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Concordant K–Ar and Rb–Sr Ages of the Tottori Granite, Western Japan

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with chemical analyses by Ei OHMORI**

Abstract

Part of the large adamellite batholith (Tottori Granite) measuring 180 km × 30 km was studied geologically, petrochemically and geochronologically. The Tottori Granite intruded the medium-grained biotite-hornblende granodiorite, which intruded Cretaceous volcanics prior to emplacement of the Tottori Granite and constitutes a small batholith measuring 5 km × 18 km. The Tottori Granite is largely composed of coarse-grained biotite adamellite, and often accompanied with more felsic rocks such as aplitic and pegmatitic facies. Three varieties of the Tottori Granite collected on an outcrop show successive intrusion from coarse-grained, through medium-grained and porphyritic, to fine-grained facies, and are all of adamellite in modal and chemical compositions. Whereas the more felsic facies of later intrusion, that is, later differentiates show progressive increase of K_2O, Rb and ratios of Fe_2O /FeO and Rb/Sr and decrease of total Fe, MgO, CaO, TiO_2 and Sr.

Both K–Ar and Rb–Sr mineral ages are 59–64 ± 3 m.y.: 61 and 61.6 m.y. on the average, respectively. Both the ages can be regarded as concordant. Rb–Sr whole-rock isochron age is 64.8 ± 2.0 m.y. with the initial $^{87}Sr/^{86}Sr$ ratio of 0.7055 ± 0.0004. No distinct difference is recognized between the mineral ages and the Rb–Sr whole-rock isochron age. K–Ar age of the biotite in the granodiorite is 69 ± 6 m.y., apparently older than the average age of the Tottori Granite.

Totally concordant K–Ar and Rb–Sr ages of the Tottori Granite together with a very short span of time from emplacement of the Granite to cooling suggest a tectonic environment of rapid cooling. Abundant joints and fault clays often accompanied with andesitic dykes in the Granite, and progressive increase of Fe_2O_3/FeO in the later differentiates provide a clue to postulate that a thin body, e. g., tabular or planar shape, drastic upheaval of the batholith, and introduction of certain meteoric water could explain a mechanism to get rapid cooling.

Introduction

A granitic batholith is usually composed of various lithologic facies, forming a complex mass showing successive intrusion into country rocks. It sounds quite natural that initially intruded and consolidated rocks should be radiometrically dated older than the later ones. But it is not steady to realize this problem, because different part of a batholith cools down in different ways, thus not always exhibiting an identical radiometric age over the entire part of the batholith. Results of radiometric dating have occasionally been reported to yield geologically inconsistent value. In this case the dating, therefore, is interpreted as incompatible or irreconcilable with geological evidence. Cross check analyses made on one sample by different methods do not always bring an indentical value, and often give scattered values significantly distinguished, i.e., discordant system.

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Nevertheless, cross check analysis provides us undoubtedly with excellent information which makes it possible to understand geologic episode of the sample.

In this paper part of an adamellite batholith (Tottori Granite) of western Japan and a neighbouring small granodiorite batholith precedingly consolidated are dealt with geologically, petrochemically and geochronologically. The Tottori Granite in this area has totally concordant results for all K–Ar and Rb–Sr mineral ages and a Rb–Sr whole-rock isochron age. A possible mechanism of emplacement to consolidation of the adamellite batholith and its shape are discussed on a basis of the concordant geochronology.

Geology of the Tottori Granite

The central divide of San-in (Japan Sea side) and San-yō (Inland Sea side) nearly runs ENE–WSW in parallel with the southern margin of the map area on Fig. 1. Geological features of this area are markedly contrasted on both sides of the divide topographically discriminated. The divide is largely composed of Cretaceous rhyolitic–andesitic rocks and closely associated with hypabyssal granitic rocks. In the San-in region, a large granitic batholith approximately measuring 180 km × 30 km is exposed stretching ENE–WSW, although the northeastern part of the batholith submerges in the Japan Sea, and the central part is covered by the Pleistocene volcanics of Mt. Daisen. The map area is located in the southeastern corner of western half of the batholith.

The batholith is mainly composed of coarse-grained biotite adamellite, characterized by pink-colored potassium-feldspar and magnetite, and has been described as **In-bi** or **San-in Granite Complex.** Later a new name was introduced, i.e., **Tottori Granite.***

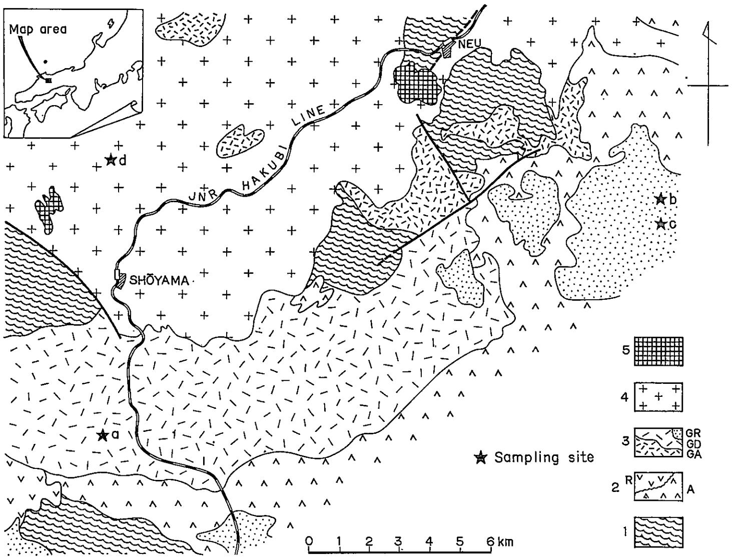

Figure 1 Simplified geologic map of the area. Adapted from HATTORI & KATADA (1964); Tottori-ken (1966) and unpublished data by HATTORI. Symbols are explained in Table 1.

* **Tottori Granite** (Tottori-ken, 1966; 1/500,000 geological sheet map 'Okayama', 1973): The batholith is not better defined by the areal extent of the two regions of In-bi or San-in. In-bi means local name for eastern Tottori-and northern Okayama-ken, and San-in is extremely elongated region reaching 500 km facing the Japan Sea. Senior author (H. H.) rather prefers the **Tottori Granite** to the **In-bi** or **San-in Granite Complex** from the above reason.

On the other hand, the geology on the southern side of the divide, i.e., the San-yō region is occupied by the Sangun metamorphics and Cretaceous volcanics, together with smaller granitic intrusives. The Sangun metamorphics, oldest in this area (Table 1), are unconformably overlain by the Cretaceous volcanics which are the main constituents in the backbone ridge of the divide. Both are invaded by mafic-intermediate-felsic intrusive rocks (Intrusive Rocks I) and the Tottori Granite (Intrusive Rocks II).

Igneous activities of the Intrusive Rocks I are likely related with the volcanic activity of the Cretaceous volcanics, as judged from their spatial relations. The igneous activities were initiated with intrusion of olivine–bearing gabbro-diorite (GA in Fig. 1 & Table 1) into the pre-existed Sangun

Table 1 Key to the symbols in Figure 1 and the samples examined.

Symbol		Rock name	Grouping & Geologic age	Sampling site	Sample no.
5		Olivine Basalt	Pliocene		
4		Biotite Adamellite (Tottori Granite)	Intrusive Rocks–II Paleocene ∼ Late Cretaceous	**d**	**458**
3	GR	Fine-grained Adamellite (Granophyre)	Intrusive Rocks–I Late Cretaceous	**b, c**	**460&1903**
	GD	Biotite-Hornblende Granodiorite		**a**	**442**
	GA	Olivine-bearing Gabbro ∼ Diorite			
2	R	Rhyolite and its pyroclastics	Cretaceous		
	A	Andesite and its pyroclastics			
1		Sangun metamorphic rocks	Metamorphism before late Triassic		

metamorphics and Cretaceous andesites. Later a small granodiorite batholith (GD) measuring 5 km × 18 km intruded all the above-mentioned, incorporating various sized gabbroic body. The last was hypabyssal facies (GR), particularly impressed by micrographic texture and prominent chloritization of biotite and abundant oval inclusions of mafic–intermediate and fine-grained igneous rocks. There are observed neither thermal effects nor mixing phenomenon in contact of any two among the three units, GA, GD and GR, although field evidences exhibiting their successive intrusive relations are good enough.

Whereas, the Tottori Granite intruded the above three units making a 10 m-wide mixture zone with the granodiorite (GD), and the Sangun metamorphics changing to hornfels. In the mixture

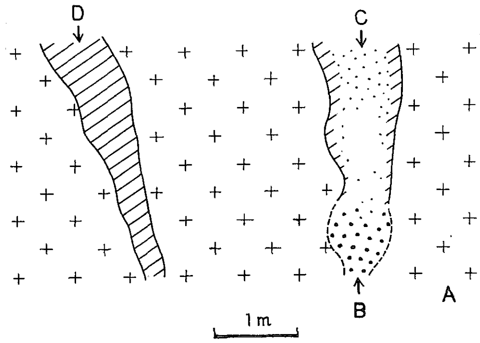

Figure 2 A sketch showing mutual relation of different lithologic features on a large cliff near Sugesawa Damsite, Tottori-ken. Striped part: fine-grained suggesting a sort of chilled facies. Larger dot: coarser-grained phenocryst than smaller dot. The samples denoted with **458** (HH–66458) were collected on this cliff.

A: Coarse-grained biotite adamellite, typical 'Tottori Granite'
B: Porphyritic potassium-feldspar bearing medium-grained biotite adamellite
C: Medium—fine-grained biotite adamellite
D: Fine-grained biotite adamellite

zone, microdioritic part of medium-grained biotite-hornblende granodiorite (GD) is irregularly intermingled with heterogeneous biotite adamellite (Tottori Granite). Granophyric–aplitic rocks, chilled facies of the biotite adamellite, occasionally appear near the contact. Aplitic dyke measuring 20–30 cm in width is abundant near the contact, and yet observed at distant places as far as 2 km.

Thermal effect by the Tottori Granite was evident on the Sangun metamorphics which became all hornfelsic, but not detected in the granodiorite (GD). When the Tottori Granite was intruding the granodiorite, the granodiorite might already have been cooled down, but have not reached the temperature low enough to be effectively reconstituted to hornfels by the heat of the Tottori Granite. Probably the temperature difference between the two units was not so large. The heat capacity of the Tottori Granite, however, must have been quite large, as suggested by the contact phenomena, volume difference between the two batholiths by the factor of 100 or so, and also the fact that open cracks made on cooling of the adamellite batholith were abundant and were filled with andesitic dykes (probably long before Miocene or shortly after the consolidation of the Tottori Granite) forming a swarm approximately trending NNW–NW, whereas very few dykes in the pre-existed rocks (HATTORI & KATADA, 1964, Fig. 10).

In the Tottori Granite, predominant is coarse-grained biotite adamellite which is very homogeneous with light pinkish look. Aplitic and pegmatitic facies is seen in various shapes and sizes throughout the batholith (HATTORI & KATADA, 1964, p. 25). Some shows clean-cut form of dyke, and the other does a gradual change.

Samples for radiometric dating were collected at three places far enough from the contact. At sampling site **a**, 1 km north of the contact with the Cretaceous andesites and 3 km south of the contact with the Tottori Granite, medium-grained biotite-hornblende granodiorite (registered as **442**) was obtained. At **c**, 2 km distant from the andesites, fine-grained adamellite (**1903**) was taken together with a comparative sample (**460**) for chemical analysis. At **d**, an outcrop (Fig. 2) of quarry in Sugesawa Damsite, three different varieties (**458A, 458C** and **458D**) were chopped off. A dyke-like intrusion shows varying textures in grain-size with a sort of chilled facies in the upper half which diminishes downwards.

Petrography and Petrochemistry

Biotite is more or less altered into chlorite with accessories of opaque minerals and sphene (Table 2 & Appendix). Chlorite content [Chlorite/(Chlorite + Biotite)] is high in the granophyre (**460** and **1903**). It is not evident, however, that chloritization observed in quite fresh samples examined took place during cooling or prominent weathering.

Intergranular oligoclase film exclusively bounding two perthitic potassium-feldspar grains (HATTORI & KATADA, 1964, PLATES II & III) is by far the most common in coarse-grained or porphyritic variety of the Tottori Granite, and never seen in any of the Intrusive Rocks I.

As far as modal composition (Table 2) is concerned, four granitic samples except **442** are of adamellite (Fig. 3). In the Intrusive Rocks I, the granodiorite (GD, as represented by **442**) occupies more than half of the respective area, the granophyre (GR, **460** or **1903**) a quarter, and gabbrodiorite (GA) one-fifth or so. These rocks successively intruded from mafic to felsic may have originated from an identical magma. On the assumption that the occupying area of each unit mentioned above is proportional to volume of each unit, the magma might roughly be assessed to be of

Table 2 Modal analysis of the granitic rocks.

	442	460	1903	458 A	458 C	458 D
Hornblende	5.1%	—%	—%	—%	tr.%	—%
Biotite	2.7	.1	.9	2.4	1.5	1.1
Chlorite	1.3	1.7	1.6	.2	tr.	.1
Opaque	1.1	.9	.4	.5	.4	.2
Others	1.0	.4	.4	.2	.1	tr.
Quartz	23.8	35.4	36.8	36.8	37.1	36.1
K-feldspar	21.0	27.6	32.7	21.4	24.4	32.0
Plagioclase	44.0	33.8	27.1	38.6	36.2	30.5
Color Index	11.2	3.1	3.3	3.3	2.1	1.4
IC Number	58	117	88	15	58	94

The IC number (identity change: CHAYES, 1956) 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.

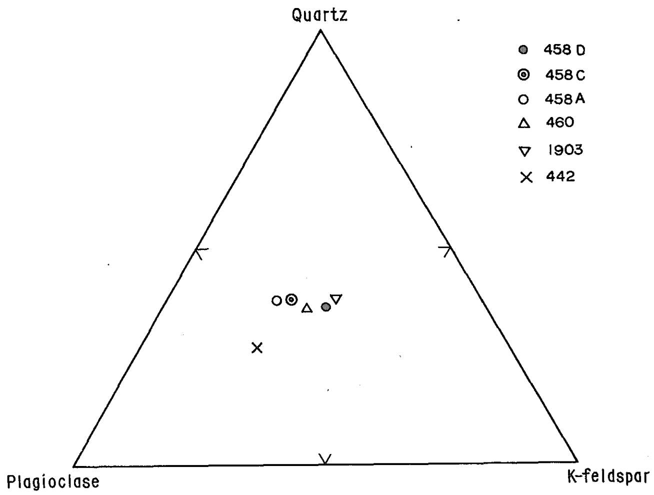

Figure 3 Modal quartz-potassium-feldspar-plagioclase diagram showing petrographic distinction.

granodiorite. Chemical composition of the original magma would be close to that of the **442** granodiorite shown in Table 3.

In the Intrusive Rocks II (Tottori Granite), coarse-grained biotite adamellite is the most dominant, and other more felsic rocks as seen in Fig. 2, relatively later or almost contemporaneous intrusives, are rather small in quantity. The more felsic ones show progressive increase of K_2O, Rb, and ratios of Fe_2O_3/FeO and Rb/Sr, and decrease of TiO_2, total Fe, MgO, CaO and Sr (Table 4), and a similar trend is also displayed by color index (Table 2). The trend (Fig. 4) can be regarded as differentiation course of the adamellite magma represented by the chemical composition of the **458A** adamellite shown in Table 3.

It is well known that Cretaceous-Paleogene granites in the San-in region are highly weathered,

Table 3 Chemical composition and C. I. P. W. norm of the granitic rocks in this area.

	442	**460**	**458 A**	**458 C**	**458 D**
SiO_2	65.67	73.72	74.85	75.02	76.91
TiO_2	.63	.29	.21	.18	.14
Al_2O_3	15.18	13.61	13.31	13.61	12.42
Fe_2O_3	1.96	1.11	.96	.81	.73
FeO	2.68	.62	.47	.31	.24
MnO	.09	.05	.06	.06	.05
MgO	1.79	.48	.36	.24	.20
CaO	4.02	1.47	1.50	1.07	.67
Na_2O	3.28	3.57	3.66	3.74	3.24
K_2O	3.18	3.67	3.84	4.35	4.89
P_2O_5	.13	.05	.04	.02	.02
$H_2O(+)$	.95	.66	.30	.21	.20
$H_2O(-)$	.11	.30	.09	.04	.04
Total	99.67	99.60	99.65	99.66	99.75

Chemical analyses by Ei OHMORI.

	442	**460**	**458 A**	**458 C**	**458 D**
Q	22.79	35.19	35.23	34.02	37.67
C	—	1.21	.50	.85	.63
or	18.79	21.69	22.69	25.71	28.90
ab	27.75	30.21	30.97	31.65	27.42
an	17.31	6.97	7.18	5.18	3.19
wo-di	.75	—	—	—	—
en-di	.46	—	—	—	—
fs-di	.25	—	—	—	—
en-hy	4.00	1.20	.90	.60	.50
fs-hy	2.18	—	—	—	—
mt	2.84	1.32	1.10	.67	.53
ht	—	.20	.20	.35	.36
il	1.20	.55	.40	.34	.27
ap	.30	.12	.09	.05	.05
An%/pl	38	19	19	14	10
DI	69.3	87.1	88.9	91.4	94.0

Table 4 Results of radiometric dating by both K–Ar and Rb-Sr methods.

Rb (ppm)	Sr (ppm)	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	**Rb–Sr age** (m.y.)	Sample	**K–Ar age** (m.y.)	K_2O (%)	^{40}Ar rad. (10^{-6}ml STP/g)	Atmospheric Ar (%)
211	30.8	0.7243	19.79		**458 D** {WR B	60±3	6.48	13.0	42.6
188 783	73.9 12.7	0.7126 0.8628	7.369 178.4	59.7	**458 C** {WR B	64±3	7.18	15.5	24.3
165 760	98.8 9.88	0.7100 0.9136	4.872 222.5	63.6	**458 A** {WR B	59±3	7.21	14.3	39.6
					1903 B	64.7±2.1*	4.43	9.64	28.2
133	255	0.7076	1.506		**442** {WR B	69±6	2.97	6.93	55.2

* More recent determination with higher accuracy.

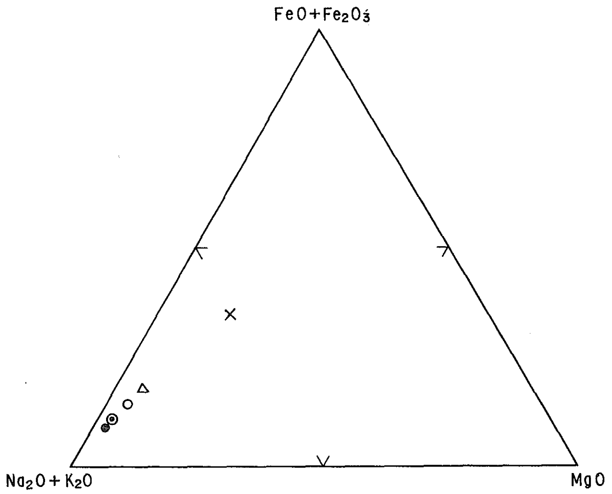

Figure 4 K_2O+Na_2O—Fe_2O_3+FeO—MgO diagram, showing composition of the granodiorite and a possible trend of differentiation of the adamellite magma (Tottori Granite). Symbols are the same as those in Fig. 3.

and thus that magnetite originally contained in the granites had been easily extracted to make iron concentrates (for local steel industry) by the classical panning of rural drainage system. Here arises a dispute on the origin of the chlorite interleaved with biotite accompanying opaque minerals, as to whether weathering was the cause or not. Chlorite is rather rich in the Intrusive Rocks I. Judging from that the ratio of Fe_2O_3/FeO gradually increases from **442** to **458D** as listed in Table 3, although total Fe content decreases, the higher state of oxidation in the Tottori Granite is not indicative of chloritization. It is not certain at present on the problem, but study on clay minerals in weathered granites may shed a new light upon the origin of the chlorite.

OYAGI et al. (1968) recognized 6 stages in progressive weathering of biotite and chlorite in the granodiorite of this neighbouring area (Daitō). Biotite in the unweathered zone changes to regularly mixed layer of biotite-vermiculite or hydrobiotite, then to vermiculite, and finally to halloysite or hydrated halloysite. Chlorite in the unweathered zone changes to randomly mixed layer of chlorite-vermiculite, and then to vermiculite following the same trend of the biotite. Similar weathering process of biotite has been reported by TSUZUKI et al. (1968). Only two examples, yet insufficient to infer any on the origin of the chlorite, however, might suggest the chlorite formed before the weathering process.

Radiometric Age Determinations

Sample Preparation

Pulverized rock samples were passed through sieves, and individual portions (**458A**: 32–42 mesh; **458C, 458D** and **1903**: 32–60; **442**: 42–60) were separated according to grain size of rocks. After rinse in water and drying up, electromagnetic separator of Hallimond type and then Frantz isodynamic separator were used. Heavy liquids, diluted methylene iodide ranging 2.708–2.896 in density were repeatedly used to refine biotite concentrates together with isodynamic separator. Biotite in the **442** granodiorite was separated with the liquids of 2.8–3.0 and further refined by use of tapping.

Experimental

K–Ar age determinations were done at the Geological Survey of Japan. Argon was extracted and purified in a pyrex high vacuum system. The samples were fused at about 1300°C for 30 minutes, ^{38}Ar spike was added during fusion, and argon was purified by titanium sponge and CuO. Isotopic ratios of argon were measured with the Mitsubishi MS–315G Reynolds-type mass spectrometer by the static operation. Potassium concentration was determined by flame photometry.

Rb–Sr analyses were done at the Geological Survey of Canada. Rb and Sr concentrations were measured using ^{87}Rb and ^{84}Sr spikes, and $^{87}Sr/^{86}Sr$ ratios were calculated from the spiked analyses. The analyses were carried out on a 6–in. 90° Nier-type mass spectrometer. The constants used for the age calculations are: $\lambda_\beta {}^{40}K = 4.72 \times 10^{-10}/y$, $\lambda e\, {}^{40}K = 0.584 \times 10^{-10}/y$, $^{40}K/K = 0.0119$ atomic %, $\lambda_\beta {}^{87}Rb = 1.47 \times 10^{-11}/y$.

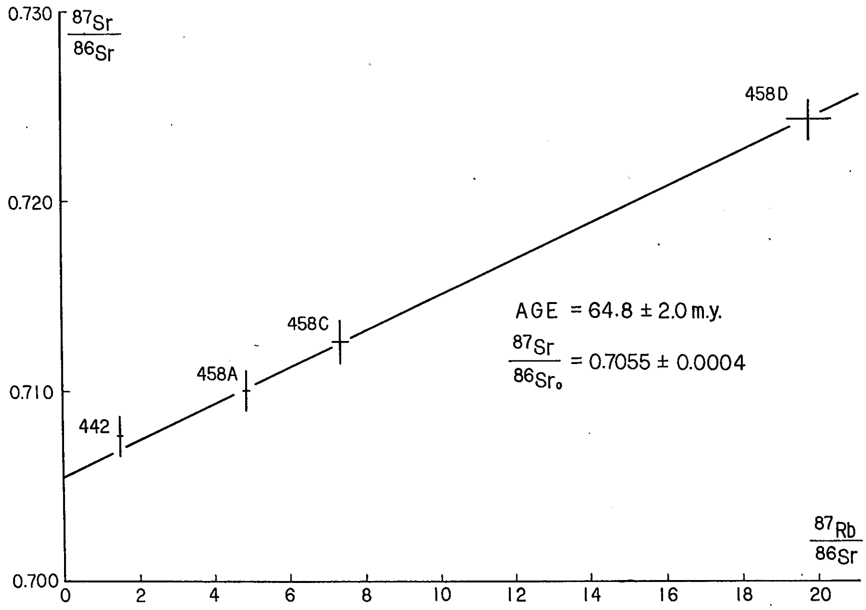

Figure 5 Rb–Sr whole-rock isochron age.

Results

Cross check analysis given in Table 4 offers a great deal of information on igneous activities of the Intrusive Rocks I and the Intrusive Rocks II (Tottori Granite). Geological interpretation will be made in the next chapter, and some comments on the experimental results are given here.

1) Tottori Granite

Taking analytical error into account, K–Ar ages of 59, 60 and 64 m.y. are almost the same. Average age is 61 m.y. for the Tottori Granite. Rb–Sr ages calculated by whole-rock–biotite isochron method indicate the identical age, averaging 61.6 m.y. Both average ages, 61 m.y. and 61.6 m.y. are nearly the same, and can be regarded as concordant.

2) Granophyre (**1903**)

64.7 m.y. of biotite is very close to the K–Ar age of **458C** biotite, and may not be discriminated from the Tottori Granite.

3) Granodiorite (**442**)

The biotite gives K–Ar age of 69 $\pm$ 6 m.y. which is fairly more than the average age of the Tottori Granite, approximately by 7–8 m.y. It seems not obvious but likely that the mineral age of the granodiorite is followed by that of the granophyre.

4) Rb–Sr whole-rock isochron age (Tottori Granite)

Three whole-rock samples of the Tottori Granite (**458A, C & D**) give a Rb–Sr isochron age of 64.8 $\pm$ 2.0 m.y. (Fig. 5) by the least-square method of YORK (1966). The age is almost identical to the K–Ar age of biotite in the granophyre (**1903**). The whole-rock point of the granodiorite (**442**) is slightly above this isochron, although its error bar falls on the isochron. The time range of 59–64 m.y. by both K–Ar and Rb–Sr datings on the Tottori Granite and errors of $\pm$3 m.y. may not offer a criterion to distinguish from this whole-rock isochron age.

Table 5. Tentative correlation of radiometric dating, unit and lithology of granitic rocks from three areas.

Sequence	Daito area 35 km WNW←			This area					→50 km ENE Ningyō-tōge area	
	K-Ar dating m.y.	Unit	Symbol	Symbol	Unit		Facies	K-Ar and Rb–Sr dating	Unit	K-Ar dating m.y.
Late	36~51	Yokota Granite (bG_2)	G_7	G_8	Intrusive Rocks II (Tottori Granite)		Aplite ~ Pegmatite	59~64	III	57, 62
↑	43~49		≀	G_4, G_5			Fine-grained ↑ Medium-grained ↑ Coarse-grained } Adamellite			
			G_5	G_7						
			G_4 ?	G_3	Intrusive Rocks I	GR	Fine-grained adamellite (Granophyre)	64.7	I	33~39
Early	44~63	Daito Granodiorite (b/h Gd_{11})	G_2, G_3	G_1, G_6		GD	Biotite-hornblende granodiorite	69	II	49~64
			G_1	G_2		GA	Gabbro ~ Diorite		I	
Reference	1, 2, 3		4	5	6				7	

Reference: 1. ISHIHARA (1967), p. 275, Table 2
2. KAWANO & UEDA (1967)
3. ISHIHARA (1971a), p. 15, Table 4
4. MURAYAMA et al. (1973)
5. HATTORI & KATADA (1964)
6. This paper (1974)
7. SHIBATA & YAMADA (1965)

5) Initial Sr ratio

Calculated initial Sr ratio $(^{87}Sr/^{86}Sr)_0$ is 0.7055 ± 0.0004 and lower than the tabulated value of 0.7078 for the initial Sr ratio of granites in the age range of 0–99 m.y. (GORAI et al., 1972). It may be allowed to postulate that magma of the Tottori Granite could be generated in depths directly from parental source material of the upper mantle.

Discussions

Geological data and radiometric dating are totally reviewed in some aspects.

1) Granitic rocks in this area are grouped on the basis of mutual intrusion relations obtained in the field into the two, i.e., the Intrusive Rocks I and Intrusive Rocks II (Tottori Granite), as given in Table 1. K–Ar ages of the biotite in the Intrusive Rocks I (Granophyre and Granodiorite) are within 69–65 m.y. Whereas three varieties of the Tottori Granite give 64–59 m.y., 61 m.y. on the average, by both K–Ar and Rb–Sr methods. Therefore, no discrepancy is recognized between geological data and radiometric dating.

On the other hand, geologically akin samples in other areas were dated differently (Table 5). It is of course a matter of opinion to make a correlation between igneous activities in two separated areas, however, the following attempts can be allowed as the large batholith of the Tottori Granite include some granitic bodies to be mentioned below. In the Daitō mining area for molybdenum where is situated about 35 km WNW from this area, the Yokota Granite is comparable to the Tottori Granite and the Daito Granodiorite to the granodiorite (GD) of this area. There is no spatial interruption but a continuation between the Yokota Granite and the Intrusive Rocks II of this area, thus both forming parts of the batholith of the Tottori Granite. The Yokota Granite and the Daito Granodiorite are dated only by K–Ar method (KAWANO & UEDA, 1967), indicating 43–49 m.y. and 44–63 m.y., respectively. The dates are fairly younger than those of this area.

In the Ningyō-tōge area (well known place for uranium deposit) about 50km ENE of this area, the granitic rocks are divided into three groups based on the sequence of intrusion: the first stage, the second stage and the third stage (MURAYAMA & OZAWA, 1961; YAMADA, 1961). The intrusive rocks of the first stage compositionally vary from gabbro to granophyre, and those of the other two stages are formed in batholithic dimension largely composed of adamellite and granodiorite. Although spatial gap may prevent a similar correlation in this case, the granite of the third stage is the main part of the Tottori Granite, and the fine-grained biotite granite of the first stage and the medium-grained hornblende-biotite granodiorite of the second stage are geologically and petrographically referred to GR and GD of the Intrusive Rocks I, respectively. 57 and 62 m.y. for the granite of the third stage are almost coeval with that of the Tottori Granite in this area, however, other results indicate more or less younger ages than those of this area.

Among all, it is remarkable that the biotite from the fine-grained biotite granite of the first stage was dated 33, 36, 39 ± 5 m.y. The K–Ar ages of the biotite are not consistent with their geological observation (SHIBATA & YAMADA, 1965), and no explanation has been postulated by them.

2) The Tottori Granite intruded the granodiorite (GD), making a mixture zone reaching 10 m in width without forming hornfels. The Granite also spreads out its apophysis of aplitic nature to 2 km distant places from the contact. The dated granodiorite was collected about 3 km apart from the contact, probably far enough to escape from heat effect of the Tottori Granite. The Tottori Granite

collected at Sugesawa Damsite is also far from the contact. Geologically it is inferred that the Tottori Granite invaded the granodiorite before the granodiorite had consolidated. This means that the adamellite magma (Tottori Granite) was successively intruding the granodiorite probably shortly after the intrusion of the granophyre or after a very short cessation of igneous activity between the Intrusive Rocks I and the Tottori Granite. Time span of the cessation may be estimated radiometrically as 7–8 m.y. from the fact that the average age of the Tottori Granite is less than that of the granodiorite by 7–8 m.y., if analytical error can be overlooked.

Above all, it is concluded that when the adamellite magma rose up the granodiorite was hot enough to make the 10 m-wide mixture zone instead of forming hornfels zone, but cold enough to retain radiogenic daughter elements in a closed system at the place a few km apart from the contact.

3) Although the low initial $^{87}Sr/^{86}Sr$ ratio can be interpreted as an indicator of direct derivative from parental source material in the upper mantle or lower crust, there are two opinions as regards Rb–Sr whole-rock isochron age. One is that Rb–Sr whole-rock isochron age indicates time of consolidation of granitic magma (ISHIZAKA, 1971). On the contrary, the other opinion is that Rb–Sr whole-rock isochron age indicates "differentiation time of magma from certain parental material" prior to its emplacement, suggesting time of magma generation probably in the upper mantle and that mineral ages represent time of crystallization of rocks (SHIRAHASE et al., 1969; KAGAMI, 1973). At present the authors are inclined to the former opinion, although the authors have no definite idea as to which of the alternatives is best suited to this case. We simply think of the Rb–Sr whole-rock isochron age being comparable to the time of emplacement of the adamellite magma and also being nearly the same as the time of magma generation.

The Rb–Sr whole-rock isochron age of 64.8 ± 2.0 m.y. with a low initial $^{87}Sr/^{86}Sr$ ratio of 0.7055 and the biotite ages of 59–64 m.y. for the Tottori Granite suggest that the assumed adamellite magma of the Granite has been generated in the upper mantle, risen up to intrude to the shallower level, and consolidated in a very short span of time. Anyway, the extremely short or negligible time range from the emplacement of adamellite magma to cooling is of prime importance, i.e., concordant system in many aspects.

As far as concordant K–Ar and Rb–Sr age determinations on granitic rocks are concerned, only a few have been reported. OZIMA et al. (1967) gave K–Ar age of 69.0–71.6 m.y. on the biotite from the Mitsuhashi granodiorite, and K–Ar age of 69.5 m.y. on the biotite of the Kiyosaki granodiorite in the Ryōke metamorphic belt, central Japan, whereas Rb–Sr age of 75.6 ± 6 m.y. on both granodiorites by mineral–whole-rock isochron method. They considered that initial $^{87}Sr/^{86}Sr$ ratio of 0.7075 ± 0.0013 may indicate that the two granodiorites were derived either from the upper mantle or some crustal rocks produced from the mantle materials immediately before the formation of the granodiorite. UENO et al. (1968) reported K–Ar age of 108 m.y. on whole-rock sample from the Kadono granodiorite in the Abukuma metamorphic belt, and similarly Rb–Sr age of 101 ± 10 m.y. by biotite–whole-rock isochron method.

On the other hand, so many discordant K–Ar and Rb–Sr ages have been known on granitic rocks in Japan. UENO et al. (1968) dealt with the Miyamoto granodiorite and the Ishikawa granodiorite in the Abukuma metamorphic belt, and gave K–Ar ages of 96 and 67 m.y., and further Rb–Sr ages of 123 ± 10 and 163 ± 16 m.y., respectively, along with the initial $^{87}Sr/^{86}Sr$ ratio of 0.705 for both granodiorites. The two granodiorites are concluded to have intruded in the upper Jurassic or in the lower Cretaceous, and have suffered thermal disturbances as indicated by K–Ar ages. YANAGI et al. (1971) determined Rb–Sr whole-rock ages on the granites of Minami-osumi and Amami-oshima, southern Kyushu. The former was dated 64 ± 11 m.y. with the initial $^{87}Sr/^{86}Sr$ ratio of 0.7071 ± 0.0002, and the latter 105 ± 27 m.y. with the ratio of 0.7065 ± 0.0002. While the biotite age in the former has been reported to be within 14–21 ± 1 m.y. by K–Ar method (MILLER et al., 1962; KAWANO & UEDA, 1966), and that in the latter within 49–56 ± 6 m.y. (SHIBATA & NOZAWA, 1966). YANAGI et al. (1971) explained that some K–Ar ages on biotite from the Minami-osumi granite may represent the time of rejuvenation of the granite when later tectonic disturbances occurred and the mylonite in the granite was formed.

In the case of the Ibaragi granitic complex, near Osaka city, the biotite of quartz diorite and adamellite in the Nose pluton were dated 73.8–75.6 ± 3.0 m.y., and the biotite of adamellite in the later intruded Myōken pluton was dated 74.0 ± 3.0 m.y. by K–Ar method (SHIBATA, 1971). On the other hand, whole-rock–feldspar isochron age and biotite–whole-rock isochron age on the rocks of the Nose pluton by Rb–Sr method are 96 ± 2 m.y. and 78–83 m.y., respectively, giving the initial $^{87}Sr/^{86}Sr$ ratio of 0.7060 ± 0.0001 (ISHIZAKA, 1971). ISHIZAKA considered that the granitic rocks in the Nose pluton suffered influence of some kind of later geologic event, i.e., the intrusion of the Myōken pluton, thus bringing the significant time gap of discordant ages.

In the metamorphic terrane of Japan, few Rb–Sr whole-rock isochron ages of granites have been determined to compare with Rb–Sr mineral ages of the same specimens. Outside the metamorphic terrane, the situation is almost quite the same as above. That is, many Rb–Sr whole-rock isochron data for granites have been known, but very few respective Rb–Sr mineral ages to be compared with are obtained. Therefore it is rather regretful that further general comments on Rb–Sr whole-rock isochron age could not be made on this occasion.

Nevertheless, as reviewed above, the result of well defined concordant K–Ar and Rb–Sr age determinations made on the Tottori Granite is the first document hitherto obtained about the granitic batholith that is not related with any regional metamorphism in Japan. Here its geologic significance of the concordant geochronology is briefly discussed. It is very likely that the Tottori Granite formed in a very short span of time from the ascent, intrusion and/or emplacement of the magma, to consolidation.

This means rapid cooling as pointed out by ARMSTRONG & SUPPE (1973). On the outcrop where three different samples of **458** were collected, successive intrusions from coarse-to fine-grained facies are observed (Fig. 2). Later intrusives, i.e., finer-grained facies, often show a sort of chilled facies at the margin of intrusive body. This indicates that the coarse-grained facies had already been cooled down to some extent when the later ones came in. Later intrusives change petrographically and petrochemically along the common trend of magmatic differentiation together with remarkable increase of oxidized iron. Although ISHIHARA (1971b) has unveiled a general character of the Tottori Granite having high ratio of Fe_2O_3/FeO, 1.5–2.0, the later intrusives in the present case, that is, later differentiates have much higher ratio up to 3.0. This evidence is well explained by the phenomenon of alteration from magnetite to hematite (martite) [see Appendix].

As stated above, two important factors for governing the formation of the Tottori Granite may be stressed: **rapid cooling** and **highly oxidizing environment.** Part of the Tottori Granite in this area might have experienced a different cooling history from the cases in the Daitō and Ningyō-tōge areas, as easily understood from the radiometric dates (Table 5). To accommodate rapid cooling, it is necessary that this part of the batholith has rather small volume. Undoubtedly this part occupies wide surface area, therefore, the supposed thickness of the batholith might be efficiently thin and the overlying coverage be thin too. That is, not bottomless but tabular or planar shape at the shallow level is expected for this part of the batholith.

Drastic upheaval is another possible mechanism to get rapid cooling. In this case, the joint system in the Granite is very useful to further better understanding of the mechanism. Major joints were probably formed upon cooling, run in the direction of NNW–NW, and are often accompanied with fault clay measuring 1–3 cm in width (HATTORI & KATADA, 1964) which is product of differential block movements of the Granite along the major joints. The direction is roughly normal to the elongation of the batholith. Drastic upheaval accelerated the differential movements, faults and joints with clay became abundant, and as a corollary rapid cooling is realized. Along the joints and faults andesitic dykes came to fill in to constitute a swarm. But before this intrusion, introduction of certain meteoric water could be assumed to get rapid cooling and highly oxidizing environment more freely and simply, because permeation of the water is facilitated in faulted granite blocks and abundant open cracks. Then dissociation of the water in hot granite batholith may release enough oxygen which might have played a key role in bringing highly oxidizing environment, and thereby making higher ratio of Fe_2O_3/FeO in the later differentiates: alteration of magnetite to hematite. Naturally all these considerations must be examined in various ways in the future.

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Appendix

Classification of granitic rocks based on WILLIAMS (1954)

442 (HH–66442): Medium-grained biotite-hornblende granodiorite

Abundant black biotite and greyish green hornblende give dark green look. Potassium-feldspar is light beige colored, quite different from that in other granitic rocks of this area. Microscopically euhedral plagioclase is strongly zoned, measuring 3.0 mm in length. Quartz appears in various forms as granular, corroded and graphic with optical continuity. Potassium-feldspar is perthitic, entirely lacking intergranular oligoclase film between potassium-feldspar-potassium-feldspar interfaces. Pale green hornblende and yellowish brown biotite are main constituents, and green chlorite is often interleaved with the biotite accompanying opaque minerals. Opaque minerals are largely ilmenite and magnetite. Allanite, zoisite and apatite are minor constituents.

460 (HH–66460): Fine-grained biotite-chlorite adamellite (granophyre)

Mafic minerals give dusty appearance, as fresh biotite with lustre is rare and dark green tabular biotite + chlorite shows no platy cleavage. Excluding milky phenocryst plagioclase, each grain outline is not clear. Fine-grained quartz and pale violet potassium-feldspar occasionally shows graphic intergrowth. Overall outlook is dirty pinkish. Microscopically a combination of chlorite + opaque minerals + sphene is obvious, suggesting an alteration product from biotite with which chlorite often interleaves. Plagioclase is euhedral and strongly zoned, measuring 0.6–0.8 mm in length on the average and attaining 3.0 mm at the maximum of porphyritic plagioclase. Quartz is rounded frequently exhibiting corroded or graphic texture. Potassium-feldspar is interstitial without forming intergranular oligoclase film. Opaque mineral is magnetite, 0.5 mm in length, and occasionally some as large as 1.5 mm. Most of magnetite is altered to hematite.

1903 (HH–70101903): Fine-grained biotite-chlorite adamellite (granophyre)

Lithologically the rock is quite the same as **460**, if the feature that this is coarser-grained and more fresh is disre- garded. It is the reason why biotite in this rock is extracted for radiometric dating. Microscopically 1.4 mm-large allanite is sporadically seen, and no other features are distinguished.

458A (HH–66458A): Coarse-grained biotite adamellite

Reddish pink potassium-feldspar reaching as large as 2 cm is euhedral and a little porphyritic, and this is determinative of the rock. Perthitic texture is easily ascertained even with the naked eyes. Flaky biotite attains to 5 mm long. Microscopically chlorite is rarely seen and exclusively interleaved with biotite flakes. Plagioclase is subhedral, measuring 6 mm across. Quartz is rounded. Potassium-feldspar is perthitic of thread type, and without exceptions intergranular oligoclase film is present at potassium-feldspar–potassium-feldspar interfaces. In the film, oligoclase is granular or mosaic and very fine-grained, and slightly larger than that in the thread of perthite. The oligoclase is distinguished optically in two sets each of which is in optical continuity with the neighbouring thread. Therefore, one of the two sets of oligoclase film is commonly in the same extinction position with oligoclasic plagioclase in one perthite. Allanite, sphene, zircon, rutile, epidote and opaque mineral are accessories. Opaque mineral is magnetite, partly altered to hematite along crack and rim.

458C (HH–66458C): Porphyritic biotite adamellite

Porphytitic pink potassium-feldspar, quartz, plagioclase are euhedral and larger than 5 mm in length. Perthitic texture is observed with the unaided eyes. Potassium-feldspar gives the rock pinkish aspect. Microscopically, green hornblende is detected. Potassium-feldspar in both porphyritic and fine-grained is perthitic of bead type which is thicker than the thread type perthite in **458A**. Naturally intergranular film becomes wider. Allanite, sphene, apatite, zircon are accessories. Magnetite is occasionally altered to hematite along crack and rim.

458D (HH–66458D): Fine-grained biotite adamellite

Appendix: Grid reference to sampling sites

Sample No.	Locality Name	Sampling Point (Approx. Long. & Lat.)	Grid Zone	1:50,000 Series L775	1:250,000 Series L506
442	Tateiwa, Nichinan-cho, Hino-gun, Tottori-ken	470867 (133°19′E 35°07′N)	53SLJ	4752–II KAMI-IWAMI	NI 53–1
460	Tawane, Hino-cho, Hino-gun, Tottori-ken	655948 (133°31′E 35°12′N)	53SLJ	4852–IV YUMOTO	NI 53–2
1903	Ditto	654943 (133°31′E 35°11′N)	53SLJ	4852–IV YUMOTO	NI 53–2
458	Sugesawa Damsite, Hino-cho, Hino-gun, Tottori-ken	471964 (133°19′E 35°12′N)	53SLJ	4752–I NEU	NI 53–1

442 :鳥取県日野郡日南町立岩

460, 1903 :鳥取県日野郡日野町峠根

458 :鳥取県日野郡日野町菅沢ダム地点(もと印賀橋近く)

Grid reference is based on the AMS maps (AFFE MAP SERVICE, SOUTHERN HONSHU, 1: 50,000).

Pinkish and aplitic appearance with scattered biotite flakes and slightly porphyritic texture is of this type. Microscopically, larger grain measuring 1.2 mm across and other smaller dominants are equigranular with average grain size of 0.4 mm across. Potassium-feldspar is less perthitic with few threads. Intergranular oligoclase film is no longer common and in place myrmekite becomes abundant. Opaque minerals are magnetite and a little ilmenite. Magnetite is altered into hematite along crack and rim. Sphene is the only other accessory mineral.

K–Ar および Rb–Sr 法による鳥取花崗岩の一致年代

服部　仁・柴田　賢

（付記：大森江いによる化学分析）

要　旨

山陰東部に分布する鳥取花崗岩は東北東—西北西にのびた 180km×30km のバソリスで，おもに粗粒黒雲母アダメロ岩からなり，若干の優白質岩を伴っている．米子市南方のこの地域では，先に白亜紀火山岩類中に貫入していた中粒黒雲母・角閃石花崗閃緑岩を鳥取花崗岩が貫いている．この鳥取花崗岩には NNW-NW 方向にのびる顕著な節理系・粘土を伴う断裂系およびこれらに沿って貫入した多数の安山岩質岩脈が認められている．花崗閃緑岩の貫入の前後には，はんれい岩～閃緑岩と細粒アダメロ岩（文象斑岩）が貫入しているが，これらをまとめて逆入岩類 I と呼び，また鳥取花崗岩は逆入岩類 II として区別している (Table 1). 以上の諸岩石についてモード分析・化学分析・年代測定を行なった.

K–Ar および Rb–Sr 法による年代測定の結果 (Table 4) は野外における観察事実に基づいた貫入順序と矛盾しない値を与えた．1 カ所で採取した鳥取花崗岩中の 3 つの岩種は，粗粒，中粒および細粒相であってこの順に貫入している．

モード分析 (Table 2) からみて，これらはいずれもアダメロ岩であるが，化学組成では末期相に向かって K_2O, Rb, Fe_2O_3/FeO 比および Rb/Sr 比の増加がみられ, TiO_2, 全鉄, MgO, CaO, および Sr が減少している (Table 3). K–Ar 法による黒雲母年代と Rb–Sr 法による黒雲母—全岩アイソクロン年代とはほぼ 61 m.y. に一致し，さらに Rb–Sr 全岩年代は 64.8±2.0 m.y. であった．誤差を見込むとほとんどの年代値は互いに区別できなくなる．また初生 $^{87}Sr/^{86}Sr$ 値が0.7055±0.0004という低い値を示すことも注目に値する．この一致年代はこの地域の鳥取花崗岩マグマの上昇・冷却・固結にわたる全過程がきわめて短時間に終了したことを示唆している．

鳥取花崗岩中の構造特性は冷却時における節理系に始まり，同時あるいは相前後する急激な上昇により花崗岩体のブロック差別運動が起こり，断層を生じ，岩脈や水の通路を作ったらしい．急激な冷却はバソリスの形状にも原因が求められよう．つまり，地表分布面積の広いわりにはこのバソリスの容積は小さそうで，その厚さは薄く，おそらく底なしではなく，板状の形状をもつのであろう．まだ十分に冷えていないバソリスの割れ目に沿って浸み込んだ水（おそらく地表水）は急激な冷却に効果的に働き，また解離してフリーの酸素を放出し，磁鉄鉱の赤鉄鉱化をうながしたらしい．K–Ar および Rb–Sr 両法による一致年代は，この地域の鳥取花崗岩の形成過程について以上のような推論を可能にした．