GEOSEA V Proceedings Vol. I, Geol. Soc. Malaysia, Bulletin 19, April 1986; pp. 51–68

Geological significance of granitic fragments found from pumice flow of 1883 eruption at the Krakatau Group, Indonesia

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Abstract: Pumice flow of the 1883 Krakatau eruption occurs at Small Rakata, Rakata and Sertung Islands, those which roughly correspond to the wall of Krakatau caldera, Indonesia. It significantly differs in both mineral and chemical compositions from any other volcanic rock or ejecta of the Krakatau Group which belong to Miyashiro's (1974) tholeiitic series. Lithic fragments of granitic rock, ranging in modal composition from quartz monzonite to quartz monzodiorite, which were found from the pumice flow are, in both mineral and chemical compositions, similar to west Malayan granitic rocks represented by biotite quartz monzonite which occurs as the dominant rock type in west Malay Peninsula (Hamilton, 1979).

No granitic rock occurs throughout the Krakatau Group, except the granitic fragments found from the pumice flow. Therefore, it should be considered that the granitic fragments came from the underlying complex at depths, where they were captured as foreign materials by the magma, and that genetically the pumice flow was closely related to the underlying granitic complex with regard to the production of its source magma. In the meantime, geochemical comparison between a suite of the 1883 Krakatau pumice flow, its related granitic fragment and selected Malayan granitic rocks and a suite of the Ata and Aira "Shirasu" pumice flows and their related granitic rocks shows that the respective pumice flows are well correlated in chemical character with the respective related granitic rocks in the locations of their plots on the AFM diagram. Such a fact suggests that the 1883 Krakatau pumice flow was genetically related to some granitic rocks nearby the Krakatau caldera.

Thus, it may be possible that sialic crustal materials, involving granitic rocks and sediments which occur in Sumatra are plunged into depths along a peculiar tectonic structure located at the Sunda Strait. This appears to be a shared portion caused by deformation of the Sunda arc due to differential movement owing to compression between the Indo-Australian oceanic plate and the Eurasian continental crust. These materials were partially melted and produced a magma of granitic composition, which was mixed with or assimilated by an ascending basaltic magma originating probably from the upper mantle resulting in a dacitic magma distinctly dominant in silica, alkalies and volatile components. As a result, the 1883 Krakatau eruption characterized by the pumice flow of dacitic composition took place. The ascending dacitic magma captured granitic fragments from the plunged sialic crustal materials at depths while passing through the peculiar tectonic structure along the shared portion. Thus the granitic fragments were erupted out together with the pumice flow.

INTRODUCTION

In 1981 and 1982, geological field studies were carried out in the Krakatau Group which includes the islands of Anak Krakatau, Small Rakata, Rakata and Sertung, in the Sunda Strait between Sumatra and Java, Indonesia. Following the field studies, analyses of mineral and chemical compositions, X-ray diffraction, differential thermal analysis, scanning electron microscopy and infrared absorption spectra were carried out for volcanic products of the Krakatau Group. Geochemical analyses of the pumice flow which erupted in 1883 at Krakatau Volcano and the genetical relationship between the pumice flow and granitic fragments found from the pumice flow have been investigated earlier (Ōba *et al.*, 1982; 1983a, b, c).

Major attention will be given in this paper to the genesis of the pumice flow and its relation to the granitic fragments found in the pumice flow with reference to Malayan granitic rocks. Attention will also be given to the geologic constituents in the areas surrounding the Krakatau Group and to the tectonic structure presumed in the Sunda Strait.

THE 1883 KRAKATAU PUMICE FLOW

Pumice flow which is characterized by abundant pumice and dacitic in both mineral and chemical compositions in most cases, is used in a narrow sense in this paper for one of the volcanic products of the 1883 Krakatau eruption. This is to be discriminated from pyroclastic flow used in a broad sense for volcanic products formed from so-called *"nuee ardente"*, *"glowing cloud"*, *"awan panas"* and others.

In 1883 pumice flow erupted out at Krakatau Volcano, and occurs at Small Rakata, Rakata and Sertung Islands. These islands are isolated from each other and roughly correspond to the wall of the Krakatau caldera.

In mineral composition, the 1883 Krakatau pumice flow is composed mainly of volcanic glass, plagioclase, hypersthene, augite, opaque minerals and others (Ōba and *et al.*, 1982). The minerals are not accompanied by quartz and hornblende. Modal analysis of one pumice flow is given in Table 1. For comparison, modal analyses of the South Kyushu Ata and Aira "Shirasu" (Oba *et al.*, 1967a) pumice flows, originating

TABLE 1

MODAL ANALYSES (VOL. "„) OF THE 1883 KRAKATAU PUMICE FLOW AND THE ATA AND AIRA "SHIRASU" PUMICE FLOWS

No.		1	2	3
Analyzed samples		1883 Krakatau pumice flow	Ata "Shirasu" pumice flow	Aira "Shirasu" pumice flow
Analysts		T. Ishii	T. Ishii	K. Inoue & K. Yokoyama
Grain size (mesh)		60–115	60–115	60–115
	Volcanic glass	92.2	87.1	86.5
Felsic minerals	Plagioclase	5.7	9.5	7.7
	Quartz	n.p.	n.p.	1.8
	Hypersthene	0.6	1.4	1.1
	Augite	0.4	0.9	0.2
Mafic minerals	Hornblende	n.p.	0.1	0.1
	Opaque mineral	1.1	0.9	2.6
	Others	p.	0.1	0.1

1, Sample no. 811, Sertung, Krakatau, Indonesia; 2, sample no. 66122505, Ōnejisme, Kagoshima, Japan; 3, arithmetic mean of 3 modal analyses; p, present; n.p., not present. Analytical data 1 and 2 from Ōba and others (1983c), and 3 from Ōba and others (1980).

from Ata and Aira gigantic calderas respectively are also given. These are believed to have had as great an eruption as the "Krakatau-type". As seen from this table, the Krakatau pumice flow is characterized by abundant vesiculated volcanic glass, which indicates that bubbles contained in the volcanic glass were expanding and gases escaping (Ōba *et al.*, 1982), as revealed in scanning electron photomicrographs (Fig. 1, A and B).

Chemical analyses of one pumice flow and pumice are tabulated in Table 2. For

TABLE 2

CHEMICAL ANALYSES (WT. %) AND CIPW NORMS OF THE 1883 KRAKATAU PUMICE FLOW, THE ATA AND AIRA "SHIRASU" PUMICE FLOWS AND PUMICES

No. Analysts	1 M.Y.	2 M.Y.	3 N.O. & H.E.	4 T.I.	5 N.O. & H.E.	6 M.M.
SiO_2	65.22	64.18	65.37	0.69	0.24	0.23
Al_2O_3	14.18	13.90	15.44	15.83	14.05	13.23
Fe_2O_3	1.39	1.06	3.77	0.73	0.83	0.54
FeO	2.16	2.22	1.65	1.20	0.97	1.47
MnO	0.13	0.12	0.10	0.14	0.09	0.02
MgO	1.10	0.88	0.93	1.13	0.54	0.59
CaO	2.54	2.38	3.51	3.10	2.20	2.13
Na_2O	4.91	5.32	3.34	3.88	3.31	3.73
K_2O	2.15	2.17	1.69	2.50	2.56	2.90
H_2O^+	4.76	4.11	3.06	3.04	3.14	2.79
H_2O^-	0.58	2.84	0.50	0.31	0.55	0.64
P_2O_5	0.15	0.13	0.15	0.27	0.07	0.29
Total	99.98	99.98	100.19	100.19	99.46	99.48
Q	21.19	18.54	29.60	25.20	32.26	32.63
Or	12.71	12.82	9.99	14.77	15.13	17.14
Ab	41.55	45.02	28.26	32.83	28.01	31.56
An	10.30	7.64	16.43	13.62	10.00	8.67
Di Wo	0.55	1.39	—	—	—	—
Di En	0.31	0.66	—	—	—	—
Di Fs	0.22	0.70	—	—	—	—
Hy En	2.43	1.53	—	2.81	1.35	1.70
Hy Fs	1.67	1.62	—	3.01	1.03	1.68
Mt	2.02	1.54	3.79	0.91	1.20	0.78
Il	1.35	1.27	1.22	1.31	0.46	0.44
Ap	0.35	0.30	0.35	0.63	0.16	0.67
C	—	—	2.09	1.75	2.17	0.78
Hm	—	—	1.16	—	—	—
En	—	—	3.70	—	—	-

1, 1883 Krakatau pumice flow, Sertung, Krakatau, Indonesia, sample no. 811; 2, pumice from pumice flow, Sertung, Krakatau, Indonesia, sample no. 811-P; 3, arithmetic mean of 2 analyses of Ata "Shirasu" pumice flow, Kagoshima, Japan; 4, arithmetic mean of 2 analyses of pumices from Ata "Shirasu" pumice flow, Kagoshima, Japan; 5, arithmetic mean of 13 analyses of Aira "Shirasu" pumice flow, Kagoshima, Japan; 6, arithmetic mean of 2 analyses of pumices from Aira "Shirasu" pumice flow, Kagoshima, Japan. Analytical data.—1 from Ōba and others (1982); 2 from Ōba and others (1983c); 3 and 5 from Ōba and others (1980); 4 from Miyachi (1964); 6 from Taneda and Irisa (1966). Analysts.—H.E., H. Ebihara; T.I., T. Irisa; M.M., M. Miyachi; N.O., N. Ōba; M.Y., M. Yamamoto.

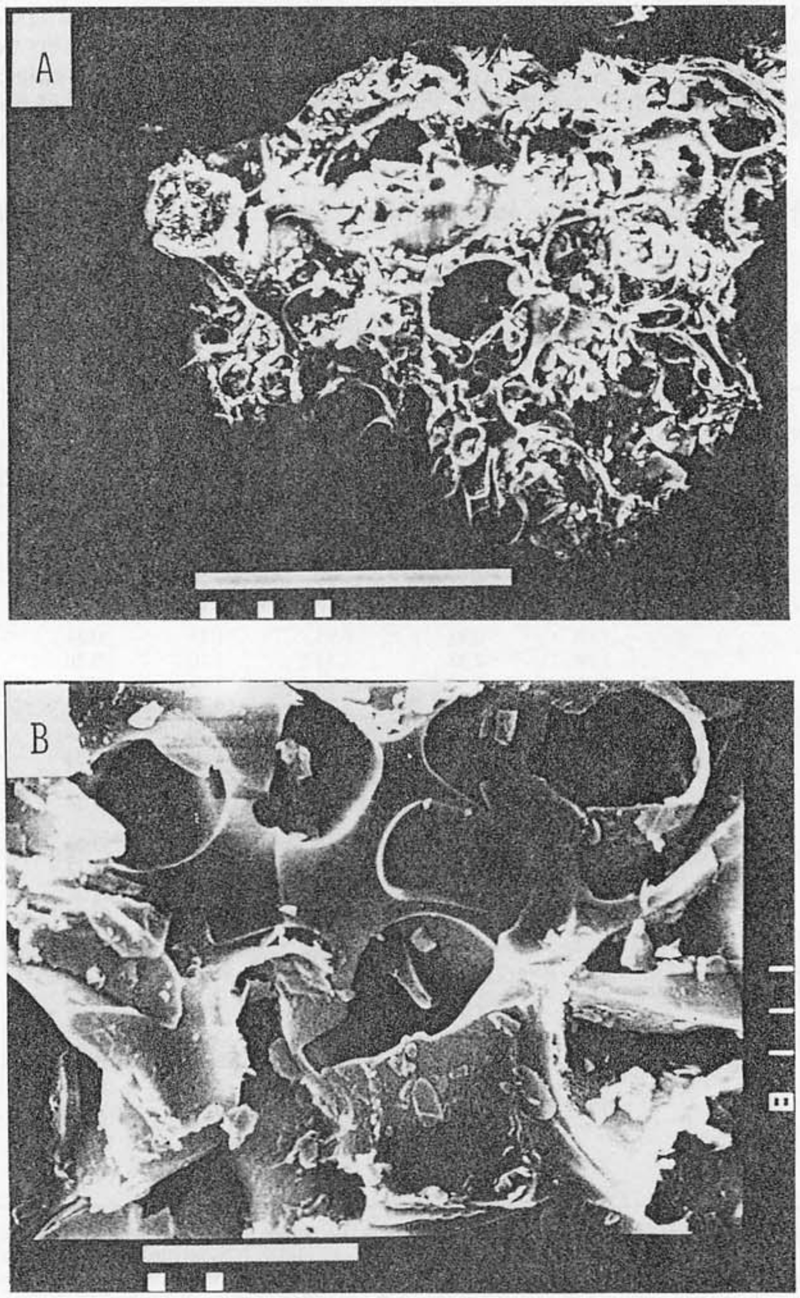

Fig. 1. Scanning electron photomicrographs of volcanic glass of the 1883 Krakatau pumice flow from Sertung, Krakatau, Indonesia. A.-Volcanic glass in a vesiculated state that bubbles contained in volcanic glass were expanding and escaping gases. Scale bar represents 100 μm. B.-Close up of vesicles developed within the same volcanic glass of the former A. Scale bar represents 10 μm.

comparison, chemical analyses of the Ata and Aira "Shirasu" pumice flows and pumices are also given in the same table. It is clear from the table, that the Krakatau pumice flow differs significantly in chemical composition from other volcanic rocks or ejecta of the Krakatau Group. It is characterized by the high contents of silica and alkalies, but is low in contents of magnesia, ferrous iron oxide and lime (Ōba *et al.*, 1983a). Naturally, a large amount of normative quartz and orthoclase are calculated. Therefore, it can be said that the pumice flow is dacitic.

GRANITIC FRAGMENTS FOUND FROM THE PUMICE FLOW

In 1981, one lithic fragment of granitic rock was found from the pumice flow at Sertung Island. Later, another small fragment of the same rock was found from the collected samples of the pumice flow in the laboratory. From this, it was suggested that this kind of granitic fragment may be more common in the pumice flow (Ōba *et al.*, 1982). Following the discovery of the granitic fragments in 1981, several granitic fragments, one of which reaches about 30 cm in maximum size, were found from the pumice flow at another place (Ōba *et al.*, 1983a).

Modal analyses of two granitic fragments are given in Table 3. For comparison, some west Malayan granitic rocks selected from modal analyses by Hutchison (1973) are also tabulated in the same table. The granitic fragments are composed of quartz, plagioclase, potash feldspar, biotite with or without hornblende, and opaque minerals and are characterized in texture by the presence of well-developed myrmekite intergrowth (Fig. 2) common in adamellite and its analogues (Ōba *et al*, 1982). Following the IUGS Sub-commission on the Systematics of Igneous Rocks (1973), the analyzed granitic fragments range in modal composition from quartz monzonite to

TABLE 3

MODAL ANALYSES (VOL. %) OF GRANITIC FRAGMENTS FOUND FROM THE 1883 KRAKATAU PUMICE FLOW AND SELECTED WEST MALAYAN GRANITIC ROCKS

No. Sample no.	1 811-1	2 2301-a	3 UM16	4 UM5306
Quartz	11.5	16.6	24	20
Plagioclase	54.0	47.2	42	44
Potash feldspar	24.9	29.4	28	26
Biotite	6.4	0.8	5	8
Hornblende	—	3.5	—	2
Opaque mineral	3.1*	2.4	0.1	0.1
Others	—	0.1	1.5	1.1

1 and 2.—Granitic fragments found from the 1883 Kraktakau pumice flow, Sertung, Krakatau, Indonesia; 1, quartz monzodiorite; 2, quartz monzonite. Analyst: S. Kiyosaki. 3 and 4.—Selected west Malayan granitic rocks: 3, porphyritic biotite adamellite, Lone Pine Hotel, Penang Island, Malaysia; 4, pink hornblende adamellite, Bukit Labohan, J.K.R. quarry, Trengganu, Malaysia. Analytical data.—1 from Ōba and others (1982); 2 from Ōba and others (1983c); 3 and 4 from Hutchison (1973). *Opaque mineral and others.

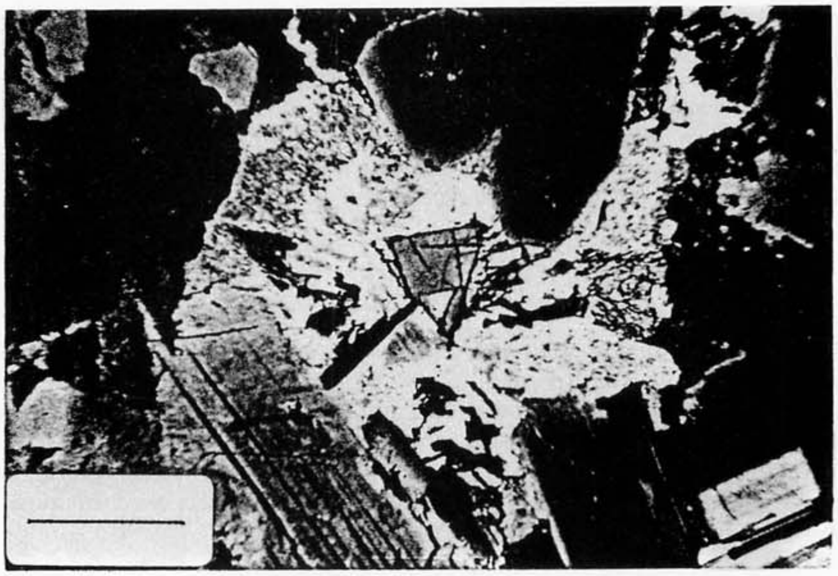

Fig. 2. Photomicrograph showing well-developed myrmekite intergrowth, consisting of quartz and plagioclase in the portion where plagioclase abuts on potash feldspar, observed in lithic fragment of quartz monzodiorite (sample no. 811–1) found from the 1883 Krakatau pumic flow at Sertung, Krakatau, Indonesia. Scale bar shows 0.05 mm.

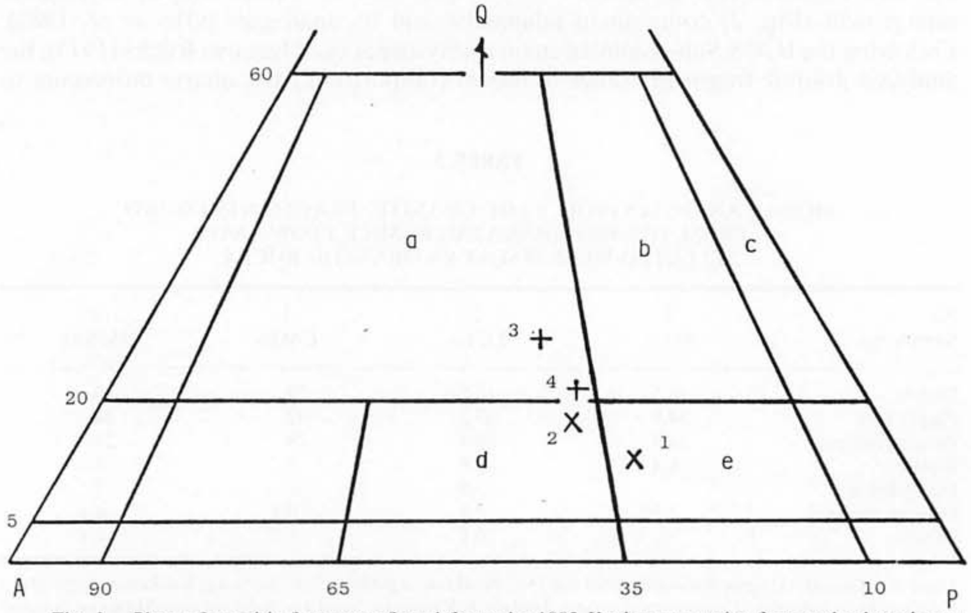

Fig. 3. Plots of granitic fragments found from the 1883 Krakatau pumice flow and selected west Malayan granitic rocks on the modal quartz (Q)-alkali feldspar (A)-plagioclase (P) diagram. Numbers agree to those in Table 3. a, Granite; b, granodiorite; c, tonalite; d, quartz monzonite; e, quartz monzodiorite. After Ōba *et al.* (1983a).

TABLE 4

CHEMICAL ANALYSES (WT. %) AND CIPW NORMS OF GRANITIC FRAGMENT FOUND FROM THE 1883 KRAKATAU PUMICE FLOW AND CHEMICAL ANALYSES OF SELECTED MALAYAN GRANITIC ROCKS

No.	1			2	3
Sample no.	2301-a			GS15072	GS27423
SiO_2	69.18	Q	20.77	70.61	67.60
TiO_2	0.62	Or	16.25	0.40	0.45
Al_2O_3	14.01	Ab	46.12	14.01	15.00
Fe_2O_3	1.25	Di Wo	2.96	0.45	1.04
FeO	2.38	Di En	1.29	2.75	3.07
MnO	0.05	Di Fs	1.67	0.07	0.09
MgO	0.75	Hy En	0.57	0.90	0.88
CaO	2.70	Hy Fs	0.74	1.85	3.02
Na_2O	5.45	Mt	1.81	2.75	3.48
K_2O	2.75	Il	1.18	4.93	3.95
H_2O+	0.48	Ap	0.23	0.98	1.12
H_2O-	0.22			0.12	0.10
P_2O_5	0.10			0.17	0.12
CO_2	—			0.09	0.07
Total	99.94			100.15	99.99

1.—Lithic fragment of quartz monzonite found from the 1883 Krakatau pumice flow, Sertung, Krakatau, Indonesia. Analyst: M. Yamamoto. 2 and 3.—Selected Malayan granitic rocks: 2, porphyritic granite, near milestone 52.5 Tranum–Gap road, Bentong area, Pahang, Malaysia; 3, biotite adamellite, Ulu Sungei Kemaman, near Kampong Ayer Puteh, Trengganu, Malaysia. Analytical data.—1 from Ōba and others (1983c); 2 and 3 from Hutchison (1973).

quartz monzodiorite on the modal quartz (Q)-alkali feldspar (A)-plagioclase (P) diagram (Fig. 3). Biotite quartz monzonite (adamellite) occurs as the dominant rock type in west coast of the Malay Peninsula according to Hamilton (1979). The analyzed granitic fragments are lithologically very much similar to the selected west Malayan granitic rocks.

Chemical analysis of one of the collected granitic fragments is given in Table 4. For comparison, chemical analyses of Malayan granitic rocks selected from Hutchison's (1973) data are also given in the same table. It is clear from the table that the analyzed granitic fragment is characterized by high contents of silica and alkalies and low contents of magnesia, ferrous iron oxide and lime. It is very similar to the selected Malayan granitic rocks.

GEOLOGIC CONSTITUENTS OF THE AREAS SURROUNDING THE KRAKATAU GROUP

Fig. 4 presents a schematic model showing movement and descending of the Indo-Australian oceanic plate into the Sunda trench and pushing up of the Eurasian continental crust. Fig. 5 shows the distribution of isolated granite plutons in the Malay

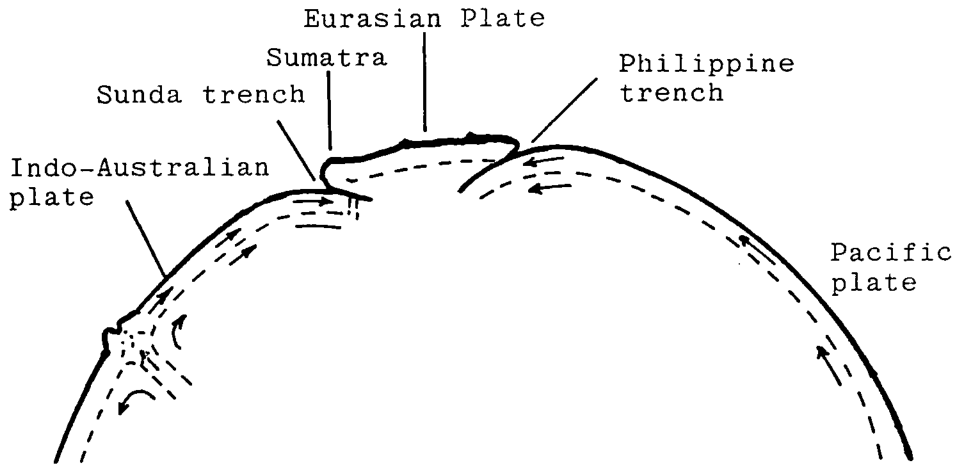

Fig. 4. Schematic model showing movement and descending of the Indo-Australian oceanic plate into the Sunda trench beneath the Eurasian continental plate. After Hirokawa (1974).

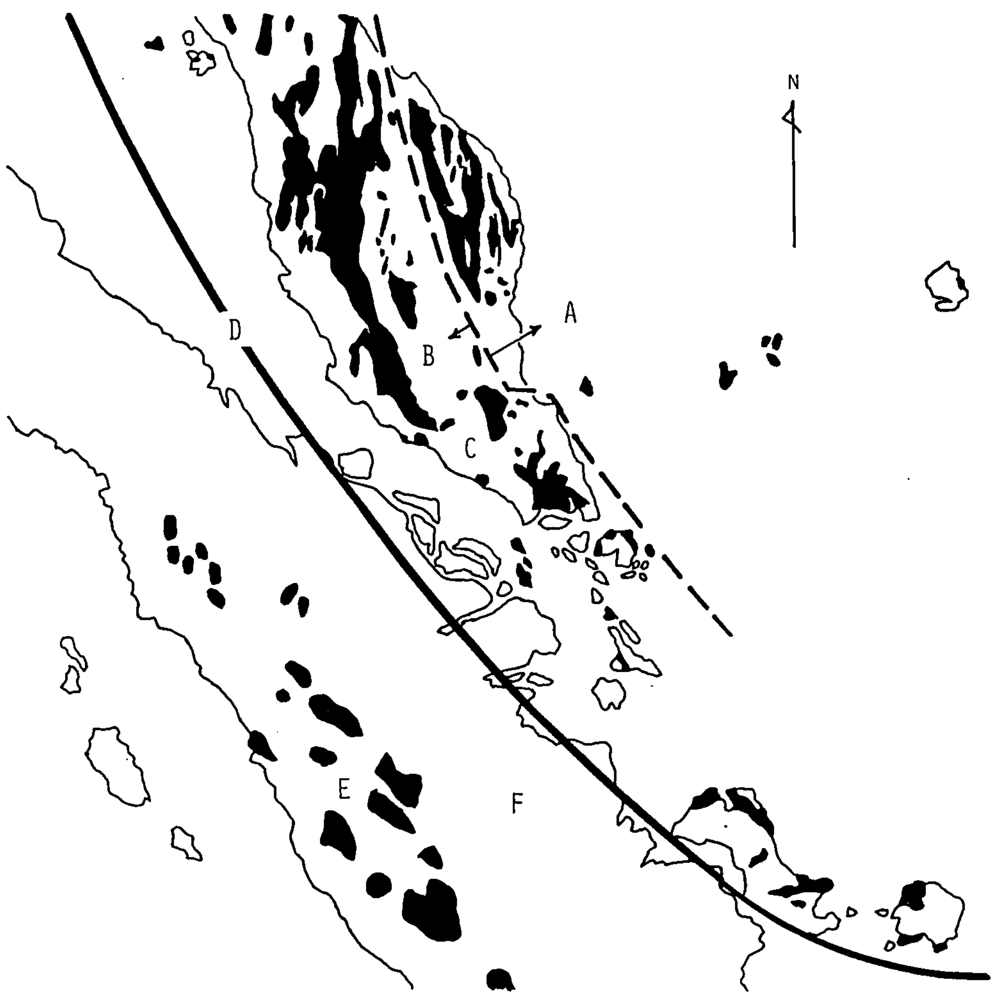

Fig. 5. Distribution of isolated granite plutons in Malay Peninsula and Sumatra. Modified in part and simplified from an original figure of Hutchison (1973). A, Granite generally of upper Carboniferous; B, granites generally of late Triassic; C, Malay Peninsula; D, Thai-Malayan orogen; E, middle Cretaceous granite; F, Sumatra.

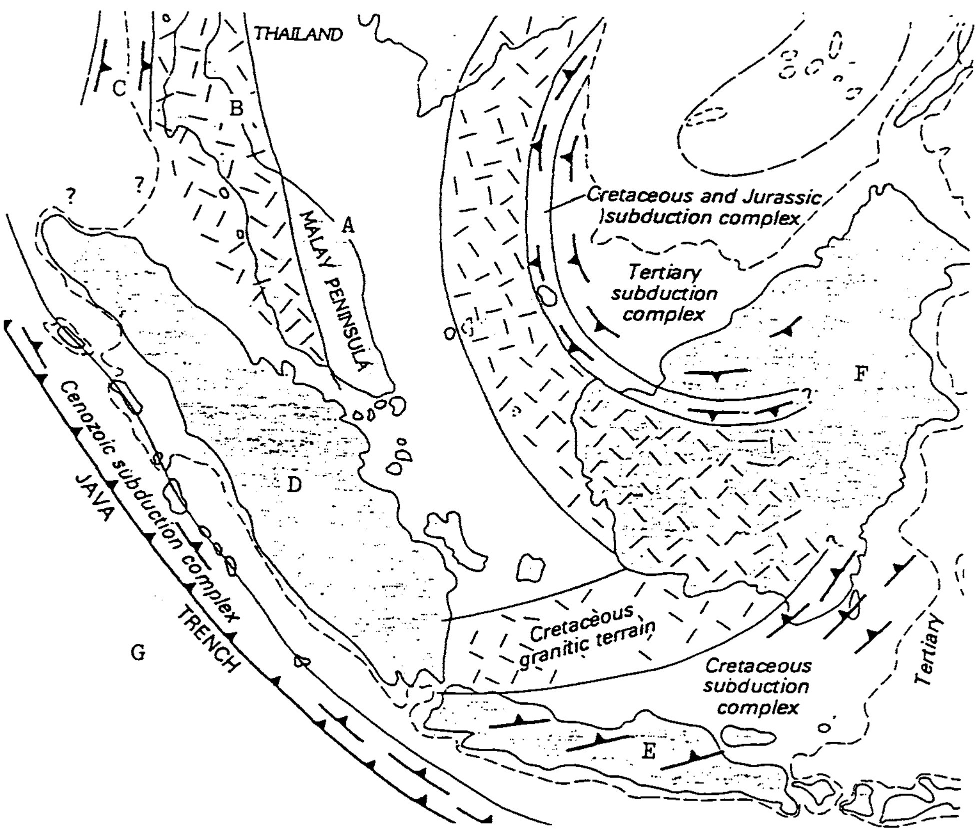

Fig. 6. Cretaceous granitic terrain passing through just the Sunda Strait between Sumatra and Java on Hamilton's (1979) figure illustrating Mesozoic and selected Cenozoic tectonic elements of Southeast Asia and Indonesia. A, Triassic and late Paleozoic; B, Cretaceous and Jurassic granitic terrain; C, Cretaceous and Jurassic subduction complex; D, Sumatra; E, Java; F, Kalimantan; G, Indian Ocean.

Peninsula and Sumatra after Hutchison (1973). The west Malayan granitic rocks, are associated with tin deposits and most of them have late Triassic ages (Hutchison, 1973) and are a continuation of the granites from the southern Peninsular Thailand. These are predominantly of Chappell and White's (1974) S-type in nature and belong to Ishihara's (1977) ilmenite-series (Ishihara *et al.*, 1980). Granitic rocks of Sumatra which have middle Cretaceous ages (Hutchison, 1973) may be similar in some respects to the west Malayan granitic rocks.

Hamilton (1979) reported the presence of a Cretaceous granitic terrain passing through the Sunda Strait between Sumatra and Java in his figure illustrating Mesozoic and selected Cenozoic tectonic elements of Southeast Asia and Indonesia (Fig. 6). Hutchison (1982) showed his "Sunda shelf continental crust" extending up to the Sunda Strait (Fig. 7) at the southern extremity. Hamilton (1979) also showed mutual relationships between continental crust, pre-subducted strata and melange deposits in

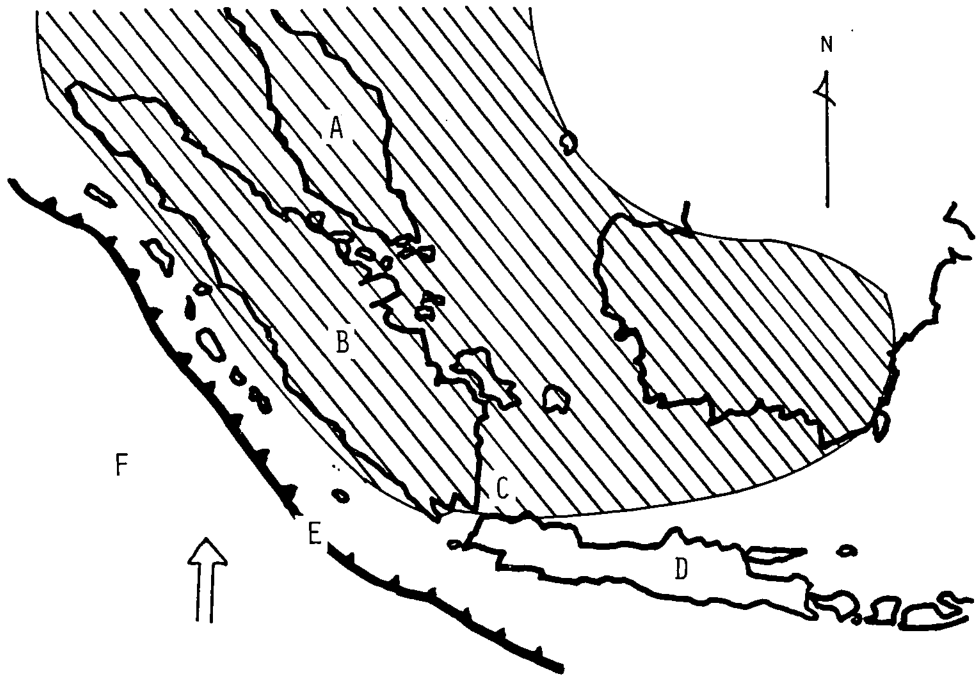

Fig. 7. "Sunda shelf continental crust" (shaded part) extending up to the Sunda Strait. Modified and simplified from an original figure of Hutchison (1982). A, Malay Peninsula; B, Sumatra; C, Sunda Strait; D, Java; E, position of trench or outcrop of Benioff zone; F, Indian Ocean.

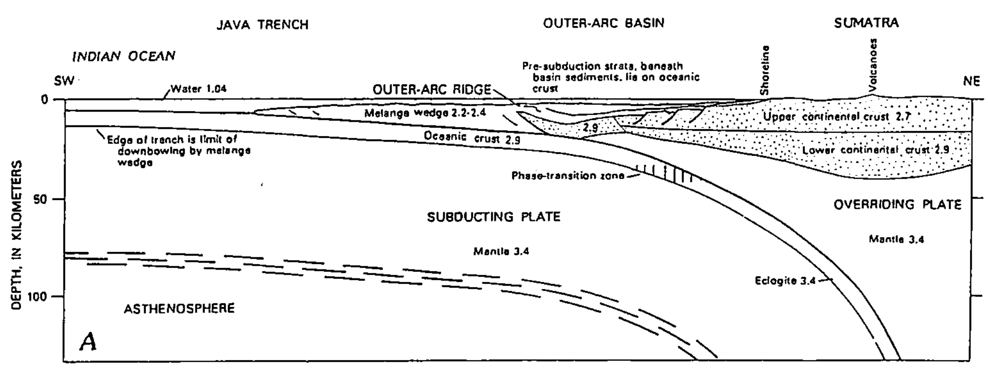

Fig. 8. Mutual relationships among continental crust, pre-subducted strata and melange deposits in section through the subduction system of southern Sumatra. After Hamilton (1979). Numbers are assumed densities.

his figure showing sections through the subduction system of southern Sumatra (Fig. 8).

These figures give the kind of geologic constituents there were around the Sunda Strait. That is, the surrounding areas northwest of the Sunda Strait. Where the Krakatau Island Group is located the area, is composed mainly of continental crust with granitic rocks, pre-subducted strata and some sediments.

CLOCKWISE ROTATION OF SUMATRA AND A TECTONIC STRUCTURE PRESUMED IN THE SUNDA STRAIT

On the basis of deviation of Sumatra from the curvature of the rest of the Indonesian arc about the Sunda Strait, westward decrease in the maximum depth and down-dip length of the Benioff zone and westward decrease in age of the post-middle Miocene phase of explosive volcanic activity, Ninkovich (1976) suggested that an increase in sea-floor spreading rate since 10 Ma BP pushed north Sumatra and Malaya northeastward along the system of faults, causing a clockwise rotation of both Sumatra and Malaya of about 20° about an axis located in or near the Sunda Strait (Fig. 9). He considered that deformation of the Indonesian volcanic arc was probably caused by a difference in resistance between an older and probably relatively thick continental crust in Sumatra and relatively young crust in the eastern branch of the Indonesian arc due to compression between the Indian oceanic plate and the Eurasian plate. He also pointed out two zones of deformation in and near the arc; one is the system of faults in Malaya and the other in the Sunda Strait.

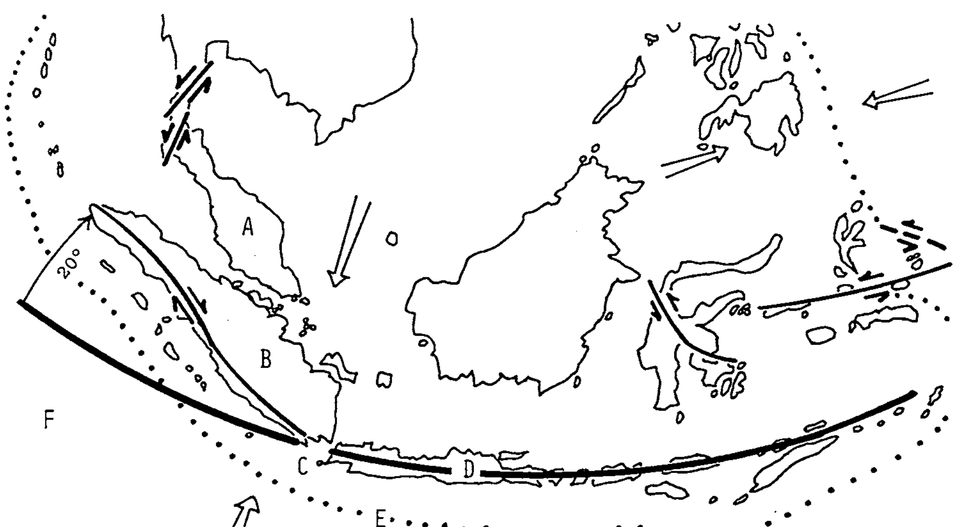

Fig. 9. An increase in sea-floor spreading rate pushed north Sumatra and Malaya northeastward along the system of faults, causing a clockwise rotation of both Sumatra and Malaya of about 20° about an axis located in or near the Sunda Strait. Simplified from an original figure of Ninkovich (1976). A, Malay Peninsula; B, Sumatra; C, Sunda Strait; D, Java; E, Sunda trench; F, Indian Ocean.

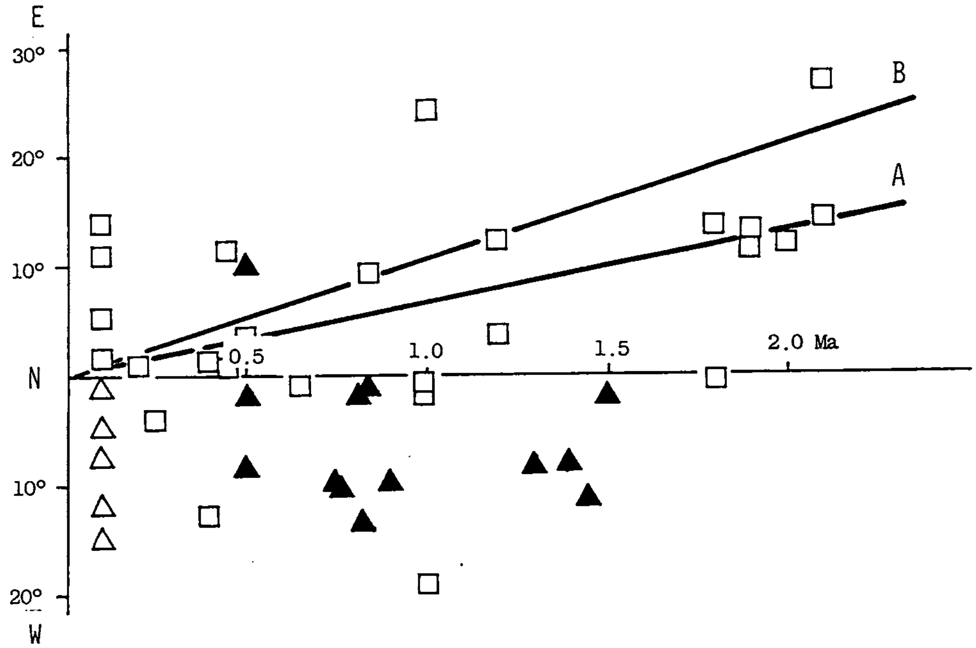

Fig. 10. Relationship of declination values and their ages of Quaternary rocks around the Sunda Strait. Simplified from an original figure of Yokoyama and others (1983). A, 5°/Ma; B, 10°/Ma; open squares, igneous rock and welded tuff in Sumatra; open triangles, ash flow in Java; solid triangles, clay sediment in Java.

On the basis of the results of palaeomagnetic measurements, Nishimura *et al.*, (1983) and Yokoyama *et al.*, (1983) pointed out that Sumatra has been rotating clockwise against Java since 2 Ma BP. at the rate of 5°–10°/Ma (Fig. 10). Their suggestion for the clockwise rotation of Sumatra at the rate of 10°/Ma against Java about a centre located in the Sunda Strait is in good accord with Ninkovich's maximum rotation of about 20°. Ninkovich's the other system of faults located in the Sunda Strait may possibly be represented by a north-south trending fracture zone, pointed out by Zen and Sudradjat (1983) as passing through the Sunda Strait (Fig. 11).

Thus, a schematic model showing a shared portion located at the Sunda Strait between Sumatra and Java is given in Fig. 12. It seems that such a sharing was caused by the deformation of the Sunda arc due to differential movement, represented by the clockwise rotation of Sumatra against Java about the Sunda Strait. This originated from the compression between the Indo-Australian oceanic plate and the Eurasian continental crust.

GENETICAL RELATIONSHIP BETWEEN THE 1883 KRAKATAU PUMICE FLOW AND GRANITIC FRAGMENTS

The granitic fragments found from the pumice flow are in both modal and chemical compositions very similar to the selected Malayan granitic rocks. On the

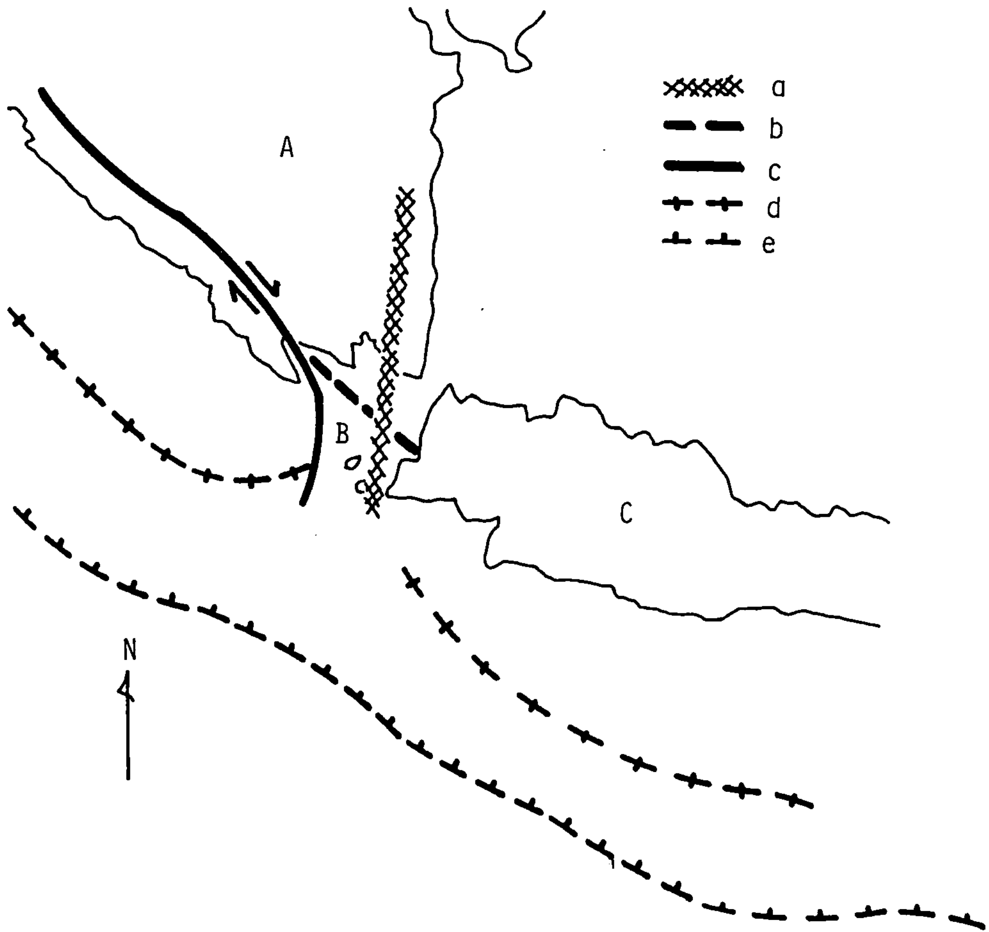

Fig. 11. A north-south trending fracture zone passing through the Sunda Strait in relation to the tectonic situation of the Krakatau Group. Simplified from an original figure of Zen and Sudradjat (1983). A, Sumatra; B, Sunda Strait; C, Java; a, fracture zone; b, assumed fault; c, outer ridge; e, trench.

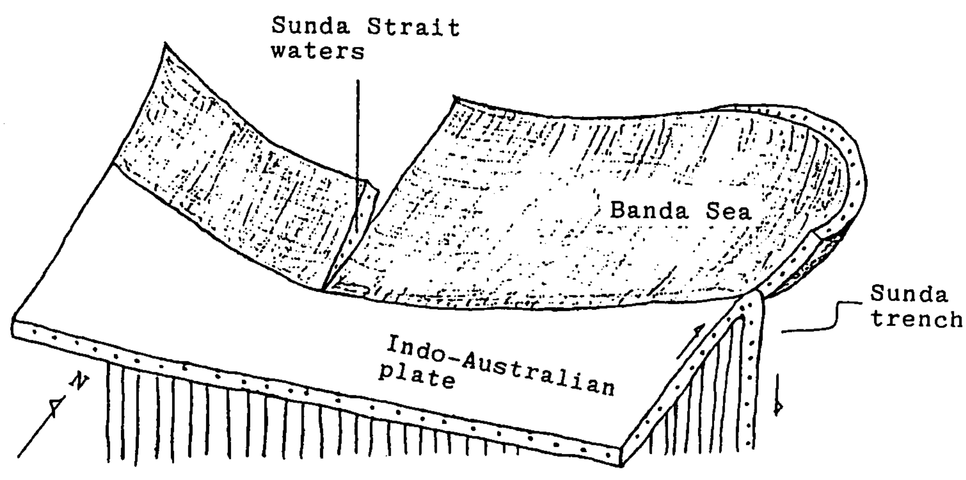

Fig. 12. Schematic model showing a shared portion which occurred just at the Sunda Strait between Sumatra and Java. Referred to a model of Ikebe and Oike (1972).

basis of the chemical and isotope data Hutchison (1977) suggested that the Malayan rocks were formed by anatexis of a continental sialic basement. However, the dacitic pumice flow significantly differs in both mineral and chemical compositions from other volcanic rocks or ejecta of the Krakatau Group which belong to Miyashiro's (1974) tholeiitic series on the SiO_2-total FeO/MgO diagram (Oba *et al.*, 1983c).

Ōba *et al.*, (1967b) pointed out that genetically, the Ata and Aira "Shirasu" pumice flows are closely related with the nearby surrounding granitic rocks of the respective caldera. Geochemical comparison between a suite of the 1883 Krakatau pumice flow,

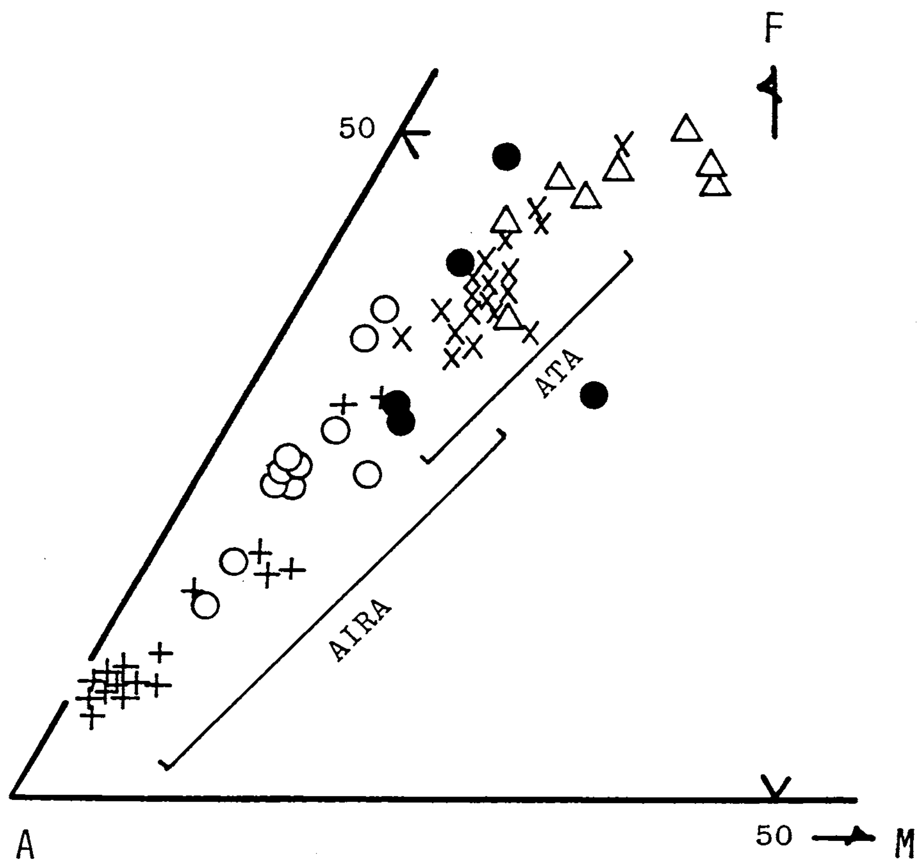

Fig. 13. Plots of the Ata and Aira "Shirasu" pumice flows and its related granitic and volcanic rocks on the A ($Na_2O + K_2O$) – F (total FeO) – M (MgO) diagram. Symbols:-solid circles, Ata "Shirasu" pumice flow and pumices; open circles, Aira "Shirasu" pumice flow and pumices; cross, Ōsumi granodiorite; plus, Takakumayama aplogranite; open triangles, lava flows of Sakurajima Volcano. Analytical data used for construction of the diagram from Ōba and others (1967, 1980, 1982) and Fukuyama and Ono (1981). After Ōba *et al.* (1983a). The plots representing the Ata "Shirasu" pumice flow and its pumices fall within or nearby the field occupied by the plots representing the Osumi granodiorite locating nearby the Ata caldera, and the plots representing the Aira "Shirasu" pumice flow and its pumices fall within or nearby the field occupied by the plots representing the Takakumayama aplogranite locating nearby the Aira caldera.

its related granitic fragment and some Malayan granitic rocks and a suite of the Ata and Aira "Shirasu" pumice flows and their related granitic rocks shows that the respective pumice flow is well correlated in chemical character with the respective related granitic rocks in the locations of their plots on the AFM diagrams, Figs. 13 and 14 (Oba *et al.*, 1983a, b). This suggests that the 1883 Krakatau pumice flow was genetically related to some granitic rocks, similar to the biotite quartz monzonite that is the dominant rock type in west Malay Peninsula and which is nearby the Krakatau Group. However, none of granitic rock occurs throughout the whole islands of the

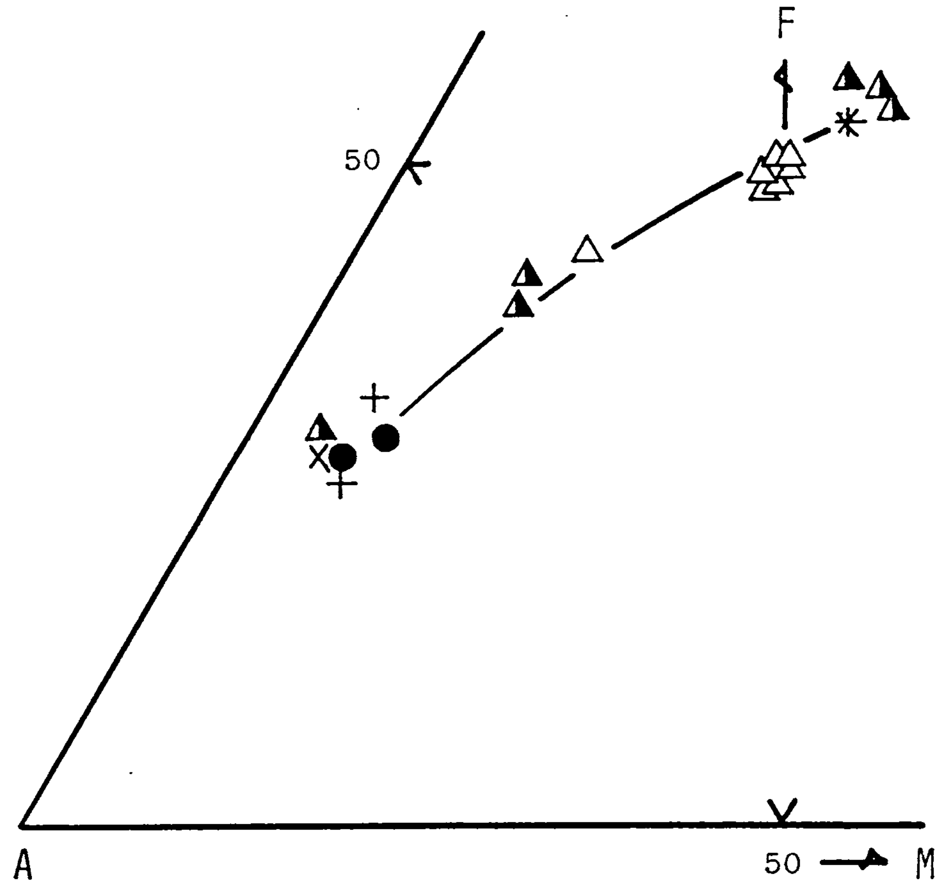

Fig. 14. Plots of the 1883 Krakatau pumice flow and its related granitic and volcanic rocks on the AFM diagram and the evolution-trend for the volcanic products of the Karakatau Group. Symbols:-solid circles, the 1883 Krakatau pumice flow and pumice; cross, granitic fragment found from the pumice flow; plus, selected Malayan granitic rocks (biotite adamellite and porphyritic granite); open triangles, lava flows and ejecta of Anak Krakatau Volcano; half solid triangles, lava flows and dike those which constitute the basement complex of the Karakatau Group except Anak Krakatau Volcano; asterisk, average composition of basaltic andesites of typical volcanoes of island arcs of western and northern Pacific and Carribean regions. Analytical data used for construction of the diagram from Oba *et al.* (1982, 1983b, c) and Ewart (1976). The plots of the 1883 Krakatau pumice flow and its pumice fall within the same field occupied by the plots of granitic fragment found from the pumice flow and selected Malayan granitic rocks.

Krakatau Group. Moreover, granitic fragments have never been reported from the pumice flow, except for a quartz diorite inclusion which was reported from Small Rakata (De Neve, 1981a, b) and may correspond to the lithic fragment of quartz monzodiorite found from the pumice flow. Therefore, it should be considered that the granitic fragments found from the pumice flow came from the underlying complex at depths, where they were captured as foreign materials by the magma, and that the pumice flow is genetically related to the underlying granitic complex with regard to the production of its source magma.

The composition of any melt would depend on that of the source rock, phase chemistry and the degree of melting (Carmichael *et al.*, 1974). Wyllie *et al.*, (1976) suggested that batholiths may be generated in different ways from different sources, and argued that batholiths composed of granite are readily generated in the continental crust. Wyllie and Tuttle (1961a) showed that liquid of granodioritic composition is produced from shales, and Van Croos and Wyllie (1968) and Wyllie and Tuttle (1961b) showed that shales begin to melt at lower temperatures if alkalies and volatile components are present in addition to water. Winkler and Platen (1961a, b) established that granitic melt can be formed by partial melting of sediments. James and Hamilton (1969) also discussed the possible process of the formation of granitic rocks in relation to the partial melting of metasediments. Therefore, it is reasonable to consider that magma of granitic composition would possibly be generated from either of granitic rocks with a wide range of composition and various kinds of sediments, that is, in general, from the continental crust.

In the meantime, ignimbrite and tuff, those which are characterized by rhyolitic, rhyodacitic and dacitic compositions at Lake Toba, Sumatra, appear to be related to the peculiar tectonic setting of Sumatra, and plate movement appears to be taken up in part at least (Whitford, 1975). As a result of chemical analysis of volcanic materials such as tuffs found around the Sunda Strait, Nishimura *et al.*, (1983) showed that the volcanic materials are similar in chemical feature to ignimbrite in north Sumatra, and inferred that ignimbrite magma was generated from the remelting of crustal materials, while basaltic and andesitic magmas were generated from the partial melting of the upper mantle. Whitford (1975) showed that rhyolitic ignimbrite and tuff from Lake Toba have an $^{87}Sr/^{86}Sr$ ratio of 0.7139, very much higher than that for any other analyzed lava from the Sunda arc, and such a ratio argues for crustal derivation rather than a mantle origin for these rocks. Such a consideration will be useful to account for the mechanism of formation of the 1883 Krakatau pumice flow.

Thus, it is suggested that the 1883 Krakatau pumice flow is formed from sialic crustal materials, involving granitic rocks similar to west Malayan granitic rocks represented by biotite quartz monzonite and sediments which occur in Sumatra. These were plunged into depths along the peculiar tectonic structure located at the Sunda Strait. The shared portion appears to be caused by deformation of the Sunda arc due to differential movement represented by the clockwise rotation of Sumatra against Java about the Sunda Strait owing to compression between the Indo-Australian oceanic plate and the Eurasian continental crust. The sialic crustal materials were partially melted and produced a magma of granitic composition, and was mixed with, or assimilated by, an ascending basaltic magma, which could have been derived from the upper mantle. This resulted in dacitic magma distinctly dominant in silica, alkalies and volatile components. Hence, the 1883 Krakatau eruption was characterized by the pumice flow of dacitic composition. The granitic fragments were captured by the ascending dacitic magma from the plunged sialic crustal materials as it passed through the peculiar tectonic structure along the shared portion in the Sunda Strait and erupted out together with the pumice flow.

ACKNOWLEDGEMENTS

Members of Japanese working group wish to express their appreciation to Indonesian co-workers of Geochemical Laboratory, Volcanological Survey of Indonesia (VSI) in Yogyakarta and VSI in Bandung, for their kind cooperation and great support. Many thanks are also given to Dr. D.S. Sastrapradja and Dr. H. Napitupulu, Indonesian Institute of Sciences (LIPI) in Jakarta, for their acceptance and assistance; to Ir. Bambang W. Hariadi and Ir. Soekardi Muryowihardjo, Gadjah Mada University, for their cooperation in field work; to Dr. S. Nishimura, Kyoto University, Dr. T. Yokoyama, Doshisha University, Dr. T.T. Khoo and Dr. C.S. Hutchison, University of Malaya, and Dr. E.J. Cobbing, British Geological Survey, for their suggestions and encouragements; and to Mr. H. Saigo and Miss. J. Nakamura, Kagoshima University, Mr. T. Ishii, Higashi Fukuoka Senior High School, Mr. S. Kiyosaki, Meiji Consultant Co., and Mr. T. Inome, Kyoto Ceramic Co., for their assistance in preparation of thin sections, modal analysis and calculations. Japanese members gratefully acknowledge the Japan Society for the Promotion of Science (JSPS), from which the financial support during 1981-1982 fiscal years was provided.

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Manuscript received 21 July 1984