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GENETICAL RELATIONSHIP BETWEEN THE 1883 KRAKATAU PUMICE FLOW AND GRANITIC FRAGMENTS FOUND FROM THE PUMICE FLOW*

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Abstract

Granitic fragments found from pumice flow of 1883 eruption at the Krakatau Group locating at the Sunda Strait, Indonesia, called the 1883 Krakatau pumice flow, are in both modal and chemical compositions very similar to west Malayan granitic rocks represented by biotite quartz monzonite of the dominant rock type in west Malay Peninsula. The pumice flow is characterized by dacitic composition and significantly differs in both mineral and chemical compositions against other volcanic rocks or ejecta of the Krakatau Group those of which belong to the tholeiitic series. Geochemical comparison shows that the pumice flow is good correlative in chemical character with its related granitic fragment and rocks. However, none of granitic rock occurs throughout over the whole islands of 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 granitic complex at depths, where they were captured by magma.

Thus, it may possibly be considered that sialic crustal meterials, involving granitic rocks and sediments those which occur in Sumatra, plunged into depths along a peculiar tectonic structure locating at the Sunda Strait, which 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, and were partially melted and produced magma of granitic composition, and mixed with or assimilated by an ascending basaltic magma originated probably from the upper mantle, and dacitic magma distinctly dominant in silica, alkalies and volatile components was produced, and, 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 during passing through within the peculiar tectonic structure along the shared portion, thus the granitic fragments were erupted out together with the pumice flow.

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Introduction

Following to volcano-geochemical investigations on pumice flow erupted out in 1883 at Krakatau Volcano, called the 1883 Krakatau pumice flow which occurs at Small Rakata, Rakata and Sertung of the Krakatau Group locating at the Sunda Strait, Indonesia (ŌBA and others, 1983a, b, c); genetical relationship between the 1883 Krakatau pumice flow and granitic fragments found from the pumice flow has been studied.

Major attention will be given in this paper to genesis of the 1883 Krakatau pumice flow and its relation to granitic fragments found from the pumice flow in referring to geologic constituents in the areas surrounding the Krakatau Group and a tectonic structure presumed in the Sunda Strait.

The 1883 Krakatau pumice flow

In mineral composition, the 1883 Krakatau pumice flow is composed mainly of volcanic glass, plagioclase, orthopyroxene, clinopyroxene, opaque minerals and other accessories. Abundant volcanic glass, which occurs in a vesiculated state that bubbles contained in the volcanic glass were expanding and escaping gases (ŌBA and others, 1982), is characteristic. None of quartz and hornblende is accompanied. In chemical composition, the pumice flow is characterized by the high contents of silica and alkalies, but, in contrast, the low contents of magnesia, ferrous iron oxide and lime as compared to any other volcanic rock or ejecta of the Krakatau Group (ŌBA and others, 1983a, c). It can be said that the pumice flow is dacitic in normative composition in which a large amount of quartz and orthoclase is calculated.

Granitic fragments found from the pumice flow

Since the discovery of granitic fragments from the 1883 Krakatau pumice flow in 1981 and 1982, a genetical relationship between the granitic fragments and the pumice flow has been discussed (ŌBA and others,1983 a, b, c; 1984). The granitic fragments are composed mainly of quartz, plagioclase, potash feldspar, biotite with or without hornblende, and opaque mineral. They range in modal composition from quartz monzonite to quartz monzodiorite and are characterized in texture by the presence of well-developed myrmekite intergrowth common in adamellite and its analogous; and they are in chemical composition characterized by the high contents of silica and alkalies and the low contents of magnesia, ferrous iron oxide and lime. It is noted that these granitic fragments found from the pumice flow are in both modal and chemical compositions very similar to selected west Malayan granitic rocks in which biotite quartz monzonite occurs as the dominant rock type in west Malay Peninsula (HAMILTON, 1979).

Geologic constituents of the areas surrounding the Krakatau Group

Fig. 1 presents a schematic model showing movement and descending of the Indo-

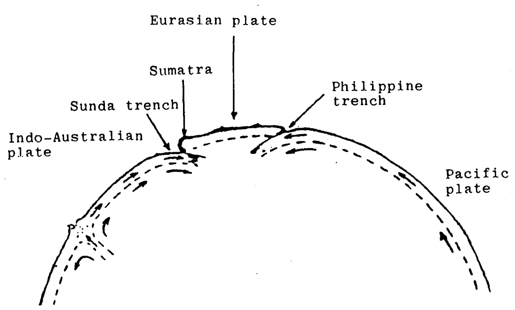

Fig. 1. Schematic model showing movement and descending of the Indo-Australian oceanic plate into the Sunda trench beneath the Eurasian continental plate. After HIROKAWA (1974).

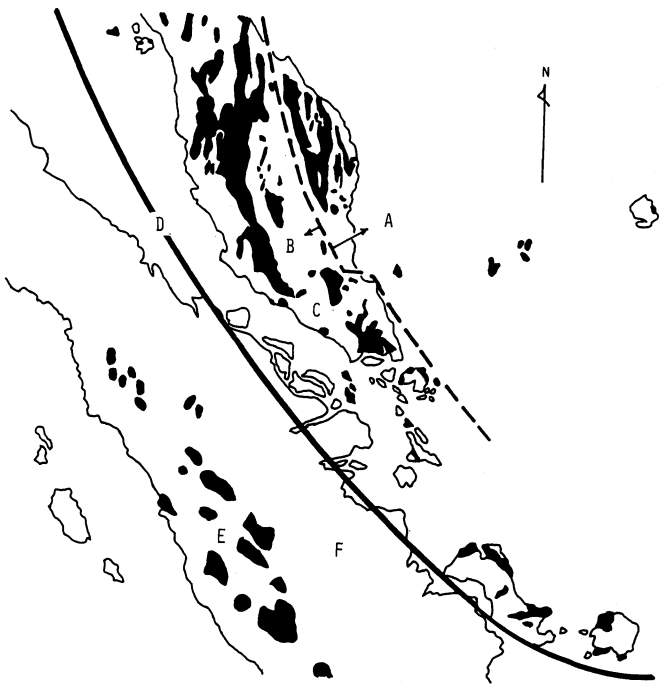

Fig. 2. Distribution of isolated granite plutons associated with tin deposits in Malay Peninsula and Sumatra. Modified in part and simplified from an original figure of HUTCHISON (1973). A, Granite generally of upper Carboniferous; B, granite generally of late Triassic; C, Malay Peninsula; D, Thai-Malayan orogen; E, middle Cretaceous granite; F, Sumatra.

Australian oceanic plate into the Sunda trench and pushing up of the Eurasian continental crust. Fig. 2 shows distribution of isolated granite plutons associated with tin deposits in Malay Peninsula and Sumatra after HUTCHISON (1973). The west Malayan granitic rocks most of which have late Triassic ages (HUTCHISON, 1973) are continued from granites of the southern Peninsular Thailand, those of which are predominant in CHAPPELL and WHITE's (1974) S-type nature and belong to ISHIHARA's (1977) ilmenite-series (ISHIHARA and others, 1980). Granitic rocks of Sumatra those of which have middle Cretaceous ages (HUTCHISON, 1973) may have similarity in some respects to the West

Malayan granitic rocks.

In 1979, HAMILTON denoted the presence of the Cretaceous granitic terrain passing through just the Sunda Strait between Sumatra and Java on his figure illustrating Mesozoic and selected Cenozoic tectonic elements of Southeast Asia and Indonesia (Fig. 3). HUTCHISON (1982) showed his "Sunda shelf continental crust" extending up to the Sunda Strait (Fig. 4) at the southern extreme. HAMILTON (1979) also showed mutual relationships among continental crust, pre-subducted strata and melange deposits in his

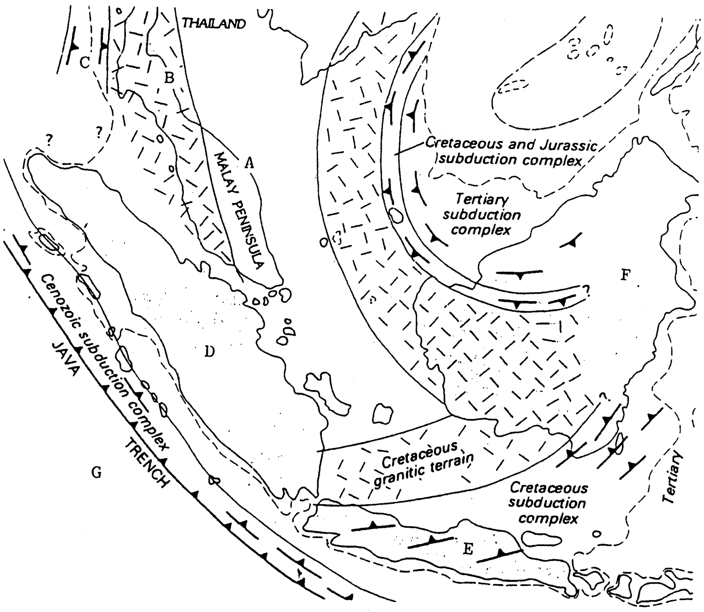

Fig. 3. Cretaceous granitic terrain passing through just the Sunda Strait between Sumatra and Java on HAMILTON's (1979) figure illustrating Mesozoic and selected Cenozoic tectonic elements of Southeast Asia and Indonesia. A, Triassic and late Paleozoic; B, Cretaceous and Jurassic granitic terrain; C, Cretaceous and Jurassic subduction complex; D, Sumatra; E, Java; F, Kalimantan; G, Indian Ocean.

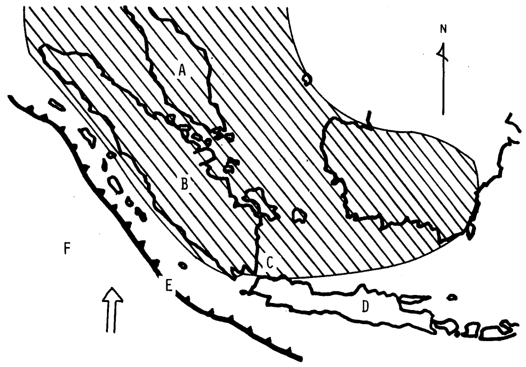

Fig. 4. "Sunda shelf continental crust" (shaded part) extending up to the Sunda Strait. Modified and simplified from an original figure of HUTCHISON (1982). A, Malay Peninsula; B, Sumatra; C, Sunda Strait; D, Java; E, position of trench or outcrop of Benioff zone; F, Indian Ocean.

figure showing sections through the subduction system of southern Sumatra (Fig. 5).

These figures give what kinds of geologic constituents are there around the Sunda Strait. That is, the surrounding areas northwest of the Sunda Strait, where the Krakatau Group is located in, are composed mainly of continental crust in which granitic rocks are involved, pre-subducted strata and some sediments.

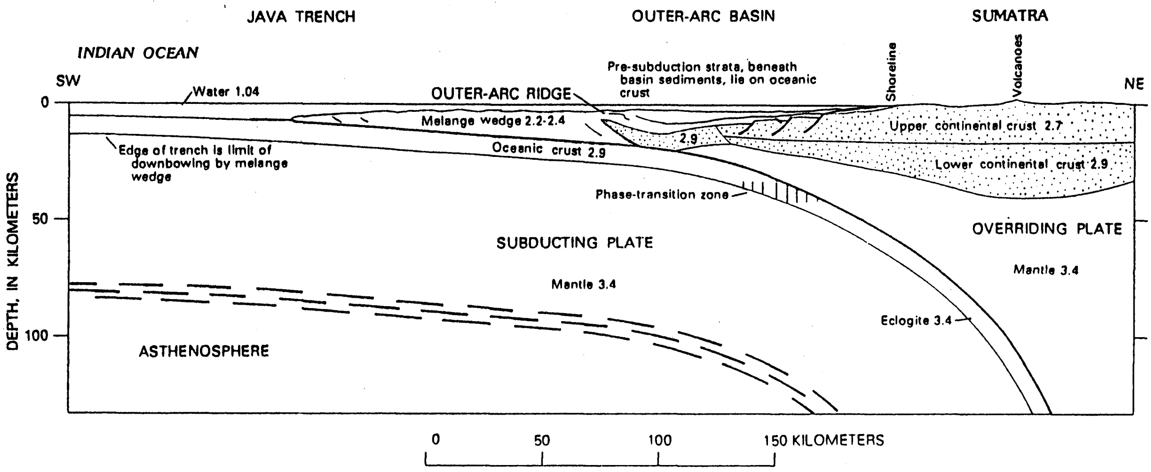

Fig. 5. Mutual relationships among continental crust, pre-sunducted strata and melange deposits in section through the subduction system of Southern Sumatra. After HAMILTON (1979). Numbers are assumed densities.

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 B. P. 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. 6). 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 blanch of the Indonesian arc due to copression between Indian Oceanic plate and 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.

Recently, NISHIMURA and others (1983) and YOKOYAMA and others (1983) pointed out that Sumatra has been rotating clockwise against Java since 2 Ma B. P. at the rate of 5°–10°/Ma on the basis of the result of paleomagnetic measurements (Fig. 7). Their

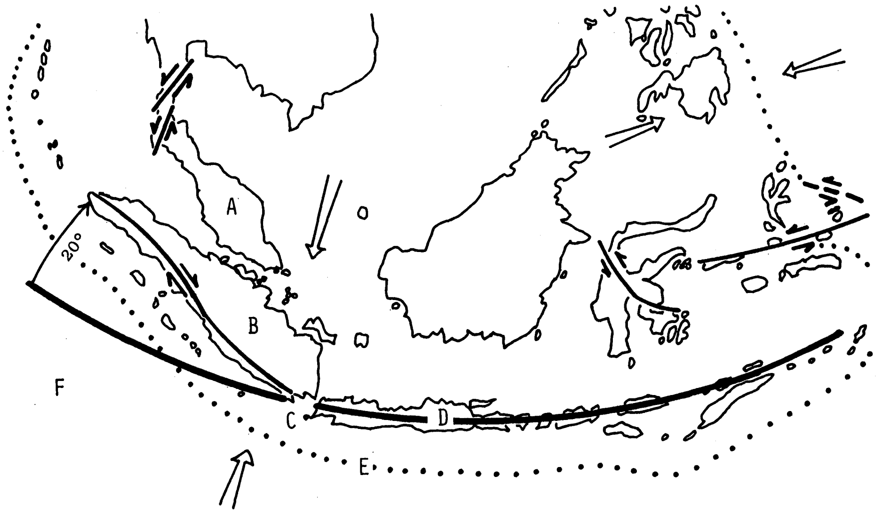

Fig. 6. An increase in sea-floor spreading rate pushed north Sumatra and Malaya northeastward along the system of faults, causing a clockwise rotation of both Sumatra and Malaya of about 20° about an axis located in or near the Sunda Strait. Simplified from an original figure of NINKOVICH (1976). A, Malay Peninsula; B, Sumatra; C, Sunda Strait; D, Java; E, Sunda trench; F, Indian Ocean.

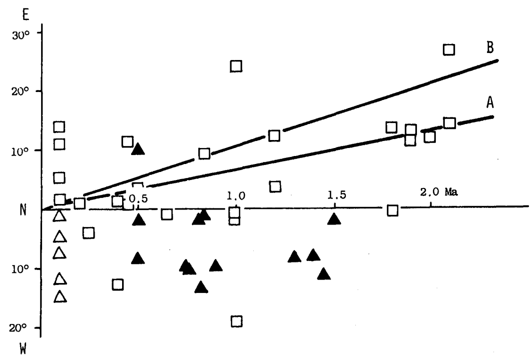

Fig. 7. Relationship of declination values and their ages of Quaternary rocks around the Sunda Strait. Simplified from an original figure of YOKOYAMA and others (1983). A, 5°/Ma; B, 10°/Ma; open squares, igneous rock and welded tuff in Sumatra; open triangles, ash flow in Java; solid triangles, clay sediment in Java.

suggestion for the clocwise rotation of Sumatra at the rate of 10°/Ma against Java about a center located in the Sunda Strait is in good accord with NINKOVICH's speculation about 20° at maximum. NINKOVICH's the other system of faults located in the Sunda Strait may possibly be reprepented by a north-south trending fracture zone, pointed out by ZEN and SUDRADJAT (1983), passing through the Sunda Strait in relation to the tectonic situation of the Krakatau Group (Fig. 8). Thus, a schematic model showing a shared portion locating just at the Sunda Strait between Sumatra and Java will be given in Fig. 9. It seems that such a sharing was caused owing to the deformation of the Sunda arc due to differential movement, represented by the clockwise rotation of Sumatra against Java about

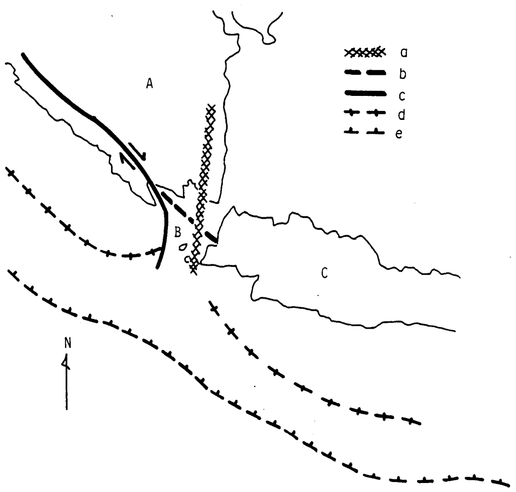

Fig. 8. A north-south trending fracture zone passing through the Sunda Strait in relation to the tectonic situation of the Krakatau Group. Simplified from an original figure of ZEN and SUDRADJAT (1983). A, Sumatra; B, Sunda Strait; C, Java; a, fracture zone; b, assumed fault; c, fault; d, outer ridge; e, trench.

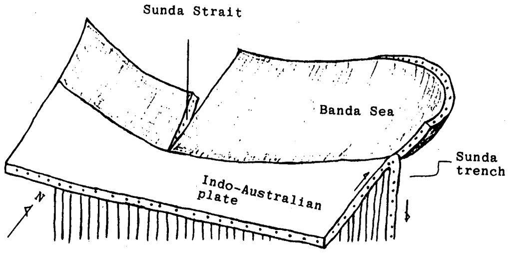

Fig. 9. Schematic model showing a shared portion which occurred just at the Sunda Strait between Sumatra and Java. Referred to a model of IKEBE and OIKE (1972).

the Sunda Strait, that which was originated in compression between the Indo-Australian oceanic plate and the Eurasian continental crust.

Discussion: 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 west Malayan granitic rocks, for which on the basis of the chemical and isotope data HUTCHISON (1977) suggested that they were formed by anatexis of a continental sialic basement. In the meantime, the pumice flow significantly differs in both mineral and chemical compositions against other volcanic rocks or ejecta of the Krakatau Group those of which belong to MIYASHIRO's (1974) tholeiitic series, and it is characterized by dacitic composition.

ŌBA and others pointed out in 1967 that genetically the Ata and Aira "Shirasu" pumice flows those which came from Ata and Aira calderas locating in South Kyushu, Japan, are closely related with the surrounding granitic rocks nearby the respective caldera. Geochemical comparison between a suite of the 1883 Krakatau pumice flow, 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 good correlative in chemical character with the respective related granitic rock in the locations of their plots on the AFM diagram (ŌBA and others, 1983a, b). It was denoted that such a fact suggests that the 1883 Krakatau pumice flow was genetically related with some granitic rocks, such as biotite quartz monzonite of the dominant rock type in west Malay Peninsula, nearby the Krakatau Group (ŌBA and others, 1983a, b; 1984). However, none of granitic rock occurs throughout over the whole islands of the Krakatau Group, except granitic fragments 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 magma, and that the pumice flow is genetically related with the underlying granitic complex in regard to the production of its source magma (ŌBA and others, 1983a; 1984).

The composition of any melt would depend on that of the source rock, phase chemistry and the degree of melting (CARMICHAEL and others, 1974). WYLLIE and others (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 KOSTER VAN CROOS and WYLLIE (1968) and WYLLIE and TUTTLE (1961b) showed that shales to melt at lower temperatures if alkalies and volatile components are present in addition to water. WINKLER and v. 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 in 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 and others (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, 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 the mechanism of formation of the 1883 Krakatau pumice flow.

Thus, an suggestion to account for the genesis of the 1883 Krakatau pumice flow is that sialic crustal materials, involving granitic rocks such as west Malayan granitic rocks represented by biotite quartz monzonite and sediments those which occur in Sumatra, plunged into depths along the peculiar tectonic structure locating at the Sunda Strait, which appears to be a shared portion 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, and were partially melted and produced magma of granitic composition, and mixed with or assimilated by an ascending basaltic magma which would have been derived from the upper mantle, and dacitic magma distinctly dominant in silica, alkalies and volatile components was produced, and, in such a way, the 1883 Krakatau eruption characterized by the pumice flow of dacitic composition took place. The granitic fragments were captured by the ascending dacitic magma from the plunged sialic crustal materials during passing through of the magma within the peculiar tectonic structure along the shared portion presumed in the Sunda Strait and erupted out together with the pumice flow at the same time.

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