RADIOACTIVITY AND CHEMISTRY OF SOME INDONESIAN ERUPTIVE ROCKS

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(WITH 13 FIGURES AND 11 TABLES)

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ABSTRACT

A collection of Indonesian igneous rocks, covering the four main fold belts and the Quaternary andesite volcanoes W of New Guinea, has been subjected to chemical bulk analyses and to the measurement of, respectively, total radioactive radiation intensities, β-emission intensities, and the Ra content of average powder mixtures, and besides to the determination of total radioactive radiations and β-emissions of individual samples.

Following NIGGLI's scheme of magma types, the tin granites of the islands on the Soenda Shelf appear to be characterized by an "engadinite granitic" or "yosemite granitic", the intrusiva of SW. Borneo by a "leucoquartz dioritic", those of the SCHWANER Mts. and the Chinese Districts in Central and W. Borneo by a "normal quartz dioritic", the lavas of the Quaternary volcanoes by a "normal dioritic", the Mesozoic granites of Sumatra by a "normal granodioritic" to "farsunditic", the Miocene intrusiva of the Soenda orogen by a "farsunditic", the peridotites of the Moluccan orogen by a "peridotitic", and the granites of the Banggai and Soela Islands by a "yosemite granitic" composition. Distinctly higher K_2O and SiO_2 contents distinguish the tin granites of the Soenda Shelf from the intrusive rocks of SW., Central, and W. Borneo, which latter undoubtedly, although being of about the same age as the former, belong to a separate and parallel branch of the late Jurassic Malayan orogen.

Appreciable variations of the mutual proportions between total radiation and β-emission intensities of individual samples, as measured with, respectively, the double ionization chamber and the GEIGER-MÜLLER counter, indicate the existence of relatively strong α-radiators beside relatively strong β-radiators. These fluctuations are very probably due to the variations between mutual proportions of Th- and U-bearing accessories.

Greatest values for total radiations and β-emissions, and Ra contents, were found with the tin granites (with about 3×10^{-12} gr. Ra/gr.), followed next in order by the granites of the Soela and Banggai Islands (with about $2{,}7 \times 10^{-12}$ gr. Ra/gr.). The SW. Borneo intrusiva show relatively high total radiations and β-emissions against a moderate Ra content (about $1{,}3 \times 10^{-12}$ gr. Ra/gr.), owing possibly to high Th: U proportions. Rather low values for both kinds of radiations chacterize the granodiorites of Central and W. Borneo (with about $1{,}2 \times 10^{-12}$ gr. Ra/gr.), the lavas of the Quaternary andesite volcanoes (with about $1{,}3 \times 10^{-12}$ gr. Ra/gr.), and the Miocene granodiorites and diorites of the Soenda orogen, whereas the Mesozoic granites of Sumatra comprise a few stronger radiators, and the peridotites of the Moluccan orogen exclusively very low ones.

Total radioactive radiatons and Ra contents of average powder mixtures representing separate rock clans increase in a rough way with SiO_2 and K_2O weight percentages.

It is concluded that the tin province of the Soenda Shelf does not continue into SW. and Central Borneo. The tin granites deserve attention as possible future sources of fissionable material.

The Soela and Banggai Islands deserve inspection for the possible occurrence of rare pegmatite minerals of Be and Nb-Ta on account of the strong radioactivity of their granites, and other indications.

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PREVIOUS STATUS OF KNOWLEDGE CONCERNING THE CHEMICAL COMPOSITION OF INDONESIAN ERUPTIVE ROCKS AND GENERAL PURPOSE OF THE PRESENT INVESTIGATIONS

Main magmatic provinces of Indonesia

The East Indian Archipelago west of Halmaheira, New Guinea, and the Sahoel [1]) Shelf is undoubtedly the finest example in the world of concentric and arcuate fold structures shaped by Mesozoic and Tertiary orogeny. It has recently been argued explicitly (Westerveld, 1949, 1952 a) that each of the island arcs connecting Burma with the Philippines is characterized by its own types of plutonic rocks and attendant ore deposits. Proceeding from the interior toward the exterior regions, we recognize the following fold systems:

(1) The presumably late Jurassic Malayan orogen, comprising the Malayan Peninsula, the Tin Islands (Riouw Archipelago, Banka, Billiton, etc.), and very probably also parts of West, Southwest, and Central Borneo.

(2) The late Cretaceous (or Paleocene) Sumatra orogen, comprising the pre-Tertiary mountain system of Sumatra (or at least important parts of it), the pre-Tertiary structures of Java (exposed in the South Serajoe Mountains, the Djiwo Hills, and in western Priangan), the Meratoes-Bobaris Mountains in Southeast Borneo, and furthermore also folded Cretaceous beds in the Kapoeas and Landak-Sekajam regions of Central and West Borneo.

(3) The approximately Middle Miocene Soenda orogen, which connects the volcanic region of West Burma with that of Central Mindanao in the Philippines over the coast ranges of Southwest Sumatra, the Southern Mountains of Java, the northern row of Lesser Soenda Islands, the volcanic Inner Banda Arc, the West Arc of Celebes, and the Sanggi Islands.

(4) The Moluccan orogen, connecting the Arakan Yoma Mountains of West Burma with the serpentine belt of eastern Mindanao over the Andamans and Nicobars, the islands off the west coast of Sumatra (Simaloe, Nias, Mentawei Islands, etc.), Timor, the islands of the non-volcanic outer Banda Arc, Ceram, Boeroe, the Boeton Archipelago, the East Arc of Celebes, the small island Tafoeré west of Halmaheira, and the Talaud and Nanoesa Islands; a fold system formed by intensive crustal deformations — *e.g.*, the creation of large-scale overthrusts of an Alpine character — at the end of the Cretaceous or during the Paleocene, with strong after-effects until the middle of the Miocene.

Relics of pre-Mesozoic structures of uncertain age are represented by

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[2]) The Dutch "oe", pronounced as the English "oo" or "u", is maintained in geographical names in this text.

the pre-Upper Carboniferous granites, gneisses, and crystalline schists of Sumatra, the crystalline schists of Central Borneo, probably part of the crystalline schists of Celebes and of some of the islands of the Outer Banda Arc, including Timor and Ceram, and furthermore by the certainly pre-Jurassic crystalline rocks of the Soela and Banggai Islands east of Celebes.

The Malayan orogen, as has been stated, is characterized by post-Triassic (presumably late Jurassic) acid granites on the Malayan Peninsula and the Tin Islands, and by batholiths of a more intermediate composition in Southwest, Central, and West Borneo. The young Mesozoic intrusive rocks of the Sumatra section of the Sumatra orogen comprise peridotites, gabbros, diorites, granodiorites, granites, and attendant dike rocks, among which the granodiorites and granites are by far the commonest. In the Meratoes-Bobaris Mountains of Southeast-Borneo, on the other hand, gabbro-peridotitic rocks build up extensive masses besides acid plutonic bodies. In the Soenda orogen Miocene plutonism produced a rather monotonous suite of diorites, granodiorites, and granites in the coast ranges of Southwest Sumatra, in the Southern Mountains of Java, on Flores and Wetar in the row of Lesser Soenda Islands, and in the West Arc of Celebes (especially in Central and North Celebes). The Moluccan orogen, finally, harbours the longest chain of pre-orogenic gabbro-peridotitic or ophiolithic intrusions on earth. Examples of these rocks are found on the Andamans and Nicobars, the islands off the west coast of Sumatra (Nias, Banjak islands, Sipoera), on Timor and the islands of the Outer Banda Arc (Leti, Moa, Dai, Babar, Lailobar?, Koer, Teor, Watoebela, Manawoko), on Ceram, Kellang, and the Ambon group, and farther on in the East Arc of Celebes, on the small island Tafoeré, and on the Talaud and Nanoesa Islands.

Older than the Mesozoic and Tertiary clans of eruptive rocks are the pre-Upper Carboniferous granites and gneissic granites of Central and South Sumatra (Upper Djambi and Lampoeng Districts), and the very typical acid granites of the Soela and Banggai Islands, already referred to as belonging to orogenic units of undetermined age.

The lavas of the late Quaternary volcanoes, which close the numerous Indonesian families of igneous rocks, are known to belong to two main groups: (1) a Pacific calc-alkaline clan, and (2) a Mediterranean potassic clan. The distribution of the Pacific lavas of this chain of volcanoes more or less follows the trend of the Soenda orogen, whereas the less important Mediterranean group, enclosed within VAN BEMMELEN'S (1937) roughly triangular Maros province, is represented by the extinct volcanoes of Southwest Celebes, the volcanic island Batoe Tara in the Flores Sea, the volcanoes of North Soembawah (*e.g.*, Mount Tambora), the extinct volcanoes Ringgit and Moeriah on Java, the volcanic rocks of the Karang-kobar region on Java, and finally by the volcanic island Bawean in the Java Sea.

Outside the scenes of present-day volcanic phenomena, relics of deeply

eroded mantles of old volcanoes and necks of eruptive rocks scattered over rather extensive regions of Northwest, Central, South, and East Borneo testify to the former importance of this island as a volcanic region. Part of these Borneo effusives and intrusives of post-orogenic times are known to be Tertiary.

As is set forth by the author (WESTERVELD, 1952 b) in another paper, the andesitic period of volcanism was preceded on Sumatra and Celebes by paroxysmal outbursts of acid pumice tuffs accumulated in extensive sheet-like deposits.

PREVIOUS KNOWLEDGE ABOUT THE BULK COMPOSITION OF INDONESIAN IGNEOUS ROCKS

Albeit the geological boundaries of the Indonesian magmatic provinces can at present be drawn with sufficient accuracy, there still remain many gaps in our knowledge of their petrochemistry. Much attention has in the past often been given to petrologically interesting rock assemblages, whereas others of great areal extent received only little consideration. Great interest has, for instance, been shown in the lavas of the Quaternary andesite and basalt volcanoes, and in the leucite-bearing effusiva of the Maros province; somewhat less so in the Miocene diorites, granodiorites, and granites of the Soenda orogen, in the very extensive family of igneous rocks which penetrate the late Mesozoic folds of Sumatra, Java, and Southeast Borneo, and in the gabbro-peridotitic masses intercalated between the complicated structures of the Moluccan fold system. As regards the great number of plutonic bodies of the Malayan orogen, the granites and allied rocks of Central, West, and Southeast Borneo have fortunately been analyzed in recent time on a rather extensive scale, but for the tin province on the Soenda Shelf existing analytical figures only bear upon a few outlying islands with deviating rock types (Poelau Berhala, Karimata Islands), and upon a few samples from a differentiated granite border zone on Billiton, whereas the chemical composition of the average type of tin granite was never determined. A similar lack of chemical data exists with regard to, e.g., the pre-Mesozoic granites of Sumatra, and the pre-Jurassic acid granites of the Soela and Banggai Islands. The last-named belong to a westward protruding spur of the old basement below the southern lowlands of Netherlands New Guinea, around which the Moluccas fold belt winds itself in a loop-shaped bend. As will be set forth on following pages, the Soela and Banggai Islands granites represent a rather unique type in the Archipelago.

It lies outside the scope of the present essay to enter into a detailed discussion of all available chemical data concerning East Indian igneous rocks, but the importance of their careful sifting according to fold systems, and of their diagrammatical representation, ought to be emphasized.

TRACE ELEMENTS IN INDONESIAN IGNEOUS ROCKS

The distribution of rare elements in Indonesian igneous rocks has only

occasionally been investigated more or less systematically. Only incidentally have the percentages of accessory constituents been determined in addition to those of the main oxides. In a limited number of cases we find bulk analyses extended with quantitative figures for one or more among the following substances: Li_2O (only indicated as "traces" in a few instances), SrO, BaO, Ra, B_2O_3, Ce_2O_3, ZrO_2, U, Th, Cr_2O_3, NiO, CuO, V_2O_3, N, S, SO_3, Cl, and F (see WILLEMS, 1937-1940, for examples). A first attempt to investigate a collection of East Indian igneous rocks exclusively for the distribution of a trace element was probably made by BÜCHNER (1913), who determined the radium content of samples of granite, quartz porphyry, diorite, diabase, basalt, and andesite from Sumatra's West Coast, of granite, dacite, andesite, diorite porphyrite, norite, diabase, and pitchstone from Borneo, and of andesite and pitchstone from the Moluccas. Afterwards, BÜCHNER (in ABENDANON, 1915-1918, p. 1381) added figures for the radium content of granites from Central Celebes, while HIRSCHI (1925) determined the quantity of Ra, U, and Th in, respectively, a shonkinite from Mount Maros in South Celebes and a shoshonite from Mount Bromo on Java.

By far the most systematical and extensive work on the distribution of rarer elements in the former Netherlands East Indies is that by VAN TONGEREN (1938), whose long list of samples subjected to spectographical analysis mainly relates to effusive rocks (lavas, pumice specimens, tuffs, and volcanic breccias) and various types of intrusiva, including basic up to acid facies. His attention, however, also turned to metamorphic rocks (crystalline schists, hornfelses, etc.), sediments (sand, sandstones, graywackes, shales, phyllites, radiolarites, limestones), and to a few minerals and mineral aggregates (zinc ore, ilmenite sand, magnetite, laumontite, tourmaline, heavy fractions of a granite, gypsum, epidote, and a manganese concretion). In all his specimens VAN TONGEREN determined the quantity of SrO, BaO, Sc_2O_3, Y_2O_3, La_2O_3, Ce_2O_3, Nd_2O_3, TiO_2, ZrO_2, V_2O_5, Cr_2O_3, MnO, NiO, CoO, Ga_2O_3, and PbO. The average values for these oxides, calculated from figures obtained from 257 specimens of eruptive rocks, were accepted by VAN TONGEREN as representing the average concentrations of the elements in question in the portion of the earth's crust covered by the former Netherlands East Indies (VAN TONGEREN, 1938, pp. 158, 159). For a number of rare lanthanides, HfO_2, Nb_2O_5, and Ta_2O_5, the quantitative distribution was, in addition, derived from their proportional relations to other trace elements as given in GOLDSCHMIDT's well-known monograph (1937). VAN TONGEREN (1938, pp. 162-173) extended his systematical determinations with some quantitative figures for Li_2O, CdO, a few rare lanthanides, In_2O_3, and Sn in a limited number of rocks and minerals.

Although VAN TONGEREN's careful spectrographical work certainly gives an idea of the order of magnitude of the quantitative distributions of a number of trace elements in the East Indies, one may object against the calculated averages that the investigated specimens have not been classified

systematically according to magmatic provinces. Since the latter are known to show in some cases mutually different geochemical characteristics, *e.g.*, the very acid tin granites of the Malayan orogen with their relative abundance of rare elements of the lanthanide series, uranium, etc., in comparison with the, in this respect very barren, ultrabasic ophiolite series of the Moluccan orogen, a more exact impression of the geochemistry of East Indian igneous rocks might be obtained by classifying VAN TONGEREN's analytical data according to petrographic clans, and by calculating average values for each of the magmatic groups, as far as possible. Averages for the East Indies as a whole might subsequently be obtained from these first mean values by putting full weight on the relative extensions of the different provinces taken into consideration. Applying the principle outlined above on a moderate scale, the present writer (WESTERVELD, 1938-1941, pp. 193-195) already showed with the aid of VAN TONGEREN's figures that the granites of Banka and Billiton, for instance, are characterized by higher percentages of Y_2O_3, La_2O_3, Ce_2O_3, and Nd_2O_3 than VAN TONGEREN's average eruptive rock of the East Indies and than the upper lithosphere, according to GOLDSCHMIDT (1937).

PURPOSE AND SCHEME OF THE PRESENT INVESTIGATIONS

In order to make up for the deficiences in our petrochemical knowledge of the East Indian magmatic provinces, the writer concerted a scheme for obtaining average bulk compositions of collections of specimens of eruptive rocks chosen among separate groups pertaining to the four fold belts indicated before, to the andesitic volcanoes, and to the intrusions of the Soela and Banggai Islands. This has been realized by analyzing mixtures of equal weights of pulverized individual samples, divided into groups according to the petrographic areas taken into consideration. This scheme was extended by systematic determinations of radioactive radiations of individual and average rock samples, and of the radium content of a few average samples. These measurements have the advantage that radium (and also its mother substance U^{238}) not only possesses a very typical lithophile character, by which it tends to concentrate in acid eruptive rocks together with other rare lithophile elements as, for instance, Sn, W, Nb, Ta, Th, Y, the lanthanides, Li, Be, etc., but also because the variations of the total and β-radiations of rock powders, which give an approximate measure of the variation of radium content, can rather quickly be determined with the aid of the ionisation chamber and the GEIGER-MÜLLER counter. In addition, the determinations of radiation intensities of individual and average samples, and of the radium content of powder mixtures, might furthermore give valuable indications with regard to the boundaries of the stanniferous area inside the Malayan orogen and to the geological relations between the granites of the Tin Islands and those of Southwest Borneo, on one hand, and between the last-

named and the granodiorites of the SCHWANER Mountains in Central Borneo, on the other hand.

The combined scheme of bulk analyses, radiation measurements, and the determination of radium contents presents the possibility of gaining a more accurate insight into the relations between the chemical compositions of eruptive rocks and their radioactivity. Although it is an established fact that radium contents increase in a rough way with the silica percentages of igneous rocks, the last-named have thus far only been indicated for comparative purposes as "basic" (i.e. $\pm$ gabbroic), "intermediate" (i.e. $\pm$dioritic), and "acid" (i.e. $\pm$ granitic), without further details on their bulk compositions. EVANS and GOODMAN (1941), for instance, classified under the heading "basic" a series comprising basalts, diabases, norites, monchiquites, andesites, gabbro-diorites, a diorite, quartz diorites, and dacites; under the term "intermediate" a suite of trachytes, dacites, a tuff, a tholeiite, quartz dolerites, and granodiorites; under "acid", finally, granites, rhyolites, an aplite, obsidians, a micro-pegmatite, a pegmatite, and unqualified lavas. Apart from having chosen their samples among groups of rather different geological origin, EVANS and GOODMAN do not give chemical compositions of the specimens investigated by them for radium contents, so that no relations can be derived from their measurements between the last-named values and the distributions of main rock-building oxides. In the same way, SENFTLE and KEEVIL (1947) give radium contents of powder mixtures of extensive suites of, mainly North American, "granites" and "intermediate" intrusiva, without further chemical data. No wonder, that the figures by, respectively EVANS and GOODMAN, and SENFTLE and KEEVIL, for "intermediate" rocks are mutually rather different. As will be shown in the following, the radium content of a "granite" may vary strongly — considering average values for series of representative specimens — with the mutual proportions of its main constituents. The very characteristic tin granites, for instance, which, according to the present writer (WESTERVELD, 1936 a), run relatively high in many lithophile trace elements, in addition show markedly increased radium contents in comparison with less potassic and siliceous types.

The rock assemblages of which the petrochemistry and radioactive qualities will be described in this paper are the following:

I. The granites of the Riouw-Lingga Archipelago.
II. The granites of Banka.
III. The granites of Billiton.
IV. The granites and allied intrusiva of Southwest Borneo (districts Soekadana and Matan).
V. The granites and allied rocks of the SCHWANER Mountains and the Chinese Districts in Central and West Borneo.
VI. The lavas of the andesitic (and basaltic) Quaternary volcanoes of Sumatra, Java, the Lesser Soenda Islands, the islands of the Inner Banda Arc.

VII. Pre-Tertiary (Mesozoic) granites and allied rocks from Sumatra.
VIII. Miocene granites and allied rocks from Sumatra, Java, the Lesser Soenda Islands, the islands in the Flores Sea, and the West Arc of Celebes.
IX. Late Cretaceous (or Paleocene), peridotitic, intrusive rocks from Timor, Moa, Leitimor, Ceram, Kabaena, and the East Arc of Celebes.
X. Pre-Jurassic granites from the Banggai and Soela Islands.

Assemblages I-III represent the granites of the Tin Islands, and together with groups V and VI from Central, West, and Southwest Borneo they belong to the large number of batholithic intrusions of the presumably late Jurassic Malayan orogen. Group VI comprises lavas of the Pacific late Quaternary volcanoes, which in a large sense follow the course of the Soenda orogen. In group VII we have Mesozoic intrusive rocks from the Sumatra branch of the Sumatra orogen, among which specimens from South and Central Sumatra are very probably all of late Cretaceous age, whereas some doubt may be raised concerning the contemporaneousness of samples from North Sumatra. The Miocene plutonic rocks of group VIII all belong to the Soenda orogen; the peridotites of group IX to the late Cretaceous or Paleocene ophiolite series of the Moluccan orogen; the granites of group X, finally, to the acid pre-Jurassic intrusiva of the Banggai and Soela Islands forming part of the median mass surrounded by a sharp bend of the Moluccas fold system.

The average chemical compositions of the magmatic groups chosen for investigation vary between ultrabasic (the peridotites of the Moluccan orogen) and very acid (the tin granites), while intermediate types approaching diorites and granodiorites are gathered in groups IV-VIII. The gabbroic clan, therefore, is not represented.

CHOICE OF SAMPLES

In the aggregate, 137 samples of Indonesian eruptive rocks covering the ten groups indicated in the previous paragraph were used for measurements of total radioactive radiation and β-emission intensities of individual samples, for the execution of chemical bulk analyses of average samples, and for the measuring of total radiation and β-emission intensities, and radium contents, of average powder mixtures. Their petrographic denominations in collections and publications and their sampling spots are listed below. [1])

Sample of tin granite from outlying section of the Malayan orogen

No. 1. *Granite*, foot of Maxwell Hill, Tayping, Federated Malay States.

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[1]) More detailed information concerning available petrographic descriptions, chemical analyses, collection numbers, etc., may be obtained from the author on request.

I. Granites of the Riouw-Lingga Archipelago

No. 2. *Biotite granite*, Semampang, West Karimoen.
„ 3. *Two-micas granite*, coast of West Koendoer.
„ 4. *Biotite granite*, West Nongsa, Batam.
„ 5. *Biotite granite*, Cape Tondang, West Bintan.
„ 6. *Biotite granite*, Poelau Ranggas, north of Bintan.
„ 7. *Biotite granite*, Poelau Mantjin, east of South Bintan.
„ 8. *Amphibole granite*, Poelau Noembing near Bintan.
„ 9. *Granite*, centre of Toemang Hill, Singkep.

II. Granites of Banka

No. 10. *Biotite granite*, island Malang Dojong, Djeboes district.
„ 11. *Granite*, east of village Penganaklaut, Djeboes district.
„ 12. *Biotite granite*, Soelan Tenoeng, northwest part of Djeboes district.
„ 13. *Porphyritic granite*, Batoe Bedahoen, Blinjoe district.
„ 14. *Granite*, Tandjoeng Raja, Soengeiliat district.
„ 15. *Granite*, Boekit Setrong, near the road from Seboga to Goedang, Permis region, Soengei Selan district.
„ 16. *Granite*, Boekit Birah, Koba district.
„ 17. *Granite*, Toboali district.
„ 18. *Granite*, island Telegan, Lepor Islands between Banka and Billiton.

III. Granites of Billiton

No. 19. *Granite*, Tandjoengpandan.
„ 20. *White granite with large feldspars*, on the road from Tikoes mine to Mount Genteng.
„ 21. *Biotite granite*, west coast of Blantoe.
„ 22. *Granite*, east flank of Mount Beloeroe, Dendang district.
„ 23. *Granite*, northeastern extremity of Mount Parang Boeloe, Dendang district.

IV. Granites and allied intrusiva of Southwest Borneo (Soekadana and Matan districts)

No. 24. *Quartz mangerite*, Soengei Tangir, a short distance southeast of village Riamkoesik, Matan district.
„ 25. *Aplite granite*, Boekit Belajan, on the boundary between the South Matan and Kotawaringin districts.
„ 26. *Aplite granite*, Mount Loempoeng, south of village Mahawa, Matan district.
„ 27. *Monzonite*, Mount Loempoeng, south of village Mahawa, Matan district.
„ 28. *Mangerite*, tributary of Soengei Landau, near Mount Belaban Toedjoeh, on the path-way to village Soengeimelajoe, Matan district.
„ 29. *Aplite granite*, on trail to Mount Selakau, Matan district.
„ 30. *Aplite granite*, road from village Pebihingan to village Toembangtitik, km 9, Matan district.
„ 31. *Microdiorite*, Soengei Patai, trail southwest of Mount Raja, east of village Batoemenang, Matan district.
„ 32. *Granosyenite*, southwest of Mount Lesoeng Boelan, on the boundary between North Matan and Kotawaringin, Matan district.
„ 33. *Aplite granite*, trail from Mandarik to Mount Mengkate, between village Nangahtajap and Mount Sangiang, Matan district.
„ 34. *Riebeckite granite*, path-way from village Telokparak to village Toelak, 17 km southwest of mouth of the Laoer River in the Pawan River, Matan district.
„ 35. *Quartz mangerite*, path-way from Mount Boeroengmenangis to village Tjali, Matan district.

No. 36. *Granite*, village Tjali, 11 km west of mouth of Laoer River in Pawan River, Matan district.
„ 37. *Alkaline granite*, Mount Paloeng, Soekadana district.
„ 38. *Granite*, top of Mount Lalang, Soekadana district.

V. Granites and allied rocks of the SCHWANER Mountains and the Chinese Districts in Central and West Borneo.

No. 39. *Quartz diorite*, Dajak village Bagak near Petengahan Lama, Chinese Districts.
„ 40. *Granitic rock*, Mount Sonko near Simpasa, Chinese Districts.
„ 41. *Granite*, Tjapkala, Chinese Districts.
„ 42. *Hornblende granite*, Pimpi near Sepang, Chinese Districts.
„ 43. *Amphibole-biotite granite*, Batoe Lajang, right bank of the Kapoeas River, 6 km down-stream of Pontianak.
„ 44. *Amphibole granite*, $^3/_4$ km down-stream of Nangah Tajan, right bank of Kapoeas River.
„ 45. *Tonalite* Soengei Dekan, tributary of Upper Serawai River, SCHWANER Mountains.
„ 46. *Granite, grading into tonalite*, Soengei Entoeka, east of village Mongkok, SCHWANER Mountains.
„ 47. *Granite*, Riam Moeloeng, Soengei Menterap, SCHWANER Mountains.
„ 48. *Tonalite*, Soengei Makap, SCHWANER Mountains.
„ 49. *Biotite granite*, Soengei Sekadan, SCHWANER Mountains.
„ 50. *Quartz diorite*, Riam Kiribat in the Upper Sekadan River, near its origin, SCHWANER Mountains.
„ 51. *Quartz diorite*, origin of Soengei Tongkong, headwaters of the Djekalindoek River, SCHWANER Mountains.
„ 52. *Granosyenite*, origin of the Geloembang River, tributary of Djekalindoek River, SCHWANER Mountains.
„ 53. *Biotite granite*, Pinoh River, SCHWANER Mountains.
, 54. *Tonalite*, north flank of Mount Raja, altitude $\pm$ 775 m, SCHWANER Mountains.
„ 55. *Amphibole-biotite granite*, Rassahooi River, $^1/_4$ km up-stream of Toembang Karang, SCHWANER Mountains.
„ 56. *Amphibole granite*, right bank of Menjoekoei River. $1\frac{1}{2}$ km up-stream of Toembang Lamihoi, SCHWANER Mountains.
„ 57. *Hornblende granite*, Kiham Tingang in Samba River, SCHWANER Mountains.
„ 58. *Granite*, Kiham Penekilloe, Samba River, SCHWANER Mountains.
„ 59. *Amphibole-biotite granite*, Kiham Pening, Mentikeh River, SCHWANER Mountains.

VI. Andesitic (and basaltic) lavas of the Quaternary volcanoes of Sumatra, Java, the Lesser Soenda Islands, the islands of the Inner Banda Arc.

No. 60. *Lava*, Mount Peuëtsagoë, Atjeh, North Sumatra.
„ 61. *Augite-hypersthene andesite*, Mount Sorik-Merapi, Sumatra, northern top, south of secondary triangulation point S. 59.
„ 62. *Hornblende-bearing augite-hypersthene andesite*, Mount Talakmau, loose block from crater B.
„ 63. *Augite-hypersthene andesite*, Mount Tandikat, Sumatra, eastern rim of crater A.
„ 64. *Augite-hypersthene andesite*, top of Mount Merapi near Fort de Kock (Boekittinggi).
65. *Lava*, top of Mount Kerintji (or Peak of Indrapoera), Sumatra.

No. 66. *Lava*, top Mount Dempo, South Sumatra, crater rim III.
„ 67. *Lava*, Krakatau group.
„ 68. *Lava*, Mount Tangkoeban Prahoe, Priangan, Java.
„ 69. *Pyroxene andesite*, steep wall west of solfataras in top region of Mount Papandajan, West Java.
„ 70. *Effusive rock with inclusions*, south slope of Mount Goentoer, Priangan, Java.
„ 71. *Basalt*, near Mount Slamat, Banjoemoedal district, Residency Tegal, Java.
„ 72. *Andesite lava*, Mount Bromo. East Java.
„ 73. *Effusive rock*, Mount Raoeng, Residency Besoeki, East Java.
„ 74. *Effusive rock*, Kawah Idjen, Residency Besoeki, East Java.
„ 75. *Pyroxene andesite*, Poelau Kambing opposite Bimah on Soembawah, in Bima Bay; top of the volcano.
„ 76. *Basalt with little olivine*, Poelau Sangean near Soembawah.
„ 77. *Basalt*, Ili Watoeomi, Solor, east of Lewonama.
„ 78. *Pyroxene andesite*, Ili Watoeomi, Solor, between Lamagoang and Lamawolo.
„ 79. *Pyroxene andesite*, Mangaälang, Andonara.
„ 80. *Pyroxene andesite*, southeast side of Mount Ili Boleng on Adonara.
„ 81. *Olivine basalt*, northwest of Mount Lewotolo, near Lewoara, Lomblen.
„ 82. *Andesitic trachy-andesite*, east of Mount Ili Lewotolo, Lomblen.
„ 83. *Olivine-bearing pyroxene andesite*, lava stream of Mount Api on the east coast of Pantar, a short distance south of Pasar Beang.
„ 84. *Glass-rich pyroxene-andesite lava*, Mount Api on the east coast of Pantar.
„ 85. *Biotite- and olivine-bearing pyroxene-andesite lava*, upper lava stream on north side of island Goenoeng Api near Wetar.
„ 86. *Olivine-bearing pyroxene-andesite lava*, old crater rim of volcanic island Daam or Dammer.
„ 87. *Pyroxene andesite*, from large blocks of lava stream on volcanic island Daam or Dammer, near hot spring at Kéli.
„ 88. *Pyroxene-andesite lava*, lava stream on west coast of volcanic island Téon, from large blocks near village Mèsah.
„ 89. *Pyroxene-andesite lava*, from lava stream of old crater rim on northnorthwest side of island Nila.
„ 90. *Olivine-bearing pyroxene-andesite lava*, from most northern lava stream issuing from main crater of island Seroea, which flowed eastward.

VII. Pre-Tertiary granites and allied rocks from Sumatra

No. 91. *Amphibole-biotite granite rich in quartz*, Aloë Panton Raba, tributary of the Geuënteuët River, Landscape Lhong, Division "Groot Atjeh".
„ 92. *Granodiorite*, Aloë Bateë Doea, Beutong, Atjeh, North Sumatra.
„ 93. *Granitite*, Aloë Dangla, 8 km south of Loekoep, Atjeh.
„ 94. *Granitite*, road near Tapatoean, Atjeh.
„ 95. *Granite*, ± 3 (Sumatran) miles before Pagaran Pisang on road Taroetoeng-Sibolga, Sub-division Silindoeng, Residency Tapanoeli.
„ 96. *Quartz diorite*, Soengei Lassie, Sumatra's West Coast.
„ 97. *Hornblende granite*, Tiemboelan, XX Kottas, Sumatra's West Coast.
„ 98. *Biotite granite*, Soengei Pemoenjin, ½ km up-stream of Moeara Toba, Residency Djambi.
„ 99. *Biotite granite*, granite mass near Mount Poengoeng Parang in Upper Djambi, environment of Mount Batoe.
„ 100. *Biotite granite*, Arai River between Taboean and village Arai, Tembesi-Rawas Mountains, Residency Djambi.
„ 101. *Kataklastic biotite granite*, Tekana River, Garba Mountains, Upper Palembang, South Sumatra.

No. 102. *Microkline granite*, headwaters of Sepoetih River, Lampoeng Districts, South Sumatra.
,, 103. *Granite*, Bakarang Bintang River, Lampoeng Districts, South Sumatra.
,, 104. *Biotite granite*, Soelan River, Lampoeng Districts, South Sumatra.

VIII. Miocene granites and allied rocks from Sumatra, Java, the Lesser Soenda Islands, the islands in the Flores Sea, and the West Arc of Celebes.

No. 105. *Granitite*, Bengkenang River, Residency Benkoelen, South Sumatra.
,, 106. *Granitite*, Padang Goetji River, Residency Benkoelen, South Sumatra.
,, 107. *Granitite*, Padang Goetji River, Residency Benkoelen, South Sumatra.
,, 108. *Biotite granodiorite*, Toeloengheni River, South Benkoelen, South Sumatra.
,, 109. *Biotite granite*, Bambang Ketjil River, South Benkoelen, South Sumatra.
,, 110. *Granodiorite porphyrite*, Kahoeroean River, South Bantam, Java.
,, 111. *Porphyritic granodiorite*, Kahoeroean River, South Bantam, Java.
,, 112. *Granodiorite*, Tendjolaoet near Karangnoenggal, Priangan, Java.
,, 113. *Granite (slightly pyritized)*, path along western boundary of Pagergoenoeng Estate, South Besoeki, East Java.
,, 114. *Granodiorite*, L. Ria, north of Watoe Tekee, Central Flores.
,, 115. *Granodiorite*, Tandjoeng Illihoi, East Wetar.
,, 116. *Granodiorite*, Poelau Tengah near island Tanah Djampea, Flores Sea.
,, 117. *Granodiorite*, Poelau Bimbee near island Tanah Djampea, Flores Sea.
,, 118. *Granodiorite*, pebble from Poeang River, in the valley of the Pintinaloa River, Tolassa, western Central Celebes.
,, 119. *Granite*, from block in Pesaloean River, western Central Celebes.
,, 120. *Gneissic amphibole-biotite granite*, pebble from Ore River near Bangga, western Central Celebes.
,, 121. *Hornblende granitite*, path-way from Paroeng to Totopo, in a small left hand side-valley, North Celebes.
,, 122. *Pyroxene granitite*, from large block in the Doeloekapa River, near a camp of the Kwandang Soemalata Mining Cy., North Celebes.
,, 123. *Pyroxene granitite, passing into hornblende granitite*, from large block on the path-way from Bohoeloh to Attingola, south flank of Mount Tihengo, main watershed, about 700 m above sea level, North Celebes.

IX. Peridotitic intrusive rocks from Timor, Moa, Leitimor, Ceram, Kabaena, and the East Arc of Celebes

No. 124. *Lherzolite*, from ophiolite-spilite complex on the Besasi River, southwest Moetis region, Timor.
,, 125. *Lherzolite*, north flank of Mount Kerbau, East Moa.
,, 126. *Peridotite*, southeast of Mount Horiel, ½ km east of Cape Noear, island Leitimor, Ambon group.
,, 127. *Plagioclase-bearing peridotite*, pebble from the Mangoeroe River, near Loehoe, west side of Piroe Bay, West Ceram.
,, 128. *Serpentinized peridotite*, trail from Oe. Merassi to Oe. Pikojaa, island Kabaena.
,, 129. *Peridotite*, trail to Mount Woemboeranoe, island Kabaena.
,, 130. *Harzburgite*, from solid rock near Cape Batoe on the shore of Lake Towoeti, eastern Central Celebes.
,, 131. *Harzburgite*, from Cape Patingkoea on the shore of lake Matana, eastern Central Celebes.
,, 132. *Harzburgite*, Tioe River, eastern Central Celebes.

No. 133. *Diopside-bearing peridotite rich in olivine*, left bank of Todjo River, a short distance up-stream of its tributary, the Oee Rate River, at the foot of Mount Oee Rate, northeast arm of Celebes.

„ 134. *Peridotite* (*harzburgite*), near gas well Tandjong Api, Landscape Todjo, northeast arm of Celebes.

X. Granites from the Banggai and Soela Islands

No. 135. *Granite*, island Bangkoeloe, Banggai Archipelago.

„ 136. *Granite*, island Mangoli, Soela Archipelago.

„ 137. *Granite*, island Banggai, Banggai Archipelago.

Figures 1-3 illustrate the sampling-spots of the 137 specimens — with the exception of No. 1, which was taken from a place outside the region of Figure 1 — and their spreading over the ten groups indicated in the headings of the list. In the drafting of the boundaries of the magmatic-tectonic provinces of the Indonesian area (Figure 3) the writer follows his earlier conceptions on the subject (WESTERVELD, 1949, 1952 a).

For the successful putting together of the igneous rock material used in the present investigations much debt is own to Prof. Dr H. A. BROUWER for his permission to make a choice among specimens of East Indian eruptiva kept in the collections of the Geological Institute at Amsterdam; to Prof. Dr H. J. F. UMBGROVE for giving his consent to search the Indonesian collections of the Mining Institute of the Technical University at Delft; and to Prof. Dr W. NIEUWENKAMP for his kind assistance in obtaining suitable material from the MOLENGRAAFF, ROGGEVEEN, and other collections in the Geological Department of the University of Utrecht. Much valuable material was also received from the Bureau of Mines of the former Netherlands East Indies. Not in the last place should words of thankfulness be voiced to Dr P. KRUIZINGA, former Curator at the Mining Institute of the Technical University, for the readiness and never abating interest with which he showed the writer through the VERBEEK, ABENDANON, and KOPERBERG collections; and to Dr W. P. DE ROEVER for his very expert searching of the Indonesian Bureau of Mines eruptive rock material, kept at Bandoeng (Java), for suitable specimens.

BULK COMPOSITIONS OF AVERAGE SAMPLES REPRESENTING OUTSTANDING INDONESIAN ERUPTIVE ROCK PROVINCES; GENERAL CHARACTERISTICS OF THEIR DIFFERENTIATION SERIES IN REGARD OF NIGGLI'S NORMAL CALC-ALKALINE SUITE

The results of chemical analyses of powder mixtures representing the average compositions of groups I-X of igneous rocks, as defined in the preceding paragraphs, are given in Table 1. In addition to the main oxides, some minor constituents, *e.g.*, Cl, S, BaO, Cr_2O_3, and NiO, were determined in a few cases. For mutual control two analyses by different analysts were made of average sample No. II. The two sets of figures are

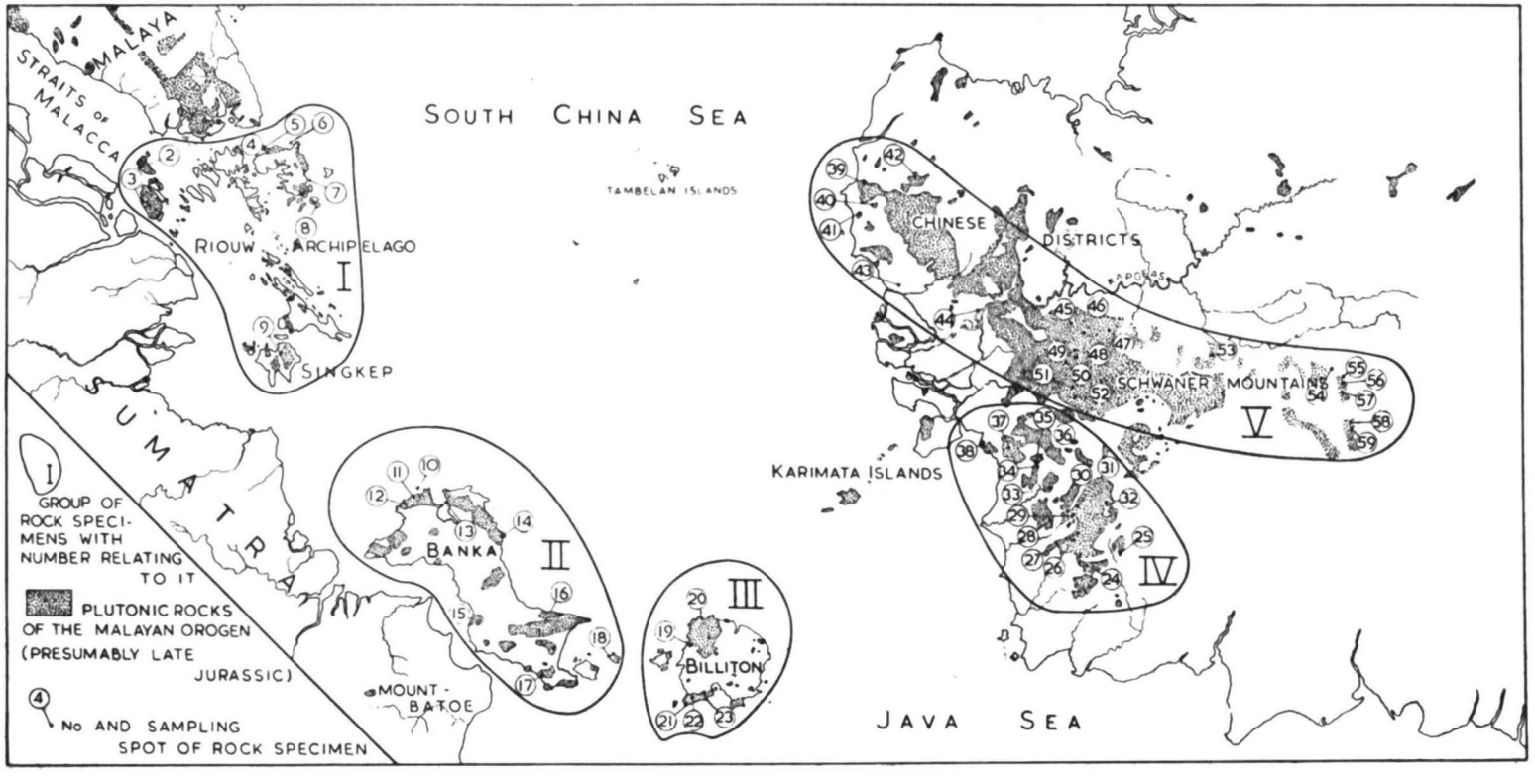

Fig. 1. Locations of samples of granites and granodiorites from the late Jurassic Malayan orogen (Nos. 2–59; groups I–V).

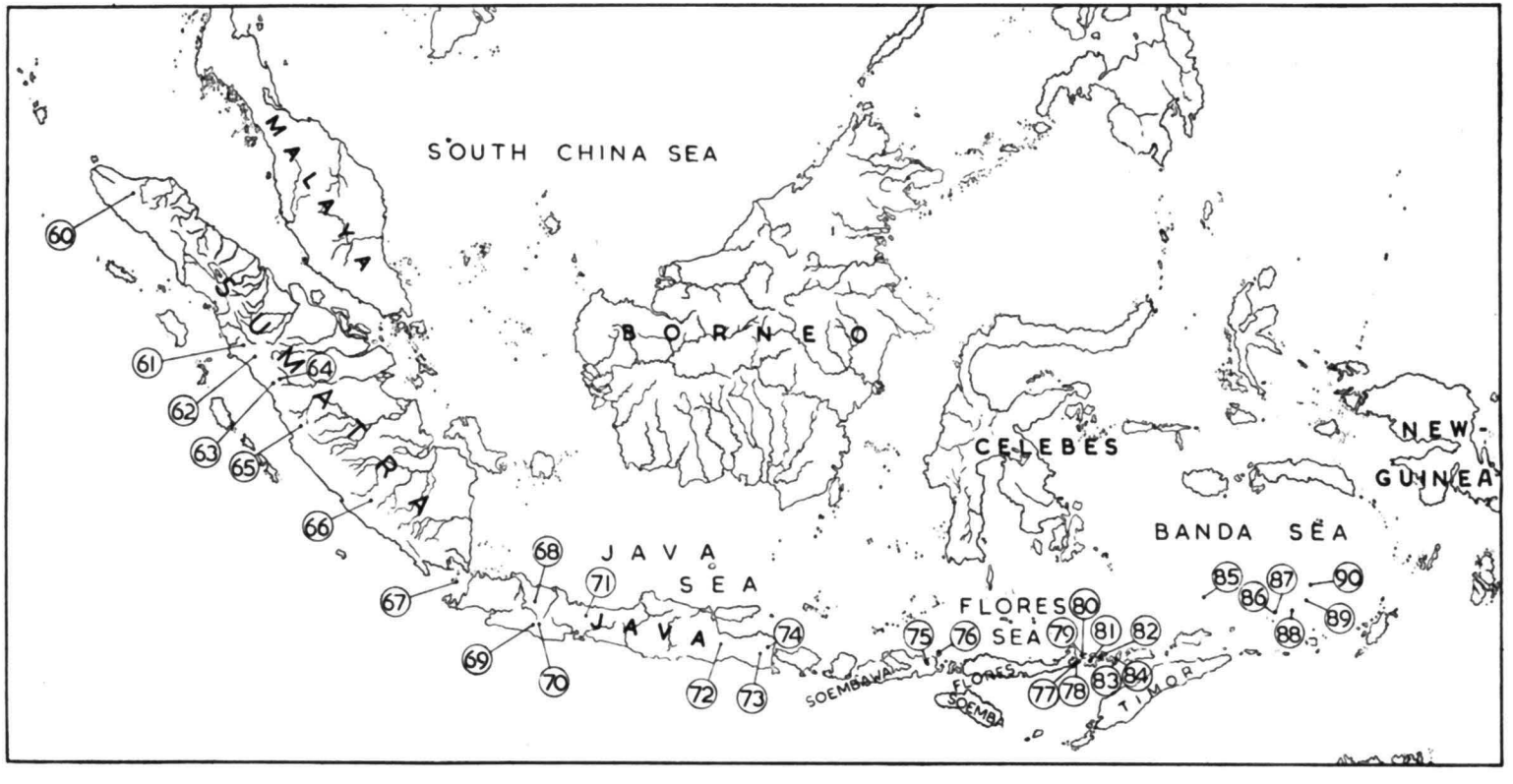

Fig. 2. Locations of samples of andesitic (to basaltic) lavas from late Quaternary volcanoes on Sumatra, Java, the Lesser Soenda Islands, and in the Inner Banda Arc (Nos. 60–90; group VI)

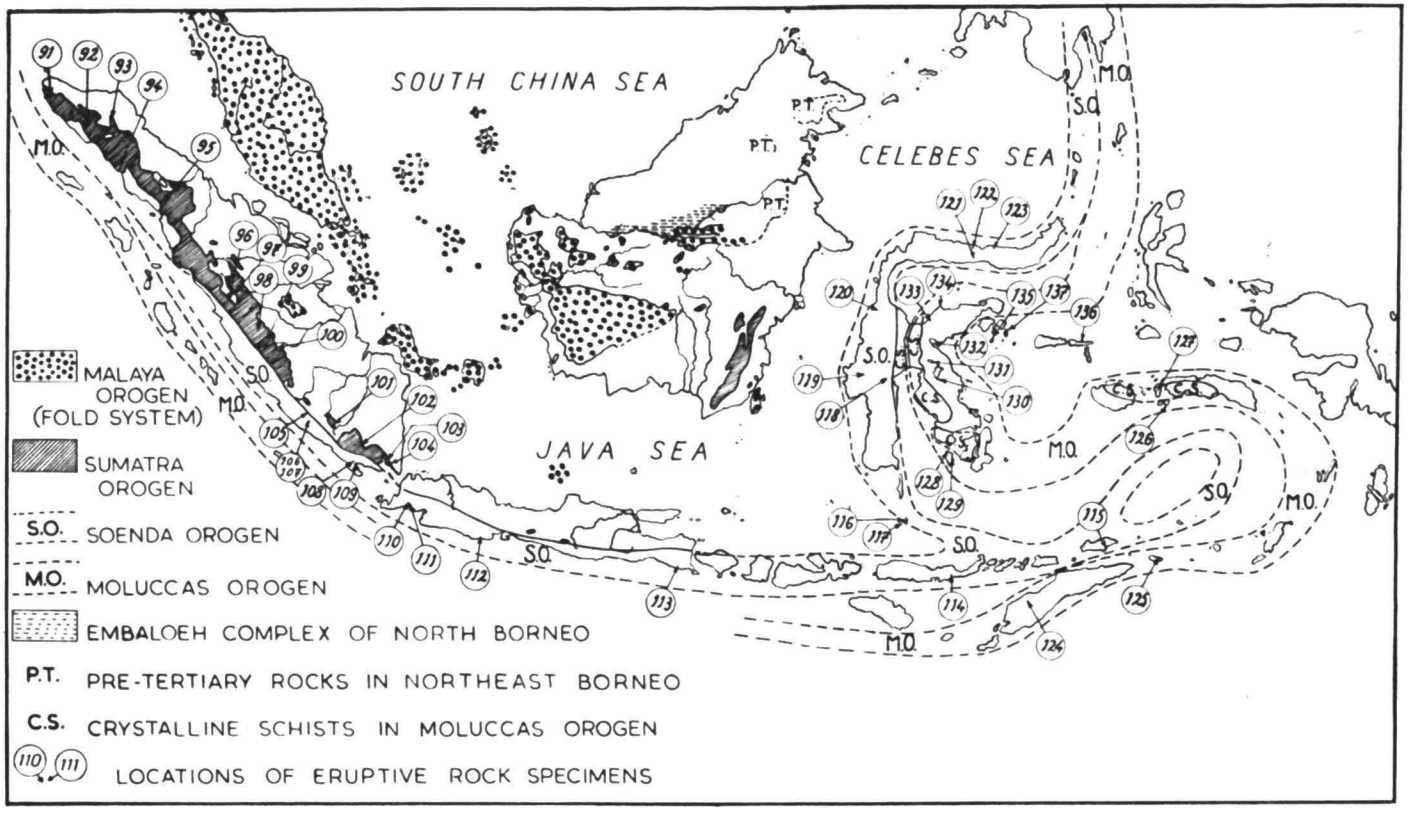

Fig. 3. Locations of samples of Mesozoic granites and granodiorites from Sumatra (Nos. 91–104; group VII); of Miocene granites and granodiorites from the Soenda orogen (Nos. 105–123; group VIII); of late Cretaceous (or Paleocene) peridotites from the Moluccan orogen (Nos. 124–134; group IX); and of pre-Jurassic 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[1])	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[1])	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[1])	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

[1]) Figures taken from a duplicate analysis.

in sufficiently good agreement, so that the mean weight percentages were used for further calculations and deductions.

A grant received from the "Nederlandse Organisatie voor Zuiver Wetenschappelijk Onderzoek" (Netherlands Organization for Pure Scientific Research) through the intermediary of the "Stichting voor Fundamenteel Onderzoek der Materie" (Foundation for the Fundamental Investigation of Matter) has made it possible to offer the important compilation of petrochemical data shown in Table 1.

In order to be able to present bulk analyses I-X in illustrative graphical forms, sets of NIGGLI parameters *si*, *al*, *fm*, *c*, *alk*, *ti*, *p*, *k*, *mg*, *L*, *M*, and *Q* were calculated and inserted below the columns of weight percentages in Table 1.

It may be re-called (see also NIGGLI, 1923, p. 51-60) that parameters *si*, *al*, *fm*, *c*, *alk*, *ti*, and *p* give the molecular proportions between, respectively SiO_2, Al_2O_3, ($FeO + 2Fe_2O_3 + MnO + MgO$), ($CaO + BaO$), ($Na_2O + K_2O$), TiO_2, and P_2O_5, the sum of $al + fm + c + alk$ being reduced to 100. Furthermore, *k* and *mg* give the molecular proportions $K_2O : (K_2O + Na_2O)$ and $MgO : (FeO + 2Fe_2O_3 + MnO + MgO)$.

Values *L* and *M*, which together with *Q* equally total 100, represent the sums of two different groups of, with regard to silica content, undersaturated base molecules (NIGGLI, 1936 a). Combined with silica all rock-building minerals can easily be formed out of these fundamental compounds, among which the leukocratic ones constitute the sum *L*, and the melanocratic the sum *M*. Orthoclase, for instance, can be computed by combining undersaturated $KAlSiO_4$ with SiO_2; biotite by adding SiO_2

I. Granites, Riouw Archipelago. Analysts KONING & BIENFAIT, Chemical Bureau, Amsterdam.

II,1 Granites, Banka. Analysts Dr. LOBRY DE BRUYN, Chemical Bureau, Amsterdam.

II,2 Granites, Banka. Analysts KONING & BIENFAIT, Chemical Bureau, Amsterdam.

III. Granites, Billiton. Analysts KONING & BIENFAIT, Chemical Bureau, Amsterdam.

IV. Granites and allied rocks, Southwest Borneo. Analysts Dr. LOBRY DE BRUYN, Chemical Bureau, Amsterdam.

V. Granites and allied rocks, SCHWANER Mountains, Chinese Districts, Borneo. Analysts Dr. LOBRY DE BRUYN, Chemical Bureau, Amsterdam.

VI. Andesitic (to basaltic) lavas, Quaternary volcanoes, Indonesia. Analysts Dr. LOBRY DE BRUYN, Chemical Bureau, Amsterdam.

VII. Late Mesozoic granites and allied rocks, Sumatra. Analysts Dr. LOBRY DE BRUYN, Chemical Bureau, Amsterdam.

VIII. Miocene granites and allied rocks, Soenda orogen. Analysts Dr. LOBRY DE BRUYN, Chemical Bureau, Amsterdam.

IX. Peridotites, Moluccan orogen. Analysts Dr. LOBRY DE BRUYN, Chemical Bureau, Amsterdam.

X. Granites, Soela and Banggai Islands. Analysts Dr. LOBRY DE BRUYN, Chemical Bureau, Amsterdam.

(and H_2O) to undersaturated $KAlSiO_4$ and Mg_2SiO_4; enstatite by combining Mg_2SiO_4 and SiO_2, etc.

Value L unites all base molecules from which the feldspars and feldspathoids can be derived; value M all base complexes of pyroxenes and olivines; value Q, finally, represents the sum of remaining SiO_2 and TiO_2. In the case of the average bulk analyses gathered in Table 1, values L, M, and Q satisfy the following equations:

$L = KALSiO_4\ (Kp) + NaALSiO_4\ (Ne) + CaAL_2O_4\ (Cal)$

$M = Ca_2SiO_4\ (Cs) + Fe_2^{III}SiO_5\ (Fs) + Fe_2^{II}SiO_4\ (Fa) + Mg_2SiO_4\ (Fo)$, or $Fe_2^{III}SiO_5(Fs) + Fe_2^{II}SiO_4(Fa) + MgAL_2O_4(Sp) + Mg_2SiO_4(Fo)$, depending on whether there exists an excess of alumina with regard to the leukocratic constituents

$$Q = SiO_2(Q') + TiO_2(Ru)$$
$$L + M + Q = 100$$

TABLE II

Base molecule coefficients and parameters L, M, and Q for average samples I–X

Average sample No.	*Kp*	*Ne*	*Cal*	*Cs*	*Fs*	*Fa*	*Sp*	*Fo*	*Ru*	*Q'*
I	17,3	17,1	3,7		0,7	1,5	0,9	0,0	0,1	58,7
	$L = 38,1$			$M = 3,1$					$Q = 58,8$	
II	17,9	16,8	5,6	0,2	0,9	2,3		1,4	0,3	54,6
	$L = 40,3$			$M = 4,8$					$Q = 54,9$	
III	18,1	15,0	6,0	0,7	0,4	3,0		1,6	0,2	55,0
	$L = 39,1$			$M = 5,7$					$Q = 55,2$	
IV	12,2	25,4	5,2	1,5	2,1	3,0		3,1	0,5	47,0
	$L = 42,8$			$M = 9,7$					$Q = 47,5$	
V	8,1	16,4	13,2		1,9	3,7	0,9	4,3	0,3	51,2
	$L = 37,7$			$M = 10,8$					$Q = 51,5$	
VI	7,7	18,5	16,6	2,8	3,4	5,6		6,9	0,5	38,0
	$L = 42,8$			$M = 18,7$					$Q = 38,5$	
VII	11,1	19,7	10,3		1,1	3,3	1,1	2,4	0,3	50,7
	$L = 41,1$			$M = 7,9$					$Q = 51,0$	
VIII	9,2	19,0	11,5	0,2	1,6	3,2		3,0	0,3	52,0
	$L = 39,7$			$M = 8,0$					$Q = 52,3$	
IX	0,1		2,9	1,0	3,6	5,8		79,2	0,0	7,4
	$L = 3,0$			$M = 89,6$					$Q = 7,4$	
X	14,9	19,3	5,8	0,2	1,4	1,4		1,9	0,3	55,0
	$L = 40,0$			$M = 4,7$					$Q = 55,3$	

Among minor constituents, Mn and Ni are reduced to the equivalent of Fe^{II}, Ba to the equivalent of Ca, Cr to that of Al.

All the calculated coefficients for the molecular proportions of leuko- and melanocratic base substances are given in Table 2, together with group figures *L*, *M*, and *Q*.

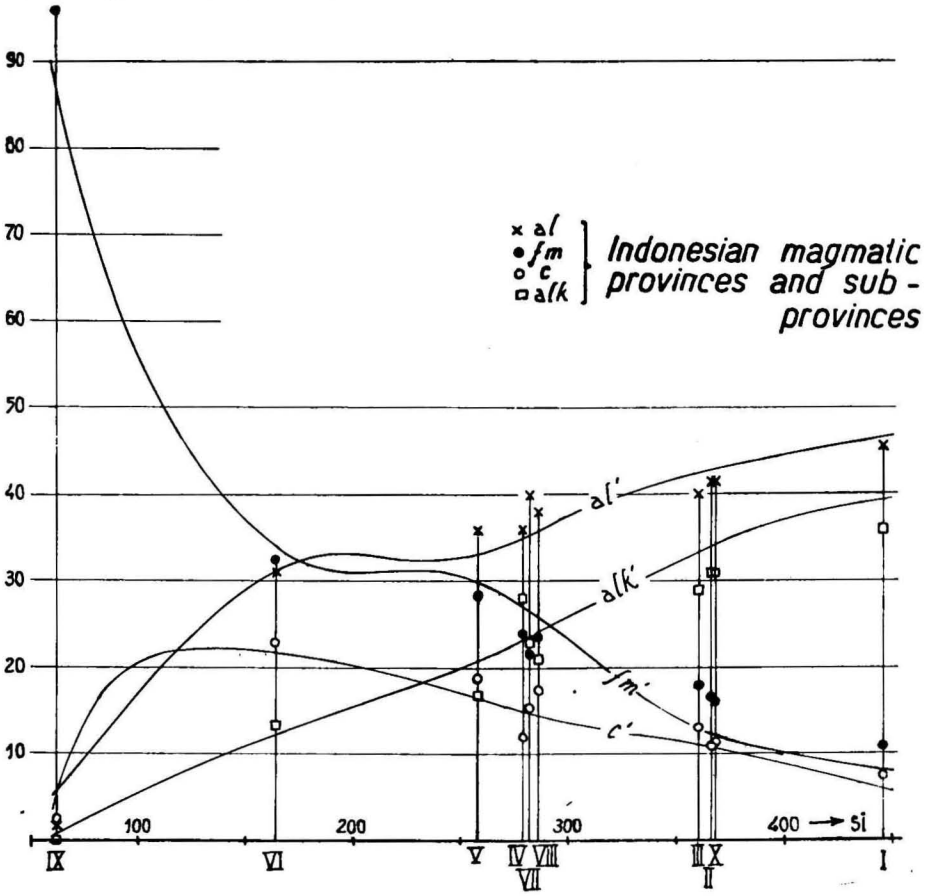

Fig. 4. Variation diagram of NIGGLI parameters *al*, *fm*, *c*, and *alk* for eruptive rock groups I–X compared with NIGGLI's normal calc-alkaline suite (represented by curves *al'*, *fm'*, *c'*, and *alk'*).

A diagram representing the variations of parameters *al*, *fm*, *c*, and *alk* as a function of *si* is shown in Figure 4, in which point symbols indicate the positions of values relating to Indonesian magmatic groups, whereas full-drawn curves indicate the trends of variation followed by these parameters in the case of NIGGLI's (1936 b) normal magma types of the calc-alkaline suite. As representative of this "normal" series of bulk compositions are considered here NIGGLI's "peridotitic", "pyroxenitic", "normal gabbroic", "normal gabbro-dioritic", "normal dioritic", "tonalitic", "normal quartz dioritic", "opdalitic", "normal granitic", "normal granodioritic", "adamellitic", "yosemite granitic", "normal trondhjem-

itic", "engandinite granitic", and "aplite granitic" standard types, written in the order of increasing silica content. The variation curves for this "normal" series correspond very closely to those given by NIGGLI in an earlier work (1923, p. 198).

Comparing, in Figure 4, the parameters for Indonesian igneous rock groups and provinces with those for the "normal" calc-alkaline suite, it becomes at once apparent that the very acid granites of the Tin Islands (groups I-III) and similar rocks of the Banggai and Soela Islands (group X) have relatively low *alk* and relatively high *fm* values. The chemical identity of groups I-III with group X is very conspicuous; characterized as they are by high K_2O percentages ($k \geqq 0{,}5$!) and the dominant "yosemite granitic" magma type. Groups IV and V, the granitic and allied rocks from Southwest Borneo and the SCHWANER Mountains (the latter including their continuation into the Chinese Districts), on the other hand, are on the average characterized by intermediate acidity, by a low *c* and a high *alk* value in the case of the SW. Borneo intrusiva, and by relatively high Na_2O percentages ($k = 0{,}32$ in both cases). As magma types, they correspond to NIGGLI's "leuco quartz dioritic" and "normal quartz dioritic" groups, respectively. Responsive to the rather sodic bulk composition of the SW. Borneo plutonic rocks are the local appearances in the Soekadana and Matan districts of, *e.g.*, "normal alkaline granitic" riebeckite-aegirite and riebeckite granites (VAN BEMMELEN, 1939, pp. 268, 269); eruptive rock species which have nowhere else been found in the East Indian Archipelago. Chemically and mineralogically, the Borneo intrusiva, therefore, show themselves to be markedly different from the typical tin granites represented by groups I-III.

To conclude the mutual comparison of igneous rock clans forming part of the Malayan orogen, attention may be drawn to the interesting phenomenon that in a few cases acid intrusive rocks found in the marginal areas of the stanniferous region, *e.g.*, on the Berhala Islands in the Straits of Malacca, on Mount Batoe southeast of Palembang on Sumatra, and on the Karimata Islands, are rather strongly potassic and consequently affected with Mediterranean tendencies.

Groups VI (the andesitic to basaltic volcanoes), VII (the late Mesozoic granites and allied rocks of Sumatra), and VIII (the Miocene granites and allied rocks) go from "normal dioritic" to "granodioritic" and "farsunditic" compositions in their average samples. Compared with NIGGLI's calc-alkaline series (Figure 4) they show rather small deviations from the normal: somewhat too high *c* and somewhat too low *fm* values in all three cases, and too high *al* figures, in addition, for groups VII and VIII. BURRI (1926, pp. 143, 149, 153) and WILLEMS (1937-1940, pp. 292, 293) already emphasized the pronouncedly Pacific character of the Indonesian andesitic volcanoes and the relatively high *c* and relatively low *fm* values of their lavas, whose "ossipitic" tendency reveals itself in their relatively high plagioclase contents. A similar tendency is also exhibited by the Miocene

plutonic bodies of the Soenda fold system, which, as will be shown in a later chapter, are likewise very similar to the Quaternary andesite lavas as regards their radioactivity.

The gabbro-peridotitic ophiolite series of the Moluccan orogen bear a

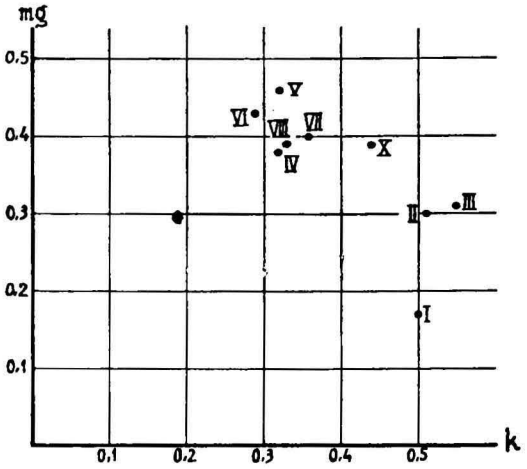

Fig. 5. *k-mg* variation diagram for Indonesian eruptive rock groups I–X.

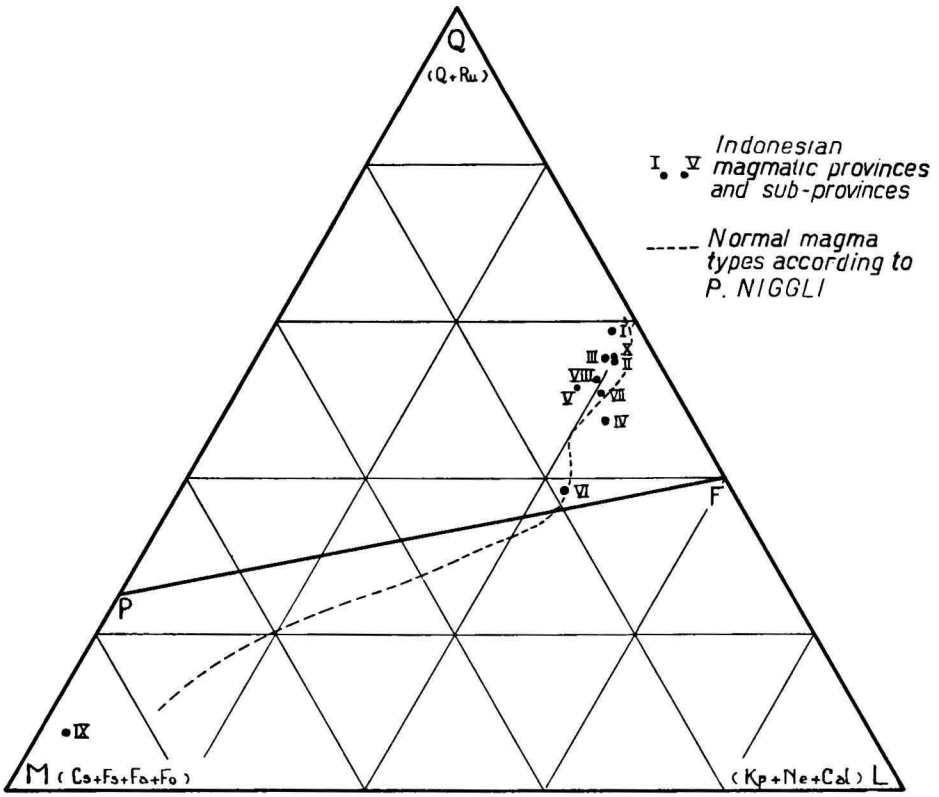

Fig. 6. *Q–L–M* variation diagram for Indonesian eruptive rock groups I–X compared with the *Q–L–M* curve for NIGGLI's normal calc-alkaline suite.

normal peridotitic character with *fm* perhaps somewhat too high, and *c* and *al* somewhat too low.

In Figure 5, *k* values are put against *mg* values. As may be noticed, the relatively more sodic character displayed by groups IV and V (the Borneo intrusiva) contrast strongly with the pronouncedly potassic character of the granites of the Tin Islands and those of the Banggai and Soela Islands (groups I-III, and X). Group IX, the peridotites, has been omitted in this diagram, because its *k* figure is too uncertain.

The triangular diagram, Figure 6, illustrates the positions of rock groups I-X on the ground of their *L*, *M*, and *Q* values. Compared with the "normal" differentiation course of the calc-alkaline series, marked by a broken line, the lavas of the andesitic to basaltic volcanoes (group VI) are again characterized by an almost "normal" position. By its high content of alkali oxides, group IV, the SW. Borneo intrusiva, falls rather much to the right of the "normal" curve, whereas groups I, II, III, V, VIII, and X are located to the left of it on account of their slight deficiency in alkali metals. It should be remarked in this context that point P represents pure metasilicates or pyroxenes (wollastonite, enstatite, hypersthene, acmite), and point F pure feldspars (orthoclase, albite, anorthite), so that line PF separates rocks saturated in silica from those undersaturated with regard to this substance. It may, therefore, be read from the diagram that group IV has an excess of normative feldspar, while groups I, II, III, V, VIII, and X are slightly deficient in it.

RADIOACTIVE RADIATIONS OF INDIVIDUAL AND AVERAGE SAMPLES, AND RADIUM CONTENT OF AVERAGE SAMPLES

METHODS USED FOR QUANTITATIVE MEASUREMENTS OF RADIOACTIVE RADIATIONS AND RADIUM CONTENTS

All measurements of radiation intensities and radium contents of individual, respectively mixed, rock powders were carried out at the Physical Laboratory of the Free University ("Vrije Universiteit") at Amsterdam. The author wishes to express sincere gratitude to the Director, Prof. Dr G. J. SIZOO, for the disinterested way in which he allowed this extensive work to be executed under the practical supervision of his assistants, especially Dr P. J. HOOGTEIJLING and Mr S. RENZEMA Jr., to whom particular indebtedness is due for their great interest in the measurements. Grateful mention should also be made of Mr E. F. DE HAAN, who did much of the preliminary testing work in order to investigate the applicability of β-emission measurements with the aid of the GEIGER-MÜLLER counter to powdered eruptive rocks. His report is mainly followed in the paragraph dealing with this subject. Prof. SIZOO, furthermore, lent his indispensable assistance in supervising the part of the present

paper dealing with physics. Financial support for this part of our work was again obtained from the "Nederlandse Organisatie voor Zuiver Wetenschappelijk Onderzoek" through the intermediary of the "Stichting voor Fundamenteel Onderzoek der Materie".

The following methods were applied for obtaining quantitative data concerning radiation intensities and radium contents.

(1) Measurements of β-emission intensities with the aid of the GEIGER-MÜLLER counter.

(2) Measurements of total radiations (α- plus β-emissions) with the aid of the double ionisation chamber (two ionisation chambers mutually connected in such a way that their zero effects compensate each other).

(3) Quantitative determinations of radium contents by complete fusion of rock powders with soda, followed by measurements of the quantities of liberated radium emanations by means of the ionisation chamber.

Measurements of β-emission intensities were effectuated with GEIGER-MÜLLER counters provided with mica window bottoms, which latter practically allow only the percolation of β-particles radiated by rock powders placed immediately below them.

Measured weights of pulverized rock fragments were evenly distributed over the flat bottom of a crystallization disk. The latter was placed on a wooden block, which could be slided easily under the mica window of the counters. Since the question arose whether the zero effects of the counters should be determined,

(a) by measuring β-emission intensities with only the wooden block placed below the counters, or

(b) by determining the same with the wooden block covered by an empty crystallization disk, or

(c) by measuring the emissions of wooden block plus crystallization disk plus a filling, in the latter, of practically inactive quartz sand, a series of β-particle countings has been made for each of the three arrangements, and in addition a few countings were executed with the wooden block covered only by quartz sand, omitting the disk. The results of these measurements are reproduced in Table 3.

It is at once apparent from columns 1 and 2 of Table 3 that the crystallization disk contributes considerably to the β-emission intensities, while mutual comparisons of columns 1 and 4, and 2 and 3, respectively, indicate the appreciable β-emission absorption power exerted by the quartz sand. Assuming that powder of eruptive rock absorbs approximately as much β-radiation as an equal weight of quartz sand, it may be concluded that for β-emission intensity measurements with the counter the β-particle radiations of the wooden block covered by a crystallization disk with a quartz sand filling equalling the rock powder in weight give the best approximations to zero effects.

As a next step it was investigated whether the counting arrangement

TABLE III

Determinations of zero effects of GEIGER-MÜLLER *counters*

Numbers of β-particles counted per minute				Measuring time
1. Wooden block alone	2. Wooden block block plus empty crystallization disk	3. Wooden block plus crystallization disk filled with quartz sand	4. Wooden block only covered by quartz sand	
81,3	113,0	81,9		30 min.
82,3	95,5	89,0		„ „
72,0	104,0	80,0		„ „
82,4	102,8	95,5	78,9	„ „
68,1	95,2	74,4		„ „
75,4	92,9	81,4		„ „
95,5	110,2	90,0	85,4	„ „

explained above can be applied to eruptive rock powders as regards the suitability to reproduction of countings. For this purpose, powder from the same specimen, granite sample no. 11, was measured on various days, and besides in states of, respectively, loose accumulation, and of tight compression. Table 4 offers the results of this second set of countings, and shows that suitability to reproduction actually exists in this case. It is shown, however, by the figures that a spread of 13 β-particles per minute should be allowed to individual intensity values. The average β-emission capacity of sample no. 11 amounts to 58 $\pm$ (7-6) particles per minute, involving an error of $\pm$ 10%, which is certainly not very much if the following facts are considered.

Taking a radiation intensity of 140 particles per minute, as is the case with the bruto registrations of sample no. 11, and taking a registration time of thirty minutes, we arrive at a total of 4200 counted particles for the time of one observation. The statistical fluctuation in this figure amounts to $\sqrt{n} = \sqrt{4200}$ = about 65. If the zero effect amounts to 80 particles per minute, an average found again by 30 minutes' counting, the total of particles registered for the determination of this effect is 2400, involving a fluctuation of $\sqrt{2300}$ = about 50 particles. For the β-emission intensity deduced from the bruto and zero effect registrations the statistical fluctuation, consequently, amounts to about 65 + 50 = 115 particles on a total of 4200 — 2400 = 1800 particles counted in 30 minutes, that is to about 7%.

Table 4 also indicates that mean values of β-particles emissions by, respectively, loosely spread and tightly stamped powders of the same specimen are practically identical, so that compression of powders previous to countings can safely be omitted.

It was then ascertained how far β-emission intensities depend on the

TABLE IV

β-particle countings on powder of granite sample no. 11, *executed on various days and applying, respectively, states of loose accumulation and of tight compression (weight of powder* 15 *grams)*

	Bruto registration, particles per minute	Registration time, minutes	Zero effect, particles per minute	Registration time, minutes	β-emission, particles per minute, of powder
Powder loosely accumulated	136,8	30	76,8	30	60
	139,2	36	82,5	53	57
	138,9	30	81,4	30	58
	140,9	30	79,1	30	62
	147,5	30	84,3	34	63
	137,2	31	86,0	33	51
	138,1	30	86,4	30	52
	139,2	33	81,4	53	58
	138,9	30	79,1	30	60
	140,9	20	76,4	36	64
	147,5	31	86	34	61
	137,2	30	86,4	33	61
Average β-emission intensity of powder					58,08
Powder tightly compressed	155,2	30	92,0	30	63
	146,5	30	92,0	44	55
	146,5	31	86,2	44	60
	145,4	31	86,2	32	59
	145,4	30	79,6	32	66
	136,8	30	79,6	30	57
	136,8	30	82,4	30	55
	134,7	30	82,4	30	52
	134,7	33	79,0	32	56
	146,5	30	86,0	30	60
	137,9	30	86,0	30	58
Average β-emission intensity of powder					58,27

quantity of powder exposed to the counter. Table 5 contains the results of a series of countings executed for this purpose, while Figure 7 presents a graphical picture of the relation between weight of powder and β-emission. As might be expected, the increase of β-countings with the quantity of powder exposed roughly follows the exponential saturation curve expressed by the equation

$$I_x = I_{max} (I - e^{-\mu x}),$$

in which I_x represents the β-emission intensity of x grams of powder, I_{max} the maximal intensity reached with an unlimited weight of powder, and μ a constant.

TABLE V

β-emission intensities measured on different weights of powder from granite specimen no. 11

Weight of powder, grams	Bruto registration, particles per minute	Measuring time, minutes	Zero effect, particles per minute	Measuring time, minutes	β-emission, particles per minute, of powder
2	103,4	30	83,7	32	20
4	112,9	30	82,3	31	31
5,5	116,8	30	79,4	30	37–38
7	136,0	30	88,9	30	47
7	136,5	30	91,3	33	45,2
8,5	126,7	30	73,6	30	53
8,5	124,3	30	76,5	30	48
10	148	30	88,1	43	60
10	135,6	31	79,7	32	56
10	128,8	30	84,5	30	42
10	128,8	30	78,9	52	47
12	128,2	30	78,3	30	50
12	127,6	30	78,8	30	49
12	127,5	30	81,3	30	47
12	143,5	30	81,9	30	61,5
14	138,1	30	86,2	30	52
14	140	30	78	30	62
14	133,3	30	78,4	30	55
16	133,7	30	79,2	30	55
16	132,8	30	77,1	30	56
18	127	30	70,5	30	56,5
18	129,7	30	70,5	30	59
18	136,5	30	76,9	10	60

Since saturation of β-emissions appears to become manifest, according to Figure 7, with powder weights exceeding 10 grams, another series of countings was started on granite specimens, nos. 1-23, from the Malayan tin belt, using successively 10 and 15 grams of each rock powder. The results of these parallel determinations are gathered in Table 6, while Figure 8 gives their graphical illustrations in the order of increasing values of countings with 15 grams of powder. In addition, Figure 8 shows the variation of total radiation intensities of the same specimens as measured with the ionisation chamber. The diagram makes it clear that, in a rough way, the curve for β-countings on 10 grams of powder parallels that for 15 grams, but also that mutual proportions between the two values for the same specimen are far from being constant. For samples nos. 1-23 the quotients of countings on, respectively, 15 and 10 grams of powder vary between 1,00 and 4,40, that is far in excess of statistical fluctuations. We may, therefore, conclude that for β-particle countings it appeared to be advisable, with the apparatus used, to take 15 grams of powder instead

TABLE VI

β-emission intensities of, respectively, ± 15 and 10 grams of powders from granite samples, nos. 1–23, from the Tin Islands (including one specimen, no. 1, from Malaya)

No.	W.	Br.	T.	Z.e.	T.	E.i.	W.	Br.	T.	Z.e.	T.	E.i.
1	15	142,7	30	80	30	63	10	122,9	30	73,5	30	49
	15			86,2	30	57						
2	14,85	144,53	30	81,07	30	64	10	130,3	30	73,5	30	58
3	15	138,6	30	89,26	27	49	10	114,5	30	73,6	30	41
4	14,92	132,53	30	85,07	30	48	10	110,4	30	73,6	30	37
				81,07	30	52						
5	15	108	30	76	41	32	10	97,3	30	73,5	30	24
				77,33	30	31						
6	15	112,13	32	76,85	33	35	10	105,3	30	73,5	30	32
				73,59	32	39						
7	14,97	115,67	81	77,03	30	39	10	100,6	30	71,5	30	29
				78,16	39	38						
8	14,98	119,50	31	77,56	32	42	10	110,3	30	73,5	30	37
				76,32	34	43						
9	14,9	138,97	30	83,75	32	55	10	120,8	30	71,5	30	49
				76,0	30	63						
10	15	139,97	79	82,1	34	58	10	116,8	30	70,1	30	47
				77,03	81	63						
11	15	140,78	41	78,88	32	62	10	128,8	30	78,9	30	47
				79,7	33	61						
12	14,80	132,2	30	78,2	31	54	10	122,5	30	73,5	30	49
				89,26	27	43						
13	14,82	122,25	30	83,07	32	39	10	108,5	30	72,3	30	36
				77,75	30	45						
14	14,96	147,57	30	86,2	30	61	10	108,7	30	72,3	30	46
				83,07	30	65						
15	14,83	122,4	30	77,33	30	55	10	101,1	30	72,3	30	29
				76,87	30	55						
16	14,96	158,23	30	83,00	31	75	10	115,9	30	71,5	30	44
				85,07	30	73						
17	15	134,93	34	76,32	30	59	10	86,4	30	71,5	30	15
18	15	137,25	32	79,7	33	58	10	97,8	30	70,5	30	27
19	14,9	122,6	30	73,59	32	49	10	66,4	30	55,2	30	11
				74,46	41	48						
20	14,99	162,7	68	81,3	31	81	10	135,7	30	70,6	30	65
				77,65	37	85						
21	14,98	127,9	34	79,74	30	48	10	84,3	30	70,5	30	14
				78,2	31	50						
22	14,97	118,12	33	77,65	37	40	10	84	30	70,5	30	14
				77,97	30	40						
23	15	123,93	30	77,97	30	46	10	69,7	30	55,2	30	14,5
				70,8	8	53						

No. = Number of specimen. W. = Weight of specimen. Br. = Bruto registration of powder + glass plate + wooden block, particles per minute. Z.e. = Zero effect measured on equal weight of quartz sand + glass plate + wooden block, particles per minute. T. = Total registration time. E.i. = β-emission intensity of rock powder, particles per minute. Voltage 1250.

of 10, because the conditions for saturation are much better satisfied by taking the larger weight.

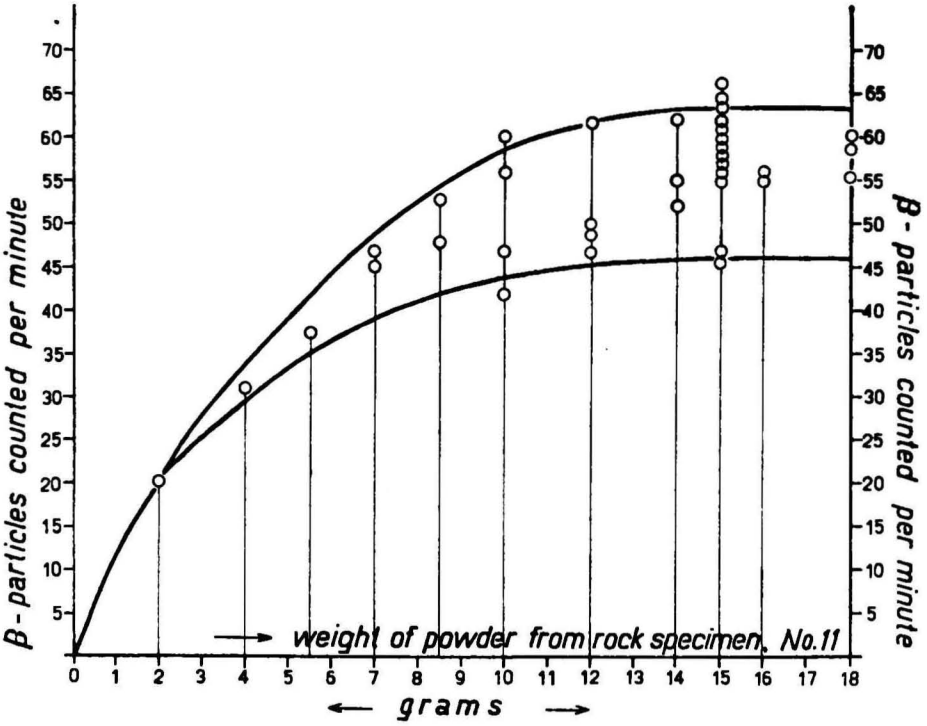

Fig. 7. Variation of β-emission intensities, expressed in numbers of particles counted per minute, as a function of weight of powder taken from sample No. 11.

Measurements of total radiation intensities were carried out with the double ionisation chamber, following the scheme described at length by KOENE (1938, pp. 41-43, 64-68), and by SIZOO and HOOGTEYLING (1947). The method has the advantage of practically eliminating the necessity of measuring zero effects and it besides furnishes data on the sum of ionisations caused by α- and β-emissions by all radio-active matter contained in rock powders, for which reason it gives a much more all-round impression of the radioactivity of rocks than β-particle counting.

The total radiation intensities are expressed in percentages of the total radiation of a standard preparation, which comparative figures are obtained as the quotients of, respectively, the time required by the standard preparation to charge the electrometer wire to a certain voltage and that required to reach the same effect with 10 grams of rock powder. According to KOENE's scheme, the final value for each radiation intensity is derived from four time determinations, corresponding to four different combinations of positions given to the standard preparation and to the rock powder, which latter is evenly distributed over the bottom of a 100 square centimeters sliding-lid. If the two ionisation chambers are indicated, respectively,

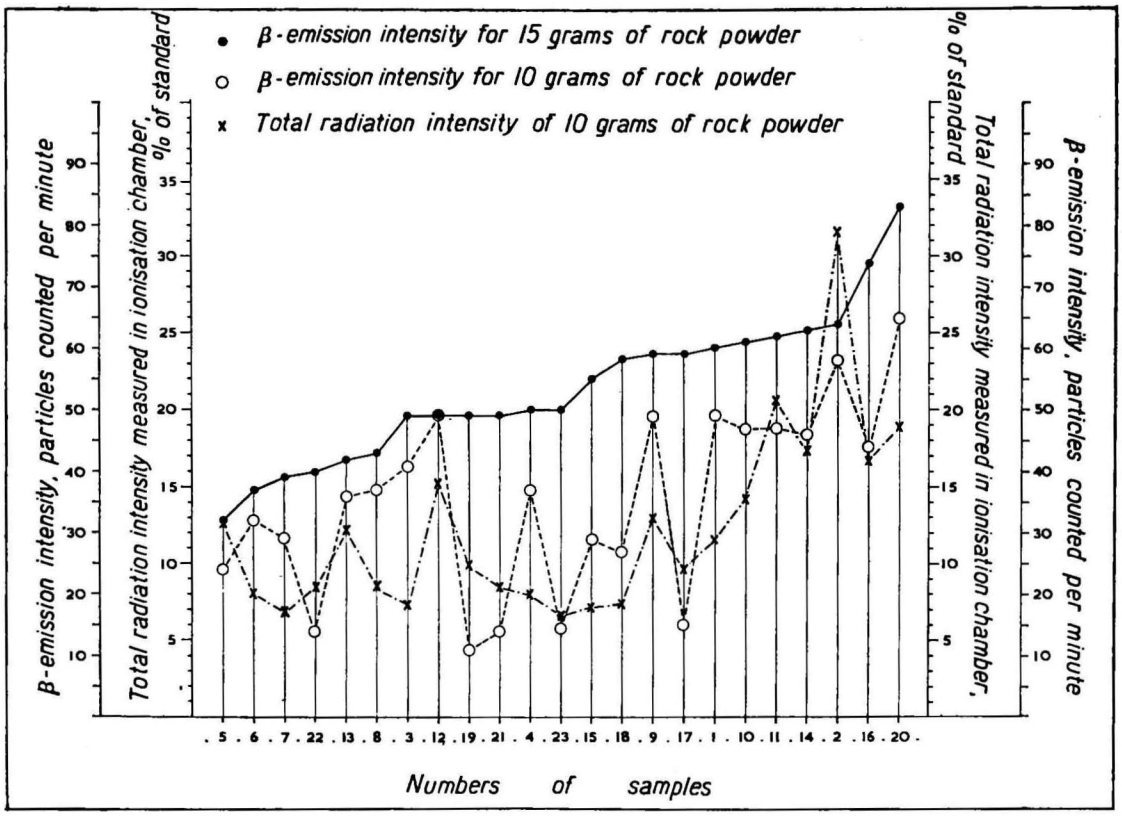

Fig. 8. β-emission intensities of, respectively, 15 and 10 grams of powder from samples 1–23 (groups I–III), and total radiation intensities of 10 grams of the same powders, set out in the order of increasing values of β-emission intensities of 15 grams of rock powder.

by 1 and 2, the standard preparation by S, and the rock powder by X, the four electrometer charging times are indicated by symbols

t_{11} for X under 1 and S beside 1,
t_{12} for X under 1 and S beside 2,
t_{21} for X under 2 and S beside 1, and
t_{22} for X under 2 and S beside 2.

From these four charging times the total radiations are calculated by means of the equation

$$\text{Total radiation intensity of X in \% of S} = \tfrac{1}{2}\left\{\frac{t_{12}-t_{11}}{t_{12}+t_{11}} + \frac{t_{21}-t_{22}}{t_{12}+t_{22}}\right\}.$$

Determinations of radium contents of powder mixtures representing average compositions of eruptive rock groups I-X were effectuated by dissolving the powdered material and measuring the Radon content of the solution according to the method described in detail by

SIZOO and KOENE (1938), and by HOOGTEYLING (1948, pp. 10-14, 63-65), which needs no further explanation here.

TOTAL RADIATION AND β-EMISSION INTENSITIES OF INDIVIDUAL SAMPLES

Total radiation intensities were determined of the complete series of specimens, nos. 1-137, whereas β-particle countings were restricted to nos. 1-90 and 135-137. The complete list of figures is given in Table 7. In order to offer a graphical picture of the proportional relations between β-particle countings and total radiation intensities, both sets of figures are set out in Figure 9 in the order of increasing values for total radiation intensities of specimens 1-90 and 135-137. This arrangement has been chosen for similar reasons as the order of increasing β-countings for 15 grams applied in Figure 8; that is with a view to getting one set of points gathered on a more or less smooth curve, whereby it becomes possible to survey the relations between one series of measurements and others at a glance. It is at once apparent from Table 7, and from Figures 8 and 9, that the quotients of β-countings and total radiation intensities vary in many cases considerably beyond statistical spreads. The latter are of the order of 10% for β-countings and of about 7% for measurements with the double ionisation chamber, so that quotients of both values are liable to statistical spreads of about 17%, which is appreciably less than the deviations from the mean value of these quotients for specimens 1-90 and 135-137. The explanation of this fact is that specimens with low β-counting versus total radiation intensity proportions are strong α-radiators, whereas the reverse is true for specimens with low values for this quotient. In a rough sense, however, as may be expected, Figure 9 indicates a certain degree of parallelism between β-countings and total radiation figures.

Apart from fluctuations caused by the variability in the proportions between relatively stronger β-radiating U-bearing minerals and relatively stronger α-radiating Th-bearing species, the intensities of total radiation and β-emissions are influenced also in a minor degree by variations in the content of radioactive isotopes of lighter elements, for instance Sm^{147}. That this influence is very subordinate in the latter case, appears immediately from the rareness of radioactive Sm. If we accept the Ce_2O_3 content of, *e.g.*, the tin granites to be about 0,01%, according to measurements by VAN TONGEREN (1938) on granites from the Tin Islands, we arrive at a Sm^{147} content of $1{,}8 \times 10^{-6}$ gr./gr. for these rocks, if the proportion between Sm and Ce is fixed at 6,47 : 46,1 in accordance with GOLDSCHMIDT's (1937) figures for the weight percentages of the rare earths in sediments, and if, moreover, the frequency of Sm^{147} is put at 15,07% of total Sm. If it is furthermore taken into consideration that the U content of the tin granites is about $9{,}3 \times 10^{-6}$ gr./gr. (Table 11), and that the proportion between the half-lives of Sm^{147} and U^{238} is $\frac{1{,}4 \times 10^{11}}{4{,}56 \times 10^{9}}$ or about 31, it becomes

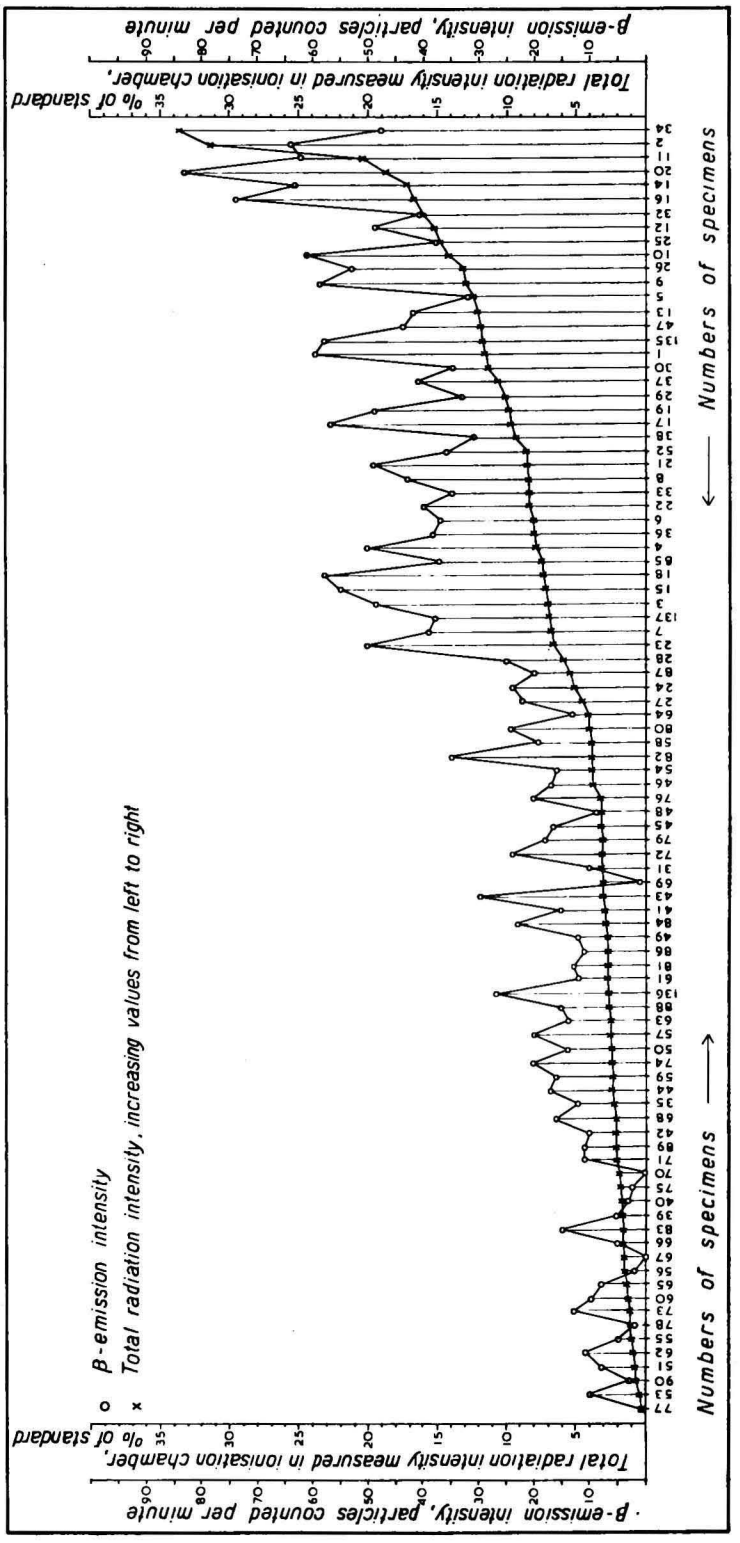

Fig. 9. Total radiation and β-emission intensities of specimens Nos. 1–90, 135–137, set out in the order of increasing values for total radiation intensities.

TABLE VII

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	A	B	C	D	A	B	C	D
	1	11,6	60		46	3,8	17		92	2,8	
					47	11,9	44		93	23,0	
I	2	31,6	64		48	3,2	9		94	3,4	
	3	7,3	49		49	2,8	12		95	11,2	
	4	8,0	50		50	2,4	14		96	2,3	
	5	12,6	32		51	0,8	8		97	2,3	
	6	8,1	37		52	8,7	36		98	4,7	
	7	6,8	39		53	0,5	10		99	5,0	
	8	8,5	43		54	3,8	16		100	4,1	
	9	13,1	59		55	1,1	5		101	2.6	
II	10	14,3	61		56	1,5	2		102	2,0	
	11	20,6	62		57	2,5	20		103	4,7	
	12	15,3	49		58	3,9	19		104	4,2	
	13	12,3	42		59	2,3	16				
	14	17,3	63					VIII	105	2,2	
	15	7,3	55	VI	60	1,4	10		106	1,9	
	16	16,8	74		61	2,7	12		107	2,6	
	17	9,7	59		62	0,9	11		108	2,1	
	18	7,4	58		63	2,5	14		109	3,5	
					64	4,1	13		110	2,8	
III	19	9,9	49		65	1,4	8		111	2,2	
	20	18,9	83		66	1,6	5		112	1,0	
	21	8,5	49		67	1,5	0		113	0,5	
	22	8,4	40		68	2,1	16		114	1,7	
	23	6,7	50		69	3,0	1		115	1,9	
					70	1,9	0		116	3,3	
IV	24	5,1	24		71	2,0	11		117	5,3	
	25	15,0	38		72	3,1	24		118	4,2	
	26	13,3	53		73	1,3	13		119	4,8	
	27	4,6	22		74	2,3	20		120	3,9	
	28	6,0	25		75	1,8	2		121	1,2	
	29	10,1	33		76	3,3	21		122	2,1	
	30	11,5	35		77	0,4	1		123	2,3	
	31	3,1	10		78	1,2	2	IX	124	0,6	
	32	16,3	41		79	3,1	18		125	1,7	
	33	8,4	35		80	4,0	24		126	0,6	
	34	33,6	48		81	2,7	13		127	1,6	
	35	2,2	12		82	3,8	35		128	0,9	
	36	8,0	38		83	1,6	15		129	0,3	
	37	10,7	41		84	2,8	23		130	0,4	
	38	9,4	31		85	7,4	37		131	0,9	
V	39	1,7	5		86	2,7	11		132	0,5	
	40	1,7	3		87	5,5	20		133	1,0	
	41	2,9	15		88	2,6	15		134	1,5	
	42	2,1	10		89	2,0	11				
	43	3,0	30		90	0,7	3	X	135	11,8	58
	44	2,3	17						136	2,6	27
	45	3,2	17	VII	91	1,8			137	6,9	

clear that the radioactive radiation inherent to Sm ^{147} is negligible in relation to that caused by uranium and thorium. [1])

TOTAL RADIATION AND β-EMISSION INTENSITIES, AND RADIUM CONTENTS, OF AVERAGE SAMPLES

Total radiation intensities and β-countings of powder mixtures corresponding to eruptive rock groups I-X are united in Table 8 together with figures for Ra contents of average samples I-VI and X. A graphical representation of these measurements is given in Figure 10, in which the three sets of values are arranged following the order of increasing total radiation intensities. For the purpose of mutual comparison, Table 8 also contains the average values of β-emission and total radiation intensities calculated from measurements on individual specimens within groups I-X. The geochemical significance of the figures given in this Table will be discussed in the next chapter. [2])

TABLE VIII

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.

[1]) Data concerning samarium are taken from the volume "Nuclear Data" issued by the U.S. Department of Commerce, National Bureau of Standards (NBS Circular 499, 1950), and from HOLLANDER, J. M., PERLMAN, I, and SEABORG, G. T., "Table of Isotopes", issued by the Radiation Laboratory of the Univ. of California, Berkeley (1952).

[2]) The determination of the Ra contents of powder mixtures VII, VIII, and IX had to be suspended for technical reasons. The author hopes to present them in the near future in a supplementary note.

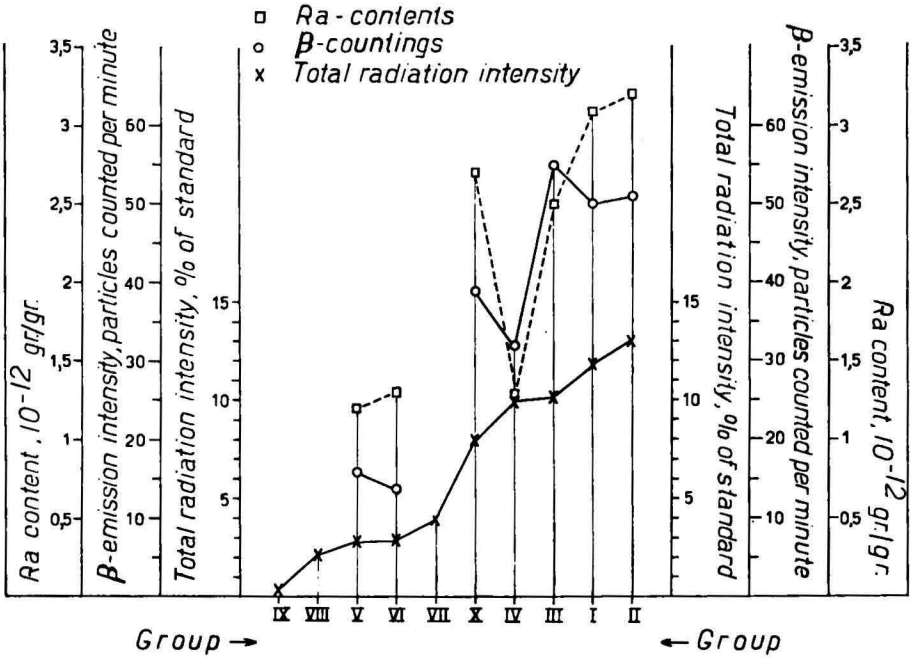

Fig. 10. Total radiation intensities of average samples I–X, and β-emission intensities and radium contents of average samples I–VI and X, set out in the order of increasing values for total radiation intensities.

VARIATION OF RADIATION INTENSITIES AND RADIUM CONTENT OF INDONESIAN ERUPTIVE ROCKS

VARIATION OF TOTAL RADIATION AND β-EMISSION INTENSITY OF INDIVIDUAL SAMPLES WITHIN EACH PETROGRAPHIC PROVINCE

To enhance the surveyability of figures obtained by radiation measurements, frequency distributions of total radiation intensities over successive intervals of 2% of standard, and of β-emissions over intervals of 10 particles per minute, are gathered in Table 9, of which Figure 11 offers a diagram. For practical purposes, eruptive rock groups I-III, comprising the consanguineous granites of the Tin Islands in the interior region of the Malayan fold system, are united under the same heading, while group X, the granites of the Banggai and Soela Islands, has been left out of consideration in the Table and Figure mentioned because of the too small number of specimens it covers. For the last-named reference is made to Table 7.

It is immediately apparent from Tables 7 and 9, and from Figure 11, that the granites of the tin belt (groups I-III) and of the Banggai and Soela Islands (group X) exhibit the strongest total radiations and β-emissions among all Indonesian eruptive rocks. They are followed, in this respect, rather closely by the granites and allied rocks of Southwest Borneo (group IV), whereas all other Indonesian irruptives considered

TABLE IX

Numerical distributions of total radiation and β-emission intensities of Indonesian eruptive rocks

A. Numerical distributions of total radiation intensities

Interval, % of standard	Groups I, II, III		Group IV		Group V		Group VI		Group VII		Group VIII		Group IX	
	Cases	% of total number of cases	Cases	% of total number of cases	Cases	% of total number of cases	Cases	% of total number of cases	Cases	% of total number of cases	Cases	% of total number of cases	Cases	% of total number of cases
0 — 2	0	0	0	0	6	28,6	14	45,2	2	14,3	6	31,6	11	100
2,1 — 4	0	0	2	13,3	13	61,9	14	45,2	5	35,7	10	52,6		
4,1 — 6	0	0	3	20,0	0	0	2	6,4	5	35,7	3	15,3		
6,1 — 8	6	26,1	1	6,7	0	0	1	3,2	0	0				
8,1 — 10	6	26,1	2	13,3	1	4,8			0	0				
10,1 — 12	1	4,3	3	20,0	1	4,8			1	7,1				
12,1 — 14	3	13	1	6,7					0	0				
14,1 — 16	2	8,7	1	6,7					0	0				
16,1 — 18	2	8,7	1	6,7					0	0				
18,1 — 20	1	4,3	0	0					0	0				
20,1 — 22	1	4,3	0	0					0	0				
22,1 — 24	0	0	0	0					1	7,1				
24,1 — 26	0	0	0	0										
26,1 — 28	0	0	0	0										
28,1 — 30	0	0	0	0										
30,1 — 32	1	4,3	0	0										
32,1 — 34			1	6,7										

B. Numerical distributions of β-emission intensities

Interval, particles counted per minute	Groups I, II, III		Group IV		Group V		Group VI	
	Cases	% of total number of cases	Cases	% of total number of cases	Cases	% of total number of cases	Cases	% of total number of cases
0 — 10			1	6,67	8	38,1	10	32,3
11 — 20			1	6,67	10	47,6	15	48,4
21 — 30			3	20	1	4,8	4	12,9
31 — 40	4	17,4	6	40	1	4,8	2	6,4
41 — 50	8	34,8	3	20	1	4,8		
51 — 60	5	21,7	1	6,67				
61 — 70	4	17,4						
71 — 80	1	4,35						
81 — 90	1	4,35						

in this paper are characterized by the predominance of lower values, and by lower average figures (Table 8 and Figure 10). Groups I-III and IV besides show a rather strong spreading of total radiation intensities, which also seems to be the case with group X, as far as the restricted number of observations in the latter case allows a conclusion to be drawn. Group VII, the pre-Tertiary granites and allied rocks from the main mountain system of Sumatra, shows moderate total radiations, but the spreading of values still remains rather great. Among groups V (the SCHWANER Mountains granodioritic intrusiva), VI (the andesitic to basaltic lavas of the Quaternary volcanoes), and VIII (the Miocene granites and allied rocks of the Soenda fold system), all characterized by small total radiation intensities in comparison with the other rock clans mentioned, the spread of values is smallest with groups VI and VIII, whereas it appears to be greater among samples belonging to group V. The remarkable agreement of total radiations shown by the Miocene irruptives of the Soenda orogen with those measured on the Quaternary lavas might perhaps be explained by the fact that these rocks were formed in periods of magmatic activity succeeding closely to each other in geological age, and bound to almost coinciding portions of the Indonesian tectonic framework. The slightly greater radiation intensity of the pre-Tertiary Sumatran granites and granodiorites, as compared with that shown, on the average, by the Quaternary lavas and the Miocene intrusive rocks, among which the last-named are chemically rather identical to the members of group VII (Table 1), may perhaps be explained by the greater alkalinity of the intrusiva belonging to the Sumatra branch of the Sumatra fold system.

As might be expected, the peridotites of the Moluccan orogen are characterized by very low total radiation intensities, varying between 0,3 and 1,7% of standard.

Surveying the whole of total radiation intensities measured, it appears that figures vary between 0,3 and 33,6% of standard. The variation ranges of these values within each magmatic province and sub-province

TABLE X

Variation ranges of total radiation intensities within Indonesian magmatic provinces and sub-provinces

Group	Variation range of total radiation intensities, %of standard
I–II–III	6,7 – 31,6
IV	2,2 – 33,6
V	0,5 – 11,9
VI	0,4 – 7,4
VII	1,8 – 23
VIII	0,5 – 5,3
IX	0,3 – 1,7
X	(2,6 – 11,8)

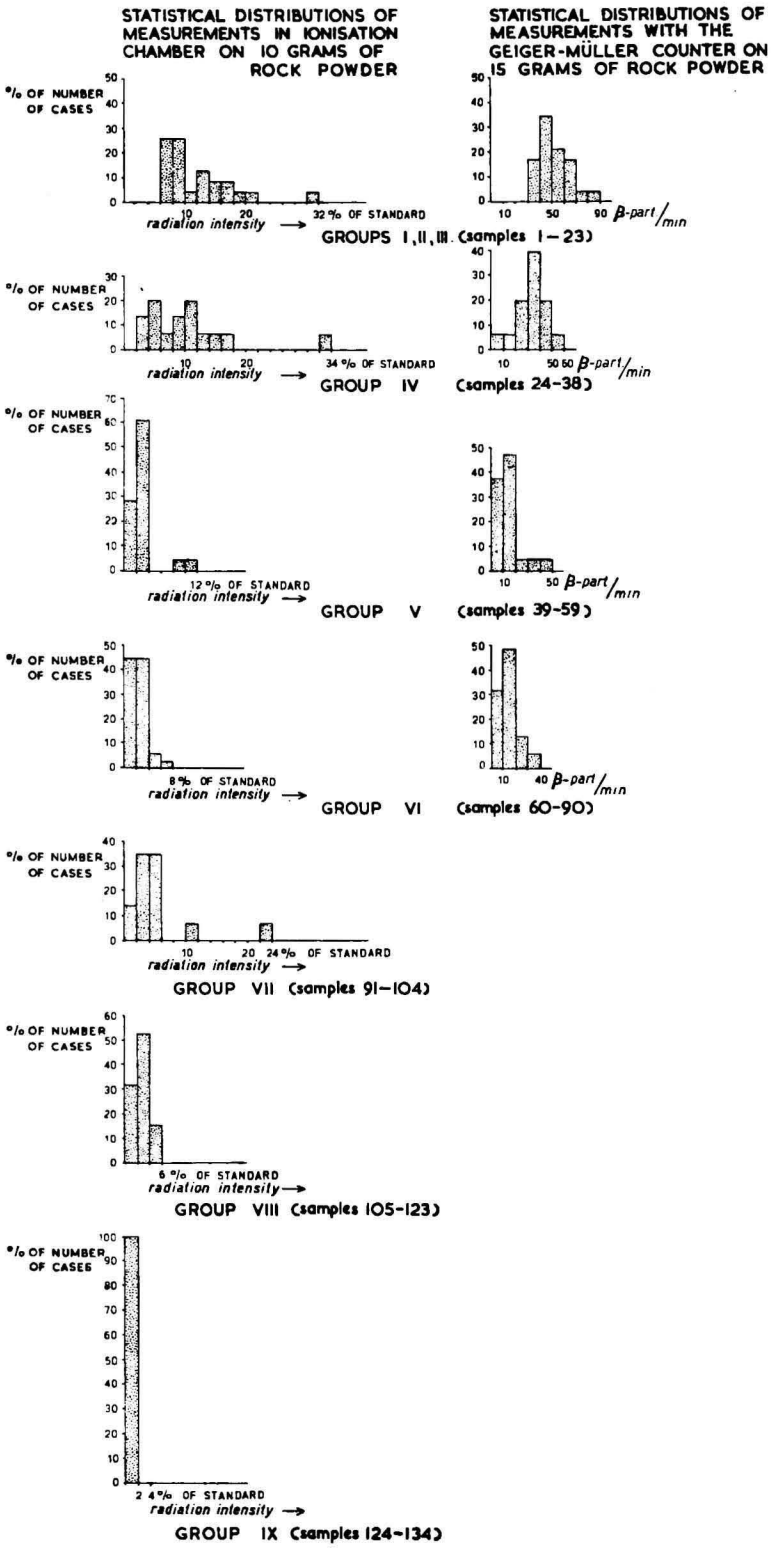

Fig. 11. Graphical statistics of numerical distributions of total radiation and β-emission intensities within Indonesian magmatic provinces.

considered here are summarized in Table 10, which shows that, *e.g.*, the radioactivities of the granites from the tin belt (groups I-III) do not vary between narrow limits, but that radioactive substances are very unevenly disseminated through them. The last-mentioned fact is certainly not connected with considerable variations in the chemical compositions of the parent rocks of the cassiterite deposits, which, according to the writer (WESTERVELD, 1936 a) are very uniform, in this respect, over the whole world, and in the Malayan tin region, too, lie within very close limits, to judge from the analyses in Table 1. The only plausible explanation is that the carriers of radioactivity are very unevenly distributed if small volumes of rock are considered. From the studies of KEEVIL (1938, 1942), LARSEN and KEEVIL (1942), and KEEVIL, LARSEN, and WANK (1944), it has become evident that among these carriers zircon is invariably the most active, although strong radiations have also been registered for apatite, sphene, and biotite. In the case of the Indonesian tin granites, an important part is certainly also played, as regards radioactivity, by allanite, and perhaps also by monazite and xenotime, which mineral species appear to be regular constituents of the Banka granites (KIEFT, 1952). Allanite (orthite) is surrounded, like zircon, by pleochroic halos in biotites of Banka granites, in which rocks sphene has besides been found to be a regular mineral (WESTERVELD, 1936 b; KIEFT, 1952). Variations in the quantities of the granite accessories referred to probably account for rather strong differences in total radiation intensities shown by individual members of collections of specimens. Taking, however, a larger number of samples, as in our case, radioactivity measurements show that the similarity of bulk compositions of Indonesian tin granites is duplicated by mutually very identical values for total radiation and β-emission intensities exhibited by powder mixtures representing, respectively, the Riouw Archipelago, Banka, and Billiton. In the same way, Ra contents of these average samples were found to be approximately equal (Table 8).

VARIATION OF TOTAL RADIATION INTENSITY, β-EMISSION INTENSITY, AND RADIUM CONTENT OF AVERAGE SAMPLES IN RELATION TO BULK CHEMICAL COMPOSITION

Table 8, illustrated by Figure 10, shows that the high total radiation intensity and high β-emission intensity, and also the appreciable radium content, of powder mixtures representing eruptive rock groups I, II, and III — the granites of the Tin Islands — is almost equalled by similar high figures for group X — the granites of the Banggai and Soela Islands. Group IV — the granites and allied rocks from Southwest Borneo —, on the other hand, is characterized by a high total radiation intensity and a moderately high β-emission activity standing against a relatively low radium content; a phenomenon which is possibly to be ascribed to a relatively high Th and a relatively low U percentage in the average eruptive rock

from the regions southwest of the SCHWANER Mountains compared to that of the Tin Islands and the Soela and Banggai Archipelago. One atom of U^{238} upon radioactive decomposition yields 8 α-particles and 6 β-particles; one atom of thorium 6 α-particles and 4 β-particles.

The strong petrochemical differences between the granites of the Tin Islands, on one side, and the Mesozoic intrusives of Borneo, on the other side, is also illustrated by the differences in radium content of powder mixtures I-III compared with that of powder mixtures IV and V. The SCHWANER Mountains granodiorites — group V — besides show a much lower total radiation and β-emission intensity than the tin granites.

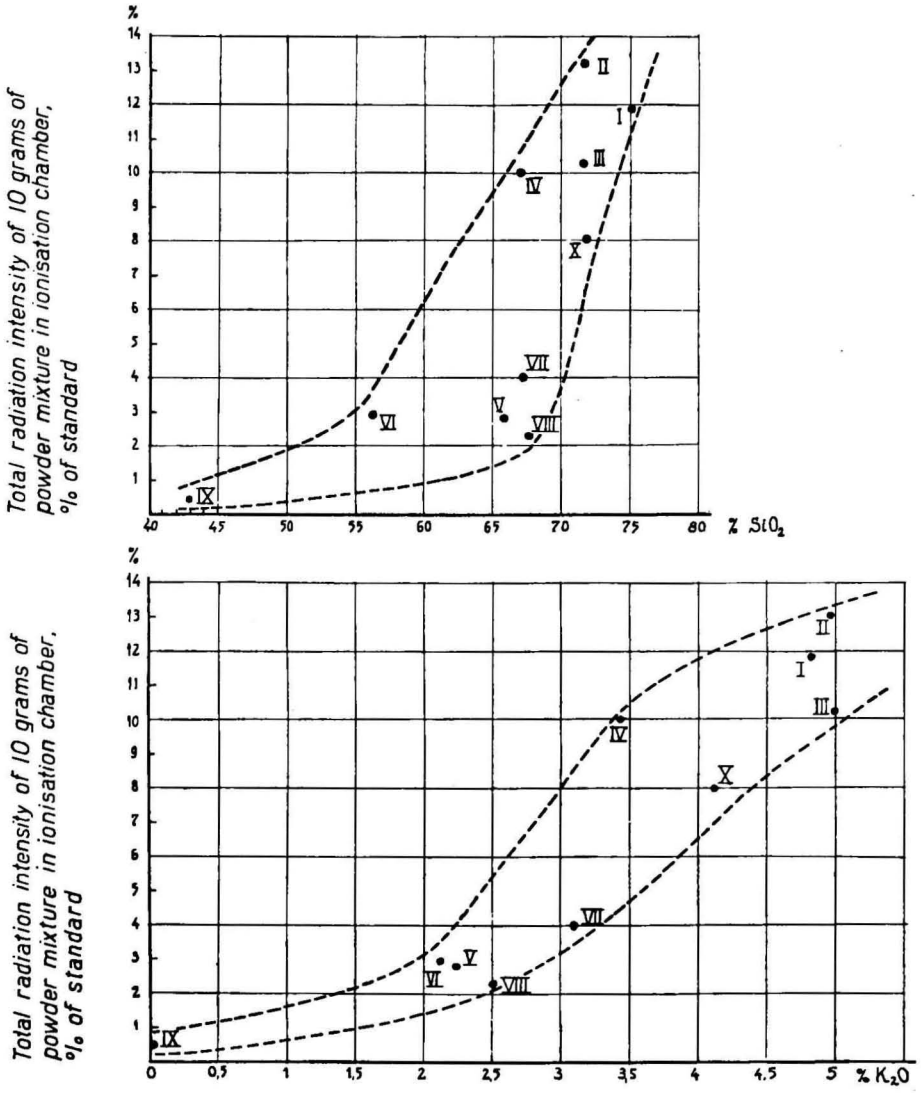

Fig. 12. Total radiation intensities of 10 grams of average samples I–X set out, respectively, as a function of SiO_2 and K_2O contents.

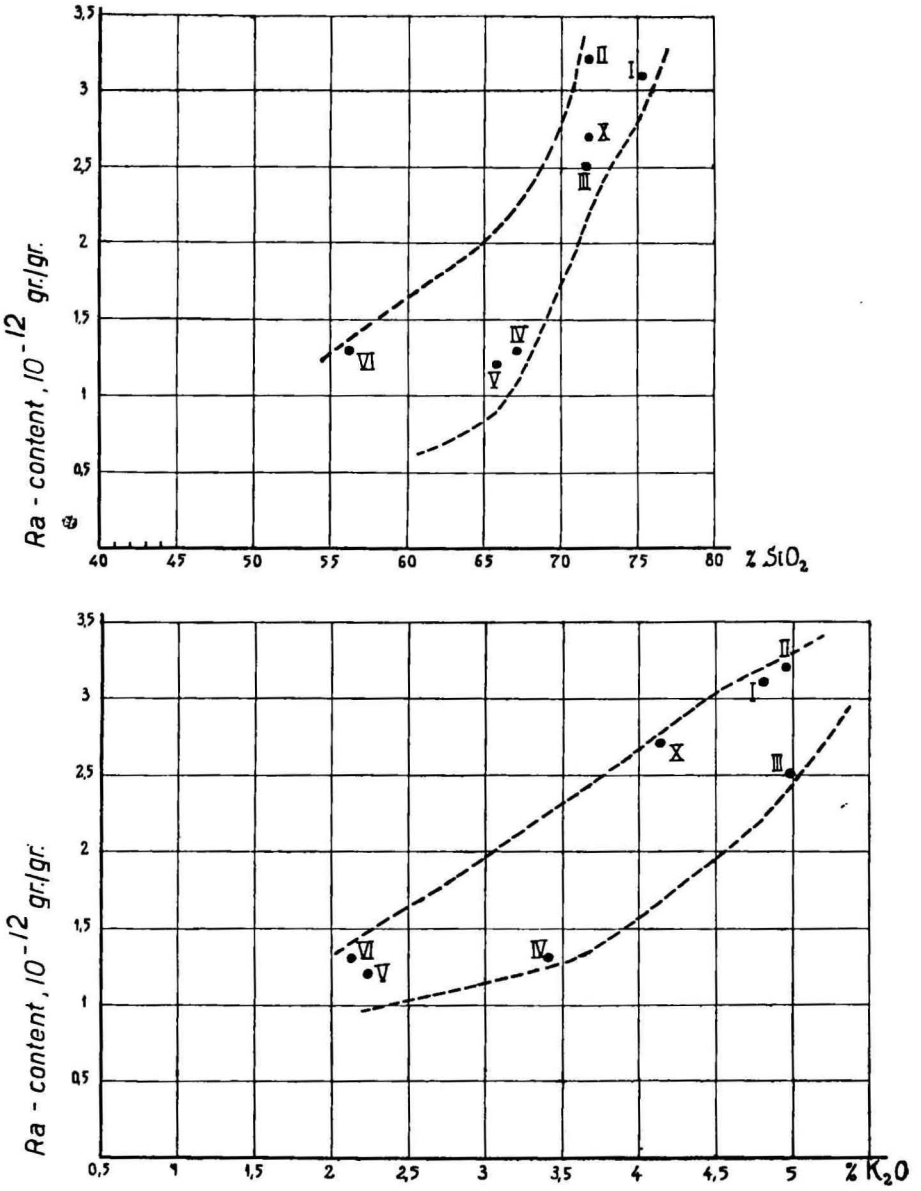

Fig. 13. Radium contents of average samples I–VI and X set out, respectively, as a function of SiO_2 and K_2O contents.

That the last-named group exhibits lower radiation values than the Southwest Borneo intrusives, in spite of almost similar radium contents, possibly finds its cause in a much lower Th content of the average sample.

Comparing total radiation intensity and radium content with bulk chemical composition, it appears that the first two values increase in a rough way with SiO_2 and K_2O weight percentages of the powder mixtures, as is made clear by Figures 12 and 13. The relations are certainly not strictly

linear, but points illustrating them for individual cases lie within rather narrow rising zones, delimitated by broken lines in the last-named diagrams.

The rise of total radiation intensity with increase of K_2O content is undoubtedly in part also due to the radioactivity of K^{40}. According to investigations on this point by HOOGTEIJLING (1948, pp. 65-68), the part played in total radiation intensities by the K isotope is however of a negligible influence in natural rocks, in his case clay samples of the Netherlands.

The relatively high Ra content of the tin granites (groups I-III), which amounts to about 3×10^{-12} gr./gr., is appreciably above that usually indicated for "granites". EVANS and GOODMAN (1941, p. 476), for instance, accept a value of $(1{,}37 \pm 0{,}17) \times 10^{-12}$ gr. Ra/gr. for "acid" eruptive rocks, while SENFTLE and KEEVIL (1947) found an average value of $1{,}395 \times 10^{-12}$ gr. Ra/gr. for a large number of, mainly North American, granite specimens. For "intermediate" intrusiva EVANS and GOODMAN arrived at an average figure of $(0{,}51 \pm 0{,}05) \times 10^{-12}$ gr. Ra/gr., and SENFTLE and KEEVIL at $0{,}917 \times 10^{-12}$ gr. Ra/gr. As has been explained before, it is not possible to make an exact comparison between Ra contents of Indonesian rocks as given in the present paper and the Ra contents indicated by the American investigators, because the values of EVANS and GOODMAN and of SENFTLE and KEEVIL do not refer to specified chemical compositions. It may be inferred, however, from the results obtained on Indonesian igneous rocks that the tin granites are appreciably above the average of the earth's crust as regards α- and β-emissions, and Ra content.

The average Ra content of "acid" or "granitic" eruptive rocks according to the American physicists is approximately shown by powder mixtures of rock groups IV, V, and VI, which have appreciably lower SiO_2 and K_2O percentages than groups I, II, III, and X. The low total radiation activity shown by each among rock groups V, VI, VII, and VIII is probably due, as has been suggested already for group V, to their low U as well as low Th content.

Since the interdependence of Ra content and, respectively, SiO_2 and K_2O weight percentages is rather manifest in Indonesian igneous rocks, an attempt is made in Table 11 to illustrate these relations by indicating the Ra and U content to be expected approximately in moderately acid and in very acid rocks of known silica content and K alkalinity. A more or less approximate value for the average peridotite of the Moluccas orogen, which has about 42,5% SiO_2 and 0,02% K_2O, might be obtained by taking the mean of comparative figures calculated from the Ra contents of powder mixtures representing rock groups I-III, V, VI, and X (leaving out the rather abnormal group IV) on the basis of proportionality between Ra content and total radiation intensity. Taking 0,65% of standard — the average between 0,4 and 0,9% as given in Table 8 — as the total radiation intensity of the powder mixture representing group IX, a Ra

content of $\pm$ 0,21 x 10^{-12} gr./gr. is found for the Indonesian peridotite clan. This value is probably somewhat too high in view of the fact that direct measurements on ultrabasic rocks (dunite, websterite, serpentinite, bronzitite, hortonolite-dunite) by DAVIS (1947) yielded figures of (0,002 — 0,142) x 10^{-12} gr. Ra/gr. In a later publication, DAVIS and HESS (1949) give 0,01 x 10^{-12} gr. Ra/gr. as the average for "ultramafic" igneous rocks.

TABLE XI

Ra and U content of Indonesian igneous rocks in relation to SiO_2 and K_2O weight percentages

	Moderately acid rocks; SiO_2 $\pm$ 63 %, K_2O $\pm$ 2,6 %	Very acid granites; SiO_2 $\pm$ 72,8 %, K_2O $\pm$ 4,9 % (tin granites)
Ra, 10^{-12} gr./gr.	$\pm$ 1,3	$\pm$ 3
U, 10^{-6} gr./gr.	$\pm$ 4	$\pm$ 9,3

For moderately acid rocks, the average has been taken of the SiO_2 and K_2O percentages of powder mixtures IV, V, and VI, while for the very acid granites the corresponding values for the tin granites, as represented by groups I-III, are given in Table 11.

As a plausible explanation of the increase of radioactivity with SiO_2 and K_2O contents of eruptive rocks it may be argued that this phenomenon finds its cause in the gradual enrichment of magmatic fluids in rare lithophile elements in the course of differentiation, which process also leads to a gradual increase of the concentration of silica and potassium. From the experiments by KEEVIL and associate workers it has become evident that U (and Ra) are mainly concentrated in heavy accessories like zircon, epidote, sphene, and apatite — to which should be added, in the case of the tin granites, allanite, monazite, and xenotime —, so that the quantity of radioactive substances largely depends on that of a few minor constituents, possibly mainly zircon, and apparently only in a subordinate degree on the substitution of major rock-building elements by uranium and thorium as in the case of some other trace elements, *e.g.*, Ga and Ge, which enter as guest elements in the place of, respectively, Al and Si.

GENERAL GEOLOGICAL CONCLUSIONS AND THEIR BEARING ON SOME ASPECTS OF INDONESIAN ECONOMIC GEOLOGY

The sharp delimitation of the Indonesian tin province with regard to the Borneo branch of the Malayan fold system on the ground of the high SiO_2, K_2O, and Ra contents exhibited by the tin granites as contrasted with the lower figures for these substances and the less potassic character shown by the Borneo intrusiva strongly supports the opinion expressed

earlier by the writer (WESTERVELD, 1949, p. M 5), according to which the folds and intrusions of the Riouw Archipelago, Banka, and Billiton do not find their immediate prolongation in Southwest and Central Borneo, but should be regarded as a separate zone of folding running more or less parallel with the northwest-southeast extension of the SCHWANER Mountains batholith.

Owing to the petrochemical similarity between the eruptive rocks of Southwest Borneo (Matan and Soekadana districts) and those of the SCHWANER Mountains, revealing itself in the moderate silica content and relatively low k value of the average sample representing each of these two regions, no solid arguments can be drawn from petrological features to accept a difference in age between the plutonic masses of Southwest Borneo and the SCHWANER Mountains batholith. In the same way, no convincing field observations are known in proof of two distinctly separate intrusive periods. The opinion put forward by ZEIJLMANS VAN EMMICHOVEN (1939, pp. 137, 138, 175-177) and VAN BEMMELEN (1939, pp. 298-308; 1949, pp. 236, 333-339) that the SCHWANER Mountains batholith and the intrusive rocks of Southwest Borneo intruded at different periods, the SCHWANER Mountains granodiorites between the Permocarboniferous and the Upper Trias, but the Matan-Soekadana plutonics in post-Triassic time, therefore, very probably needs revision on account of available data.

In view of the conspicuous petrochemical differences between the granites of the Tin Islands and the Mesozoic Borneo plutonics, and of the moderate Ra content of the latter, it does not seem probable that a search for cassiterite deposits in West Borneo would meet with much success. The relatively high total radiation intensity and β-emission activity displayed by many of the Southwest Borneo intrusives, however, does not make it altogether impossible that magmatic differentiation entailed the formation of deposits of other ore minerals, for which a less advanced stage of differentiation already suffices to initiate their segregation. From a mineralogical standpoint, attention should, for this reason, not be diverted from the area south of the SCHWANER Mountains. The absence of cassiterite deposits of any importance in West Borneo is already known by experience in the Chinese Districts, formerly — and still on a moderate scale — worked for their placer gold, and known to harbour some unimportant (or perhaps insufficiently explored) Mo, Cu, and Pb veins, which are likewise related to the Mesozoic intrusions.

As possible future sources of fissionable material, that is of uranium and thorium, the tin granites with their 3 x 10^{-12} gr. Ra/gr. deserve special mention. Investigations in the writer's laboratory (KIEFT, 1952) resulted in the identification in Banka granites of zircon, allanite, monazite, xenotime, and a few other accessories. BAIN (1950, p. 292, 293), from this standpoint, called attention to the possible importance of monazite and xenotime, which two species are appreciably concentrated in the mother rocks of the cassiterite deposits and in sands derived from them.

The highly siliceous, rather strongly potassic, and appreciably radioactive granites of the Soela and Banggai Islands for this reason alone deserve some attention from the standpoint of economic geology. This view is strengthened by the fact that reports from the very few visits paid by geologists to this archipelago (VERBEEK, 1908, pp. 103, 220; KOOLHOVEN, 1929, p. 196) already indicate the development of coarse-bladed muscovite in a kind of gneissic rock (pegmatite?) on the island Peling (or Pèlèng) in the Banggai group. The mica seems to have been exploited by the native population for ornamental purposes. From the existence of tourmaline-bearing granite cut by quartz veins on the island Bangkoeloe (or Bangkoeroeng), according to VERBEEK, it may also be concluded that the Banggai and Soela granites mineralized their cap rocks to some degree. This supposition finds further support in a note received after the Japanese occupation of Indonesia from Japanese sources, according to which mica has been exploited during the last war on one of the Banggai Islands, where coarsely crystalline beryll and tantalite are besides recorded to have been found in pegmatite veins.

With regard to the younger fold systems of Indonesia, little need be added to what has been remarked about them before. On the average, the pre-Tertiary granites and allied rocks of Sumatra are not much different in a mineralogical and petrochemical sense from the Miocene intrusives of the Soenda orogen, albeit the former seem to be a little more potassic. The Miocene irruptives, on the other side, show a rather narrow relationship to the more basic andesites and basalts of the Quaternary volcanoes; a phenomenon which, as has been suggested already, possibly finds its explanation in the not very great difference in age between Neogene and Quaternary volcanism, and in the approximate coincidence of the row of recent volcanoes with the course of the Soenda orogen. In contrast with the rather appreciable variations in petrochemistry exhibited by the different zones of the Malayan fold system, the younger zones of tectonic disturbance and plutonic action of Indonesia, with the exception of the Sumatra orogen in a larger sense, are petrologically much more uniform

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