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# Radiometric Dating of Pre-Neogene Granitic and Metamorphic Rocks in Northwest Kyushu, Japan —With Emphasis on Geotectonics of the Nishisonogi Zone

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**Abstract**: Based on newly determined fourteen mineral dates and previously reported twenty four dates, geotectonic divisions of northwest Kyushu are discussed. Granitic rocks in the Ainoshima Zone yield biotite dates within the narrow range of 89.2–93.1 Ma, and to the contrary, the Nagasaki Metamorphic Rocks in the Nishisonogi Zone have diversified radiometric dates of hornblende, muscovite and chlorite in the wide range of 60–92 Ma. New radiometric dating was performed on the coarse-grained fraction of mineral concentrates, 0.25–0.5 mm in diameter, corresponding to the grain size of porphyroblast of the crystalline schists. And the mineral dates, with concordant age given by a pair of muscovite and chlorite, fall in the younger side of the wide range, representing the time related to porphyroblast formation. Four muscovite dates of the crystalline schists from Kounoura damsite are incredibly scattered in a wide range of 60–81 Ma, but its cause may be explained by the determination made on muscovite concentrates with different grain size, that is, by grain size effect. It is certain that the Nishisonogi Zone underwent progressive and retrograde metamorphism, uplift, erosion and subsidence marked with unconformity differently in different places: early to the south in Amakusa-shimoshima and late to the north in the Nishisonogi peninsula.

A wedge-shaped area of the Nishisonogi Zone is bordered by the Yobikonoseto Fault on its west and by the Omurawan-Ariakekai Fault on its east. The Nishisonogi Zone where granitic stocks are locally formed is supposed to be united to the Sangun Metamorphic Belt with intervening 'Arita Zone' which is newly proposed to underlie between the two separate areas.

## 1. Introduction

Metamorphic minerals yield diversified radiometric dates depending on determinative methods and minerals. This raises a complex picture in placing an exact time for each event during an evolution of metamorphic belt. Actually in the Nagasaki Metamorphic Rocks of northwest Kyushu, it has been known that some mineral concentrates separated from crystalline schists in one locality revealed scattered radiometric dates, and no definite idea was given (UEDA and ONUKI, 1968). Likewise mineral ages of granitic rocks indicate various stages from ascent of magma for intrusion and consolidation to cooling in response to uplift and erosion.

In this paper fourteen radiometric dates are newly determined on muscovite and chlorite from crystalline schists of the Nagasaki Metamorphic Rocks and biotite from granitic rocks, and are presented together with twenty-four dates previously reported. Through careful petrographic examination, several stages are detected as main geologic events which governed complex processes of the Nagasaki Metamorphic Rocks. And to account for

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a possible origin of scattered dates in the Nagasaki Metamorphic Rocks, an attempt is made to evaluate radiometric dates of muscovite and coexisting chlorite using coarser-grained fraction of metamorphic minerals, that is, porphyroblasts.

Concerned with geotectonics of the Nagasaki Metamorphic Rocks, many opinions were presented in relation to prominent parallel metamorphic belts in Southwest Japan, to the element of the Ryukyu arc, or to an independent and isolated metamorphic terrane in westernmost Kyushu. The present writers are of the opinion that it is still in the melting pot to decide equivocally which opinion is correct. However, one of the writers (H.H.) intends to forward a working hypothesis that the Nishisonogi Zone for the Nagasaki Metamorphic Rocks could be linked to the Sangun Metamorphic Belt with an intervening zone, the Arita Zone (newly proposed geotectonic division).

## 2. A Brief Outline of the Geology of Northwest Kyushu

Geotectonically northwest Kyushu and surrounding sea area are divided into four divisions (Isomi *et al.*, 1971); from north to south, Tsushima Zone, Goto Zone, Ainoshima Zone, and Nishisonogi Zone (Figure 1). The Tsushima Zone is mainly composed of Paleogene—Miocene sedimentary rocks which are exposed chiefly in the Tsushima islands and Iki island. The Goto Zone is characterized by thick piles of Neogene sedimentary rocks and basal pyroclastic rocks of felsic to intermediate nature. In both zones late Miocene granites intruded the sedimentary sequences, and then Pliocene and Quaternary volcanisms accompanied by alkali basalt took place to cover land surface.

In the Ainoshima Zone and the Nishisonogi Zone Paleogene sedimentary rocks with coal seams and Pliocene to Pleistocene volcanics rest unconformably on the pre-Neogene granitic and metamorphic rocks which are dealt with in this paper for radiometric dating. The Ainoshima Zone is largely composed of thermally metamorphosed rocks from Cretaceous volcanic and sedimentary rocks and granitic rocks. The zone is bounded on its northwest side by the Goto Zone with a NE–SW trending fault, the Ainoshima Fault, and on its east and southeast sides by the Nishisonogi Zone partly with a N–S trending salient fault, the Yobikonoseto Fault.

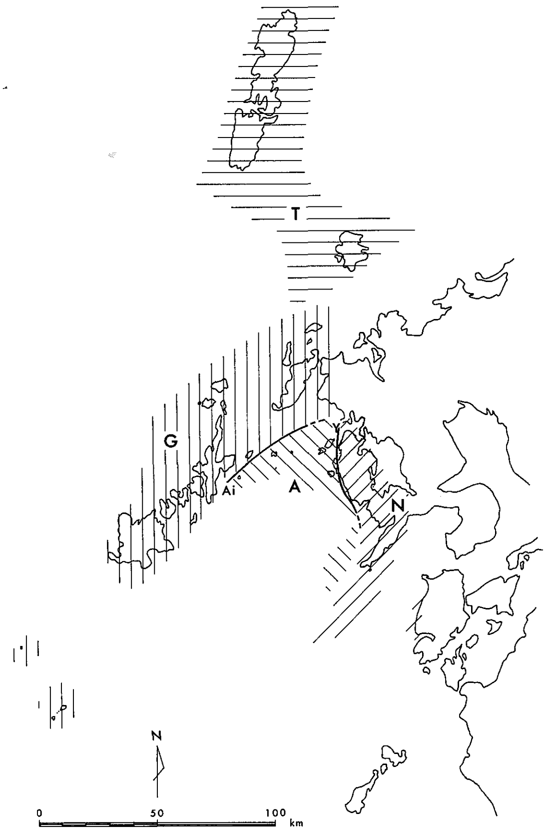



Fig. 1 A map showing geotectonic divisions of northwest Kyushu. Reproduced from Figure 2 of Isomi *et al.* (1971).
T: Tsushima Zone G: Goto Zone A: Ainoshima Zone N: Nishisonogi Zone Y: Yobikonoseto Fault Ai: Ainoshima Fault

The Nishisonogi Zone is largely composed of regionally metamorphosed sedimentary rocks characterized by the presence of large porphyroblastic albite-bearing crystalline schists (Nagasaki Metamorphic Rocks) and serpen-

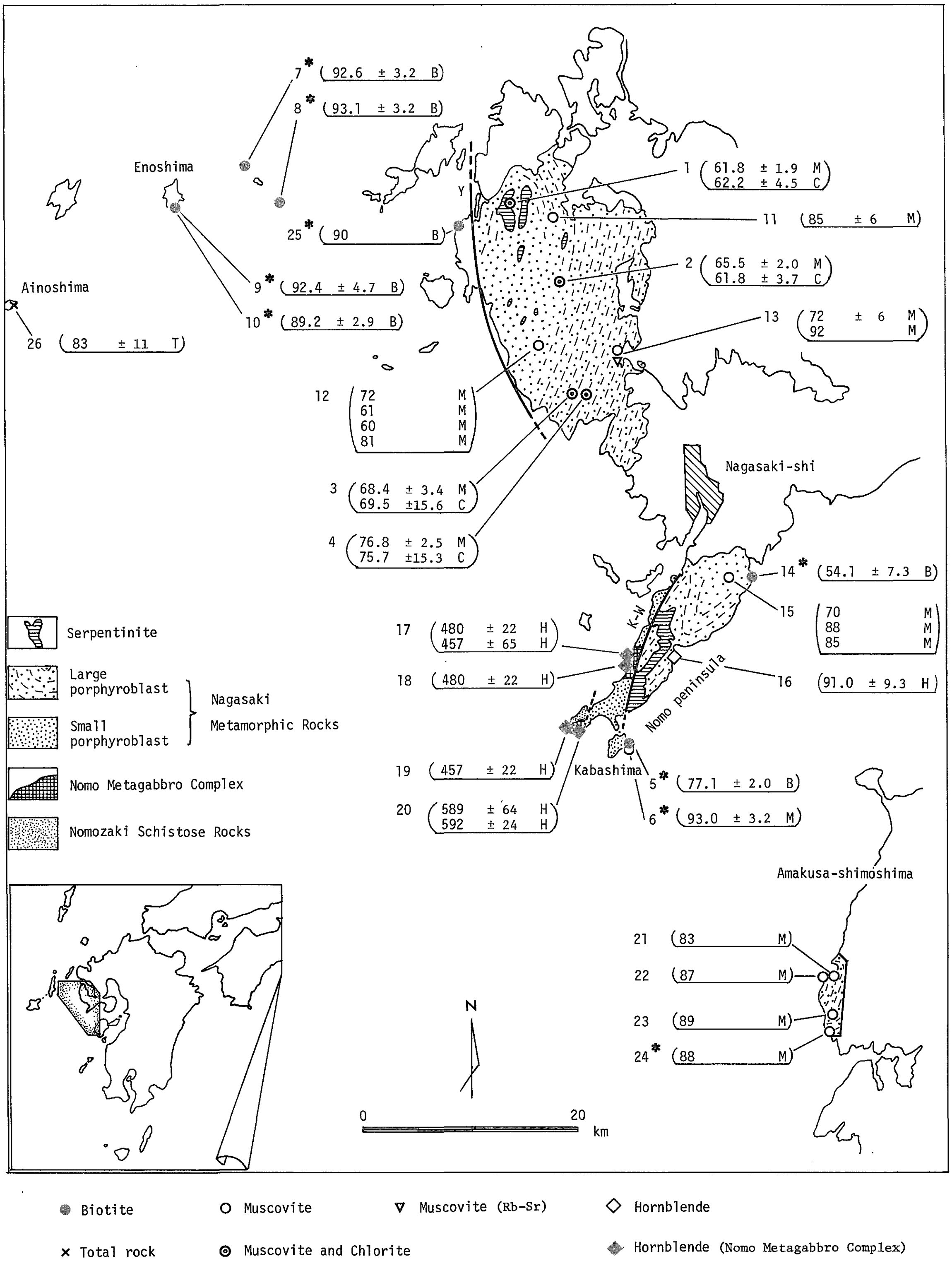



Fig. 2 A map showing a simplified geology and available radiometric dates of the pre-Neogene of northwest Kyushu. Numeral before parenthesis indicates Loc. no., and numerals in parenthesis denote radiometric date and error in Ma with symbols of minerals or total rock. Loc. no. with asterisk means that host is granitic rock. New mineral dates for Loc. nos. 1–10. Y: Yobikonoseto Fault; K–W: Kayaki-Wakimisaki Fault.

tinites (Figure 2). Nature of the metamorphism is glaucophanitic. In the Nishisonogi Zone several small granitic stocks are exposed in the Nomo peninsula and gave thermal effect upon the Nagasaki Metamorphic Rocks.

To the north in the Nishisonogi peninsula both zones are terminated by the Yobikonoseto Fault, and a geological contrast between the two zones is quite evident. To the contrary, the boundary of the two zones becomes obscure toward the south in the Nomo peninsula. No fault contact has been observed until now. Concerned with the nature of the Yobikonoseto Fault, particularly in pre-Tertiary time, ISOMI *et al.* (1971) assumed that it is almost like that of the Median Tectonic Line which divides Southwest Japan into the Inner Zone and Outer Zone, putting emphasis on the presence of mylonitized Cretaceous granodiorite (Ainoshima Zone) along the fault. HATTORI and ISOMI (1976) forwarded an hypothesis that dislocation along the Yobikonoseto Fault in pre-Tertiary time was large to form mylonite and a big contrast between the two zones, probably marked by succeeding rapid upheaval of granitic intrusion, and became apparently negligible toward the south, thus constituting a hinge-type fault.

Recently, IGI *et al.* (1976a, b) and IGI *et al.* (1979) made it clear that sporadically exposed small masses of metagabbroic rocks (Nomo Metagabbro Complex) and metamorphic rocks (Nomozaki Schistose Rocks) in the Nomo peninsula are old enough to place the age of intrusion to the Ordovician and postulated the Saihi Structural Zone in the Nishisonogi Zone as a clue to the pre-Silurian basement geology in Japan.

## 3. Previous Geochronology

Twenty-four age determinations have been reported until now on granitic and metamorphic rocks in northwest Kyushu. In this paper, all the twenty-four dates are revised using new decay constants (STEIGER and JÄGER, 1977), and the recalculated dates are shown in Table 1, together with the original dates.

In the Ainoshima Zone, a biotite from the granodiorite (northwest of Takabo-yama, Loc. no. 25, KAWANO and UEDA, 1966), and a total rock of the biotite hornfels (Ainoshima, Loc. no. 26, SHIBATA, 1968) were dated 90 and 83 Ma, respectively.

In the Nishisonogi Zone, the Nagasaki Metamorphic Rocks yielded 60–92 Ma. In the Nishisonogi peninsula, seven muscovites (Loc. nos. 11 and 13, MILLER *et al.*, 1963; Loc. nos. 12 and 13, UEDA and ONUKI, 1968) were dated 60–92 Ma, showing scattered values. The muscovite from a quartz schist (Loc. no. 13) was dated 72 and 92 Ma by K–Ar and Rb–Sr methods, respectively, giving discordant ages. In the Nomo peninsula, three muscovites (Loc. no. 15, UEDA and ONUKI, 1968) and one hornblende (Loc. no. 16, IGI *et al.*, 1976a, b) were dated 70–91.0 Ma. In Amakusa-shimoshima, three muscovites (Loc. nos. 21 and 22, UEDA and ONUKI, 1968; Loc. no. 23, UEDA *et al.*, 1977) were dated 83–89 Ma, giving a short span of time, in which 88 Ma for one muscovite from the pegmatitic rock in the crystalline schist (Loc. no. 24, UEDA and ONUKI, 1968) is confined.

In the Nishisonogi Zone, too, a granitic stock and gabbroic masses from the Nomo peninsula have been examined. In the northeast Nomo peninsula, a biotite (strongly chloritized) from the granitic stock (10 km southeast of Nagasaki-shi, Loc. no. 14, IGI *et al.*, 1976a, b) was dated 54.1 Ma. In the west and southwest Nomo peninsula, four hornblendes from the metagabbro of the Nomo Metagabbro Complex (Loc. nos. 17, 18 and 19, IGI *et al.*, 1979) were dated 457–480 Ma. In the southwestern tip of the Nomo peninsula, two hornblendes in different grain size from an amphibolite xenolith in the metagabbro (Loc. no. 20, IGI *et al.*, 1979) were dated 589 and 592 Ma.

Table 1 Summary of previously determined radiometric dating. Both original and recalculated dates using new decay constants are shown.

| References | Locality Name | Collector's No., etc. | Rock Name | Mineral | $K_2O$ (%) | Date (Ma) Original | Date (Ma) Recalculated | Location No. |
|---|---|---|---|---|---|---|---|---|
| MILLER et al. (1963) | Ooishi, Sonogi | 5001271 | Quartz schist | Muscovite | 8.25 | 70 ± 6 | 72 ± 6 | 13 |
| | Hirayamakoba, Sonogi | 5002051 | Pelitic schist | Muscovite | 6.23 | 83 ± 6 | 85 ± 6 | 11 |
| KAWANO & UEDA (1966) | Takabo-yama | G-290 | Granodiorite | Biotite | 2.51 | 88 | 90 | 25 |
| HAYASE & ISHIZAKA (1967) | Ooishi, Muramatsu | S-904(5001271) | Muscovite schist | Muscovite | Rb-Sr | 94 | 92 | 13 |
| UEDA & ONUKI (1968) | Kounoura damsite | Kounoura No. 1 | Psammitic & pelitic schist | Muscovite | 7.12 | 70 | 72 | 12 |
| | | Kounoura No. 2 | | Muscovite | 2.74 | 60 | 61 | |
| | | Kounoura No. 3 | | Muscovite | 5.56 | 59 | 60 | |
| | | Kounoura No. 4 | | Muscovite | 6.38 | 79 | 81 | |
| | 500 m east of Tomachi-dake | Tomachidake a | Schist | Muscovite | 3.91 | 68 | 70 | 15 |
| | | Tomachidake b | | Muscovite | 4.65 | 86 | 88 | |
| | | Tomachidake c | | Muscovite | 5.14 | 83 | 85 | |
| | Amakusa-shimoshima | Shimoshima | Pegmatitic rock | Muscovite | 8.42 | 86 | 88 | 24 |
| | | Takahama a | Psammitic & pelitic schist | Muscovite | 1.82 | 81 | 83 | 21 |
| | | Takahama b | | Muscovite | 3.93 | 85 | 87 | 22 |
| SHIBATA (1968) | Ainoshima | 47 | Hornfels | Total rock | 2.52 | 81 ± 11 | 83 ± 11 | 26 |
| IGI et al. (1976) | Tameshi, Sanwa | YD-73-11-8 | Gabbroic rock as pebble in conglomeratic schist | Hornblende | 0.363 | 91.4±13.9<br>86.5±11.7 | 91.0± 9.3 * | 16 |
| | Nomozaki | YD-73-11-11 | Metagabbro | Hornblende | 0.229,0.230 | 449 ± 22 | 457 ± 22 | 19 |
| | Tsunakake-iwa | YD-73-11-13 | Metagabbro | Hornblende | 0.137,0.143 | 472 ± 18<br>472 ± 38 | 480 ± 22 * | 17 |
| | | YD-73-11-14 | Metagabbro | Hornblende | 0.125,0.132 | 449 ± 64 | 457 ± 65 | |
| | Mogi, Nagasaki-shi | YD-73-11-15 | Biotite granite | Biotite | 0.470 | 52.8 ±7.1 | 54.1 ±7.3 | 14 |
| UEDA et al. (1977) | Nonaka, Ooe | TN 67022301 | Muscovite quartz schist | Muscovite | 5.75 | 87 | 89 | 23 |
| IGI et al. (1979) | Meoto-iwa | HH-75-511C | Pegmatitic gabbro | Hornblende | 0.140 | 472 ± 22 | 480 ± 22 | 18 |
| | Nomozaki | HH-75-515-2 | Amphibolite | Hornblende-1<br>Hornblende-2 | 0.127<br>0.142 | 580 ± 64<br>583 ± 24 | 589 ± 64<br>592 ± 24 | 20 |

* Two dates appeared in the original article are duplicate analyses of potassium and radiogenic argon, measured on one mineral concentrate, and in this paper the average date is shown.

## 4. New Determinations

For new age determination, little dated portions of the Nagasaki Metamorphic Rocks and granitic rocks were chosen. Fourteen minerals were separated by conventional means of magnetic separator and heavy liquids, and dated by K–Ar method: four biotites extracted from the granitic rocks in the Ainoshima Zone; four pairs of muscovite and coexisting chlorite from the crystalline schists of the Nagasaki Metamorphic Rocks, and one biotite and one muscovite from the granitic stock in the Nishisonogi Zone.

[Geology]

In the Ainoshima Zone, granitic rocks and thermally metamorphosed rocks are widely distributed in Goto-nada, and exposed on the islets and the northwest Nishisonogi peninsula. On Ainoshima island, thermally metamorphosed conglomerate, mudstone and sandstone (Ainoshima Formation, TACHIBANA, 1961) are recognized, and about 2-m wide dike of quartz porphyry (TACHIBANA, 1961) in the formation was later identified as of granite porphyry (KATADA and MATSUI, 1973). On Enoshima island, thermally metamorphosed rocks from andesitic to felsic pyroclastic rocks and lava with conglomerate and mudstone (Enoshima Formation, TACHIBANA, 1961) are exposed together with intrusive granodiorite as a small stock. Further to the east porphyritic biotite granite with pegmatitic dikes and cavities emerges on three islets; Irose, Oodate-jima and Kodate-jima (KATADA *et al.*, 1972). To the easternmost Ainoshima Zone, that is, on the northwest Nishisonogi peninsula, hornblende-biotite granodiorite with a foliation trending N30°W is seen along the Yobikonoseto Fault (HATTORI and ISOMI, 1976). A general atmosphere of geotectonics in the Ainoshima Zone is characterized by the shallower facies of granitic intrusion being to the west and the deeper facies to the east. For the present study, three granitic masses of shallow to intermediate facies on the islets of Irose, Kodate-jima and Enoshima (Loc. nos. 7, 8, 9 and 10) which have not yet been dated are examined.

In the Nishisonogi Zone, granitic rocks intruded the crystalline schists of the Nagasaki Metamorphic Rocks only in the northeast and southeast Nomo peninsula. Whereas biotite-bearing pegmatite intruded the crystalline schist (Loc. no. 24, TACHIBANA, 1967; HATTORI and ISOMI, 1976) in westernmost Amakusa-shimoshima. Therefore, in the Nishisonogi Zone little dated portions of the crystalline schists in the northern, central and southern Nishisonogi peninsula (Loc. nos. 1, 2, 3 and 4), and of a granitic stock on Kabashima (Loc. nos. 5 and 6) are chosen for dating.

[Mineral]

Detailed petrographic description on examined samples are shown in Appendix 2. A new attempt was made to study any feasibility on chlorite age, together with offering more determinative age by coexisting muscovite. Four pairs of muscovite and chlorite which were separated from one schist each, have been prepared for this purpose. However, difficulty was experienced to extract 100% pure muscovite from chlorite-interleaved muscovite. Through hand-picking of chlorite and chlorite-bearing muscovite under the microscope, purity of muscovite has risen to around 95% or above, i.e., a few percent impurity of chlorite, confirmed by X-ray diffraction method. In a similar way, purity of chlorite was attained to around 98%. Grain size of all separated minerals (Loc. nos. 1–10) is kept in the range of about 0.25–0.5 mm in diameter (60–32 mesh).

[Determinative method]

The experimental procedure is essentially the same as described in SHIBATA (1968). The K–Ar ages of fourteen mineral concentrates are calculated using new decay constants: $\lambda_\beta = 4.962 \times 10^{-10}$/y, $\lambda_e = 0.581 \times 10^{-10}$/y, $^{40}K/K = 0.01167$ atom% (STEIGER and JÄGER, 1977), and are shown in Table 2.

Table 2 Fourteen new mineral dates of the granitic and metamorphic rocks in the Ainoshima Zone (A) and Nishisonogi Zone (N), northwest Kyushu.

| Location No. | Host Rock | Mineral | $K_2O$ (%) | $^{40}Ar$ rad. ($10^{-6}$ml/g) | Atm. $^{40}Ar$ (%) | Date (Ma) |
|---|---|---|---|---|---|---|
| 1 | Garnet-albite-quartz-chlorite-muscovite schist (N) | Muscovite<br>Chlorite | 8.94<br>0.739 | 18.1<br>1.51 | 9.7<br>63.7 | 61.8 ± 1.9<br>62.2 ± 4.5 |
| 2 | Chlorite-muscovite-albite-quartz schist (N) | Muscovite<br>Chlorite | 6.94<br>0.860 | 14.9<br>1.75 | 10.1<br>67.9 | 65.5 ± 2.0<br>61.8 ± 3.7 |
| 3 | Muscovite-chlorite-quartz-albite schist (N) | Muscovite<br>Chlorite | 0.740<br>0.118 | 1.66<br>0.271 | 42.0<br>81.2 | 68.4 ± 3.4<br>69.5 ±15.6 |
| 4 | Muscovite-chlorite-calcite-albite schist (N) | Muscovite<br>Chlorite | 5.83<br>0.155 | 14.8<br>0.387 | 11.4<br>85.8 | 76.8 ± 2.5<br>75.7 ±15.3 |
| 5 | Porphyritic biotite granite (N) | Biotite | 2.13<br>2.16 | 5.55 | 24.4 | 78.5 ± 2.5<br>75.7 ± 3.1<br>77.1 ± 2.0 |
| 6 | Garnet-bearing biotite-muscovite granite (N) | Muscovite | 10.61 | 32.7 | 10.7 | 93.0 ± 3.2 |
| 7 | Porphyritic biotite granite (A) | Biotite | 5.61 | 17.2 | 33.9 | 92.6 ± 3.2 |
| 8 | Porphyritic biotite granite (A) | Biotite | 4.44 | 13.7 | 33.3 | 93.1 ± 3.2 |
| 9 | Porphyritic hornblende-biotite granodiorite (A) | Biotite | 2.01 | 6.15 | 61.7 | 92.4 ± 4.7 |
| 10 | Porphyritic hornblende-biotite granodiorite (A) | Biotite | 2.45<br>2.40 | 7.15 | 26.5 | 89.2 ± 2.9 |

Table 3 Summary of available radiometric dates.

| Category | Geology | Number of dates | Time range (Ma) | Specimen | Number of dates | Time range (Ma) | Time span (Ma) | Maximum error (Ma) |
|---|---|---|---|---|---|---|---|---|
| 1 | Granitic rocks and metamorphic rocks (Ainoshima Zone) | 6 | 83 — 93.1 | Biotite | 5 | 89.2 — 93.1 | 3.9 | 4.7 |
| | | | | Total rock | 1 | 83 | | 11 |
| 2 | Granitic rocks and pegmatitic rock (Nishisonogi Zone) | 4 | 54.1— 93.0 | Biotite | 2 | 54.1 — 77.1 | 23.0 | 7.3 |
| | | | | Muscovite | 2 | 88 — 93.0 | 5.0 | 3.2 |
| 3 | Large porphyroblastic albite spot-bearing crystalline schists [Nagasaki Metamorphic Rocks] (Nishisonogi Zone) | 22 | 60 — 92 | Muscovite | 17 | 60 — 92 | 32 | 6 |
| | | | | Chlorite | 4 | 61.8 — 75.7 | 13.9 | 15.6 |
| | | | | Hornblende | 1 | 91.0 | | 9.3 |
| 4 | Metagabbro and amphibolite [Nomo Metagabbro Complex] (Saihi Structural Zone in Nishisonogi Zone) | 6 | 457 — 592 | Hornblende (Metagabbro) | 4 | 457 — 480 | 23 | 65 |
| | | | | Hornblende (Amphibolite) | 2 | 589 — 592 | 3 | 64 |

## 5. Summary of Available Data

### 5.1 General remarks

Thirty-eight available values, that is, previously reported twenty-four dates and newly determined fourteen dates are shown on the simplified geological map (Figure 2). The age data can be classified into four categories based on the geological features, the granitic and metamorphic rocks in the Ainoshima Zone (Category 1), the granitic rocks in the Nishisonogi Zone (Category 2), the crystalline schists of the Nagasaki Metamorphic Rocks (Category 3) and the basement rocks of the Saihi Structural Zone (Category 4), and are shown in Table 3.

In the Ainoshima Zone (Category 1), only six dates are available and these are in a short span of time, particularly 3.9 Ma on the biotites. By contrast a wide range of time, 54.1–93.0 Ma, is obvious in the Nishisonogi Zone (Category 2 and Category 3), even though taking no account of the age data on the metagabbros and the amphibolite (Category 4). In Category 2, the muscovite from garnet-bearing biotite-muscovite granite (Kabashima, Nomo peninsula, Loc. no. 6) yields 93.0±3.2 Ma, which is not much different from 88 Ma of the muscovite from biotite-muscovite pegmatitic rock (Loc. no. 24, Kawano and Ueda, 1966; R 12311, Hattori and Isomi, 1976).
In Category 3, the muscovite dates of the crystalline schists from the Nagasaki Metamorphic Rocks are scattered in a wide range of time, 60–92 Ma, and 60–89 Ma if the date of 92 Ma by Rb–Sr method is disregarded. In the three districts; the Nishisonogi peninsula, the Nomo peninsula and Amakusa-shimoshima where the Nagasaki Metamorphic Rocks are exposed separately, age patterns can be outlined as below.

In the Nishisonogi peninsula, the muscovite dates by K–Ar method are in a wide range of time, 60–85 Ma (the date by Rb–Sr method is omitted). In the Nomo peninsula, the three dates are 70–88 Ma, and in Amakusa-shimoshima the three dates are 83–89 Ma. Roughly speaking, time span shown by the muscovite dates varies 25–18–6 Ma from the north of the Nishisonogi peninsula to the south of Amakusa-shimoshima. The older dates are recorded around 85–90 Ma in all of the three districts and tend to appear frequently to the south where younger age is scarcely found. In other words, it is apparent that the younger age becomes common to the north.

The four chlorite dates available only for the Nishisonogi peninsula are in good harmony with those of the coexisting muscovite. The hornblende date of metagabbroic pebbles embedded in conglomeratic schist of the Nagasaki Metamorphic Rocks is 91.0 Ma.

### 5.2 Reproducibility and reliability of mineral dates

Reproducibility of the present radiometric dating by K–Ar method ranges from about 3 to 13% (1$\sigma$) depending on atmospheric contamination, and is shown with error range for each of determination (Table 2). With regard to cross check analysis of mineral age, the muscovite (Loc. no. 13, Collector's no.: 5001271) has been made by both K–Ar method (Miller *et al.*, 1963) and Rb–Sr method (Hayase and Ishizaka, 1967), representing only one example available till now. That is, 72±6 Ma by K–Ar method and 92 Ma by Rb–Sr method, respectively, demonstrating a big difference of 20 Ma.

Another approach to make cross check analysis is attempted in this paper by the mineral pair of muscovite and coexisting chlorite separated from one rock specimen. Each of four pairs offers extremely good coincidence in age, giving maximum difference of 3.7 Ma in the case of Loc. no. 2.

From the fact stated above, it can be said that the muscovite date by K–Ar method is almost identical to the chlorite one, but is fairly young compared with that by Rb–Sr method. General concordance between muscovite and chlorite dates for the crystalline schist demonstrates the importance of chlorite for K–Ar dating.

On the other hand, unusual dates are occasionally recorded in age data of muscovite and biotite. At Kounoura damsite (Loc. no. 12) and near Tomachi-dake (Loc. no. 15), the muscovites extracted from crystalline schists gave scattered dates. No reasonable explanation has been attempted, but the following factors can be pointed out as giving erroneous date: 1) purity of mineral concentrates, 2) grain size effect, and 3) alteration.

Thirteen muscovites (Category 3), including one muscovite by Rb–Sr method and excluding newly determined four muscovites, do not furnish description on degree of purification and alteration and on grain size. One of indices to indicate purity and alteration of muscovite is expressed by $K_2O$ contents, as muscovite can contain stoichiometrically up to about 10.7%$K_2O$. Whereas the contents become far less when replaced by other alkalies and when altered. Therefore, the contents do not always mean the index. Eventually, muscovite with high contents of $K_2O$ (8.94%) yielded 61.8 Ma (Loc. no. 1) and one with low contents (1.82%) 83 Ma, and any tendency with younger dates to lower contents is not detected.

Biotite can contain $K_2O$ up to 9.2%, and is often altered to chlorite. The seven biotites under consideration, five separated biotite concentrates and two from the cited references, contain varying contents from 5.0 to 2.0% $K_2O$. Similarly in the case of muscovite, $K_2O$ contents in biotite have nothing to do with cause of scattered dates.

Concerned with grain size effect, no systematic analysis has hitherto been known yet, however, an explanation is to be made later.

### 5.3 Spatial relation of different mineral dates

Concerned with mineral concentrates extracted not from one rock specimen but from each of several rock specimens of which geological situation is the same but locations are different, several cases are to be reviewed as below.

**5.3.1** Difference of mineral dates from sampling sites at a distance of about 100 meters

(1) Southeast coast of Kabashima, south Nomo peninsula (Loc. nos. 5 and 6)

The porphyritic biotite granite which retains xenolith-like massive bodies implying palimpsest texture yields biotite date of 77.1±2.0 Ma. Alteration of biotite to chlorite is common, as well indicated by a low content of $K_2O$. 150 meters south of the site of Loc. no. 5, garnet-bearing biotite-muscovite granite occurs in a dike measuring 5–30 cm wide (Loc. no. 6), and intrudes discordantly the crystalline schists. The muscovite from this granite gives fairly older date (93.0±3.2 Ma) than the biotite of porphyritic biotite granite. The dike might have branched off from the nearby rooted main mass of the porphyritic biotite granite, although any direct evidence has not been found in the field.

If the dike and main mass were formed coevally, then two minerals, the biotite from the main mass and the muscovite from the dike should be dated almost the same. Counter to the expectation, the difference between the two dates, 15.9 Ma, that is, the time lag is not negligible. One may explain the reason that the dike was cooled down to a closed state shortly after the intrusion to retain the argon in the muscovite, and to the contrary the main mass was hot enough to have kept in an open state until the biotite was subjected to chloritization.

(2) South coast of Ebisu-jima, south Enoshima (Loc. nos. 9 and 10)

The two examined rocks are in a distance of about 90 meters, and are petrographically identical. The porphyritic hornblende-biotite granodiorite (Loc. no. 9, R 18247) contains large clots of hornblende reaching 10 mm in length, whereas the other granodiorite (Loc. no. 10, R 18246) contains booklet-shaped spots of biotite aggregates together with more potassium-feldspar than the former granodiorite. The latter granodiorite is darker-colored than the former granodiorite and contains plenty of mafic oval xenoliths. Chloritization of biotite is stronger in the former granodiorite as exhibited by the modal ratio of biotite/chlorite=7.1/6.0 and by the $K_2O$ content. The biotite from the former granodiorite yields 92.4±4.7 Ma, whereas the other biotite extracted from the latter granodiorite which has a lesser portion of chlorite than that of R 18247 yields 89.2 ± 2.9 Ma. The time lag of 3.2 Ma can simply be attributed to within the error range.

(3) Kounoura damsite, Nishisonogi peninsula (Loc. no. 12, UEDA and ONUKI, 1968)

Four muscovites of pelitic—psammitic schists (graphite-chlorite-muscovite-albite-quartz) were from the bored cores at Kounoura damsite. Detailed description on the sampling sites, the depth of bored cores and their petrography is not available, and this makes it difficult to evaluate a meaning of four scattered dates; 60, 61, 72 and 81 Ma, with a time span of 21 Ma at one limited location.

(4) 500 meters east of Tomachi-dake, 5 km south of Nagasaki-shi (Loc. no. 15, UEDA and ONUKI, 1968)

Three muscovites of crystalline schist (epidote-chlorite-muscovite-albite-quartz) may be from each of the nearby outcrops, however their detailed description on the sampling sites and petrography is not available. The scattered dates; 70, 85 and 88 Ma with a time span of 18 Ma resemble the above-mentioned pattern for Kounoura damsite. The reason can not be explained well.

**5.3.2** Difference of mineral dates from sampling sites at a distance of about 1 km

(1) No. 5 Tunnel, near Tosaka-yama, Nishisonogi peninsula (Loc. nos. 3 and 4)

The two sampling sites are at a distance of 1,350 m in No. 5 Tunnel which has been excavated for water supply from Kounoura damsite to a water-purifier tank at Nagasaki-shi. Both rocks are pale-green colored and coarse-grained crystalline schist interbedded in graphite schist with large porphyroblastic albite spots, giving an appearance of quartzo-feldspathic gneiss.

In both rocks albite porphyroblasts contain plenty of various inclusions and post-crystalline deformation is common as suggested by sutured boundaries of quartz or curved and dislocated twin lamellae of albite. The muscovite-chlorite-quartz-albite schist (Loc. no. 3, R 18322) gives muscovite date of 68.4±3.4 Ma, whereas the muscovite-chlorite-calcite-albite schist(Loc. no. 4, R 18153) does muscovite date of 76.8 ±2.5 Ma, demonstrating significant time gap of 8.4 Ma which is out of error ranges. Although both rocks have undergone an identical geologic process, a slight time gap was brought about with no reasonable explanation.

(2) Westernmost Amakusa-shimoshima

(i) Loc. nos. 21 and 22 (UEDA and ONUKI, 1968)

The two sampling sites are located to the west of Takahama, at a distance of 0.7 km. Petrographically identical schists with the mineral assemblages of chlorite-muscovite-albite-quartz with accessory minerals of garnet and stilpnomelane yielded muscovite dates of 83 and 87 Ma, indicating quite the same age within probable error ranges which have not been reported in the original article.

(ii) Loc. no. 23 (UEDA *et al.*, 1977) and Loc. no. 24 (UEDA and ONUKI, 1968)

Both places are in a distance of 1.2 km. Muscovite-quartz schist with accessory minerals of albite, chlorite, calcite, stilpnomelane and apatite yielded 89 Ma (Loc. no. 23) which is almost the same date of 88 Ma given to the muscovite of a pegmatitic rock containing booklet muscovite measuring 10 mm across and a small amount of biotite flakes (Loc. no. 24, TACHIBANA, 1967; R 12311, HATTORI and ISOMI, 1976).

## 6. Discussion

### 6.1 Cause of scattered dates

Quite contrary to the narrow time range, 89.2–93.1 Ma, of five dates measured on the biotites of the granitic rocks (Ainoshima Zone, Category 1) in a long distance of about 25 km, the mineral dates of the rocks from the Nishisonogi Zone are scattered in a wide time range, even in a limited distance of about 100 m, as already summarized in Table 3 and foregoing chapter: a time span of 38.9 Ma (Category 2); 32 Ma (Category 3); 135 Ma (Category 4).

In Category 2, two muscovite dates of 93.0±3.2 Ma (Loc. no. 6) and 88 Ma (Loc. no. 24) are obviously older than the biotite date of 77.1±2.0 Ma (Loc. no. 5) and much older than the biotite date of 54.1±7.3 Ma measured on the weathered granite (Loc. no. 14). The reason why this happened can be explained by the different capability of minerals for retaining argon during successive geological processes such as cooling and chloritization. Apparently muscovite tends to keep older date than biotite does in the case of the granitic rocks.

Situation is much more complicated in the case of the crystalline schists (Category 3). Main feature of the crystalline schists is manifested by the presence of large porphyroblastic albite measuring more than 0.5 mm across, occasionally reaching 5 mm, as explained by the petrographic description in Appendix 2. The porphyroblast often contains various inclusions of finer-grained minerals which are aligned to show helicitic texture or rotated like a snowball. Epidote is zoned with several bands. Some of zoned epidote does not show optical continuation of gradual change, but has a sharp boundary between two bands (Loc. nos. 1 and 4). Polygonal and granoblastic textures made by quartz and albite in the groundmass (Loc. no. 1) are worthy of particular attention, for the textures are generally observed in thermally metamorphosed rocks. Sutured boundary of quartz (Loc. no. 3) and curved and dislocated twin lamellae of albite (Loc. no. 4) are of mortar texture and are probable indication of post-crystalline mechanical deformation in the retrograde stage. These textures mentioned above strongly suggest that the crystalline schists have undergone diversified range of metamorphism from progressive to retrograde stage (Table 4). In addition, any change at each of various stages is not infrequently gradual, but abrupt, as clarified in the crystalline schists in Amakusa-shimoshima (HATTORI and ISOMI, 1976). In this connection, elaborated analysis of diversified range of metamorphism could be performed and materialized to describe its geologic history, if individual single mineral grains, that is, of porphyroblasts or of groundmass were able to be radiometrically dated with reasonable accuracy. However, the present situation does not permit such an idealized and reasonable analysis, so that grain size effect of the newly dated minerals is only commented upon in this paper.

The four muscovites and four chlorites have the same grain size distribution of 0.25–0.5 mm, as can be seen in Appendix 2. The grain size distribution is a little smaller than the average grain size of porphyroblastic minerals in the crystalline schists and obviously larger than that of the groundmass. Concerned with the observed mechanical deformation at the retrograde stage, growth of minerals such as quartz, chlorite, muscovite is just localized to a limited extent to produce only minute mineral grains measuring 0.05 mm across or less, that is, far

Table 4 Idealized geologic history showing various stages of the main geologic events of the Nagasaki Metamorphic Rocks. Based partly on Table 2 of HATTORI and ISOMI (1976).

| Stage | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|---|
| Events | Sedimentation | | ———→ | | | | | | |
| | Metamorphism | Burial | | ———→ | | | | | |
| | | Porphyroblast | | | ——— | ———→ | | | |
| | | Local heating | | | | ———→ | | | |
| | | Retrograde | | | | | ———→ | | |
| | Uplift | | | | | | - - - | ———→ | |
| | Subsidence | | | | | | | | ———→ |
| Features | | | Conglomerate with pebbles of Nomo Metagabbro | Recrystal-lization to fine-grained | Various porphyroblasts<br>Segregated vein | Large porphyroblast<br>Pegmatite Granites | Granulation<br>Various veins | Hydrous minerals | Pebbles to overlying strata |
| | | | | Glaucophanitic amphibole | | Barroisite | Deformation | Hydration by weathering | Unconformity |

smaller than porphyroblast and even the groundmass. These petrographic evidences indicate that all of the dated minerals are extracted only from porphyroblast itself or its pulverized portion and never include any portion of the groundmass. Geologically, the dated minerals are from the area of 'large porphyroblast'-bearing Nagasaki Metamorphic Rocks (provisionally classified and shown in Figure 2), and the mineral dates correspond to the time of geologic events at Stages 3 and 4 (Table 4). The newly dated muscovites are in the range of 61.8–76.8 Ma, and coexisting chlorites 61.8–75.7 Ma (Table 2). Both mineral dates represent the time related to the growth of porphyroblast, and are placed on the fairly younger side of the time range of 60–92 Ma by the 17 muscovites (Table 3). It may be formulated as an apparent tendency of probable grain size effect that the younger ages are recorded on the porphyroblasts which are formed later than the groundmass. However, it is unfortunately not possible to ascertain whether the older dates with around 85–90 Ma in all of the three districts, the Nishisonogi peninsula, the Nomo peninsula and Amakusa-shimoshima (Category 3) record an older geologic event related to recrystallization of the groundmass. In the case of hornblende, little is known yet though, it seems unlikely that hornblendes from an amphibolite xenolith in the Nomo Metagabbro Complex (Category 4) yielded different dates, as seen on dates of 589±64 Ma for a fraction of 60–100 mesh and 592±24 Ma for another fraction of 100–150 mesh (Loc. no. 20, Igi *et al.*, 1979). It can be stressed that the hornblende date, 91.0±9.3 Ma (Loc. no. 16, Category 3) can be compared with the older dates stated here on the muscovites, and yet further older and very close to or coeval with the muscovite date by Rb–Sr method. Prominently scattered dates in a limited location, of Kounoura damsite (Loc. no. 12) and of nearby Tomachi-dake (Loc. no. 15), 60–81 Ma and 70–88 Ma, respectively, cannot simply be clarified, but as referred to in the foregoing discussion, the cause might be explained in this way of grain size effect: measured on the muscovites of different grain size distribution.

As a coronary, it is naturally concluded that the newly dated muscovite and chlorite of the crystalline schists tend to record the time related to the formation of porphyroblasts, comparatively younger ages than the groundmass of metamorphic minerals which were formed prior to various porphyroblasts. Concerned with geographical distribution of the younger ages, a tendency is detected in the Nishisonogi Zone with getting old toward the south.

### 6.2 Main geologic events of the Nagasaki Metamorphic Rocks

Regional metamorphism in the Nishisonogi Zone which made the Nagasaki Metamorphic Rocks was initiated from burial metamorphism (Stage 2 in Table 4) and upgraded to the higher degree to form various porphyroblasts and segregated vein (Stage 3). The environment might have been maintained for a long duration of geologic time until sudden increase of temperature and release of pressure happened and caused to recrystallize barroisite from glaucophanitic amphibole with abrupt and sharp boundary between the core part and the surrounding rim, and large porphyroblast (Stage 4). The change might have been triggered by intrusion of pegmatite and granites of which roof is only locally emerged as a minor stock.

On the other hand, granitic intrusion may soon be followed by uplift when the granitic body is hot and large enough to get buoyant force. The zone would have undergone differential movement of dislocation. This may be the case in the Ainoshima Zone, of which the eastern border attained maximum uplift and brought up the deeper lithofacies of gneissose granodiorite. The gneissose granodiorite body is terminated by the mylonite and the fault, and then the Yobikonoseto Fault was formed for the first time. Magnitude of uplift at the first stage in the Ainoshima Zone was tremendous because of big buoyancy, but any clue for estimating amount of differential movement from the level of the Nishisonogi Zone is not obtainable.

In the Nishisonogi Zone, a small granitic stock or intrusion of pegmatite may not have heated up to such an extent that thermal contact effect prevails to form hornfels. And any effective buoyant force may not be expected to have been operative at the time of intrusion in the entire area of the Nishisonogi Zone. This causes delay of time in uplift from the time of granitic intrusion, quite different from the observed rapid uplift in the Ainoshima Zone. In the succeeding stage (Stage 6), the crystalline schists emerged on land and were subjected to weathering, and then turned to subsidence to be covered by younger sediments with unconformity (Stage 7).

As regard to assessing radiometric dating, one of focal points is which stage of geologic events is preferred to mineral dates determined by different methods. Empirically it has been clarified that muscovite becomes closed in respect to radiogenic argon at about 350 °C and radiogenic strontium at about 400 °C. It is stated that the Rb–Sr and K–Ar mineral dates tend to give younger ages than the time of recrystallization for fine-grained metamorphic rocks, and it was pointed out that mineral date of higher metamorphic grade is deviated from the main events of metamorphism (Hattori, 1968; Yamaguchi and Yanagi, 1970).

In the present study, all dated muscovites of the Nagasaki Metamorphic Rocks were extracted from the coarse-grained fraction of constituent minerals, corresponding to the grain size of various porphyroblasts and large porphyroblast (Table 4) or its pulverized part, and not to the groundmass. Therefore the muscovite dates offer without doubt the time of porphyroblast formation (Stage 3) or of later than Stage 3. It is not known the exact time and physico-chemical environments to get closed in respect to radiogenic argon in muscovite. However, it is likely that the time must be in or before Stage 5 when sufficient cooling can be attained (Table 4). When the previously determined muscovite dates are taken into account, much diversified dates may provide a complicated history.

### 6.3 Upper age limit of the Nagasaki Metamorphic Rocks

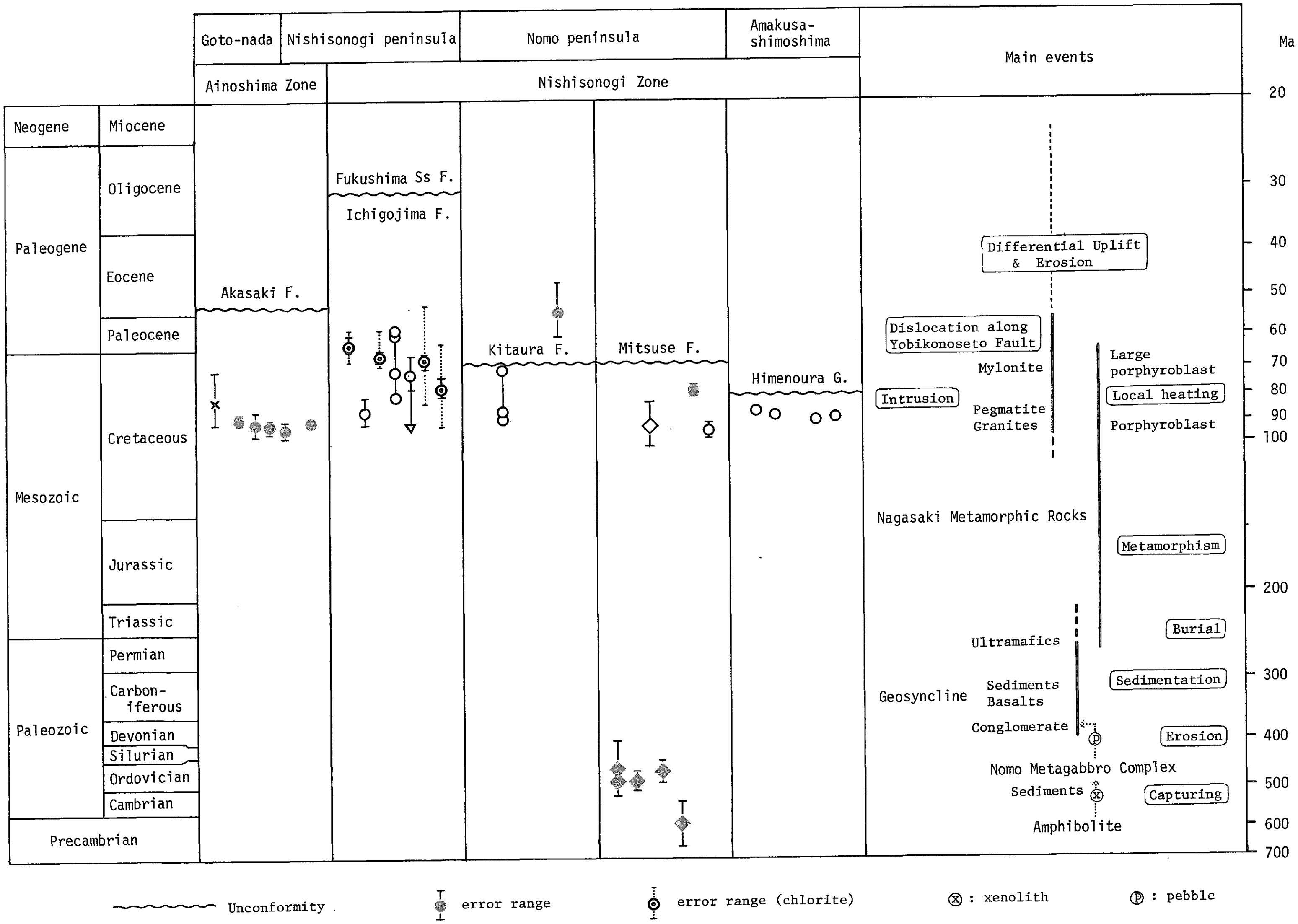
Stratigraphically, unconformable relation between the Nagasaki Metamorphic Rocks and overlying strata is of prime importance to place the upper age limit of the underlying crystalline schists (Tables 4 and 5).

To the north in the northern Nishisonogi peninsula (near Loc. nos. 1, 2, 11 and 25), the crystalline schists are directly covered by the Middle to Late Oligocene Fukushima Sandstone Formation of the Nishisonogi Group with unconformity. Prior to the deposition of the Nishisonogi Group, pebbles of the crystalline schists were incorporated into the Early Oligocene Ichigojima Formation of the Matsushima Group, as reported by Inoue (1964). From these observation, it is concluded that the crystalline schists of the Nagasaki Metamorphic Rocks were uplifted and eroded, and subsided by Early Oligocene time in the northern Nishisonogi peninsula.

South of Nagasaki-shi (near Loc. nos. 14 and 15) the crystalline schists of the Nagasaki Metamorphic Rocks are covered by the Kitaura Formation (Early Eocene by Imai *et al.*, 1965 or Late Cretaceous by Kamada *et al.*, 1979 and Imai *et al.*, 1980). However, the dated granitic rock with $54.1 \pm 7.3$ Ma which intruded the crystalline schists is not directly underlain by the formation, as the unconformity is observed in the area only one kilometer apart from the granitic rock beyond Mogi Harber.

In the middle Nomo peninsula (near Loc. nos. 16, 17 and 18), the Mitsuse Formation containing *Trachodon* sp. and *Inoceramus* sp. of

Table 5 Summary of succession of main geologic events in northwest Kyushu. Graduations of ordinate are shown by logarithmic scale (Ma). Symbols for radiometric dating are the same as those in Figure 2.



Late Cretaceous age, probable equivalent to the lower part of the Koyagi Formation, overlies the crystalline schists (NISHIMURA, 1979). This means that the crystalline schists of the Nagasaki Metamorphic Rocks were raised and submerged by Late Cretaceous time.

In westernmost Amakusa-shimoshima (near Loc. nos. 21–24), the crystalline schists are unconformably covered by the Late Cretaceous Himenoura Group.

In all of the above four places, it is quite evident that the radiometric dates of metamorphic minerals from the crystalline schists never contradict the age of the overlying strata with unconformity. It is also apparent that the age of the unconformity in each of the places becomes young toward the north (Table 5). Therefore, the stratigraphic positioning of the unconformities suits quite well a trend recognized in the geographical distribution pattern of the younger ages of the muscovite from the Nagasaki Metamorphic Rocks.

Based on the assumption that the older date should be recorded in the finer-grained fraction of mineral concentrates and the younger date in the coarser-grained one, the main geologic events in the Nagasaki Metamorphic Rocks can be summarized as follows. The upper age limit of the metamorphism (Stage 6), that is, uplifting to terminate the regional metamorphism at depth and to lead to the cessation of mineral growth to coarser grains with retrograde mineral growth differ from place to place in the terrane of the Nagasaki Metamorphic Rocks (Stages 5 and 6). Roughly speaking, the last events happened early to the south in Amakusa-shimoshima, and late to the north in the northern Nishisonogi peninsula.

### 6.4 Geotectonic meaning of different uplifting of the terrane

Uplifting as the last events to mark the cessation of regional metamorphism took place differently in different places in the Nishisonogi Zone. With regard to the geographical distribution of all of the thirty eight examined dates, the most outstanding contrast is seen along the Yobikonoseto Fault and the Kayaki-Wakimisaki Fault (Figure 2). To the west of the Kayaki-Wakimisaki Fault, the Ordovician Nomo Metagabbro Complex and the Nomozaki Schistose Rocks were an emerged basement to supply clastic material into the original sedimentary sequences of the Nagasaki Metamorphic Rocks which lie to the east of the fault, and contain pebbles of the complex (Table 5), as stated by IGI *et al.* (1979).

In the case of the Yobikonoseto Fault, the biotite date of 90 Ma from the hornblende-biotite granodiorite with foliation to the west of the fault differs prominently from the muscovite date of 61.8 Ma and the chlorite date of 62.2 Ma on the crystalline schist to the east. Stratigraphically, upper age limit of the granodiorite is shown by the overlying Early Eocene Akasaki Formation (NAGAHAMA and MATSUI, 1958) and that of the crystalline schists is by the Middle to Late Oligocene Fukushima Sandstone Formation (INOUE, 1964). This means that uplift and erosion on the east side of the fault was retarded to the west side. Amount of dislocation in the pre-Neogene along the fault must have been great causing the formation of the remarkable contrast, as considered from the fact that the deeper part of granitic rocks (granodiorite with foliation) is exposed with mylonite along the fault.

Nature of dislocation in pre-Tertiary along the Yobikonoseto Fault was once assumed to resemble that of the Median Tectonic Line of Southwest Japan (ISOMI *et al.*, 1971). But one of the present writers (H.H.) inclined to regard this with a hinge-type fault of which dislocation becomes little and obscure toward the south (HATTORI and ISOMI, 1976), and the view is strongly reinforced by the radiometric dates and stratigraphic facts mentioned in the preceding discussion.

### 6.5 Geotectonic setting of the Nagasaki Metamorphic Rocks

A geotectonic belonging of the Nishisonogi Zone which is largely occupied by the Nagasaki Metamorphic Rocks is very controversial. Many attempts have been made to correlate the zone with the parallel metamorphic belts in Southwest Japan. HIROKAWA (1976) gave an historical perspective on this matter. Unless a large-scale southward movement or bending of northern Kyushu (KOBAYASHI, 1941; HIROKAWA, 1976) is proved, a relation of the Nagasaki Metamorphic Rocks with geographically the nearest metamorphic terrane (Sangun Metamorphic Belt) to the east in the Tsukushi mountains and Chikuhi mountains becomes important. However, there is an apparent discontinuity or gap between the two terranes structurally and geochronologically, as judged from schematic geologic maps by KARAKIDA *et al.* (1969) and HIROKAWA *et al.* (1976) and radiometric age maps of granitic rocks and metamorphic rocks by NOZAWA (1975, 1977).

On the metamorphic rocks of the Tsukushi mountains, there is no date for the Sangun Metamorphic Rocks. Whereas to the south in the Chikuhi mountains several old dates suited for the Sangun Metamorphic Rocks have been reported in the metamorphic rocks. The Sangun Metamorphic Rocks are covered by the late Middle Triassic Tsubuta Group in western Honshu, about 200 km east of the Nishisonogi Zone. The terrane of the Sangun Metamorphic Rocks in northern Kyushu does not constitute an apparent zonal arrangement and is dominated by various granitic intrusions of Cretaceous age. The granitic rocks yield biotite dates in the range of 78–99 Ma and can be comparable to the granitic rocks in the Ainoshima Zone (Category 1). Therefore, any radiometric dates primarily indicative of Triassic diastrophism for the Sangun Metamorphic Belt have been influenced and obliterated by the Cretaceous granitic intrusion.

Concerning geologic structures of the Nagasaki Metamorphic Rocks in the Nishisonogi peninsula there is an anticlinal axis trending N20°E with northerly plunge, and in the Nomo peninsula folding axes trending along an elongation of the peninsula (N40°E). Both trends quite differ from the trends dominated with N70°W—E–W—N60°E in the Tsukushi mountains, and E–W—N70°W in the Chikuhi mountains.

From the structural discontinuity clearly indicated on the maps, it can be inferred that the presence of hidden large faults might have been formed in pre-Tertiary basements between the two terranes (Figure 3). Trend and location of the hidden faults are speculative of course, however, one of the faults can be matched with the well-defined actual fault, the Hatashima Fault (KOBAYASHI *et al.*, 1956). This is because the fault is situated between the pre-Tertiary granites (schistose hornblende-biotite granodiorite, two mica granite and mylonitic granodiorite) on its northeast, and the Paleogene Ochi and Kishima Groups on its southwest. It is worthy of note that in parallel with the fault mylonitic granodiorite was recognized and described as originated in granodiorite itself (KOBAYASHI *et al.*, 1953), giving a suggestion that weak lineament had already been formed before the Paleogene. The occurrence of mylonitic granodiorite along the Hatashima Fault resembles that of the Yobikonoseto Fault.

The Hatashima Fault can be extended southwards passing through in Ariake-kai in a direction from NW–SE to NNW–SSE to off the coast of Omuta-shi, and in this paper a new term '**Hatashima-Ariakekai Fault**' is given (Figure 3). Another fault with a similar pattern is located in Omura-wan, exactly the same of the fault shown in Figure 1 of KARAKIDA *et al.* (1969), and here is also called '**Omurawan-Amakusa Fault**'. Nature of the two faults is not known yet in detail, but geotectonic significance of the Hatashima-Ariakekai Fault would not be less than that of the Yobikonoseto Fault.

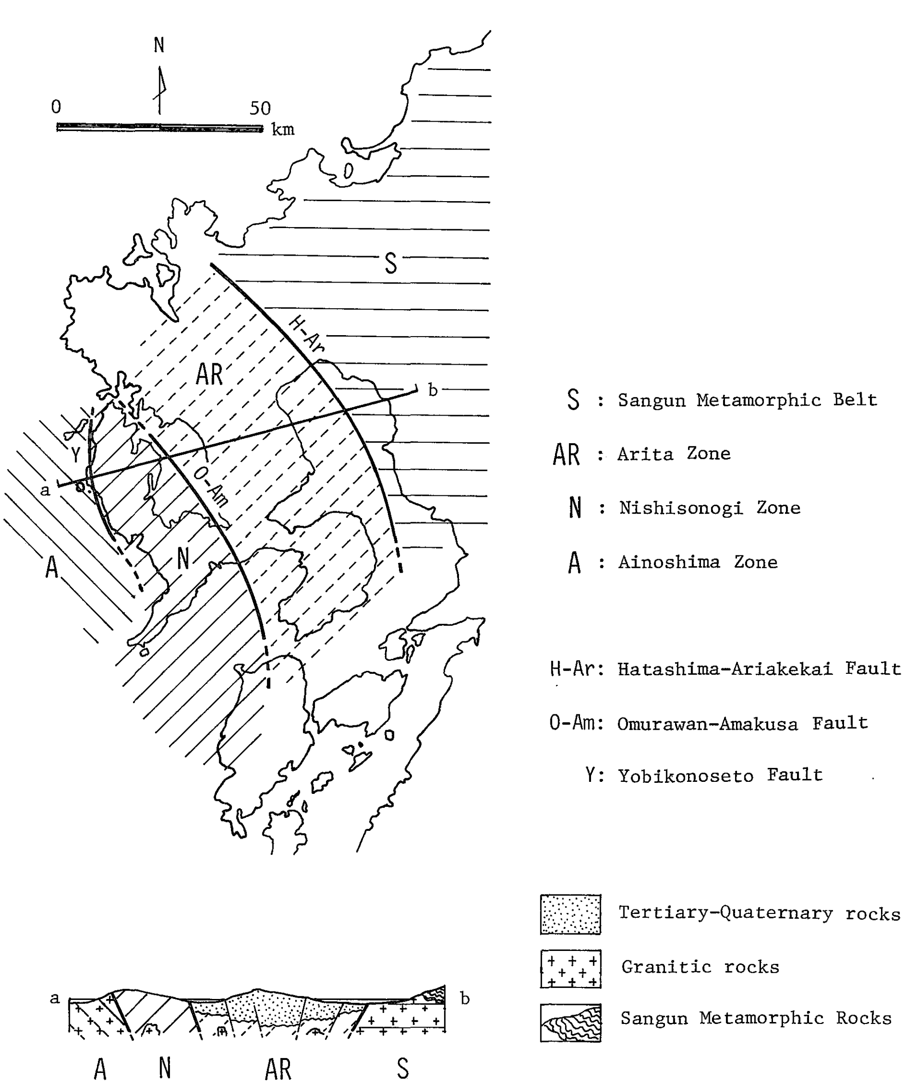



Fig. 3 A map showing geotectonic divisions of northwest Kyushu, with schematic cross-section along a–b. A newly proposed 'Arita Zone' is illustrated on the map and cross-section.

The area between the newly defined two faults thus stretches southwards in a direction from NW–SE to NNW–SSE with a width of about 40 km, and forms a graben where the Paleogene sedimentary rocks with coal seams, Neogene sedimentary rocks and Neogene to Quaternary volcanics were thickly laid down. Underneath these Cenozoic coverings, there would underlie metamorphic rocks, judging from the occurrence of black schist with porphyroblastic spot as xenolith trapped in the Arita Rhyolite (Karakida *et al.*, 1969) of probable Pliocene to Pleistocene age.

Based on the evidences, the writers intend to postulate an hypothetical existence of metamorphic terrane in the above-mentioned area of which lower level might have not emerged on land until now, and to call the area '**Arita Zone**' for convenience sake. Metamorphic rocks in the Arita Zone may vary in composition, and are supposed to be quite similar to the Nagasaki Metamorphic Rocks, probably accompanied by little intrusion of granitic magma. In this connection, it is possible that the Nagasaki Metamorphic Rocks are extended to occur in the Arita Zone too. The Arita Zone, a speculative geotectonic zone probably affiliated with the Nishisonogi Zone, cannot be defined well in its areal extent before the formation of the Hatashima-Ariakekai Fault. However, it is highly probable that the Arita Zone might have been united with the Sangun Metamorphic Belt to the east prior to various granitic intrusions of Cretaceous age. This means that the Nishisonogi Zone can be linked to the Sangun Metamorphic Belt, with the intervening Arita Zone.

There is a clue to date the time of uplift of the Arita Zone in early Tertiary time, by elucidating nature of clastic sediments of the Paleogene Ochi and Kishima Groups of which conglomerates contain angular pebbles of siliceous rock and slate (KOBAYASHI *et al.*, 1953). Provided that the angular pebbles of siliceous rock and slate would have been supplied from the nearby emerged land of the least metamorphosed strata not influenced by granitic intrusion, it seems likely that the least metamorphosed strata might represent the only superficial part of metamorphic rocks in the Arita Zone. In a similar manner, it is suggested that the black schist with porphyroblastic spot trapped in the Arita Rhyolite comes from the deeper facies of the metamorphic rocks in the Arita Zone. Therefore, at the time of sedimentation of the Ochi and Kishima Groups, the main part of the Arita Zone was still in certain depth, whereas the Nishisonogi Zone emerged on land to supply pebbles of the crystalline schists with large porphyroblast.

The Nishisonogi Zone where granitic stocks were locally formed is therefore bordered by the Omurawan-Amakusa Fault on its east, and by the Yobikonoseto Fault on its west. Now the zone can accurately be defined to constitute a wedge-shaped geotectonic zone, which is featured by a tendency of later uplift toward the north.

Amount of dislocation along each of the faults is roughly exhibited in an idealized cross-section of Figure 3. The geotectonic features in Paleogene time or earlier have been modified later more or less in the directions parallel to the Ainoshima Fault (NE–SW—ENE–WSW, designated as Ai in Figure 1) and dominant faults trending a NW–SE direction in northern Kyushu, and also possibly to the Ryukyu arc. A newly proposed structural unit by KIZAKI (1979), the area for the Kyushu Western Marginal Shear of which borders have not been defined clearly, may be included in the wedge-shaped Nishisonogi Zone.

Lastly, it can be resumed that radiometric dates are not conclusive proof and determinative factor to locate geotectonically the Nishisonogi Zone, as mineral dates seem to indicate diversified times from recrystallization, via growth of porphyroblast to cessation of metamorphic events and uplift. Newly proposed 'Arita Zone' is merely significant and competent, unless any large-scale southward movement or bending of the parallel metamorphic belts is realized.

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** in Japanese

## 地 名 対 応 表

| | | | |
|---|---|---|---|
| Ainoshima | 相の島 | Mitsuse | 三つ瀬 |
| Akasaki | 赤崎 | Mogi | 茂木 |
| Amakusa-shimoshima | 天草下島 | Muramatsu | 村松 |
| Ariake-kai | 有明海 | Nishisonogi | 西彼杵 |
| Arita | 有田 | Nomo | 野母 |
| Chikuhi | 筑肥 | Nomozaki | 野母崎 |
| Ebisu-jima | 蛭子島 | Nonaka | 野中 |
| Enoshima | 江の島 | Ochi | 相知 |
| Fukushima | 福島 | Omura-wan | 大村湾 |
| Goto | 五島 | Omuta | 大牟田 |
| Hatashima | 畑島 | Oodata-jima | 大立島 |
| Himenoura | 姫浦 | Ooe | 大江 |
| Hirayamakoba | 平山木場 | Ooishi | 大石 |
| Hizen Takashima | 肥前高島 | Ooseto | 大瀬戸 |
| Ichigojima | 苺島 | Ryukyu | 琉球 |
| Iki | 壱岐 | Saihi | 西肥 |
| Irose | 色瀬 | Sakito | 崎戸 |
| Isanoura | 伊佐浦 | Sangun | 三郡 |
| Kabashima | 樺島 | Sotome | 外海 |
| Kakinoura | 蛎の浦 | Takabo-yama | 高帆山 |
| Kayaki | 蚊焼 | Takahama | 高浜 |
| Kishima | 杵島 | Tameshi | 為石 |
| Kitaura | 北浦 | Tomachi-dake | 戸町岳 |
| Kodate-jima | 小立島 | Tosaka-yama | 土佐賀山 |
| Kounoura | 神浦 | Tsukushi | 筑紫 |
| Koyagi | 香焼 | Tsunakake-iwa | 綱掛岩 |
| Matsushima | 松島 | Tsushima | 対馬 |
| Meoto-iwa | 夫婦岩 | Wakimisaki | 脇岬 |
| Mie | 三重 | Yake-yama | 焼山 |
| Mine | 美祢 | Yobikonoseto | 呼子の瀬戸 |

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# 北西九州における先新第三紀の花崗岩類及び変成岩類の放射年代

## ——特に長崎変成岩類の地質構造区分について

服部　仁・柴田　賢

## 要　旨

北西九州の先新第三紀変成岩類及び花崗岩類は地質構造区分から相の島帯と西彼杵帯とに二分される．この変成岩類及び花崗岩類について，新たに14個の鉱物の放射年令を測定した．既存の24個の年令を加えた38個の資料に基づき長崎変成岩類の地質構造区分上の問題を考察する．両帯の間には呼子の瀬戸断層が通っている．相の島帯は花崗岩類により特徴づけられ，東端の呼子の瀬戸断層沿いにはマイロナイトを生じている．この花崗岩類の黒雲母年令は 89.2-93.1 Ma の狭い範囲に入るのに対して，西彼杵帯での鉱物年令は大きくばらついている．

西彼杵帯では花崗岩類の貫入が極めて少ないのが特徴である．野母半島では茂木及び樺島にストック状の花崗岩体が，天草下島ではペグマタイトが貫入しているが，西彼杵半島では確認されていない．

西彼杵帯は，①長崎変成岩類，②長崎変成岩類中に貫入する花崗岩の小岩体及びペグマタイト，及び③先シルル紀の基盤（西肥構造帯を構成する野母変斑れい岩複合岩体及び野母崎片状岩）に細分できる．長崎変成岩類の鉱物年令は 60-92 Ma の広い範囲にわたる．今回，一個の結晶片岩から分離した白雲母・緑泥石の一組について得た鉱物年令は良く一致している．年代測定に用いた鉱物はいずれも 0.25-0.5 mmの大きい粒径のもので，結晶片岩の構成鉱物のうちでは斑状変晶の粒径に相当する．すなわち，4組の白雲母-緑泥石の年令は61.8-76.8 Ma の間であり，長崎変成岩類の鉱物年令のなかでは若い年令に当たり，斑状変晶が変成作用の後期に生じていることと矛盾しない．長崎変成岩類の白雲母年令は，西彼杵半島60-92 Ma で約60 Ma の若い年令が多く，野母半島では 70-91 Ma，天草下島では 83-89 Ma と年令幅が狭くなっている（西彼杵半島では，一地点の4個の結晶片岩について白雲母年令が60-81 Ma という著しい不一致年令が知られている）．

長崎変成岩類を不整合で覆う堆積岩は，西彼杵半島では松島層群の福島砂岩層（漸新世），野母半島では三つ瀬層（白亜紀後期），天草下島では姫浦層群（白亜紀後期）である．長崎変成岩類は，上記の3地域において，変成作用終了後，上昇・削剝・沈降・不整合の形成のそれぞれが異なった時期に進行し，鉱物年令はこれらの地質現象と矛盾しない結果を示している．すなわち，長崎変成岩類は天草下島でもっとも早期に変成作用を終了して直ちに不整合を形成しているが，北方の西彼杵半島ではおそくまで地下深所に留め置かれ，上昇に転じてから不整合形成までの間でも長時間を要している．以上のように長崎変成岩類の場合西彼杵帯のなかでも地域によって地質事象の起った時期が明らかに異なっている．このことは鉱物年令から直ちに変成岩類あるいは変成域の地質構造区分上の帰属を決めることが適当でないことを示している．

西彼杵帯の西縁は呼子の瀬戸断層であるが，東縁は明らかでない．長崎変成岩類の帰属をもっとも近隣の三郡変成帯との関係で考察すると，両帯の間には唐津炭田を包む陥没帯があり，直接の関係は分らない．しかし，この地帯の有田流紋岩中に斑状変晶を含む結晶片岩の捕獲岩が発見されていること，及び杵島層群（漸新世）中の礫岩に粘板岩の礫が含まれていることは，長崎変成岩類及び三郡変成岩に類似の変成岩の伏在する可能性を暗示している．この地帯の東縁すなわち，三郡変成帯との境界には，マイロナイトを伴う畑島—有明海断層があり，その性質が呼子の瀬戸断層に類似していることに注目したい．この地帯を新たに“有田帯”と呼ぶことを提唱し，現地表に露出していない変成岩を含むこの有田帯が西彼杵帯と三郡変成帯とを地下で互いに結びつけていると解釈したい．

## Appendix 1: List of sampling sites and their grid references of ten locations (Loc. nos. 1–10)

| Location No. | GEMS No. | Collector's No. | Longitude (E) | Latitude (N) | Topographic Map | Locality Name | Distance |
|---|---|---|---|---|---|---|---|
| 1 | R 18373 | HH-69316B | 129° 40' 48" | 33° 00' 07" | Kakinoura (NI-52-17-06) | 1.5 km east of Isanoura, Sakito-cho (*) | |
| 2 | R 17967 | HH-66107A | 129° 42' 48" | 32° 56' 07" | Kounoura (NI-52-17-07) | 1.0 km northeast of Yake-yama, Ooseto-cho (*) | |
| 3 | R 18322 | HH-69290 | 129° 44' 18" | 32° 50' 46" | Kounoura (NI-52-17-07) | Underneath Tosaka-yama, Sotome-cho (*), in No. 5 Tunnel | 1,350 m |
| 4 | R 18153 | HH-68254 | 129° 45' 10" | 32° 50' 34" | Oomura (NI-52-17-03) | 1.3 km east of Tosaka-yama, Mie-cho, Nagasaki-shi | |
| 5 | R 18398-1 | HH-70371 | 129° 47' 32" | 32° 33' 19" | Hizen Takashima (NI-52-18-01) | Southeast coast of Kabashima, Nomozaki-cho (*) | 150 m |
| 6 | R 18234 | HH-70369A | 129° 47' 32" | 32° 33' 16" | Hizen Takashima (NI-52-18-01) | Southeast coast of Kabashima, Nomozaki-cho (*) | |
| 7 | R 18252 | HH-70396A | 129° 25' 12" | 33° 01' 44" | Hizen Enoshima (NI-52-17-10·11) | Irose islet, Sakito-cho (*) | 4.5 km |
| 8 | R 18245 | HH-70393 | 129° 27' 12" | 33° 00' 02" | Hizen Enoshima (NI-52-17-10·11) | Kodate-jima, Sakito-cho (*) | |
| 9 | R 18247 | HH-70397C | 129° 20' 16" | 32° 59' 44" | Hizen Enoshima (NI-52-17-10·11) | South coast of Ebisu-jima, Enoshima, Sakito-cho (*) | 90 m |
| 10 | R 18246 | HH-70397D | 129° 20' 17" | 32° 59' 44" | Hizen Enoshima (NI-52-17-10·11) | South coast of Ebisu-jima, Enoshima, Sakito-cho (*) | |

GEMS No. : Registered sample number stored in the Geological Museum, Geological Survey of Japan.

(*) Locality Name: Nishisonogi-gun, Nagasaki-ken.

## Appendix 2: Petrographic description of the dated samples.

Loc. no. 1 [R 18373]
*HH-69316B* Garnet-albite-quartz-chlorite-muscovite schist

Macroscopically: A 5-m thick micaceous schist interbedded in pyrite-bearing green schist. This rock is extremely rich in muscovite with sericeous luster, and has pale-green spots of chlorite measuring 3–4 mm across. Separated chlorite shows a clear, pale-green color with glassy luster.

Microscopically: The constituent minerals are muscovite, chlorite, quartz, albite and garnet, with epidote, sphene and tourmaline as accessories. The grain size of albite and garnet porphyroblasts is 0.5 mm. Both porphyroblasts contain plenty of various inclusions which commonly aligned in helicitic texture or rotated like a snowball. The average grain size of groundmass is 0.1 mm. Quartz and albite in the groundmass exhibit granoblastic and polygonal textures. Epidote is zoned with three bands, each of which does not show gradual change but often has a sharp boundary.

Loc. no. 2 [R 17967]
*HH-66107A* Chlorite-muscovite-albite-quartz schist

Macroscopically: The rock is 40–100 cm thick layer having pale-green tint, interbedded with graphite-rich schist. The rock is commonly light greenish with sericeous luster. Grey spot of chlorite aggregates reaching 2 mm long and white spot of albite reaching several mm across are scattered sporadically. Very thin quartzose strings are also seen. Separated chlorite has a dusty grey color.

Microscopically: Porphyroblastic albite is commonly 1 mm in length, occasionally reaching 4 mm, and apparently coarser than the average grain size (0.2 mm or less) of other minerals. The most abundant minerals are quartz, albite, muscovite and chlorite, with small amounts of garnet, sphene, tourmaline, opaque minerals and calcite. Porphyroblastic albite not uncommonly contains inclusions of finer-grained minerals.

Loc. no. 3 [R 18322]
*HH-69290* Muscovite-chlorite-quartz-albite schist

Macroscopically: A 30-m thick pale-green schist interbedded in graphite schist. This rock is similar to *HH-68254* [R 18153] in color and grain size, and looks like quartzofeldsphathic gneiss. Separated chlorite has grey color with pale-green tint.

Microscopically: The constituent minerals are albite, quartz, chlorite and muscovite, with garnet, sphene, calcite, epidote and tourmaline as accessories. The average grain size of porphyroblasts is 1–3 mm and that of the groundmass is less than 0.15 mm. Porphyroblastic albite often reaches 5 mm across, and contains plenty of various inclusions. Quartz grains show sutured boundaries, apparently indicating post-crystalline deformation.

Loc. no. 4 [R 18153]
*HH-68254* Muscovite-chlorite-calcite-albite schist

Macroscopically: This rock is coarse-grained part of several 10 meters thick quartzofeldspathic schist with light green color which is interbedded in graphite schist. Chlorite- and muscovite-enriched clots are often aligned in the plane of foliation, thus giving an impression of quartzofeldspathic gneiss. Separated chlorite has a clear, pale grass green color with glassy luster.

Microscopically: Porphyroblastic albite measuring larger than 3 mm across is characteristic of this rock. No idiomorphic mineral is found. The average grain size of porphyroblast is 0.5–2.0 mm, and that of the groundmass is 0.15 mm. The porphyroblastic albite has rounded outline, and contains plenty of various inclusions. The constituent minerals are calcite, albite, epidote, chlorite and muscovite, with calcic amphibole, quartz, garnet, sphene, apatite and opaque minerals as accessories. Epidote is optically zoned with several bands. Calcic amphibole shows pale-green color of blue tint. Twin lamellae in albite are often curved and dislocated, showing probable mechanical deformation in the retrograde stage.

Loc. no. 5 [R 18398–1]
*HH-70371* Porphyritic biotite granite
Macroscopically: This rock is a darker portion of coarse-grained and leucocratic grey granite, and medium-grained, weakly porphyritic, and grey to dark grey colored. The darker portion is irregularly distributed in the coarser-grained and leucocratic granite, showing xenolith-like massive bodies measuring several 10 cm across in shape and ghost image (palimpsest texture) with tiny trails to remind of slumping or folded patterns. In a case, these features look like a relic of gneissic structure, suggesting a hybrid rock.
Microscopically: The coarser-grained part has the average grain size of 2–4 mm, and is composed of plagioclase, quartz, potassium-feldspar and biotite. Plagioclase is euhedral and zoned, and strongly altered to sericite±carbonate minerals. Potassium-feldspar is microclinic and weakly perthitic with strings. Biotite is light-brown, and often changed to chlorite along cleavages. In the finer-grained part, the constituent minerals are less than 0.3 mm across, and composed of almost the same minerals as the coarser-grained part. Plagioclase often has myrmekitic texture, and potassium-feldspar is enriched compared to the coarser-grained part. A small amount of muscovite is found. Apatite, sphene, zircon and opaque minerals are also recognized. Opaque minerals are rarely found, but usually confined within biotite altered to chlorite.
Modal analysis: Quartz 27.0%, potassium-feldspar 28.6%, plagioclase 37.4%, biotite 5.2%, chlorite 1.8%. [Identity change numbers: 38]

Loc. no. 6 [R 18234]
*HH-70369A* Garnet-bearing biotite-muscovite granite
Macroscopically: This rock intrudes discordantly microfolded biotite-muscovite schist in a dike measuring 5–30 cm wide. This rock is leucocratic and heterogeneous, varying lithologically in the dike, but does not always show a regular pattern of finer-grained and muscovite-poor (aplitic) in the central part and coarser-grained and muscovite-rich (pegmatitic) in the margin of the dike. Muscovite flakes exceed biotite ones in quantity.
Microscopically: The coarser-grained part has the average grain size of 3–4 mm, and is composed of potassium-feldspar, plagioclase, quartz, muscovite and biotite. Potassium-feldspar is perthitic and shows microclinic extinction. Plagioclase is subhedral to euhedral, and occasionally has myrmekitic texture along the faces with potassium-feldspar. Quartz sometimes becomes graphic in texture. Biotite with light brown color is commonly altered to chlorite. In the finer-grained part, the average grain size is 0.2–0.5 mm, and garnet attaining 0.5 mm across is the only mineral other than the constituent minerals of the coarser-grained part. Tiny acicular rutile is rarely seen. Muscovite often shows zigzag outlines, suggesting symplektite intergrowth.
Modal analysis: Quartz 40.9%, potassium-feldspar 23.3%, plagioclase 29.5%, muscovite 5.3%, biotite 0.5%, chlorite 0.1%, garnet 0.4%. [Identity change numbers: coarser-grained part 31; finer-grained part 134]

Loc. no. 7 [R 18252]
*HH-70396A* Porphyritic biotite granite
This rock is rich in coarse-grained potassium-feldspar and biotite, giving much more porphyritic appearance than the rock of *HH-70393* [R 18245]. Other features are quite the same as those of *HH-70393.*
Modal analysis: Quartz 31.7%, potassium-feldspar 26.2%, plagioclase 36.0%, biotite 4.6%, chlorite 0.7%, opaque minerals 0.7%,

others 0.1%. [Identity change numbers: 29]

Loc. no. 8 [R 18245]
*HH-70393* Porphyritic biotite granite
Macroscopically: This rock is light grey, and poorly porphyritic. Potassium-feldspar with light pinkish tint is occasionally recognized, and some reaches 10 mm in length. Milky plagioclase is also grown to 10 mm in length. Biotite flakes do not exceed 2 mm across.
Microscopically: The constituent minerals are potassium-feldspar, quartz, plagioclase and biotite with apatite, sphene, zircon and opaque minerals as accessories. Large potassium-feldspar reaches 10 mm across, and contains plenty of finer-grained plagioclase, biotite and quartz measuring 0.3 mm across. Potassium-feldspar does not show microclinic extinction, and rarely intergranular plagioclase film occurs along grain boundaries between potassium-feldspar and potassium-feldspar. Quartz is often rounded and its corroded form is rarely seen. Plagioclase is always euhedral and zoned. Dark brown biotite is intensely altered to chlorite. This rock is rich in opaque minerals, showing two modes of occurrence: euhedral cube-shaped and very tiny grains along cleavage planes of biotite and chlorite.
Modal analysis: Quartz 32.0%, potassium-feldspar 27.7%, plagioclase 36.6%, biotite 1.6%, chlorite 1.8%, opaque minerals 0.3%. [Identity change numbers: 28]

Loc. no. 9 [R 18247]
*HH-70397C* Porphyritic hornblende-biotite granodiorite
Macroscopically: This rock is dark green colored, and contains large clots of hornblende reaching 10 mm in length.
Microscopically: The coarser-grained minerals have the average grain size of 1–2 mm, and the finer-grained ones have that of less than 0.3 mm. Plagioclase is euhedral and strongly zoned, but alteration to sericite ± carbonate minerals, particularly in inside core, is prominent. Quartz and potassium-feldspar are interstitial. Biotite is light brown colored and often altered to chlorite with sphene ± opaque minerals. Hornblende is light green colored. Other minor constituents are sphene and opaque minerals. Opaque minerals often show euhedral form.
Modal analysis: Quartz 21.7%, potassium-feldspar 11.3%, plagioclase 48.3%, biotite 7.1%, chlorite 6.0%, hornblende 3.4%, opaque minerals 0.3%, others 1.9%. [Identity change numbers: 66]

Loc. no. 10 [R 18246]
*HH-70397D* Porphyritic hornblende-biotite granodiorite
Macroscopically: This rock is darker-colored than the rock of *HH-70397C* [R 18247], and contains plenty of mafic oval xenoliths. Biotite aggregates in booklet-shaped spots.
Microscopically: The coarser-grained plagioclase and colored minerals reach 2–3 mm across, and the finer-grained constituent minerals are less than 0.3 mm across. Green hornblende is euhedral, but 0.15 mm long. Light brown biotite flakes make clots as large as 1–2 mm across. Plagioclase is euhedral and strongly zoned. Interstitial potassium-feldspar does not show microclinic extinction. Biotite is strongly altered to chlorite ± opaque minerals, sphene. Apatite and zircon are other accessories. Opaque minerals have commonly irregular shapes, and occasionally a cube-shape.
Modal analysis: Quartz 22.7%, potassium-feldspar 14.7%, plagioclase 43.4%, biotite 11.0%, chlorite 1.1%, hornblende 6.1%, opaque minerals 0.4%, others 0.6%. [Identity change number: 51]

N.B. 1) Grain size of separated minerals [Loc. nos. 1–10] for radiometric dating is all the same in the range of 0.25–0.5 mm in diameter (60–32 mesh).
2) Identity change number is an average value of two measurements by which the number of major mineral boundaries is determined along 25 mm length of line on a thin-section, based on the method by Chayes (1956).

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