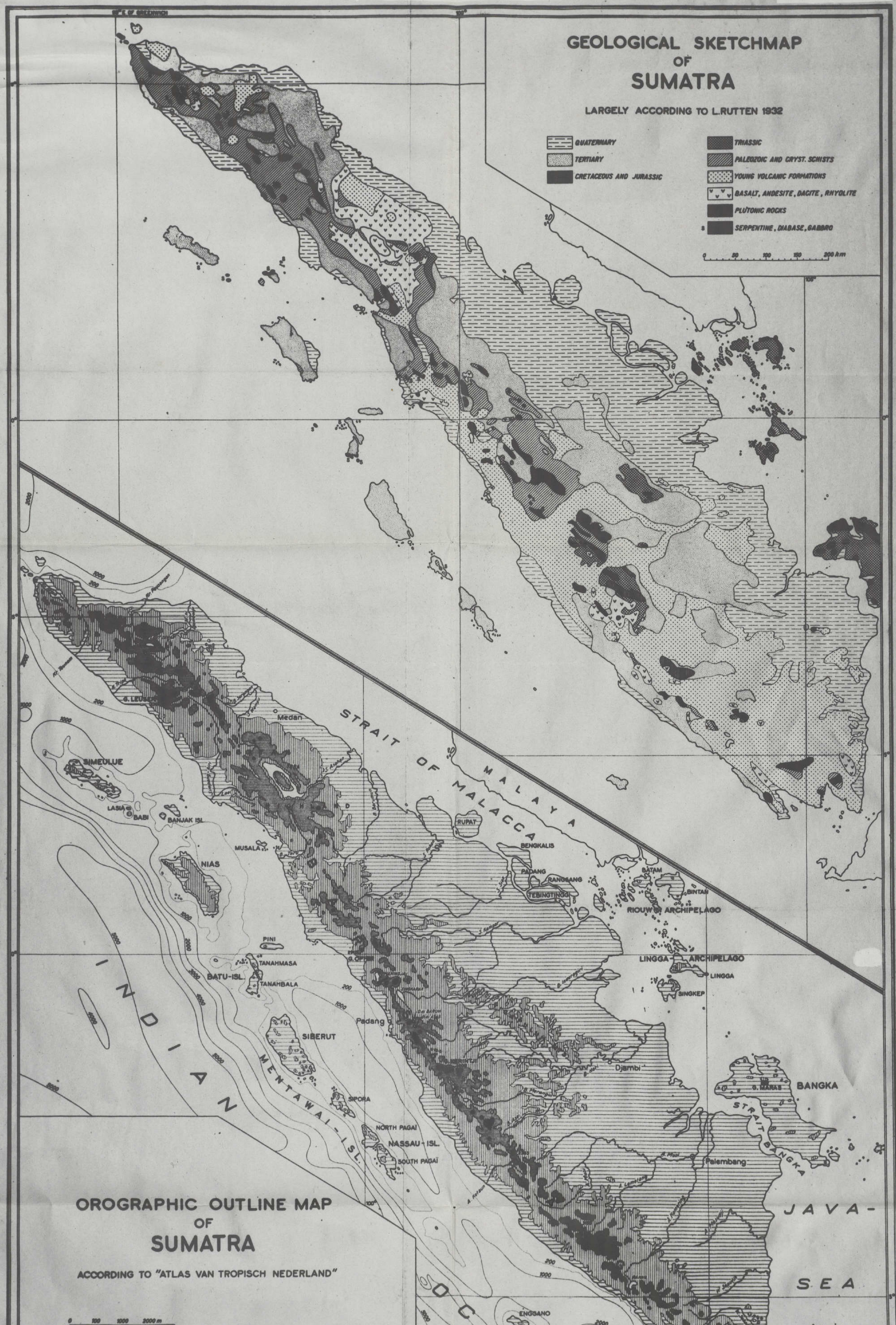
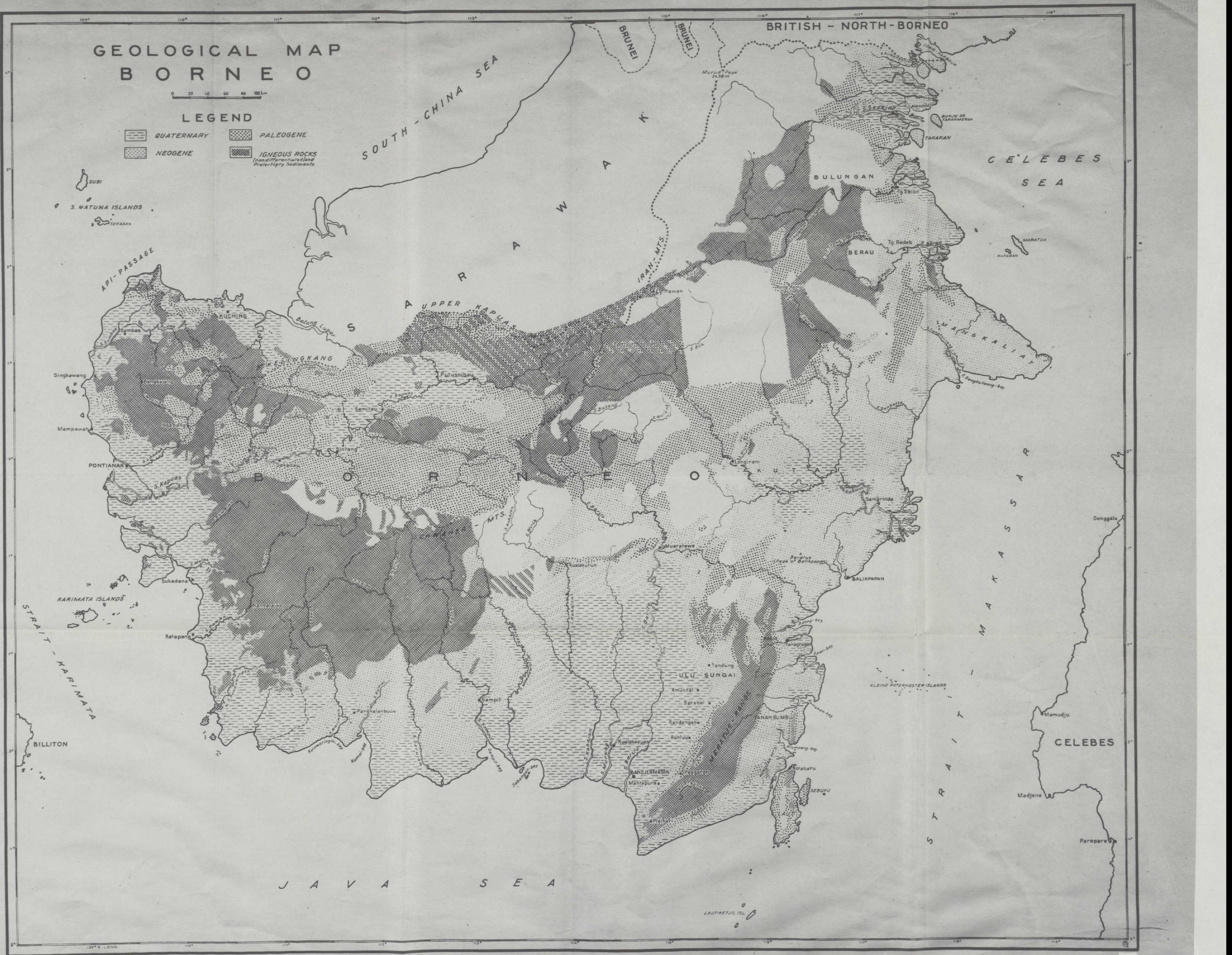

GEOLOGICAL SKETCHMAP
OF
SUMATRA
LARGELY ACCORDING TO L. RUTTEN 1932
QUATERNARY
TERTIARY
CRETACEOUS AND JURASSIC
TRIASSIC
PALEOZOIC AND CRYST. SCHISTS
YOUNG VOLCANIC FORMATIONS
BASALT, ANDESITE, DACITE, RHYOLITE
PLUTONIC ROCKS
SERPENTINE, DIABASE, GABBRO
0 50 100 150 200 km
OROGRAPHIC OUTLINE MAP
OF
SUMATRA
ACCORDING TO "ATLAS VAN TROPISCH NEDERLAND"
0 100 1000 2000 m
0 50 100 150 200 km
STRAIT OF MALACCA
MALAYA
INDIAN
OCEAN
JAVA-
SEA
JAVA
STRAIT BANGKA
BANGKA
Medan
Padang
Djambi
Palembang
SIMEULUE
LASIA
BABI
BANJAK ISL.
MUSALA
NIAS
PINI
TANAHMASA
TANAHBALA
BATU-ISL.
SIBERUT
MENTAWAI-ISL.
SIPORA
NORTH PAGAI
NASSAU-ISL.
SOUTH PAGAI
ENGGANO
RUPAT
BENGKALIS
PADANG
RANGSANG
TEBINGTINGGI
BATAM
BINTAN
RIOUW ARCHIPELAGO
LINGGA ARCHIPELAGO
LINGGA
SINGKEP
105° E. OF GREENWICH

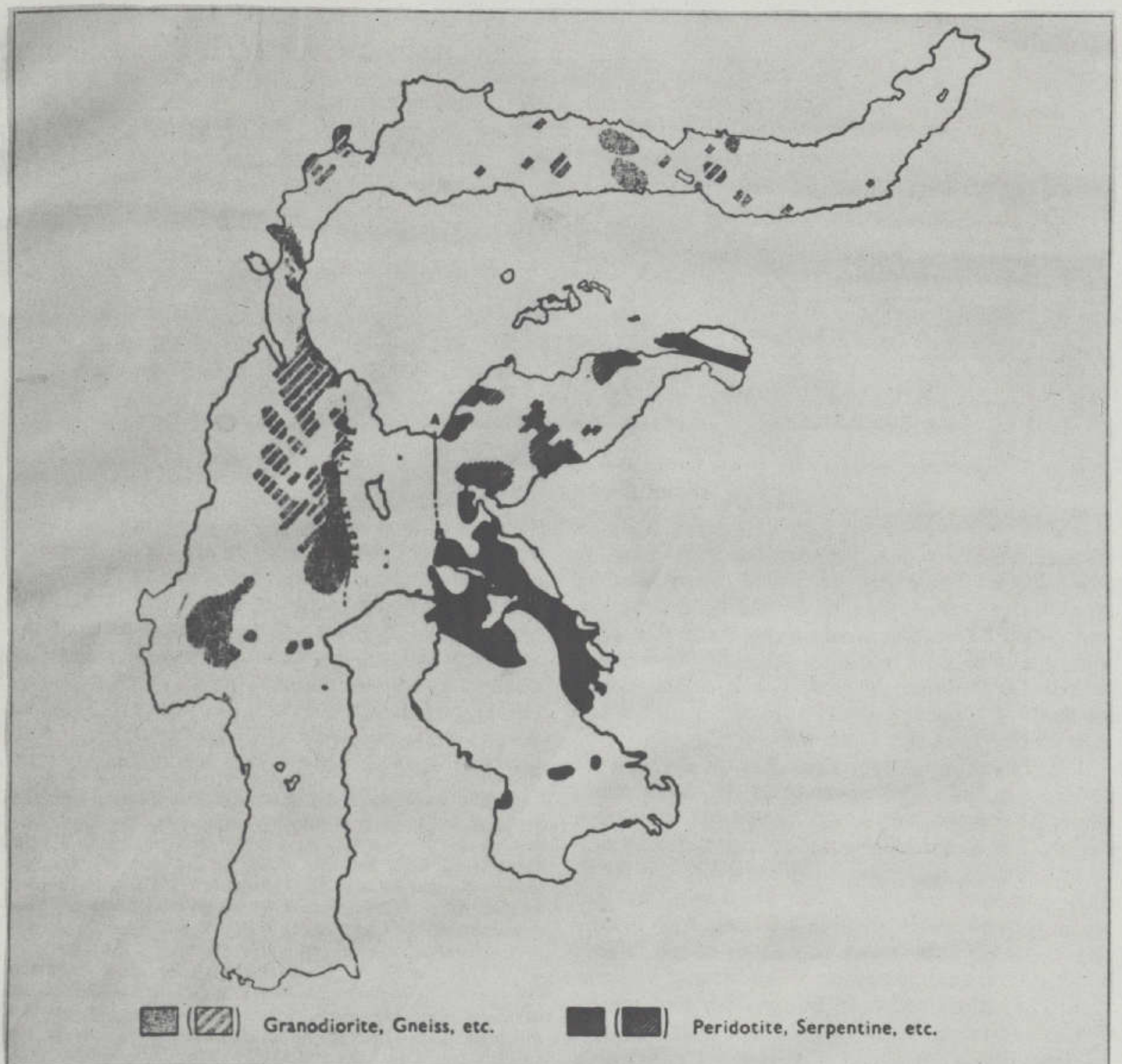
PLATE 4

PLATE V



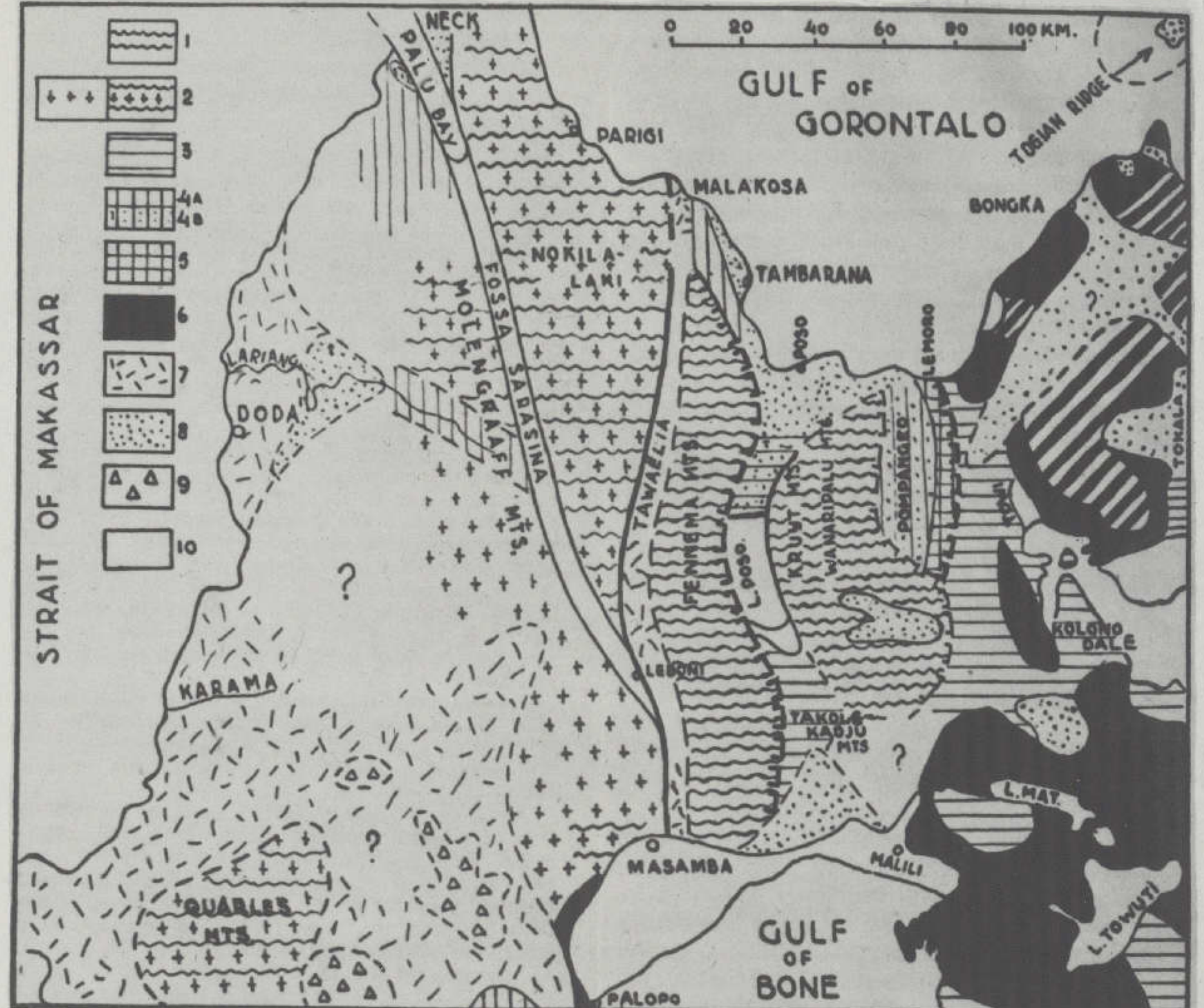
Geological map of West and Central Borneo, according to ZEYLMANS VAN EMMICHOVEN

PLATE 5



Schematic map illustrating the separated occurrences of grano-dioritic and gabbro-peridotitic rocks in Celebes.
(From BROUWER, 1947, fig. 1)

Line A–B: Approximate eastern boundary of the glaucophanitic metamorphism in Central Celebes.

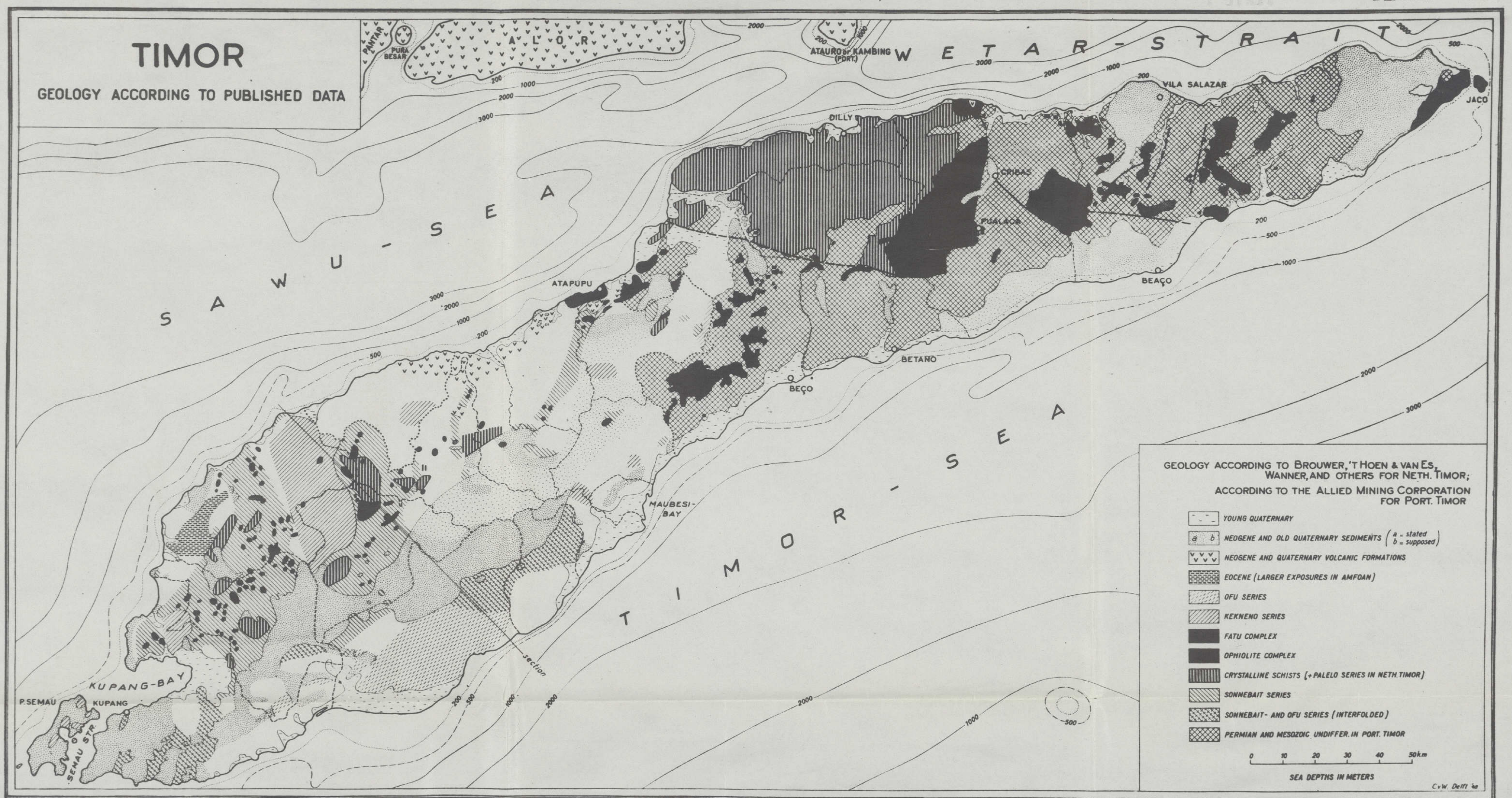


Geological sketchmap of Central Celebes.

Legend:

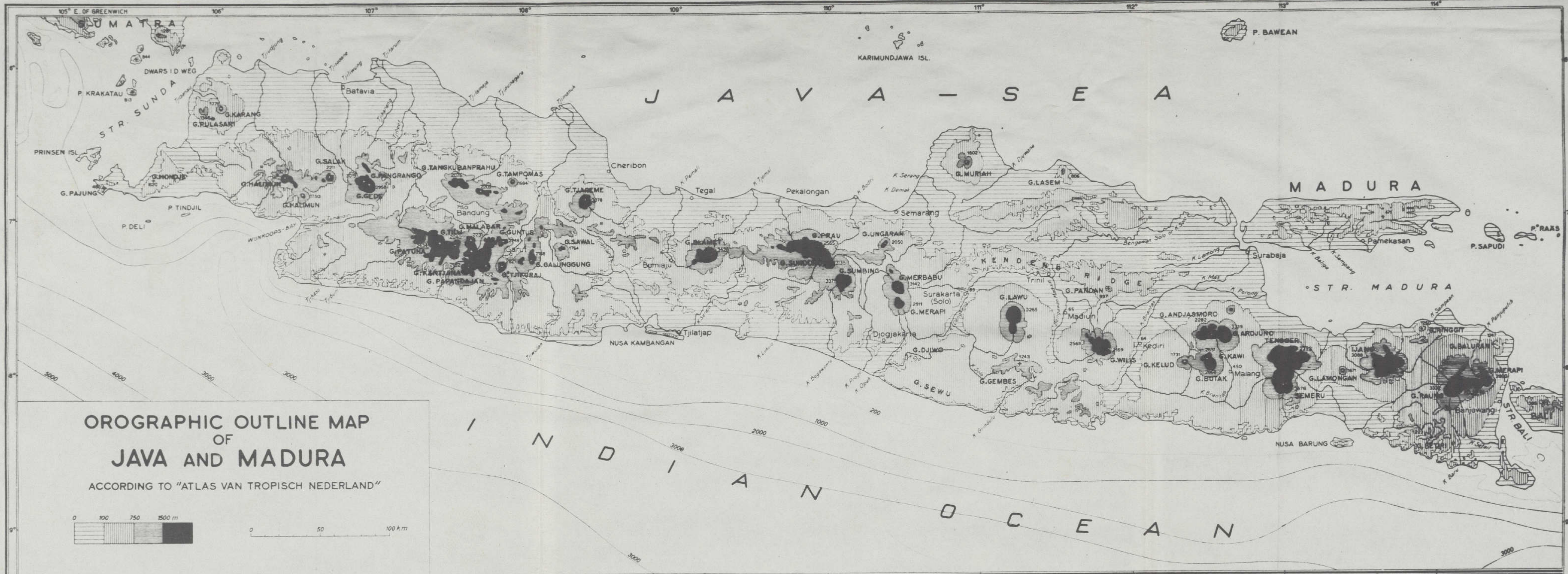
1. Crystalline schists.
2. Plutonic igneous rocks, gneisses, and schists.
3. Mesozoic rocks.
4*a*. Tinombo- and Maroro Formation (Young Mes.-Eoc.).
4*b*. Pompangeo Formation (Young Mesozoic-Eocene).
5. Mixed belt of Peleru.
6. Basic- and ultrabasic rocks (ophiolites).
7. Tertiary of the Palu Zone and the Tawaëlia Graben.
8. Celebes Molasse and elevated coral reefs of the Poso Zone and the East arm.
9. Plio-pleistocene Barupu tuffs.
10. Quaternary alluvium, unknown, sea, and lakes.

PLATE 6



Geological sketchmap of Timor

PLATE 7


OROGRAPHIC OUTLINE MAP
OF
JAVA AND MADURA
ACCORDING TO "ATLAS VAN TROPISCH NEDERLAND"
0
100
750
1500 m
0
50
100 km
105° E. OF GREENWICH
SUMATRA
J A V A – S E A
I N D I A N O C E A N
MADURA
STR. MADURA
STR. SUNDA
STR. BALI
P. BAWEAN
KARIMUNDJAWA ISL.
P. KRAKATAU
PRINSEN ISL.
G. PAJUNG
P. TINDJIL
P. DELI
P. SAPUDI
P. RAAS
NUSA KAMBANGAN
NUSA BARUNG
Batavia
Bandung
Cheribon
Tegal
Pekalongan
Semarang
Surabaja
Pamekasan
Bumiaju
Tjilatjap
Djogjakarta
Surakarta (Solo)
Madiun
Kediri
Malang
Trinil
Banjuwangi
KENDENG RIDGE
G. KARANG
G. PULASARI
G. SALAK
G. GEDE
G. PANGRANGO
G. TANGKUBANPRAHU
G. TAMPOMAS
G. TJAREME
G. MALABAR
G. PATUHA
G. GUNTUR
G. SAWAL
G. GALUNGGUNG
G. PAPANDAJAN
G. SLAMET
G. PRAU
G. SUNDORO
G. SUMBING
G. UNGARAN
G. MERBABU
G. MERAPI
G. MURIAH
G. LASEM
G. LAWU
G. DJIWO
G. GEMBES
G. SEWU
G. PANDAN
G. WILIS
G. KELUD
G. ANDJASMORO
G. ARDJUNO
G. KAWI
G. BUTAK
TENGGER
SEMERU
G. LAMONGAN
G. BALURAN
G. MERAPI
G. RAUNG

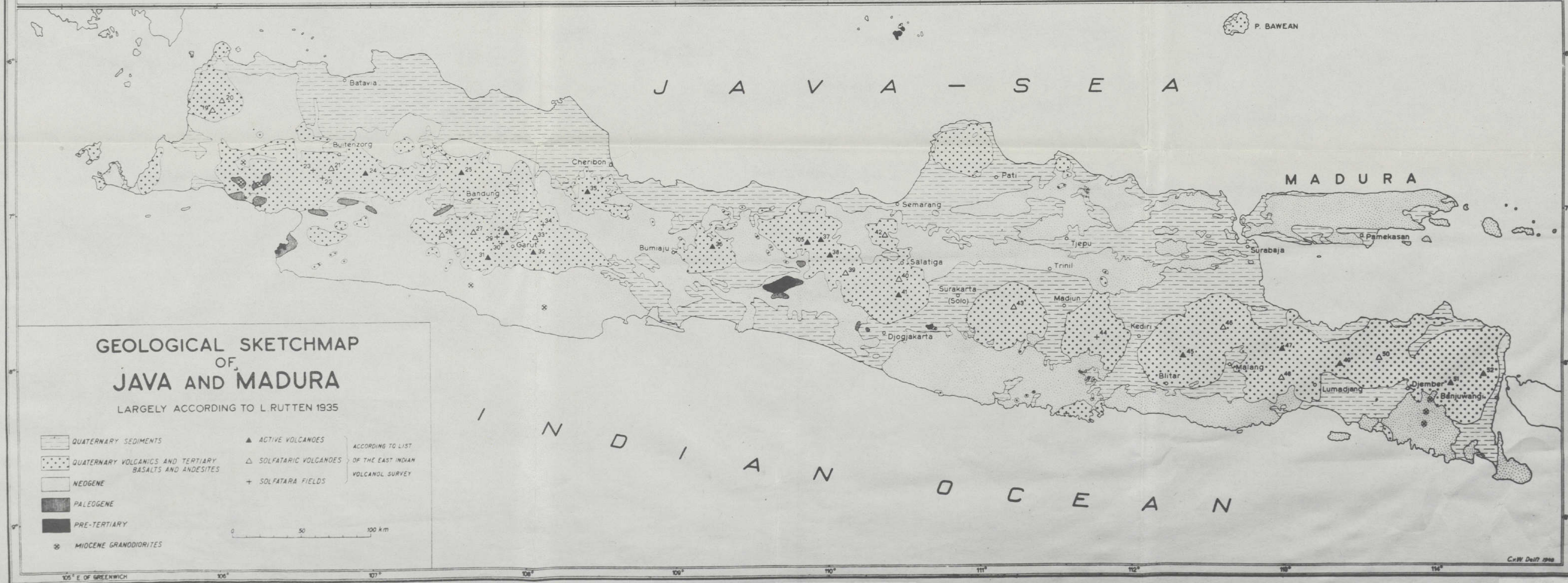
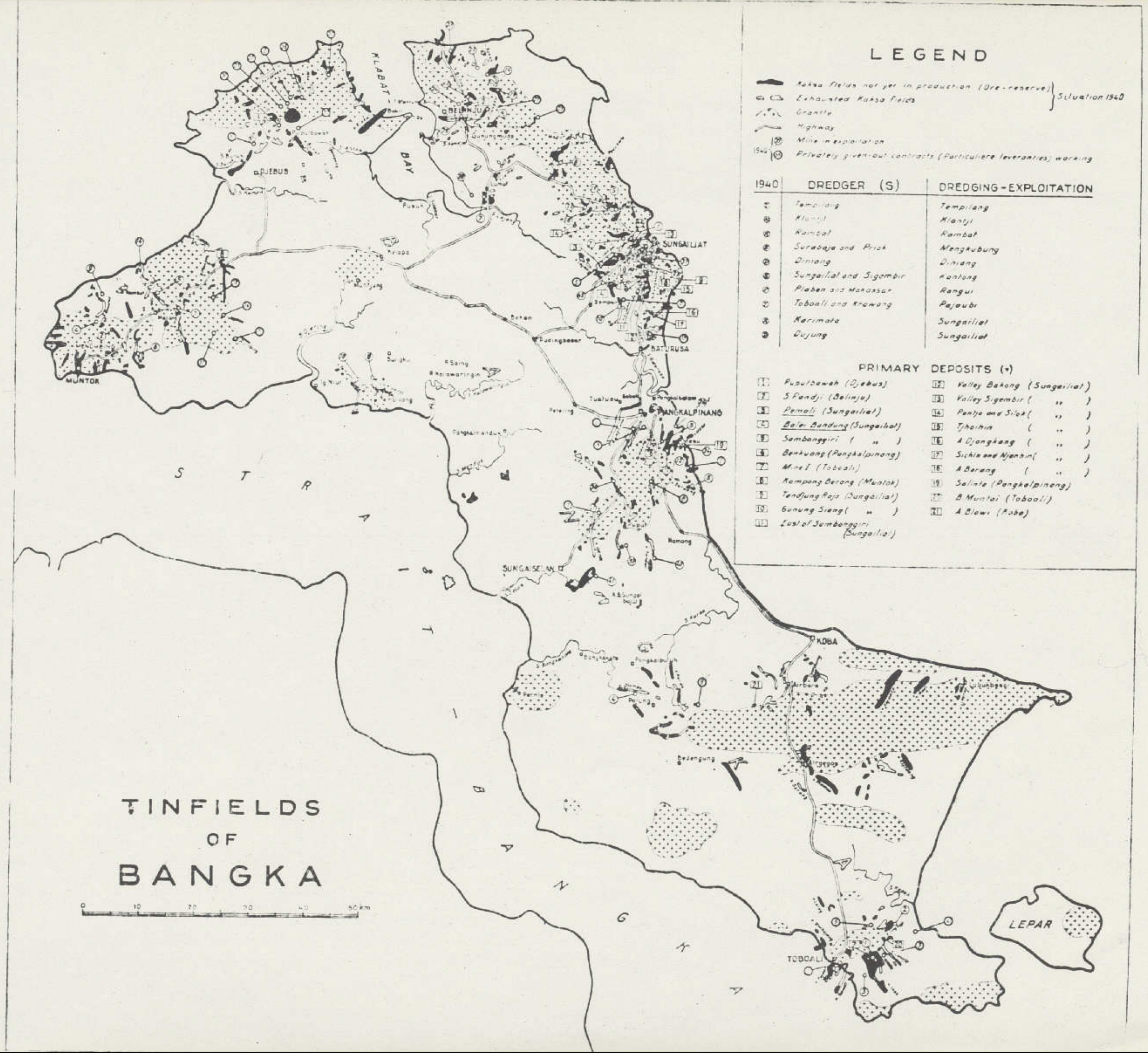
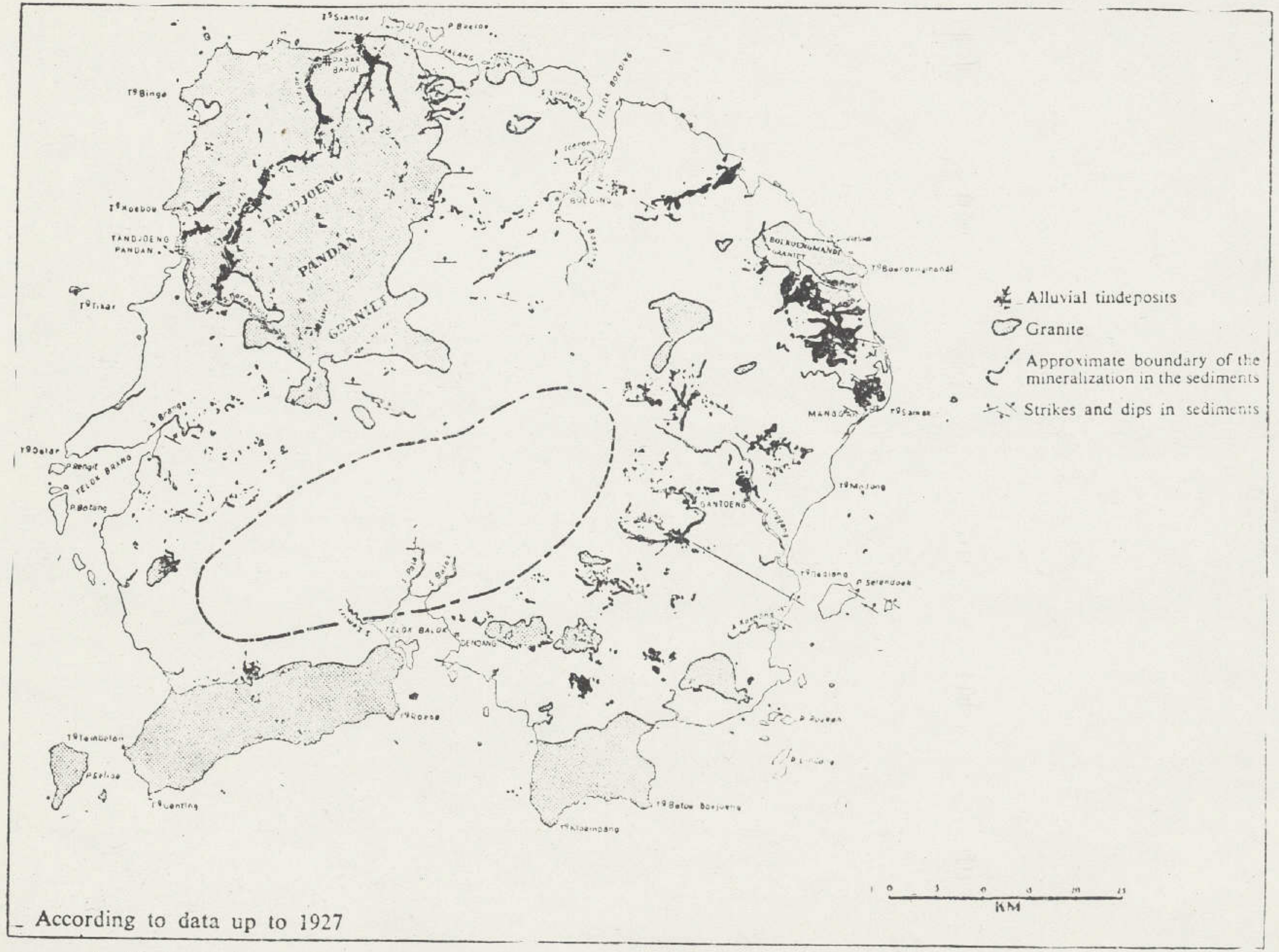

GEOLOGICAL SKETCHMAP
OF
JAVA AND MADURA
LARGELY ACCORDING TO L. RUTTEN 1935
QUATERNARY SEDIMENTS
QUATERNARY VOLCANICS AND TERTIARY BASALTS AND ANDESITES
NEOGENE
PALEOGENE
PRE-TERTIARY
MIOCENE GRANODIORITES
ACTIVE VOLCANOES
SOLFATARIC VOLCANOES
SOLFATARA FIELDS
ACCORDING TO LIST OF THE EAST INDIAN VOLCANOL SURVEY
0
50
100 km
105° E. OF GREENWICH
J A V A – S E A
I N D I A N O C E A N
MADURA
P. BAWEAN
Batavia
Buitenzorg
Bandung
Garut
Cheribon
Bumiaju
Semarang
Pati
Tjepu
Salatiga
Trinil
Surakarta (Solo)
Madiun
Kediri
Djogjakarta
Surabaja
Pamekasan
Blitar
Malang
Lumadjang
Djember
Banjuwangi
C.v.W. Delft 1940

PLATE 8

PLATE IX

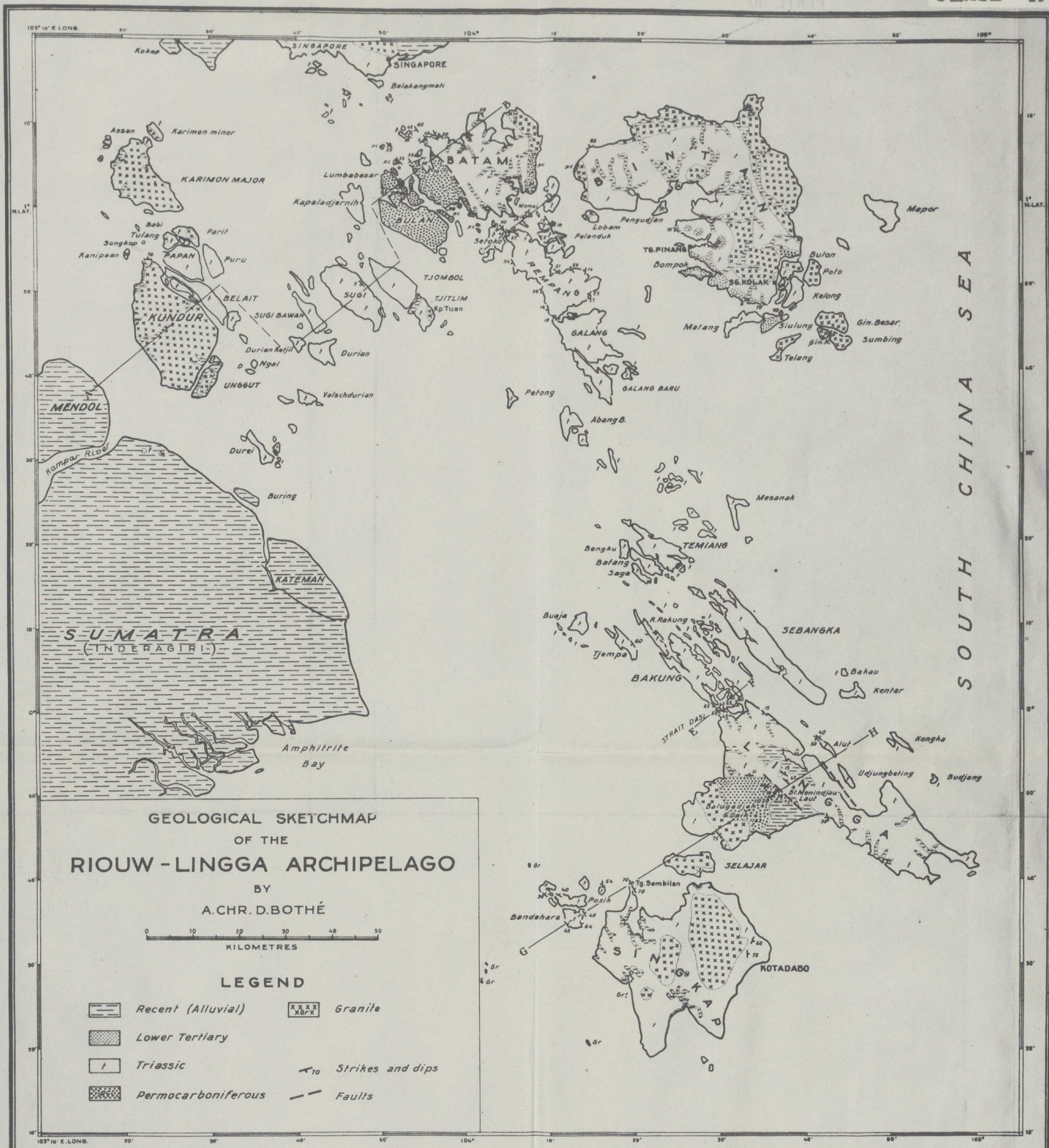




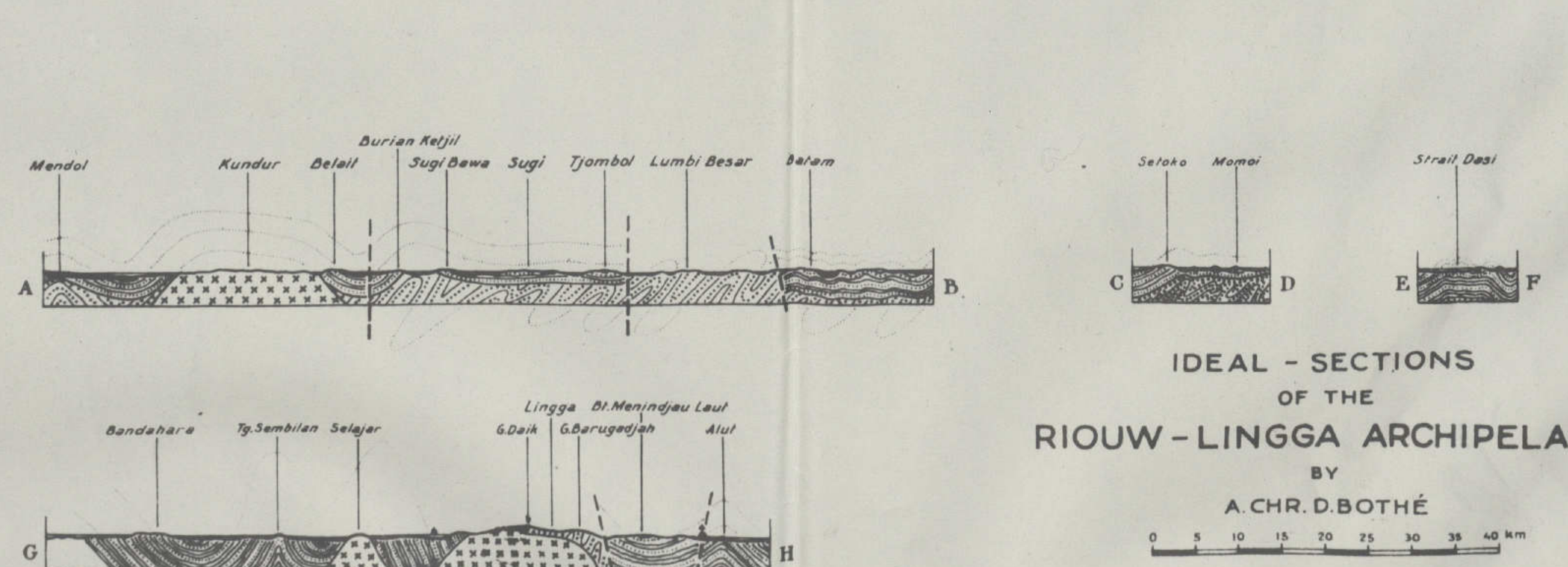
Geological sketchmap of Billiton (according to Westerveld, 1949)

PLATE IX

PLATE X

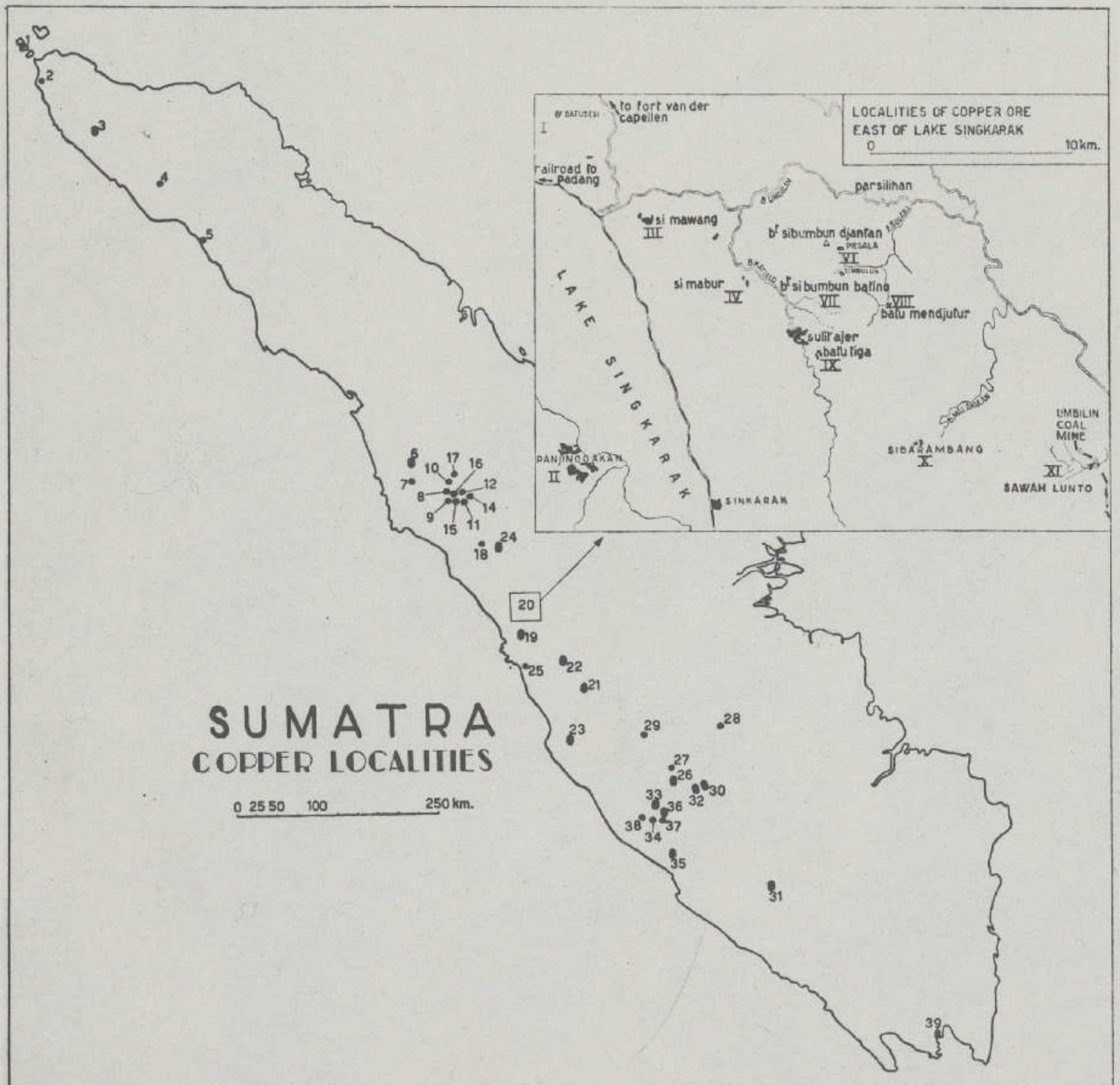


GEOLOGICAL SKETCHMAP
OF THE
RIOUW-LINGGA ARCHIPELAGO
BY
A.CHR. D.BOTHÉ
KILOMETRES
LEGEND
Recent (Alluvial)
Granite
Lower Tertiary
Triassic
Strikes and dips
Permocarboniferous
Faults
SOUTH CHINA SEA
SINGAPORE
Belakangmati
Kokop
Assan
Karimon minor
KARIMON MAJOR
BATAM
BINTAN
Lumbabesar
Kapeladjernih
BULAN
Mapor
Lobam
Pengudjan
Pelanduk
Setoko
TG.PINANG
Bompok
SG.KOLAK
Buton
Poto
Kelong
REMPANG
Babi
Tulang
Sungkop
Kanipaan
Parit
PAPAN
Puru
KUNDUR
BELAIT
SUGI BAWAH
SUGI
TJOMBOL
TJITLIM
Kp.Tuan
GALANG
Malang
Siulung
Gin.Besar
Sumbing
Telang
Durian Ketjil
Durian
Ngal
UNGGUT
Valschdurian
GALANG BARU
Petong
MENDOL
Abang B.
Kampar River
Durei
Buring
Mesanak
TEMIANG
Bengku
Batang
Saga
KATEMAN
SUMATRA
(INDERAGIRI)
Bueja
R.Rakung
SEBANGKA
Tjempa
Bakau
BAKUNG
Kentar
STRAIT DASI
LINGGA
Alut
Kongka
Amphitrite
Bay
Udjungbeting
Budjang
Bt.Menindjau Laut
SELAJAR
Tg.Sembilan
Posik
Bendahara
SINGKAP
KOTADABO



Mendol
Kundur
Belait
Burian Ketjil
Sugi Bawa
Sugi
Tjombol
Lumbi Besar
Batam
A
B
Setoko
Momoi
C
D
Strait Dasi
E
F
Bandahara
Tg.Sembilan
Selajar
Lingga
Bt.Menindjau Laut
G.Daik
G.Barugedjah
Alut
G
H
IDEAL - SECTIONS
OF THE
RIOUW-LINGGA ARCHIPELAGO
BY
A.CHR. D.BOTHÉ
LEGEND
Alluvium
Granite
Lower Tertiary
Triassic
Fossiles
Permocarboniferous
Hotspring

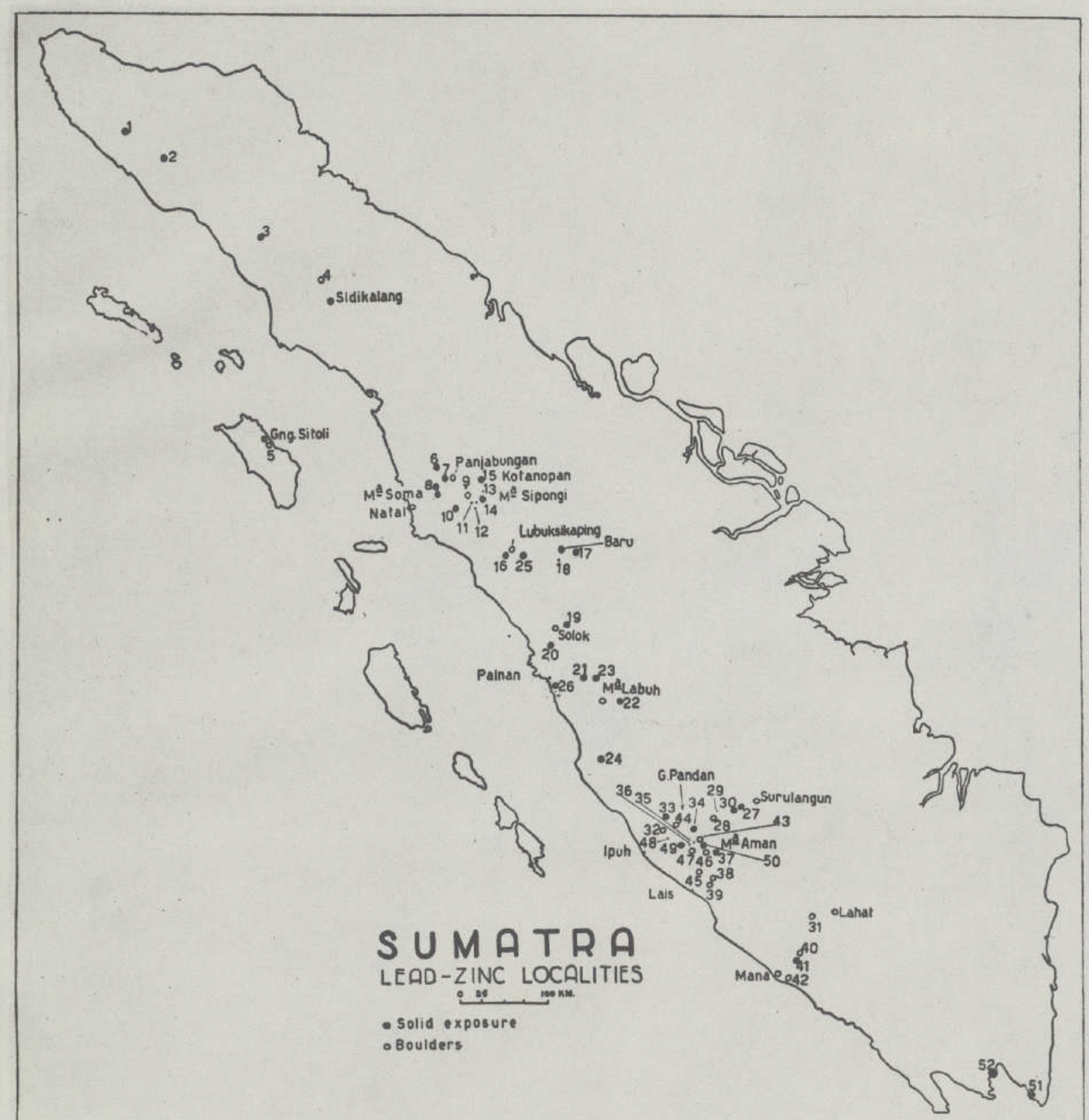
PLATE 10



Copper localities of Sumatra.

Number	Residency	Name
1	Atjeh	Pulu Bras
2		Province Gle Broë
3		Aer Talu
4		Province Beutong
5		Aloe Baru
6	Tapanuli	Aer Si Hajo
7		Muara Soma
8		Singengu
9		Tambang Obi
10		Kota Pungkut
11		Pakanten
12		Malilir
13		Muara Sipongi
14		Aer Sipongi
15		Gunung Marisi
16		Pagaran Si Aju
17		Sidingin
18	Sumatra's West coast	Sumpu
19		Lubuk Sulassih
20		Copper ore deposits around Lake Singkarak:
		I. Gunung Besie
		II. Paningahan
		III. Samawang (Si Mawang)
		IV. Si Mabur
		Deposits in the Sibumbun Mts:
		V. Pasilian
		VI. Timbulon
		VII. Lenawang
		VIII. Batu Mendjulur
		IX. Batu Tiga
		X. Sibrambang
		XI. Sumpahan
21		Sungei Pagu
22		Sulangsi-concessions
23		Tepan (Gunung Korintji)
24		Mangani
25		Gunung Arum
26	Djambi	Talang Kepajang
27		Sungei Bulu
28		Sungei Letung
29		Sungei Sengering
30	Palembang	Sungei Tuboh
31		Kikim-Besar
32		Bukit Rajah
33	Benkulen	Gunung Batu Bertulis
34		Aer Penedjun (Ulu Klumbuk)
35		Taba Tembilang
36		Aer Loh
37		Lebong Sulit
38		Simau-mine
39	Lampong Districts	Gunung Ratai

PLATE XII



Lead and zinc ore localities in Sumatra.

Number	Residency	Name
1	Atjeh	Krueng Beureueng
2		Krueng Isep
3		Pasir Putih
4	Tapanuli	Bulu Laga
5		Nias
6		Si Hajo
7		Huta Bargot
8		Muara Soma
9		Ulu Si Dingin and Ulu Aek Panono
10		Estella
11		Pagaran Si Aju
12		Bukit Pionggu
13		Malilir
14		Gunung Marisi
15	Westcoast of Sumatra	Sidingin
16		Sumpu
17		Balung
18		Batang Bio
19		Batu Mendjulur
20		Lubuk Sulassih
21		Sungei Talang
22		Sungei Pagu
23		Bulangsi
24		Tepan
25		Mangani
26		Gunung Arum
27	Palembang	Sungei Tuboh
28		Aer Kulus
29		Aer Seri
30		Bukit Rajah
31		Kikim Besar
32	Benkulen	Sungei Ipuh Pandjang I
33		Sungei Ipuh Pandjang II
34		Gunung Batu Bertulis
35		Aer Penedjun (Ulu Klumbuk)
36		Aer Saleh
37		Aer Piaten
38		Aer Bagus
39		Taba Tembilang
40		Aer Anget
41		Aer Limpur Tjapaj
42		Aer Kedurang
43		Aer Loh
44		Muara Impu Tanah
45		Lebong Simpang
46		Lebong Donok
47		Lebong Sulit
48		Lebong Kandis
49		Simau
50		Tambang Sawah
51	Lampong Districts	Radjabasa
52		Gunung Ratai