J. Min. Petr. Econ. Geol.
88, 265-271, 1993

K-Ar ages of hornblendes in andesite and dacite from the Cretaceous Kanmon Group, Southwest Japan

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New K-Ar ages of hornblende in volcanic rocks from the type localities of the Shimonoseki Subgroup, upper half of the Kanmon Group are presented. The obtained ages are 105.2±3.3 Ma for andesite and 106.7±3.3 Ma for dacite. These data indicate igneous activity during Albian, late Early Cretaceous and support the age estimation by Shibata *et al*. (1978) based on stratigraphic and paleomagnetic evidences.

Keywords: Kanmon Group, K-Ar age, Hornblende, Albian, Andesite, Dacite

I. Introduction

The Inner Zone of Southwest Japan is characterized by an enormous distribution of Cretaceous felsic to intermediate volcanic rocks. These volcanic rocks distributed in the western Chugoku district can be divided into the Kanmon, Shunan, Hikimi and Abu Groups (Murakami, 1974). Voluminous andesites and dacites closely associated with rhyolites are the major constituents of the Shimonoseki Subgroup in the Kanmon Group. They have been investigated geologically and petrologically (Hase, 1958; Imaoka and Murakami, 1979; Murakami and Imaoka, 1980; Imaoka, 1986), but not chronologically, because the rocks are more or less altered and are thought to be unsuitable for dating. During systematic mineralogical study of the Cretaceous volcanic rocks (Imaoka and Murakami, 1979; Imaoka *et al*., 1982; Imaoka, 1986), we found "fresh" hornblende andesites that allow K-Ar dating. In this paper K-Ar ages of the hornblende in andesite and dacite from the type localities of the Shimonoseki Subgroup are presented to investigate the space-time relation of the volcanic rocks in the Inner Zone of Southwest Japan.

II. Geological setting

The Cretaceous Kanmon Group is distributed in an area extending from northern Kyushu through Kanmon Straits to the Chugoku district. It unconformably overlies the Jurassic to early Cretaceous Toyonishi Group and is intruded by the dioritic and granitic rocks (Fig. 1). This group is divided into two subgroups, the lower Wakino Subgroup and the upper Shimonoseki Subgroup between which the boundary is a disconformity (Hase, 1958; Fig. 1). The latter is composed of large-volume (estimated to be 3,500 km^3, Ichikawa *et al*., 1968) of andesitic to dacitic lavas and pyroclastic rocks and minor amounts of rhyodacitic to

(Manuscript received, January 18, 1993; accepted for publication, February 26, 1993)

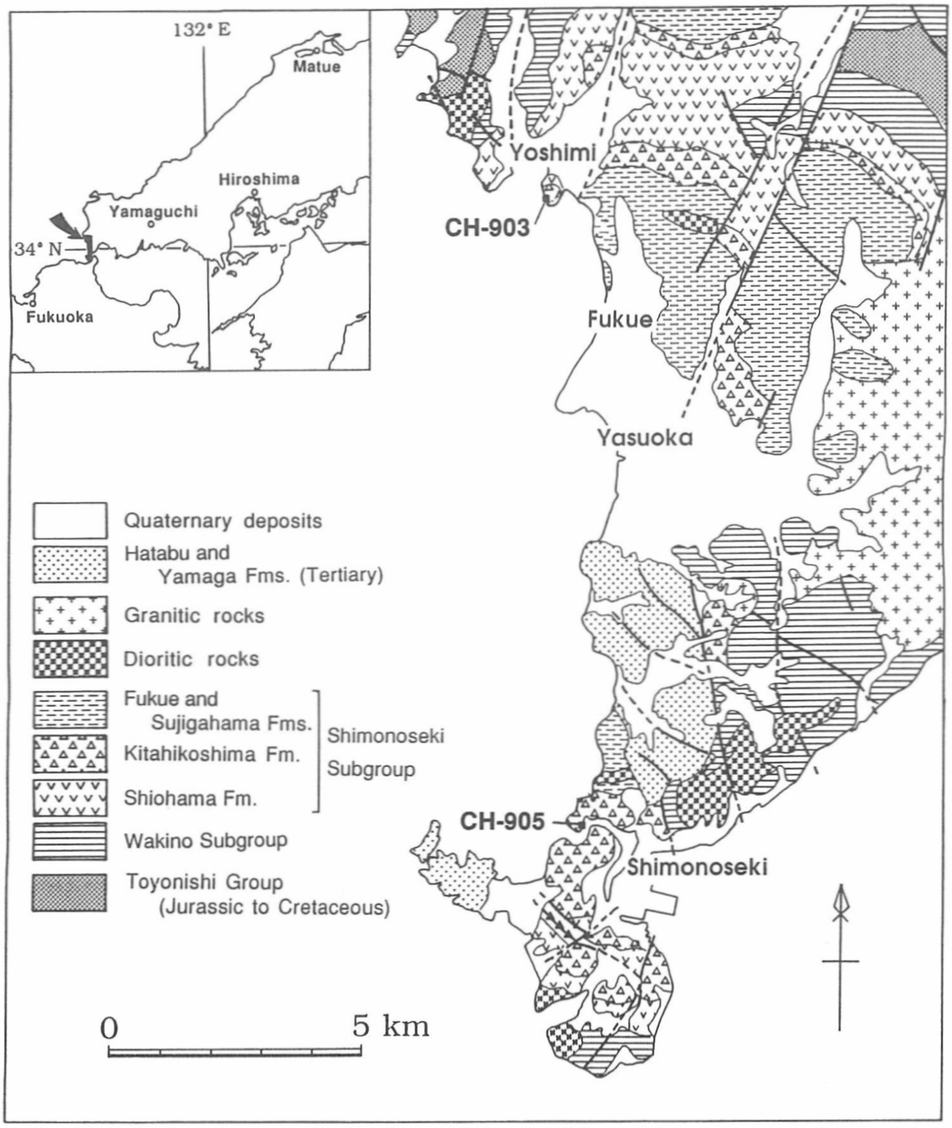

Fig. 1. Simplified geological map of the Shimonoseki area, Yamaguchi Prefecture and sampling localities of dated rocks.

rhyolitic lavas and pyroclastic rocks, while the former consists mainly of sedimentary rocks intercalating small amounts of felsic tuff or tuffaceous sediments. The Shimonoseki Subgroup is further divided into four formations, Shiohama, Kitahikoshima, Sujigahama and Fukue in ascending order (Hase, 1958).

III. Petrography of dated rocks

The andesite lava (CH-905) is megascopically slate gray in color. It shows porphyritic and pilotaxitic texture and contains phenocrysts of plagioclase (An=68-54%), augite, amphibole and magnetite and groundmass of plagioclase (An=55-38%), augite, mag-

Table 1. Electron microprobe analyses of augite phenocrysts in andesite of the Kanmon Group

No.	CH-905 core		rim
SiO_2	52.79	51.60	51.59
TiO_2	0.44	0.41	0.43
Al_2O_3	1.98	2.33	2.48
Cr_2O_3	0.10	0.15	0.18
FeO*	6.79	7.55	7.54
MnO	0.31	0.34	0.34
MgO	16.07	15.66	15.22
CaO	22.17	21.92	21.47
Na_2O	0.40	0.41	0.41
K_2O	0.00	0.00	0.01
Total	101.05	100.37	99.67
	Number of ions (O=6)		
Si	1.932	1.912	1.921
Al^{IV}	0.068	0.088	0.079
Al^{VI}	0.018	0.014	0.030
Ti	0.012	0.011	0.012
Cr	0.003	0.004	0.005
Fe	0.208	0.234	0.235
Mn	0.009	0.011	0.011
Mg	0.877	0.865	0.845
Ca	0.870	0.870	0.857
Na	0.029	0.029	0.029
K	0.000	0.000	0.000
Wo	48.9	48.2	48.2
En	35.4	34.4	34.1
Fs	15.7	17.4	17.7
Mg#	80.2	77.9	77.5

FeO*: Total Fe as FeO,
Mg#= Mg x100/ (Fe + Mn + Mg)

netite and ilmenite. Plagioclase phenocryst up to 0.7 mm is euhedral and highly zoned. The phenocrystic augite up to 0.8 mm occurs as subhedral, short and prismatic form. It shows little variation in Mg# (=Mg×100/(Fe+Mn+Mg)) of 80.2 to 77.5, of which the values slightly decrease from core to rim (Table 1). The phenocrysts of amphibole from 0.5 to 3.0 mm in length have an euhedral, acicular or bladed form, and opacite rims are observable. It is optically and chemically homogeneous within grain and grain-by-grain. They have lower Mg# of 65.2 to 63.7 (Table 2) than those of coexisting augite, suggesting that amphiboles crystallized after augite. The analyzed amphiboles belong to ferroan pargasite and ferroan pargasitic hornblende according to the Leake's (1968) classification. The phenocrystic magnetite up to 0.2 mm in diameter is subhedral to anhedral and commonly contains oriented lamellae of ilmenite a few to several tens of microns wide (Imaoka *et al*., 1982).

The dacite welded tuff (CH-903) is massive and dark gray with purplish tinge in color. Plagioclase, amphibole and small amounts of quartz are set in a devitrified matrix. Plagioclases up to 2.5 mm are euhedral and subhedral and have been altered. Amphiboles occur as euhedral to subhedral acicular or bladed crystals up to 1.8 mm in length and are always surrounded by dark opacitized rim. They show restricted range of composition with Mg# of 62.7 to 64.9 (Table 2), belonging to magnesio-hornblende and ferroan pargasitic hornblende after Leake's (1968) classification. The chemistry of these hornblendes resembles those in andesite lava, CH-905, and grain-by-grain difference is small, therefore the hornblende crystals in this sample are not accidental crystal fragments, but mean phenocrysts.

Major and trace element compositions for two dated rock samples were determined by X-ray fluorescence analysis (Table 3). Detailed procedures and accuracy of trace element analysis by this method were given by Kakubuchi *et al*. (1989). The relation between the SiO_2 and FeO*/MgO ratio is compared with general calc-alkaline rocks in orogenic belts. The abundance of analyzed incompatible elements in two rock samples normalized to the "primitive" mantle (Wood *et al*, 1979) is plotted on a logarithmic scale with a decreasing order of element incompatibility: the most incompatible elements are plotted on the left (Fig. 2). The element abundance pattern of the Kanmon andesite and dacite is characterized by enrichment of large ion lithophile elements, Ba, Rb and K and by depletion of high-field strength

Table 2. Electron microprobe analyses of amphibole phenocrysts in the andesite and dacite of the Kanmon Group

No.	CH-905 Ph-1	Ph-2	Ph-3	CH-903 Ph-1	Ph-2	Ph-3	Ph-4
SiO_2	43.25	42.29	41.82	47.20	43.06	46.88	47.26
TiO_2	2.00	2.10	2.08	1.46	2.02	1.13	1.26
Al_2O_3	11.63	11.57	12.17	7.54	11.84	7.85	7.57
Cr_2O_3	0.10	0.06	0.06	n.d.	n.d.	n.d.	n.d.
FeO*	12.88	13.03	13.16	13.52	12.77	13.82	14.51
MnO	0.27	0.27	0.28	0.49	0.27	0.45	0.54
MgO	13.83	13.85	13.25	14.56	13.48	14.29	14.18
CaO	11.61	11.76	11.86	11.38	12.03	11.80	11.46
Na_2O	2.32	2.42	2.51	1.32	2.02	1.41	1.35
K_2O	0.85	1.06	0.88	0.57	0.94	0.70	0.69
Total	98.74	98.41	98.07	98.04	98.43	98.33	98.82
	Number of ions (O=23)						
Si	6.335	6.250	6.203	6.906	6.327	6.866	6.899
Al^{IV}	1.665	1.750	1.797	1.094	1.673	1.134	1.101
Al^{VI}	0.343	0.265	0.331	0.206	0.378	0.221	0.201
Ti	0.220	0.233	0.232	0.160	0.224	0.125	0.139
Cr	0.011	0.007	0.007	-	-	-	-
Fe	1.578	1.611	1.633	1.654	1.569	1.692	1.772
Mn	0.033	0.033	0.036	0.061	0.034	0.056	0.067
Mg	3.019	3.049	2.929	3.176	2.952	3.121	3.086
Ca	1.822	1.862	1.884	1.784	1.894	1.852	1.792
Na	0.658	0.693	0.723	0.376	0.575	0.399	0.381
K	0.158	0.199	0.167	0.106	0.171	0.131	0.128
Mg#	65.2	65.0	63.7	64.9	64.8	64.1	62.7
Na+K	0.816	0.892	0.890	0.482	0.746	0.530	0.509
Ca+Na+K	2.638	2.754	2.774	2.266	2.640	2.382	2.301

FeO*: Total Fe as FeO, Mg#= Mg x100/ (Fe + Mn + Mg)
Abbreviations: Ph=phenocryst.

elements, Zr and Ti. This pattern is similar to that of volcanic rocks from island arcs and active continental margins (*e.g.*, Pearce, 1983).

IV. Sample preparation and analytical procedure

The andesite sample (CH-905) was collected at the southwestern part of the Shimonoseki and the dacite sample (CH-903) at the west coast of the Cape Kushiyama, Yoshimi area, Yamaguchi Prefecture (Fig. 1). These rock samples were crushed and sieved, and the 60 to 80 mesh size fraction was used for the separation of hornblende. The sieved fraction was washed by using distilled water to exclude powder residue from the fraction and then dried in an oven (80°C). Hornblende was separated with an isodynamic separator and heavy liquid. Impure crystals such as magnetite attached to the hornblende crystals were decomposed by 1 : 1 hydrochloric acid on a water bath.

Potassium was determined by flame photometry (Nagao *et al.*, 1984). ^{40}Ar was analyzed by the isotope dilution method with ^{38}Ar as a tracer using the mass spectrometer of Okayama University of Science (Nagao and Itaya, 1988 ; Itaya *et al.*, 1991). The K-Ar age was calculated using the physical constant's $\lambda_e=0.581\times10^{-10}/y$, $\lambda_\beta=4.962\times10^{-10}/y$, $^{40}K/K=0.0001167$ (Steiger and Jäger, 1977).

Table 3. Chemical analysis of andesite and dacite of the Kanmon Group

No.	CH-905	CH-903
SiO_2 *wt.%*	57.62	62.73
TiO_2	0.65	0.56
Al_2O_3	17.17	16.48
Fe_2O_3	1.81	0.74
FeO	4.49	4.06
MnO	0.05	0.10
MgO	3.07	2.01
CaO	5.02	3.75
Na_2O	5.26	3.48
K_2O	2.95	3.97
H_2O+	1.31	1.53
H_2O-	0.16	0.59
P_2O_5	0.13	0.19
Total	99.69	100.19
Li *ppm*	19	n.d.
V	396	135
Cr	69	11
Co	17	n.d.
Ni	42	1
Cu	24	n.d.
Zn	47	68
Rb	78	46
Sr	486	458
Y	21	n.d.
Zr	95	79
Nb	6.4	2.6
Ba	576	387
Pb	15	14
Th	5.5	4.4

n.d.= not determined

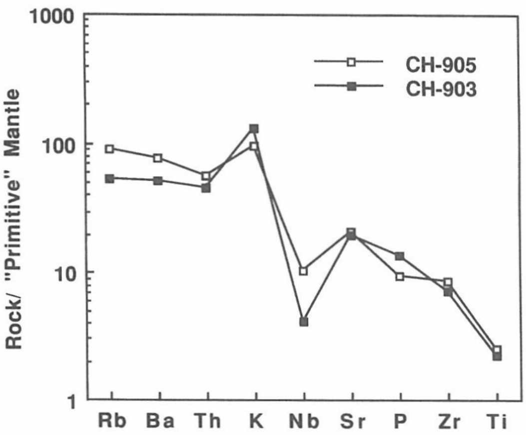

Fig. 2. Normalized abundance pattern for the Kanmon andesite and dacite. Elemental concentrations are normalized to the "primitive" mantle abundance (Wood *et al.*, 1979).

V. Results and discussion

Analytical results of measurements are shown in Table 4. The K-Ar ages of hornblende in andesite and dacite are the same within each analytical error, the andesite being 105.2±3.3 Ma, and the dacite 106.7±3.3 Ma. These data indicate igneous activity during Albian, late Early Cretaceous. The dated rocks are obtained from the lower horizon of the Shimonoseki Subgroup, thus the beginning of the Cretaceous volcanism is at least traced up to the Albian. Hitherto, as for the geologic age of the Kanmon Group, the Wakino Subgroup has been correlated with the upper Neocomian by fossil evidence (Ota, 1960), while the Shimonoseki Subgroup that rests disconformably upon the Wakino Subgroup has been estimated stratigraphically to the Aptian to Albian (Matsumoto, 1963 ; Murakami, 1974), though fossil and reliable radiometric age data had not been obtained. From the paleomagnetic view point, samples from the lower half of the Shimonoseki Subgroup have normal polarity (Sasajima and Shimada, 1966). On the basis of their paleomagnetic studies, geomagnetic time scale (Larson and Pitman, 1972) and Geologic Time Table (Armstrong and McDowall, 1974), Shibata *et al.* (1978) estimated that the Shimonoseki Subgroup is the Albian. The newly obtained ages are the direct, reliable radiometric age data, supporting the estimation of Shibata *et al.* (1978).

Voluminous volcanic rocks in the Kanmon Group have the nature of calc-alkaline rock series of the active continental margin. Recently, these unusually voluminous calc-alkaline magmatism is explained by a model of buoyant ridge subduction (*e.g.*, Kinoshita and Itô 1986 ; Itaya, 1992). The systematic geochronological studies are desired for a basic information to reveal the tectonic setting of Cretaceous magmatism and further work is planned on the volcanic rocks.

Table 4. K-Ar age data of hornblende in andesite and dacite of the Kanmon Group, Southwest Japan

Specimen (Longitude, Latitude)	Potassium (wt.%)	Rad. argon 40 (10^{-8}ccSTP/g)	K-Ar age (Ma)	Non Rad. Ar (%)
CH-905 (130° 54'37"E, 33° 56'58"N)	0.666 ± 0.020	279.9 ±3.4	105.2 ±3.3	12.3
CH-903 (130° 54'12"E, 34° 03'40"N)	0.631 ± 0.019	269.1 ±3.2	106.7 ±3.3	13.2

l_b=4.962x10^{-10}/y, λ_e=0.581x10^{-10}/y, ^{40}K/K=0.01167 atm %

Acknowledgements: The authors would like to thank Prof. Y. Nishimura of Yamaguchi University for his kind instruction on separation method of hornblende. We also thank Assoc. Prof. K. Kiminami for his critical comment on this manuscript. Assoc. Prof. T. Nagao is thanked for the use of XRF. The present study was partly supported by the grant-in aid for scientific research from the Ministry of Education, Science and Culture, Japan (No. 04302022: K. Kiminami).

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関門層群の安山岩およびデイサイト中の角閃石のK-Ar年代

今岡　照喜・中島　　司・板谷　徹丸

関門層群の上部層である下関亜層群の模式地に分布する火山岩中の角閃石についてK-Ar年代測定を行った。その結果，安山岩中の角閃石で105.2±3.3 Ma，デイサイト中の角閃石で106.7±3.3 Maの値が得られた。測定結果は，それぞれの測定誤差範囲内で良い一致を示す。従来，下関亜層群の時代は層序関係および古地磁気のデータから，Albianと推定されていた(Shibta *et al.*, 1978)。今回の報告はそれを裏づけるものである。