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K-Ar Ages of Illite from Clay Veins Distributed in Granitic Rocks in the Korean Peninsula

국내 화강암 중의 점토세맥에 포함되는 일라이트의 K-Ar 연대

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ABSTRACT : Numerous clay veins along fractures such as fault, joints, cracks and small fissures are found in granitic rocks in the Korean Peninsula. Granitic rocks of three geological stages (Jurassic, Cretaceous and Paleogene) occur in the Korean Peninsula, and are known as the Daebo, Bulguksa and Hoam granites, respectively. Specimens from clay veins composed of mainly mica clay mineral (illite) were dated using the K-Ar method with the hosted granitoids. The respective ages were as follows. Jurassic: granites 143.7 Ma and 160 Ma, clay mineral veins 104 Ma and 107 Ma; Cretaceous: granite 133.2 Ma, clay mineral veins 93.6 Ma, 84.2 Ma and 84.3 Ma; Paleogene: granite 39.7 Ma and 35.4 Ma, clay mineral veins 27.1 Ma and 23.9 Ma. The ages of the clay veins in the Korean Peninsula are clearly much younger than those of their hosted granitoids. This contrasts with data for similar clay veins in Cretaceous and Paleogene granitoids in southwest Japan, where the K-Ar ages of mica clay minerals are slightly younger than their host rocks, or are almost the same.

Key words : K-Ar dating, clay vein, mica clay mineral, granite, hydrothermal activity

요약 : 국내 화강암에는 수많은 점토세맥들이 단층, 절리, 열극 등을 따라 형성되어 있다. 화강암은 지질시대로 보아 쥬라기의 대보화강암, 백악기의 불국사 화강암, 고제3기의 호암 화강암으로 나누어진다. 이들 중에 운모점토광물(일라이트)을 주성분으로 하는 점토세맥의 시료와 그 모암에 대하여 K-Ar 방법에 의해 연대측정을 행하였다. 그 결과, 쥬라기 화강암은 143.7 Ma 및 160 Ma이고 그 점토세맥은 104 Ma 및 107 Ma이였고, 백악기 화강암은 133.2 Ma이고, 그 점토세맥은 93.6 Ma, 84.2 Ma, 84.3 Ma를 보였고, 고제3기 화강암은 39.7 Ma와 35.4 Ma이고, 그 점토세맥은 27.1 Ma 및 23.9 Ma를 나타냈다. 이와 같이 점토세맥의 연대는 모암인 화강암의 연대와는 큰 차이로 젊게 나타났다. 이러한 결과는 일본 남서부에 분포하는 백악기 및 고제3기 화강암류 중 점토세맥의 연대가 모암의 연대와 약간

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젊든지 혹은 거의 같은 것으로 알려진 것과는 큰 대조를 보인다.

주요어 : K-Ar 연대, 점토세맥, 일라이트, 화강암, 열수작용

INTRODUCTION

Numerous clay veins which formed along fractures such as joints, faults and small cracks (less than one cm in width in general), occur in Cretaceous to Paleogene granitic rocks in the Sanyo and San'in provinces of southwest Japan (Kakitani and Kitagawa, 1977; Kitagawa and Kakitani, 1978a, b, c). These fractures, which clay minerals are filling, seem to be formed during regional lateral compression occurred in Cretaceous to Paleogene age, based on analysis of preferred orientation of vein strikes and dips with K-Ar age determinations (Kitagawa and Okuno, 1983; Kitagawa. 1989). The veins consist mainly of llite, smectite and kaolin minerals, along with a small amount of interstratified minerals, such as illite/smectite (Kitagawa and Kakitani, 1978a, b, c). It is notable that the constituent clay minerals commonly change vertically, from the lower to the upper parts of the veins (Kitagawa, 1989). The mineralogical characteristics of the clay minerals in these veins were reported by Kitagawa and Kakitani (1978a, b) and Kitagawa (1989). From these results, it is considered that the southwest Japan clay veins were formed by hydrothermal activity following granitic magmatism (Kitagawa, 1989).

Mesozoic to Paleogene granitic magmatism in Korean peninsula can be simply divided into three different stages of Jurassic, Cretaceous and early Tertiary. Crystallization ages of the Jurassic granites range from 148 Ma to 183 Ma, whereas those of the Cretaceous to Paleogene granites range from 63 to 109 Ma (Lee, 1971; Koh *et al.*, 2000). The Jurassic and Cretaceous granites are named the Daebo and Bulguksa granites, respectively. A number of small granitic bodies occur in the Kyeongju-Gampo area, in the southeastern part of Korean peninsula (Fig. 1). These bodies include the Teogdong, Hoam, Taebon and Oyuri granitoids (Kim *et al.*, 1995). Numerous clay veins occur within these Korean peninsula granitoids, as in SW Japan.

For this study, specimens from clay veins composed mainly of illite were collected from three localities on the Korean peninsula. The formation ages of the clay specimens and their host rocks were determined by K-Ar analysis to investigate the age relations between clay mineralization and granite magmatism. In relation to the igneous history of the district, three different ages of clay mineralization are envisaged, namely: 1) post-magmatic activity of the host granitoids, 2) hydrothermal solutions provided by other igneous or volcanic activity and 3) Quaternary weathering. Ages of illite samples can thus constrain the stage of mineralization.

SAMPLES AND METHODS

Locality and Occurrence

Specimens were collected from clay veins composed mainly of illite representing the three different geological ages, the Daebo (Jurassic), Bulguksa (Cretaceous) and Hoam (Paleogene) granites (Fig. 1). Several specimens for dating were collected from each different clay vein.

As shown in Fig. 1, the Daebo granite occurs mainly in the central Korean peninsula (Geological Society of Korea, 1987). Clay veins (several cm in width and pale green in color) occur in weakly weathered Daebo granite at our sample site in south of Seoul city.

Bulguksa granite crops out sporadically throughout the Korean peninsula (Fig. 1). Specimens were collected from clay veins (5 cm in width and pale green in color) formed along the boundary between the granite and an acidic dike (ca. 50 cm in width) in a strongly altered outcrop near Kwangju.

The Hoam granite body is located in the Kyeongju area (Fig. 1), and numerous clay veins occur within

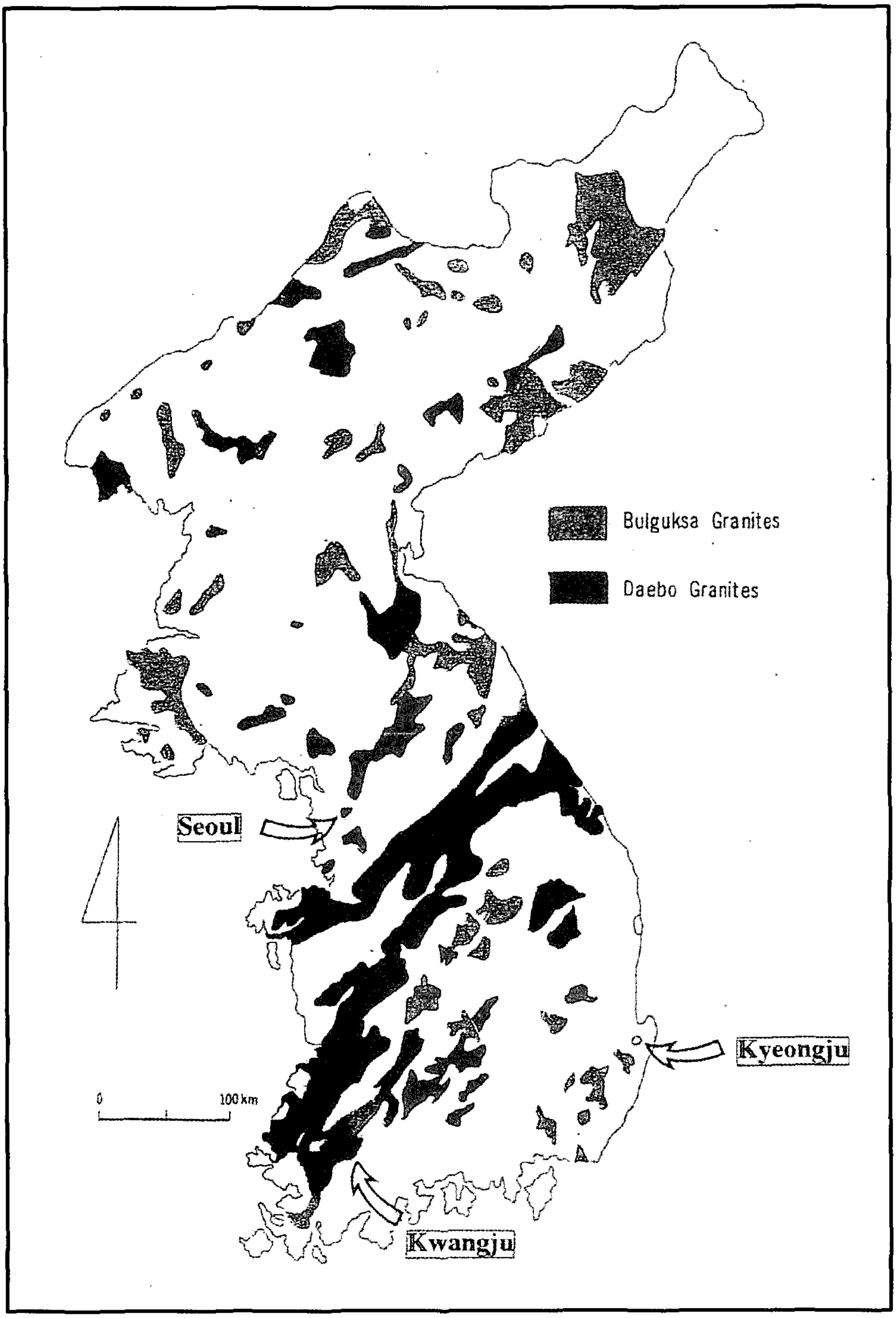

Fig. 1. Sampling localities and distribution of granitoids in the Korean Peninsula (Korean Institute of Energy and Resources, 1981).

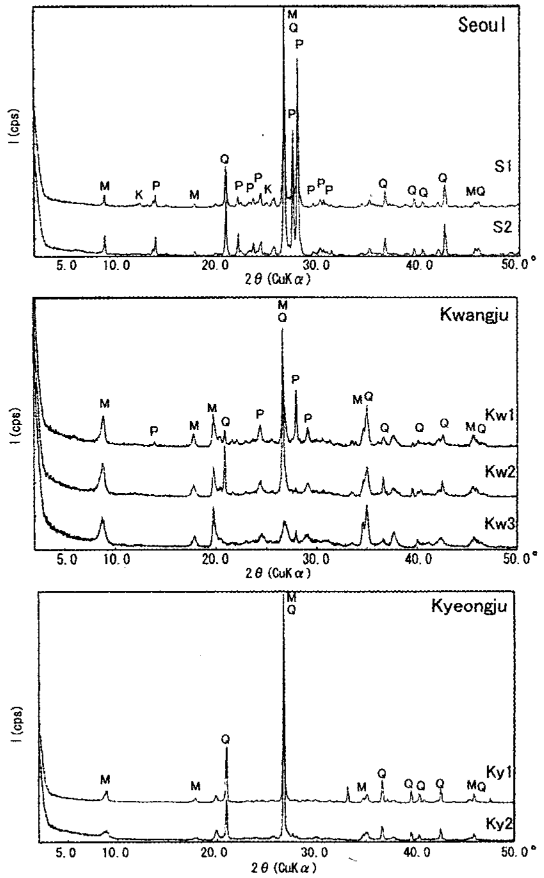

Fig. 2. X-ray powder diffraction patterns of bulk specimens from the clay veins. M:mica clay mineral (illite), K:kaolin mineral, P:plagioclase, Q:quartz.

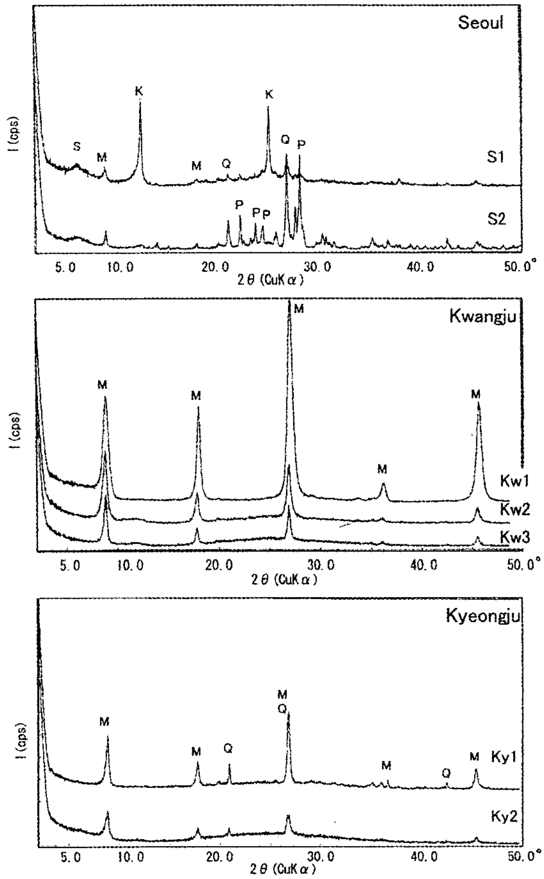

Fig. 3. X-ray powder diffraction patterns of clay fractions from the clay veins. M:mica clay mineral (illite), K:kaolin mineral, P:plagioclase, Q:quartz.

this granite. Two clay specimens were taken to represent two different modes of occurrence. The first one (2 cm in width and pale green in color) was collected from a fault situated at the boundary between the granite and its surrounding volcanic rock, and the second one was taken from a fissure (ca. 3 cm in width and grayish in color) within the granite body.

Mineralogical Characteristics

Mineralogical characteristics (constituent minerals, polytype, morphology and grain size) of the analyzed specimens from veins were investigated by X-ray powder diffraction and transmission electron microscope techniques.

X-ray diffraction patterns of bulk specimens and clay fractions are shown in Figs. 2 and 3. They consist mainly of illite of 1 Md polytype and associated quartz, plagioclase and kaolin minerals in specimen from Seoul. Potassium feldspar was not recognized by X-ray diffraction method.

Transmission electron microscope observation showed that the morphology of illite crystals consist of irregularly-shaped plates, as indicated in Fig. 4. Particle size of illite was commonly in the range between 0.1 to 3 μm.

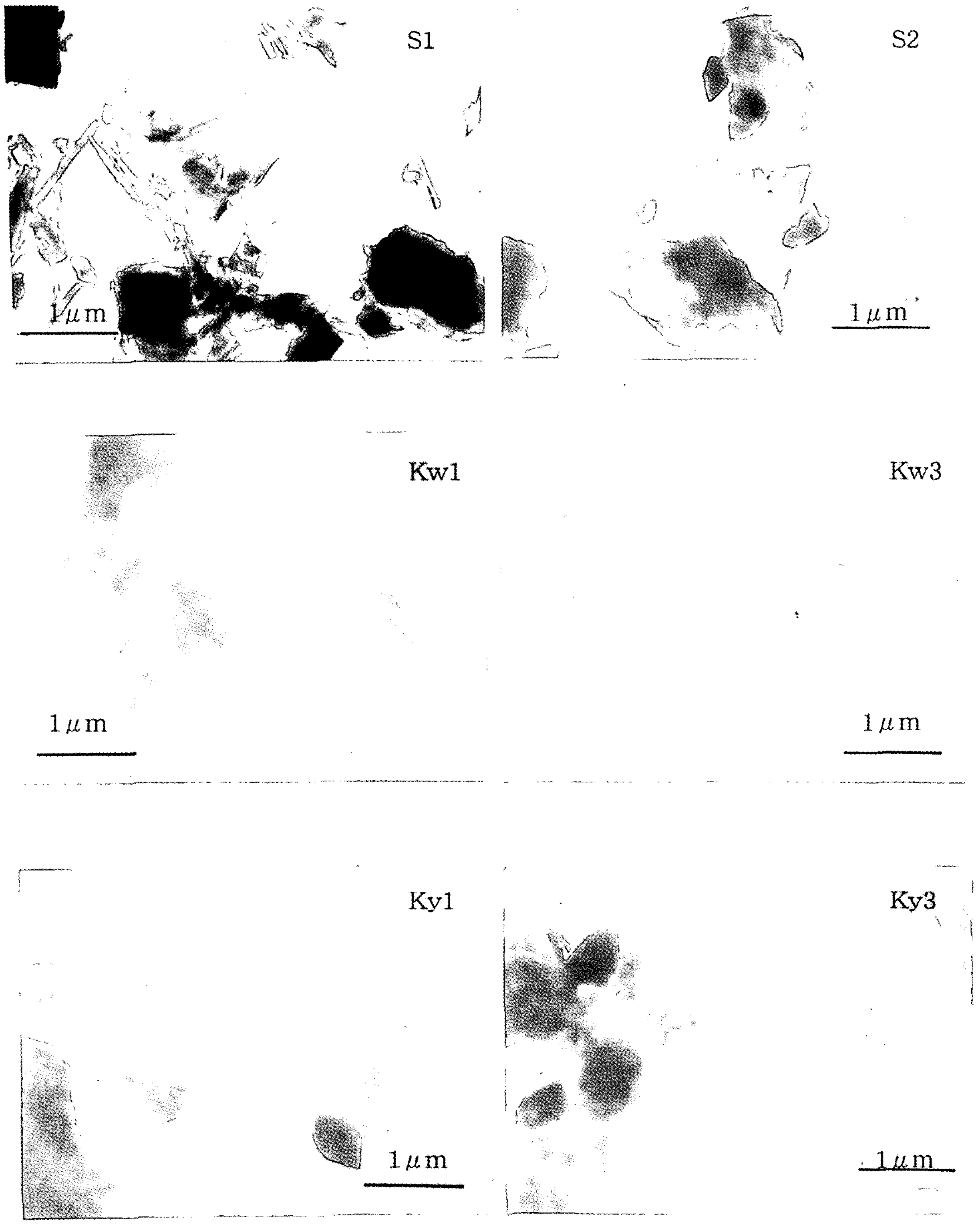

Fig. 4. Transmission electron micrographs of clay fractions from the clay veins. S1 and S2: specimens from Seoul district, Kw1 and Kw3: specimens from Kwangju, Ky1 and Ky2:specimens from Kyeongju.

Table 1. K-Ar ages of clay vein specimens and host granitoids in the Korean Peninsula

Sample	K (wt.%)	Rad.^{40}Ar (10^{-8} ccSTP/g)	Non Rad. Ar (%)	Age (Ma)
		Daebo granite (Jurassic)		
Seoul				
Vein (S1)	2.53	1054	3.9	104.3±2.3
Vein (S2)	3.25	1392	3.5	107.2±2.3
Granite				
(whole rock)				160*
(whole rock)	3.52	2043	3.8	143.7±3.1
		Bulguksa granite (Cretaceous)		
Kwangju				
Vein (Kw1)	6.17	2299	0.8	93.6±2.0
Vein (Kw2)	5.69	1902	1.6	84.2±1.8
Vein (Kw3)	7.25	2429	1.2	84.3±1.9
Granite				
(whole rock)	2.42	1298	3.9	133.2±2.9
		Hoam granite (Paleogene)		
Kyeongju				
Vein (Ky1)	3.2	339	3.2	27.1±0.6
Vein (Ky2)	3.8	335	30.3	23.9±0.6
Granite				
(Rb-Sr)				39.7**
(whole rock)	3.43	475	0.4	35.4±0.8

* Geological Society of Korea (1987), ** Kim *et al.* (1992)

K-Ar Method

K-Ar ages of the specimens were determined by H. Nishido at Okayama University of Science. The K-Ar dating techniques used in this study follow the methods reported by Nagao *et al.* (1984) and Itaya *et al.* (1991).

RESULTS AND DISCUSSION

The K-Ar age determinations on the samples from the Korean peninsula are summarized in Table 1. Ages of clay veins in granitic rocks from southwest Japan are already obtained by Kitagawa (1989) and Kitagawa and Nishido (1994), Kitagawa *et al.* (1996; 1997). These results are also summarized in Tables 2 and 3. As seen in Table 1, the ages of the clay veins from Korean peninsula range from middle Cretaceous to Paleogene, and the ages of the host granitoids range from early Jurassic to Paleogene (Geological Society of Korea, 1987).

Specimens taken from the clay veins in the Seoul district were dated as 107.2 Ma and 104.3 Ma (middle to late Cretaceous). However, Rb-Sr ages of host granitic rock (Daebo granitic rocks) are 160 Ma, corresponding to the Jurassic (Geological Society of Korea, 1987). In this study, we obtained a whole rock K-Ar age of 143.7 Ma for Daebo granite at the clay vein sample locality.

Clay veins from the Kwangju district were dated at

Table 2. K-Ar ages of clay vein specimens and host granitoids from the San'in Belt (Paleogene) of southwest Japan

Sample	K (wt.%)	Rad.^{40}Ar (10^{-8} ccSTP/g)	Non Rad. Ar (%)	Age (Ma)
		San'in granite (Paleogene)		
		Mizuho - Hasumimura (Ohchi-gun, Shimane Pref.)		
Vein	8.13	1161.3	3.8	36.4±1.8
Granite				
(biotite)	4.56	739	57.8	41.3±1.9*
(biotite)	3.90	548	65.0	36.0±1.8*
(K-feld.)	4.60		50.71	34*
		Ohasa (Yamagata-gun, Hiroshima Pref.)		
Vein	4.38	658	5.7	38.3±1.9
Granite				
(biotite)	6.15	934	58.5	38.7±1.8**
		Mitoya (Iishi-gun, Shimane Pref.)		
Vein	8.15	1623	10.6	50.6±2.5
Vein	6.50	1286	3.6	50.3±2.5
Veim	7.80	1580	20.2	51.3±1.6
Granite				
(biotite)	5.28		28.86	45*
(biotite)	4.88		5.87	64*
(biotite)	6.86		7.28	52*
		Yokota (Nita-gun, Shimane Pref.)		
Vein	4.81	1053	3.1	55.6±2.8
Granite				
(biotite)	5.69	1370	28.9	60.8±2.4

*Kawano and Ueda (1966), ** Shibata and Ishihara (1974). Other dates from Ishihara *et al.* (1980) and Kitagawa *et al.* (1988).

93.6 Ma, 84.3 Ma and 84.2 Ma. The age of the host granitoid (Bulguksa granite) was 133.2 Ma (whole rock) in this study.

Clay veins in the Hoam granite body in the Kyeongju area yielded ages of 27.1 Ma and 23.9 Ma, and the K/Ar whole rock age of the granitoid host was 35.4 Ma. The latter compares with a Rb-Sr whole rock age of 39.7 Ma for the Hoam granite (Kim *et al.*, 1995). Both results indicate Paleogene age.

In all three cases, the formation ages of illite in the clay veins are much younger than those of their hosted granites.

According to Ishihara *et al.* (1980), Kitagawa and Kakitani (1981), Kitagawa and Nishido (1994), and Kitagawa *et al.* (1996, 1997), ages of the mica clay mineral from clay veins in southwest Japan are close to those of their host granites (Tables 2 and 3). Two granitoid types of contrasting age occur in southwest Japan. These are the Sanyo (Cretaceous) and San'in (Paleogene) belts, as shown in Fig. 5. As the names imply, the former is distributed in the Sanyo province, while the latter is in the San'in province. The ages of granitic rocks were determined in both

Table 3. K-Ar ages of clay vein specimens collected and host granitoids from the Sanyo Belt (Cretaceous) in southwest Japan

Sample	K (wt.%)	Rad.^{40}Ar (10^{-8} ccSTP/g)	Non Rad. Ar (%)	Age (Ma)
		Sanyo granite (Cretaceous)		
		Kure (Hiroshima Pref.)		
Vein	9.02	1370	89.7	68.4±3.4
Granite				
(biotite)	2.80	838	26.9	79.7±4.8**
(biotite)	6.10	2070	18.7	85.7±4.3**
		Toyohira (Yamagata-gun, Hiroshima Pref.)		
Vein	6.36	1779	1.0	70.7±3.5
		Kake (Yamagata-gun, Hiroshima Pref.)		
Vein	4.34	1124	9.4	65.5±1.5
Vein	6.41	1888	2.9	74.3±3.7
		Ohno (Saeki-gun, Hiroshima Pref.)		
Vein	5.86	1779	1.1	76.6±3.8
Vein	3.00	924	4.3	77.7±1.7
Granite				
(biotite)	6.61		63.33	93*
		Higashihiroshima (Hiroshima Pref.)		
Vein	4.55	1570	3.7	86.4±2.6
Vein	5.88	1871	1.9	80.2±2.4
Granite				
(biotite)	6.46		6.42	82*
		Hatsukaichi (Hiroshima Pref.)		
Vein	3.00	924	4.3	77.7±1.7
		Hiroshima (Hiroshima Pref.)		
Vein	2.16	498	14.8	58.5±1.3
Granite				
(whole rock)	3.33	948	16.4	71.9±1.7
(whole rock)	3.48	930	12.7	67.6±1.5
(biotite)	6.92		3.21	78*
		Yoshiwa (Saeki-gun, Hiroshima, Pref.)		
Vein	3.08	847	15.0	69.5±1.6
Vein	4.03	948	3.2	59.7±1.3
		Miyashi (Hiroshima, Pref.)		
Vein	2.44	739	3.6	76.5±3.8
Granite				
(biotite)	5.59		10.93	89*

*Kawano and Ueda (1966),

** Higashimoto *et al.* (1985). Other data from Ishihara *et al.* (1980), Kitagawa and Kakitani (1981), Kitagawa *et al.* (1996) and Kitagawa *et al.* (1997).

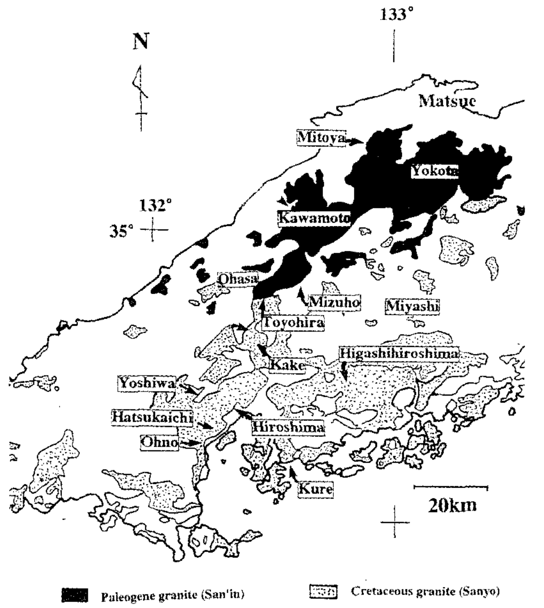

Fig. 5. Distribution of granitic rocks and sampling localities in southwest Japan.

provinces by Shibata and Yamada (1965), Shibata and Nozawa (1967), Kawano and Ueda (1966), Shibata and Ishihara (1974) and Shibata (1979). Imaoka *et al.* (1994) summarized the radiometric ages of Cretaceous to Tertiary igneous rocks from southwest Japan. According to them, the range of the granite ages obtained in southwest Japan is varied between 31 Ma and 114 Ma. The ages of four clay veins in San'in granitic rocks are 36.4 Ma (Mizuho-Hasumimura); 38.3 Ma (Ohasa); 50.3, 50.6 and 51.3 Ma (Mitoya) and 55.6 Ma (Yokota), as shown in Table 2 (Kitagawa and Nishido, 1994). Ages of the host granitic rocks in these four areas as determined by Kawano and Ueda (1966) and Shibata and Ishihara (1974) are 34～41.3 Ma, 38.7 Ma, 45～64 Ma and 60.8 Ma, respectively. The ages of the clay veins in the San'in Belt and their host rocks show the similar age range each other (Tables 2 and 3). This is similar case in the Sanyo Belt. For example, in the Higashihiroshima district, Hiroshima Prefecture, K-Ar ages of clay veins are 80.2 Ma and 86.4 Ma and the host rock (Sanyo granite) is dated as 82 Ma (Table 2). Therefore, the formation of mica clay minerals in southwest Japan seems to be contemporaneous with solidification of the host granitoids. This time concordance suggests a genetic relationship between the two. But the host granitoids and illite veins show a little different ages in the another areas of Sanyo belt. Illite veins are a little younger than the hosted granitoids same as San'in Belt. We infer that the mica clay mineral veins in southwest Japan were formed during the hydrothermal stage of their host granitoids and hydrothermal activity after granite emplacement.

In contrast, the mica clay minerals in Korean peninsula are clearly much younger than their host granitoids. The differences in formation ages of mica clay minerals compared to host granitoids between Korean peninsula and southwest Japan are inferred to be due to:

1) In Korea, deeper zones of the granitic bodies now crop out on the surface due to deeper weathering and erosion. It is inferred that the beginning of the hydrothermal stages in the deeper parts of the bodies was later than in the shallower zones.

2) Other granitic magmatism may have taken place beneath the host granitoids.

However, the cause of the differing age relations cannot be determined solely from K-Ar ages. More detailed studies are necessary to clarify the precise genetic relationship.

CONCLUSIONS

K-Ar ages of clay veins found in granitic rocks of three different geological stages (Jurassic, Cretaceous and Paleogene ages) in Korean peninsula were measured, yielding the results below:

1) 104～107 Ma from Daebo granite (Jurassic) in Seoul (143.7 Ma: whole rock).

2) 84～93 Ma from Bulguksa granite (Cretaceous) in Kwangju (133.2 Ma: whole rock).

3) 23～27 Ma from Hoam granite (Paleogene) in Kyeongju (35.4 Ma: whole rock).

Formation ages of illite in the veins found in the Korean peninsula were compared with those of similar occurrences in southwest Japan previously reported by Kitagawa (1989), Kitagawa and Nishido (1994), and Kitagawa *et al.* (1996, 1997). Differences in formation ages between the host granites and clay veins are very small or almost absent in southwest Japan, but are significant in the Korean Peninsula.

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REFERENCES

Geological Society of Korea (1987) Isotopic age map of Korea, (Lee, Dai-Sung ed.), Geology of Korea, Kyohak-Sa pub., 499-514.

Higashimoto, S., Matsuura, H., Mizuno, K., and Kawada, K. (1985) Geology of the Kure district. Geological survey of Japan (in Japanese with English abstract).

Imaoka, T., Ohira, T., Sawada, Y., and Itaya, T. (1994) Radiometric ages of Cretaceous to Tertiary igneous rocks from Chugoku and Shikoku districts, southwest Japan. Bull. Research Institute Natural Sci., Okayama Univ. Sci., 20, 3-57 (in Japanese).

Ishihara, I., Shibata, K., Kitagawa, R., and Kakitani, S. (1980) K-Ar ages of sericites from the Chugoku district, Japan. Bull. Geol. Soc. Japan, 31, 221-224.

Itaya, T., Nagao, K., Inoue, K., Honjou, Y., Okada, T., and Ogata, A. (1991) Argon isotope analysis by a newly developed mass spectrometric system for K-Ar dating, Miner. Jour., 15, 203-221.

Kakitani, S. and Kitagawa, R. (1977) Clay minerals in the veins and veinlets found in the granitic rocks of Hiroshima Prefecture. Jour. Miner. Soc. Japan, 13, Spec. 187-196 (in Japanese).

Kawano, Y. and Ueda, Y. (1966) K-Ar dating on the igneous rocks in Japan (V) -Granitic rocks in southwest Japan-, Assoc. Mine. Pet. Econ. Geol., 56, 191-211 (in Japanese with English abstract).

Kim, G.S., Kim, J., Young, K.K., Hwang, J.Y., and Lee, J.D. (1995) Rb-Sr whole rock geochronology of the granitic rocks in the Kyeongju-Gampo area. Jour, Korean Earth Sci., 16, 272-279 (in Korean with English abstract).

Kim, H.H., Satake, H., and Mizutani, Y. (1992) Oxygen isotopic compositions of Mesozoic granitic rocks in south Korea. Min. Geol., 42, 311-322.

Kitagawa, R. (1989) Clay veins and clay minerals in the granitic rocks in Hiroshima and Shimane Prefectures, southwest Japan; Effect of the hydrothermal activities on the decomposition of the granitic rocks. Jour. Sci. Hiroshima Univ., Ser. C., 8, 47-80.

Kitagawa, R. and Kakitani, S. (1978a) Mode of occurrence and mineralogy of clay veins in granitic rocks with special reference to the genesis of clay minerals in them. Jour. Miner. Soc. Japan, 3, Special issue, 187-196 (in Japanese with English abstract).

Kitagawa, R. and Kakitani, S. (1978b) The pale-green clay vein in the granitic rock at the Ondo-cho district, Hiroshima Prefecture, Jour. Clay Sci. Japan, 18, 31-39 (in Japanese with English abstract).

Kitagawa, R and Kakitani, S. (1978c) The white clay vein in the granitic rock at the Hachihonmatsu district, Hiroshima prefecture. Jour. Clay Sci. Soc. Japan, 31-39 (in Japanese with English abstract).

Kitagawa, R. and Kakitani, S. (1981) K-Ar ages of mica clay minerals in clay veins found in granitic and rhyolitic rocks of Hiroshima Prefecture, Japan. Jour. Min. Pet. Econ. Geol., 76, 176-179.

Kitagawa, R. and Nishido, H. (1994) Orientation analysis and formation ages of fractures filled with clay minerals in Hiroshima and Shimane Prefect, Soc. Eng. Geol. 35, 60-68.

Kitagawa, R., Nishido, H., and Takeno, S. (1988) K-Ar ages of the sericite and kaolin deposits in the Chugoku district, southwest Japan. Min. Geol., 38, 279-290.

Kitagawa, R., Nishido, H., Inoue, M., and Mondo, M. (1996) K-Ar ages of fault clays (Gouge) in granitic rocks in the western part of Hiroshima Prefecture. Jour. Japan Soc. Eng. Geol., 37, 410-414 (in Japanese).

Kitagawa, R., Nishido, H., Inoue, M., and Matsui, A. (1997) K-Ar ages of gouge of the Koi and Otake active faults. Jour. Japan Soc. Eng. Geol. 38, 299-303 (in Japanese).

Kitagawa, R. and Okuno, T. (1983) Formation mechanism of clay veins found in granitic rock in Higashihiroshima district, Hiroshima Prefecture. Jour. Clay Sci. Soc. Japan, 23, 45-60 (in Japanese with English abstract).

Koh, S.M., Takagi, T., Kim, M.Y., Naito, K., Hong, S.S., and Sudo, S. (2000) Geological and geochemical characteristics of the hydrothermal clay alteration in south Korea. Res. Geol., 50, 229-242.

Korea Institute of Energy and Resources (1981) Geological map of Korea (Chun, H.Y., ed.), Korean Research Institute of Energy and Resources Seoul, Korea Pub.

Lee, D.S. (1971) Study for the igneous activity in the

Middle Ogchon geosynclinal zones. Korea Jour. Geol. Soc., 7, 153-216.

Nagao, K., Nishido, H., Itaya, H., and Ogata, K. (1984) An age determination by K-Ar method. Bull. Hirzen Research Institute. Okayama Univ. Sci., 9, 19-38 (in Japanese with English abstract).

Shibata, K. (1979) K-Ar ages of granitic rocks in eastern Chugoku, Southwest Japan. Memoirs of Geol. Soc. Japan, 17, 69-72.

Shibata, K. and Ishihara, S. (1974) K-Ar ages of biotite across the central part of the Hiroshima granite. Jour. Geol. Soc. Japan, 80, 431-433.

Shibata, K. and Nozawa, T. (1967) K-Ar ages of granitic rocks from the outer zone of southwest Japan. Geochem. J., 1, 131-137.

Shibata, K. and Yamada, N. (1965) Potassium-argon ages of the granitic rocks in the vicinity of Ningyotoge, Chugoku district, west Japan. Bull. Geol. Surv. Japan, 16, 437-442.

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