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K-Ar ages of the hydrothermal clay deposits and the surrounding igneous rocks in southwest Korea

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ABSTRACT : From the K-Ar age determinations for the clay deposits and their surrounded rocks in southwest Korea, the ages of the ore formation in all clay deposits fall in very narrow range from 78.1 to 81.4 Ma. K-Ar ages of clay deposits are slightly younger than those of the Cretaceous volcanic rocks (Hwangsan Formation, 81.4 to 86.4 Ma) and are slightly older than those of the Cretaceous granitic rocks (77.1 to 81.5 Ma). These results indicate that clay deposits were formed with genetical relation to late Cretaceous felsic magmatism. Weolgagsan granite, which has been previously considered to be Cretaceous, is proved to be formed its age in Jurassic (140.9 and 144.8 Ma). The close relationships of K-Ar ages between the clay deposits and Cretaceous granitic rocks suggest that the clay deposits were formed during the hydrothermal alterations caused by the thermal effects (hydrothermal circulation) of the granitic intrusions rather than by the hydrothermal activities associated with volcanic activities.

Key Words : K-Ar age determinations, clay deposits, late Cretaceous felsic magmatism

INTRODUCTION

Most of the clay deposits, which are included in Cretaceous volcanic rocks, are distributed in the southwestern and the southeastern parts of the Korean Peninsula. The study area is located in the Haenam area, southwestern part of Korean Peninsula (Fig. 1). A large number of the hydrothermal clay deposits including the Seongsan, Ogmaesan, Haenam and Dogcheon deposits in the area are generally considered to be genetically related to Cretaceous felsic magmatism.

Since the clay deposits of the area were first described by Kinosaki (1935), many revisions on geology and genesis of the clay deposits in the area have been made. Cho and Kim (1989) studied the mineralogical properties of alunite from the clay deposits in the area. Kim (1989, 1992a and 1992b) established the hydrothermal alteration zones in the Seongsan mine and surrounding area. He estimated the condition of sulfuric acid hydrothermal alteration, such as formation temperature, formation pressure and composition of hydrothermal solution on the basis of chemical compositions of altered rocks and minerals, stability of minerals, and fluid inclusion studies. Kim *et al.* (1990) considered that Ogmaesan clay deposits has been formed by hydrothermal solution of magmatic origin, which has been diluted by low δD meteoric water. In addition, Cha and Yun (1988) reported that volcanic rocks in the area have a caldera structure.

Determination of precise age of ore deposition in the mining area is important to construct the history of mineralization. Paleontological determination of the ages for pre- and post-ore units commonly shows broad ranges (Silberman and Ashley, 1970). Direct radiometric dating of alteration minerals such as alunite and sericite

*Present address: Center for Mineral Resource Research (5-1, Anam-dong, Seongbuk-ku, Seoul 136-701, Korea) exhibits more reliable evidence of their formation ages. Silberman and Ashley (1970) pointed out that K-Ar ages from hypogene alunite can give reliable ages in comparison to independently determined age controls. The radiogenic K-Ar ages of rocks and clay deposits in the Haenam area have been reported by Lee and Lee (1976) and Moon *et al.* (1990). However to clarify the relationship between the clay deposits and surrounding rocks, more detailed age determination on both the igneous rocks and clay deposits is indispensable.

In the present study, we discuss not only the history of igneous activity and associated mineralization but also the caldera-forming processes.

GEOLOGICAL SETTING

Geology

The study area consists of Precambrian metamorphic rocks, Jurassic and Cretaceous granitic rocks and Cretaceous volcanic rocks (Fig. 1). The generalized stratigraphic section of the Haenam area is given in Fig. 2. The area belongs to the southwestern part of the Youngdong-Kwangju Depression Zone (Lee, 1987).

Precambrian Metamorphic Rocks

These rocks are distributed in the center, western and eastern parts of the area. In the western part of the area, they occur in fault contact with Cretaceous Hwawon Formation. They are intruded by Jurassic and Cretaceous granitic rocks, and are unconformably covered by Cretaceous volcanic rocks in the eastern part of the area. They are composed mainly of biotite gneiss and mica schist. Biotite gneiss, hereafter called Sanyi gneiss, is distributed in the central and eastern parts of the area. The rock is fine- to medium-grained and foliated. Mica schist is distributed in the western part of the area.

Jurassic Granitic Rocks

These rocks are distributed in the central and eastern part of the area. They, hereafter called Weolgagsan granite, intruded Precambrian metamorphic rocks, and are unconformably covered by Cretaceous volcanic rocks, and are intruded by Cretaceous granitic rocks. Weolgagsan granite

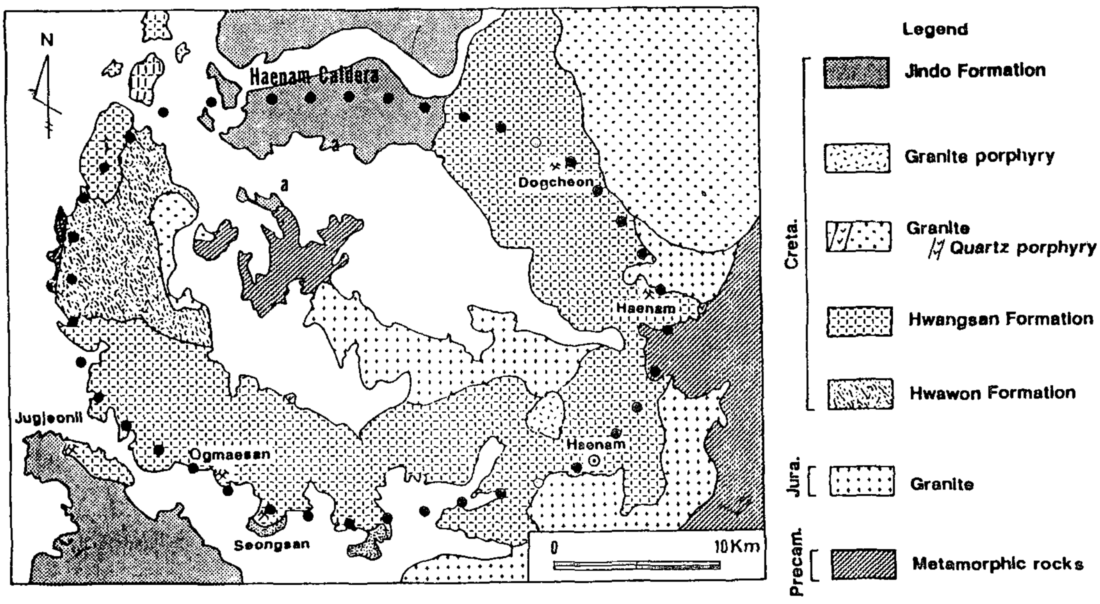

Fig. 1. Geological map of the Haenam area. The location of clay deposits are shown.

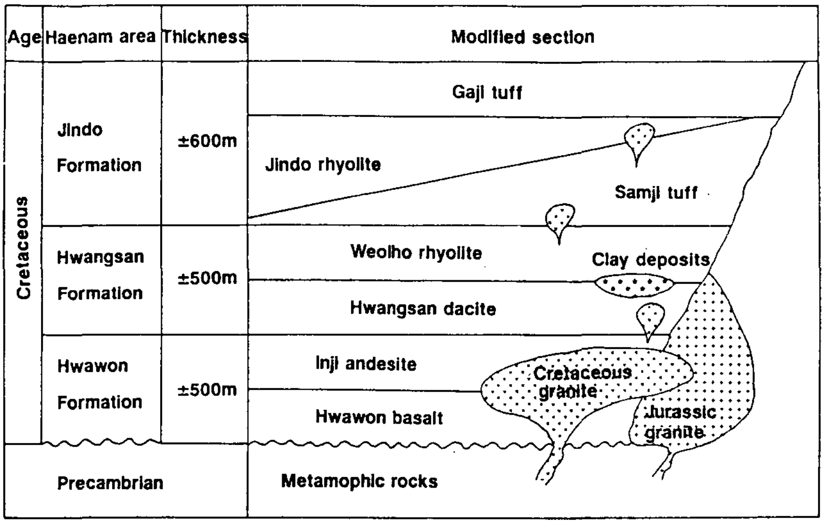

Fig. 2. Generalized stratigraphic section of the Haenam area.

consists of hornblende-biotite, biotite and two mica granites. Hornblende-biotite granite is a medium- to coarse-grained and slightly porphyritic rock. Biotite granite is a fine- to medium-grained one with slightly porphyritic texture. Two-mica granite is a fine- to medium-grained equigranular rocks. In the some part of the area, these rocks have been weakly altered.

Cretaceous Volcanic Rocks

These rocks are widely distributed in the area, and have suffered extensive propylitization, and in some places have undergone strong hydrothermal alterations producing clay deposits. The rocks are divided into three formations in the present study: Hwawon, Hwangsan and Jindo Formations.

Hwawon Formation is distributed in the western part of the area and covers Precambrian rocks with fault-contact. The Formation is divided into the Hwawon basalt and Inji andesite. The Formation is about 500 meters in maximum thickness (Fig. 2). Hwawon basalt is mainly composed of basalt having a flow texture, and intercalating small amounts of tuffaceous sandstone. It shows poikilitic texture and is weakly propylitized. Inji andesite is composed mostly of andesite, andesitic welded tuff and andesitic tuff breccia. The size of breccia fragments in the rock is 5 to 40 cm in length. Volcanogenic sedimentary rocks are intercalated in some parts. These intercalated rocks are composed of tuffaceous sandstone, sandstone, oily shale, black shale and chert. These rocks are called Uhangri formation by Lee and Lee (1976). The Inji andesite is dark grey to pale green in color, and shows flow and welding textures. The rock is also weakly propylitized.

Hwangsan Formation is divided into the Hwangsan dacite and Weolho rhyolite. Hwangsan Formation is the most widely distributed Cretaceous volcanic rocks in the area. The total thickness of the Formation exceeds 500 m (Fig. 2). The Formation conformably overlies Hwawon Formation. Hwangsan dacite is widely distributed in the area, and is mainly composed of dacite flow, welded tuff and small amounts of ash flow tuff and lapilli tuff. The rock shows light grey to pale green in color, and has flow, bubble wall and welding textures. The rock includes xenoliths of the Hwawon Formation, Weolgagsan granite and Precambrian basements. The rock is widely propylitized. In some parts, it has suffered strong hydrothermal alteration, and makes clay deposits. The original textures of the rock are still preserved even in some clay deposits. Weolho rhyolite is mainly distributed in the northwestern and northeastern parts of the area. It conformably overlies Hwangsan dacite. The rock is commonly red in color, and usually shows flow texture and rarely spherulitic texture. White-colored rhyolite flow is observed in some parts. The rhyolite flow changes to rhyolitic tuff breccia in some parts. Rock fragments in tuff breccia are mainly rhyolite flow and small amounts of shale. The size of breccias is commonly smaller than 50 cm in length. The Formation is weakly propylitized, and also altered to clay deposits in some parts.

Jindo Formation is distributed in the north-western and southwestern parts of the area, and conformably overlies Hwangsan Formation. The Formation is divided into the Samji tuff, Jindo rhyolite and Gaji tuff in ascending order. The total thickness of the Formation is about 600 m (Fig. 2). Samji tuff is mainly composed of welded tuff and crystaline tuff. The rock is propylitized. Welded tuff shows welding and bubble wall textures. Crystalline tuff includes rock fragments of rhyolitic composition, and weakly shows bubble wall texture. Jindo rhyolite is mainly distributed in the southwestern part of the area. The rock overlies the Samji tuff and intrudes Hwangsan dacite in a small scale at some parts. The rock is deep red in color, with numerous spherulites, and shows flow structure. It is very weakly propylitized. Gaji tuff is distributed in the northwestern part of area. The rock consists of lapilli and breccia tuffs, most of which include not only breccias of aphanitic rhyolite fragments and volcanic ash but also accidental breccias of all rocks in the area, such as red- and black-shale, sandstone, and granitic rock fragments. The rock shows very weak propylitic alteration.

Cretaceous Granitic Rocks

These rocks are mainly distributed in the eastern and western parts of the area. The rocks are divided into Jiyoungsan granite, Weolchulsan granite, Weolgangdu quartz porphyry and Jangseong granite porphyry. Jiyoungsan granite is distributed in the western part of the area, and intrudes Hwawon Formation. Jiyoungsan granite is composed of hornblende-biotite and biotite granites. Hornblende-biotite granite is medium-grained. Biotite granite is a fine- to medium-grained and has slightly porphyritic texture. Weolchulsan granite is distributed in the eastern part of the area, and intrudes Precambrian basement, Weolgagsan Jurassic granite and Hwangsan Formation. It is biotite granite. Biotite granite is medium- to coarse-grained rock with porphyritic texture. Weolgangdu Quartz Porphyry is distributed widely in the area, and intrudes Hwangsan Formation as small stocks. The rock shows typical porphyritic texture. Jangseong Granite Porphyry occurs in the central part of the area. It intrudes Weolgagsan Jurassic granite and Hwangsan Formation. It is fine-grained, and shows micrographic textures.

Outline of Ore Deposits

Representative clay deposits in the south-western part of Korea as follows: Seongsan, Ogmaesan, Haenam and Dogcheon mines in the Haenam area, Gushi mine in the Hyounsan area, Jugjeonil mine in the Jindo island, Nohwa, Wando and Gwangmyoung mines in the Nohwa island, Jangsan mine in the Jangsan island, and Gasa mine in the Gasa island. These deposits can be classified into Pyrophyllite and Kaolin types on the basis of main mineral. Pyrophyllite type includes Haenam, Dogcheon, Gushi, Nohwa, Wando and Gwangmyoung mines, and Kaolin type includes Seongsan, Ogmaesan, Jugjeonil, Jindo, Jangsan and Gasa mines. Most of these deposits are distributed in the Cretaceous volcanic rocks and are considered to be genetically related to Cretaceous felsic magmatisms.

These clay deposits were studied in terms of mineral assemblages, zoning patterns and zonal structures (Kim, 1991 and 1992b). In the present study, four representative deposits, such as the Seongsan, Ogmaesan, Haenam and Dogcheon mines, were investigated. Kim (1992b) pointed out that central part of zone in the Seongsan clay

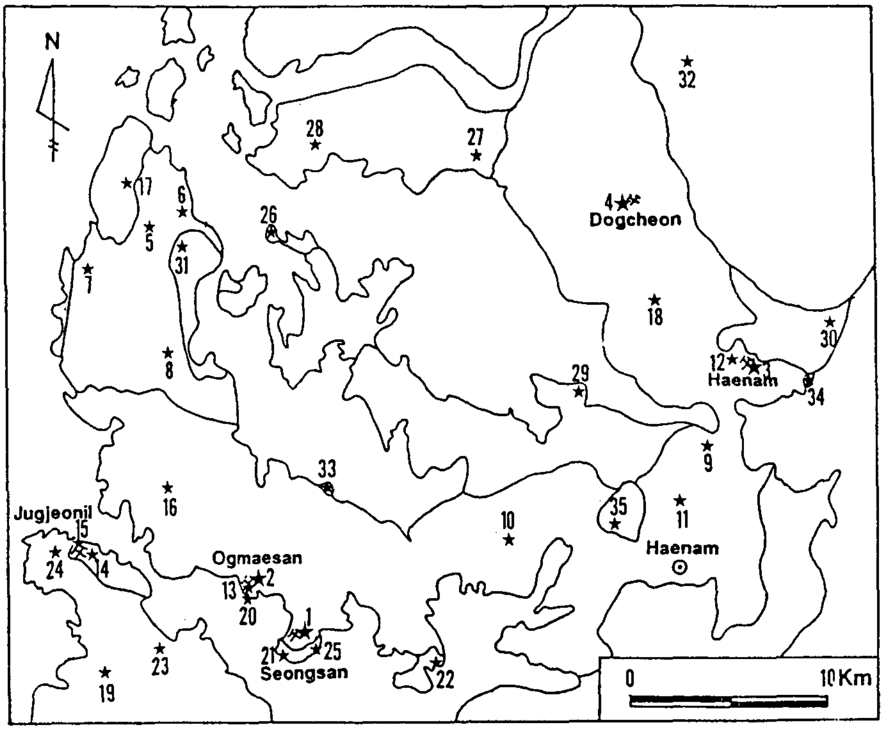

Fig. 3. Sampling sites for K-Ar age determinations in the Haenam area.

deposits is Kaolin zone, whereas that in the Ogmaesan clay deposits is Quartz zone. This fact indicates that the two deposits were formed by different conditions. Although the two deposits are included in the same Kaolinite type, each deposit can be classified into different subgroup.

K-Ar AGE DATING

Sampling Site

The samples analyzed for K-Ar age determination were collected in and around the clay deposits in the Haenam area. The whole-rock samples, which represent the least altered rock in the area, were prepared for analysis. Four samples collected near the clay deposits are very altered rocks (89110440, 89101401, 89031203 and 89101501), because they are thought to be important to establish the relationship between the acidic and propylitic alterations. The sampling sites collected for K-Ar age measurement are shown in Fig. 3. Table 1 shows the sample number given in Fig. 3.

K-Ar method was used to estimate the ages of the alunite and sericite in clay deposits, and whole-rocks in the area.

Analytical Procedures

Only 40-80 mesh fractions of alunite and whole-rocks except sericite were used in order to determine argon isotopic ratio. Sericite was separated from the rock samples using gravitational techniques, and then purity of the separated samples was determined to be higher than 95% using an XRD. The quantitative analysis of radiogenic argon was performed by the isotopic dilution method at the Institute for Study of the Earth's Interior, Okayama University.

30-100 mg of the samples, depending on their potassium concentration, was fused at 1500℃ for 30 minutes in an electric heater. Argon was extracted and purified in a stainless steel ultra-high vacuum system (up to 10^{-9} Torr) designed by Nagao and Itaya (1988). The isotopic ratios of

Table 1. Serial and sample numbers of Fig. 3

Sampling point	Sample number	Name of sheet*	Locality (nat'l grid)
1	86101905	Hwawon	1441/1164
1	87051627	Hwawon	1440/1164
1	87051410	Hwawon	1447/1158
1	87061512	Hwawon	1449/1175
2	89101905	Hwawon	1416/1196
2	89101806	Hwawon	1418/1195
2	89101814	Hwawon	1416/1195
2	89101801	Hwawon	1417/1194
3	89110419	Haenam	1644/1298
3	89110413	Haenam	1645/1295
4	90103005	Haenam	1604/1375
4	90103001	Haenam	1603/1372
4	91102901	Haenam	1606/1345
5	89062803-1	Hwawon	1363/1358
6	89062706	Hwawon	1384/1365
7	89102111	Hwawon	1377/1330
8	89101201	Hwawon	1644/1298
9	89061509	Haenam	1644/1255
10	89110905	Haenam	1658/1205
11	89103005	Haenam	1631/1226
12	89110440	Haenam	1639/1297
13	89031202	Hawwon	1417/1185
14	89101401	Hwawon	1347/1198
15	89101501	Hwawon	1325/1202
16	89101101	Hwawon	1378/1227
17	89062806	Hwawon	1362/1381
18	89103112	Haenam	1265/1358
19	89070102-1	Hwawon	1330/1142
20	89061704	Hwawon	1413/1183
21	88012016	Hwawon	1433/1155
22	88020131	Hwawon	1508/1160
23	89070203	Hwawon	1380/1156
24	89063004	Hwawon	1314/1134
25	88012220	Hwawon	1449/1156
26	88013107	Hwawon	1429/1355
27	89061505	Hwawon	1536/1382
28	89031103-1	Hwawon	1451/1392
29	89110102	Haenam	1585/1280
30	89110107	Haenam	1710/1353
31	89062702	Hwawon	1383/1345
32	89061501	Youngam	1403/1680
33	89031206	Hwawon	1454/1236
34	90102801	Hwawon	1750/1285
35	89061701	Haenam	1600/1210
36	88020413	Wando	1612/1105
37	88020418	Wando	1601/1106
38	86092902	Soan	1622/0810
39	90110301	Wando	1650/1110
40	88020401	Haenam	1563/1120
41	88020404	Wando	1568/1104
42	88020409	Wando	1579/1080

*The names of sheets are from the new edition of topographic map (1 : 50,000). Some Sampling point (36~42) is not distributed in Fig. 3.

mixed argons were measured by a Micromass Spectrometer (VG5400). The absolute amount of argon isotopes is calculated using the argon content and the isotopic ratio in atmospheric air after Nier (1950). In the quantitative analysis of radiogenic argon, the isotopic dilution method using an ^{38}Ar spike (Wasserberg and Hayden, 1955) was used. The method requires a well calibrated spike system. This calibration system of ^{38}Ar spike is quite different from other laboratories where geological working standard samples such muscovite or biotite has been used in the calibration (e.g., Lanphere and Dalrymple, 1965; Shibata, 1968). Nagao *et al.* (1984) and Nagao and Itaya (1988) have described in detail a new calibration system in which standardized air argon was used.

Potassium concentration was determined by flame photometry using a Polarized Zeeman Atomic Absorption Spectrometer (Z-6100) at the Geological Institute, Faculty of Science, University of Tokyo. Sample powder used on potassium solution for flame photometry was dissolved using HF, $HClO_4$ and HCl.

The decay constants and isotopic abundance ratio used in the age calculations are: $\lambda_\beta = 4.962\times10^{-10}$/yr, $\lambda e = 0.581\times10^{-10}$/yr (Steiger and Jäger, 1977) and $^{40}K/K = 0.01167$ (atomic %).

The equation of age calculation presented by Nagao and Itaya (1988) is as follows:

$$t(\mathrm{Ma}) = 1.804\times10^{3}\ \ln\{1 + 1.428\times10^{-4}\times[^{40}Ar]_{rad}\ (10^{8}ccSTP/g)/[K](wt.\%)\}.$$

Errors of potassium determination are indicated at one standard deviation and errors of K-Ar age are estimated by combining uncertainties in potassium and argon determinations, using the equation presented by Nagao and Itaya (1988):

$$\Delta t = \{(1.804\times10^{3}\times1.428\times10^{-4}[^{40}Ar]_{rad})/([K] + 1.428\times10^{-4}[^{40}Ar]_{rad})\}\times\{(\Delta[^{40}Ar]_{rad}/[^{40}Ar]_{rad})^{2} + (\Delta[K]/[K])^{2}\}^{1/2}.$$

RESULT

The results of K-Ar age determinations are

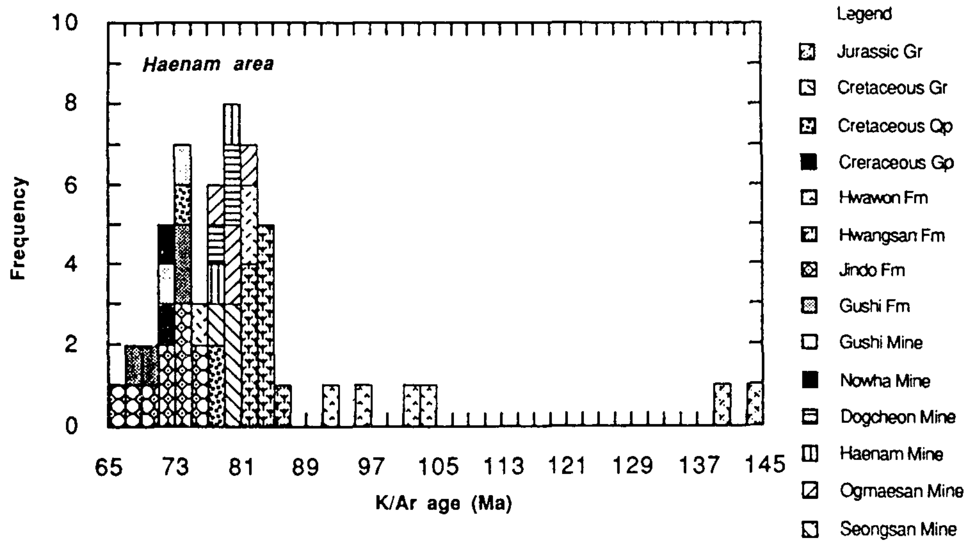

Fig. 4. Frequency diagram of K-Ar ages of whole-rocks. Abbreviations: Gr, granite; Qp, quartz porphyry; Gp, granite porphyry; Fm, Formation.

summarized in Table 2, and shown in Fig. 4. K-Ar ages of clay deposits in the study area are restricted in a narrow range from 78.1 to 81.4 Ma, late Cretaceous.

Alunite and sericite taken from the ore body in the Seongsan mine and Ogmaesan mine give the ages from 78.1 to 80.9 Ma and from 79.0 to 81.4 Ma, respectively (Fig. 4). K-Ar ages of sericite in the Haenam mine were determined to be 78.9 and 79.6 Ma (Fig. 4). The ages of alunite and sericite in the Dogcheon mine were determined to be 78.8 and 80.6 Ma, respectively (Fig. 4). The ages of sericite in other clay deposits (Gushi and Nohwa) were also measured to be 72.3 to 74.6 Ma.

K-Ar ages of biotites of the Weolgagsan granite show 140.9 and 144.8 Ma. Jiyoungsan granite gives an age of 81.5 Ma. K-Ar ages of K-feldspar and whole rock of Weolchulsan granite show 77.0 and 81.2 Ma, respectively. K-Ar ages of biotite and whole rocks of Weolgangdu quartz porphyry show 75.0 and 77.1 to 77.9 Ma, respectively. K-Ar age of whole-rock of Jangseong granite porphyry shows 71.8 Ma. K-Ar whole rock ages of volcanic rocks are given as follows: Hwawon Formation (92.7 to 103.4 Ma), Hwangsan Formation (81.4 to 86.4 Ma) and Jindo Formation (66.2 to 76.3 Ma). The Gushi Formation occurring near the study area (Hyounsan area), gives ages of 68.4 to 73.6 Ma.

K-Ar ages of alunite in the Seongsan, Ogmaesan and Haenam deposits are almost the same as those of sericite, thus all clay deposits gives almost the same ages (Fig. 5). It means that all clay deposits were formed at almost the same time. K-Ar ages of sericite and hypogene alunite of the clay deposits are slightly younger than or the same as those of the host volcanic rocks, and are slightly older than or the same as those of the granitic rocks. It clearly indicates that the clay deposits were formed in association with late Cretaceous felsic magmatism. Thus, it is evident that K-Ar age determination is highly useful for clarifying the temporal relations among the igneous rocks, hydrothermal alteration and ore deposition.

DISCUSSION AND CONCLUSION

Relationships of the K-Ar Ages between the Clay Deposits and Igneous Activity

K-Ar ages of alunites (80.8 to 81.4 Ma) from the Seongsan, Ogmaesan and Dogcheon deposits

Table 2. K-Ar ages of specimens from the clay deposits and of whole-rocks collected from the Haenam area.

Sample	Mineral and rock dated	K (wt.%)	$[^{40}Ar]_{rad}$ (10^{-8} cc/g)	Air* (%)	K-Ar age (Ma)
• Clay deposits					
Seongsan mine					
86101905	Alunite	8.35± 0.06	2682± 35	28.1	80.9± 1.2
87051627	Alunite	8.10± 0.05	2600± 27	5.1	80.8± 0.9
87051410	Sericite	6.35± 0.05	2009± 21	12.1	79.7± 1.0
87061512	Sericite	6.54± 0.07	2026± 21	3.1	78.1± 1.1
Ogmaesan mine					
89101905	Alunite	8.30± 0.06	2663± 27	17.4	80.8± 1.0
89101806	Alunite	6.37± 0.05	2059± 21	8.5	81.4± 1.0
89101814	Sericite	5.16± 0.05	1643+17	5.8	80.2± 1.1
89101801	Sericite	7.09± 0.08	2223± 23	1.4	79.0± 1.2
Haenam mine					
89110419	Sericite	6.82± 0.07	2156± 27	7.7	79.6± 1.1
89110413	Sericite	5.09± 0.04	1593± 16	3.0	78.9± 1.0
Dogcheon mine					
90103005	Alunite	3.05± 0.07	975.7± 10.0	19.7	80.6± 1.9
90103001	Alunite	2.31± 0.04	737.3± 33.3	16.7	80.4± 3.8
90102901	Sericite	0.21± 0.03	65.6± 2.7	90.9	78.8± 4.8
• Other clay deposits					
Gushi mine					
88020413	Sericite	6.26± 0.07	1808± 20	29.4	72.9± 1.1
88020418	Sericite	7.85± 0.04	2262± 23	9.0	74.6± 1.8
Nohwa mine					
86092902	Sericite	0.27± 0.01	77.4± 0.8	39.2	72.3± 2.7
• Hwawon Formation					
Hwawon basalt					
89062803-1	Whole-rock	0.88± 0.02	363.4± 3.7	16.7	103.4± 2.5
89062706	Whole-rock	1.19± 0.03	484.4± 5.0	18.4	101.9± 2.7
Inji andesite					
89102111	Whole-rock	0.68± 0.01	258.6± 2.7	26.9	95.4± 2.9
89101201	Whole-rock	0.97± 0.02	358.1± 3.7	22.6	92.7± 2.1
• Hwangsan Formation					
Hwangsan dacite					
89061509	Whole-rock	2.38± 0.03	799.2± 8.2	8.7	84.5± 1.3
89110905	Whole-rock	3.09± 0.04	1062± 11	15.9	86.4± 1.8
89103005	Whole-rock	3.07± 0.05	1038± 11	9.0	85.0± 1.6
Altered Hwangsan dacite					
89110440	Whole-rock	5.96± 0.09	1986± 21	23.7	83.9± 1.4
89101401	Whole-rock	2.99± 0.03	991.4± 49.6	12.6	83.4± 4.1
89031202	Whole-rock	4.90± 0.11	1617± 16	3.0	83.1± 1.6
89101501	Whole-rock	3.08± 0.04	1002± 10	11.0	81.9± 1.7

Abbreviation: Air*=Air fraction

Table 2. (continued)

Sample	Mineral and rock dated	K (wt.%)	$[^{40}Ar]_{rad}$ (10^{-8} cc/g)	Air* (%)	K-Ar age (Ma)
Weolho rhyolite					
89101101	Whole-rock	4.73± 0.05	1536± 16	6.0	81.8± 1.3
89062806	Whole-rock	3.77± 0.06	1222± 12	5.5	81.6± 1.5
89103112	Whole-rock	2.38± 0.04	768.8± 7.9	20.0	81.4± 2.8
• Jindo Formation					
Samji tuff					
89070102-1	Whole-rock	4.74± 0.09	1434± 15	5.8	76.3± 1.2
89061704	Whole-rock	3.77± 0.05	1109± 11	9.8	74.2± 1.7
88012016	Whole-rock	4.04± 0.06	1184± 12	6.0	73.9± 1.6
Jindo rhyolite					
88012220	Whole-rock	3.71± 0.06	1066± 11	10.3	72.5± 1.3
88020131	Whole-rock	3.75± 0.06	1078± 11	7.7	72.6± 1.7
89070203	Whole-rock	3.19± 0.04	937.6± 9.6	8.6	74.2± 1.5
89063004	Whole-rock	4.21± 0.07	1258± 13	5.1	75.4± 1.7
Gaji tuff					
89031103-1	Whole-rock	3.05± 0.04	820.0± 8.4	8.4	68.0± 2.1
88013107	Whole-rock	2.10± 0.03	589.3± 6.1	16.5	70.9± 1.5
89061505	Whole-rock	2.24± 0.04	586.7± 29.4	17.6	66.2± 3.4
• Other volcanic rocks					
Gushi Formation					
90110301B	Whole-rock	1.43± 0.03	387.1± 4.0	16.3	68.4± 1.5
88020401D	Whole-rock	2.90± 0.06	812.0± 40.6	16.5	70.7± 3.6
88020404_{Dt}	Whole-rock	2.37± 0.05	686.4± 7.2	12.6	73.1± 2.8
88020409^{R}	Whole-rock	4.09± 0.05	1193± 12	6.1	73.6± 1.3
• Granitic rocks					
Weolgagsan granite					
89110107	Biotite	6.02± 0.04	3425± 35	1.5	140.9± 1.7
89110102	Biotite	5.46± 0.05	3196± 33	2.5	144.8± 1.9
Jiyoungsan granite					
89062702	Whole-rock	3.10± 0.04	1003± 50	16.7	81.5± 4.0
Weolchulsan granite					
89061501	K-feldspar	8.00± 0.16	2443± 25	14.5	77.0± 1.2
89061501	Whole-rock	3.68± 0.04	1186± 59	8.9	81.2± 4.0
Weolgangdu quartz porphyry					
89031206	Whole-rock	3.35± 0.54	1035± 52	15.6	77.9± 3.8
89102801	Biotite	1.09± 0.04	324.5± 3.4	35.9	75.0± 2.8
89102801	Whole-rock	3.44± 0.06	1052± 53	14.3	77.1± 3.8
Jangseong granite porphyry					
89061701	Whole-rock	3.79± 0.06	1078± 54	11.3	71.8± 3.6

Abbreviation: B, Basalt; D, Dacite; Dt, Dacitic tuff; R, Rhyolite

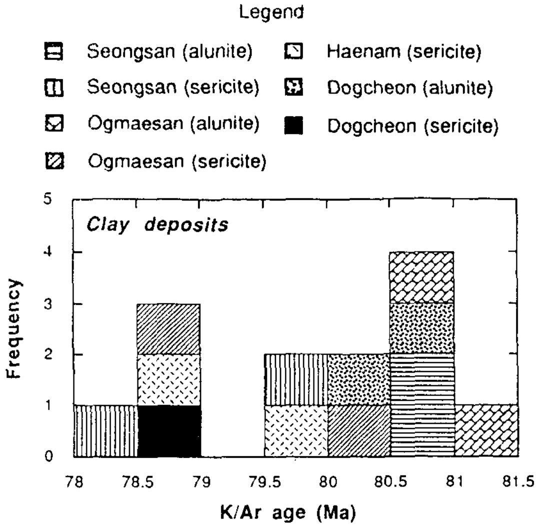

Fig. 5. Frequency diagram of K-Ar ages of alunites and sericites from the clay deposits.

are conformable with those of sericites (78.1 to 80.2 Ma). Although alunite is not present in the Haenam deposit, K-Ar ages of sericites (78.9 and 79.6 Ma) are the same as those of other deposits. Furthermore, K-Ar ages of these minerals (78.1 to 81.4 Ma) are in good agreement with those of host rocks (Hwangsan Formation, 81.4 to 86.4 Ma) and heat source rocks (Cretaceous granitic rocks, 77.1 to 81.5 Ma).

Kim (1991) reported that kaolin minerals and alunite are hypogene in origin, and are thought to have been formed by oxidation of hydrogen sulfide in the steam-heated environment, that produces the spectacular solfataric alteration seen at the surface in hydrothermal system. The clay deposits, therefore, were formed through the hydrothermal activities caused by circulation of hydrothermal solution (magmatic water mixed with meteoric water) of magmatic origin from the thermal effects of the granitic intrusions.

Reconsideration on Ages of Rocks and on Caldera

The ages of the granitic rocks have been reported by many workers as follows: Rb-Sr ages of granitic gneiss in Mogpo area are 2,300 Ma, 1,990 Ma and 1,090 Ma (Choo, 1987). Rb-Sr ages of Jurassic granitic rocks in the Mogpo area were determined as 180 Ma by Choo (1987). K-Ar age of 161.0 Ma on biotite separated from biotite granite (Jindo island) was reported by Moon *et al.* (1990). Hornblende granodiorite at Mt. Ilseong has K-Ar age of 67 Ma (Lee and Lee, 1976). Weolgangdu quartz porphyries at locality have the ages of 63 Ma (Lee and Lee, 1976) and 79.6 Ma (Moon *et al.*, 1990). The ages of the granitic rocks obtained in the present study are as follows: K-Ar ages of K-feldspar and whole rock of Weolchulsan granite show 77.0 and 81.2 Ma, respectively. K-Ar ages of biotite and whole rock of Weolgangdu quartz porphyry show 75.0 and 77.1 Ma, respectively. K-Ar age of whole-rock of Jangseong granite porphyry shows 71.8 Ma. The data on Cretaceous granitic rocks obtained in the present study fall in a narrow range.

Recently, Moon *et al.* (1990) reported the ages of the volcanic rocks and the clay deposits as follows: Andesite gives 94.1 Ma, and rhyolite and acidic tuffs give 79.4 and 82.8 Ma in the Haenam area. Later stage andesite in the Hyounsan area (Gushi mine area) gives 68.6 Ma. Clay deposits give a range from 71.8 to 76.6 Ma. The ages of the volcanic rocks and the clay deposits obtained in the present study are as follows: Hwawon Formation gives the ages of 92.7 to 103.4 Ma. Hwangsan Formation gives the ages of 81.4 to 86.4 Ma. Jindo Formation gives the ages of 66.2 to 76.3 Ma. Gushi Formation gives the ages of 68.4 to 73.6 Ma. The ages of these rocks are very close to those given by Moon *et al.* (1990). Clay deposits give a range from 78.1 to 81.4 Ma. This range is slightly older than that given by Moon *et al.* (1990). Base on these results the following problems should be considered: (1) formation ages of the clay deposits; (2) relationship between the clay deposits and the their host rocks; (3) relationship between the clay deposits and the heat source rocks. Formation age of the clay deposits is considered as about 80 Ma by present results. Although Moon *et al.* (1990) pointed out that clay deposits appear to have been related with Cretaceous volcanic rocks rather than

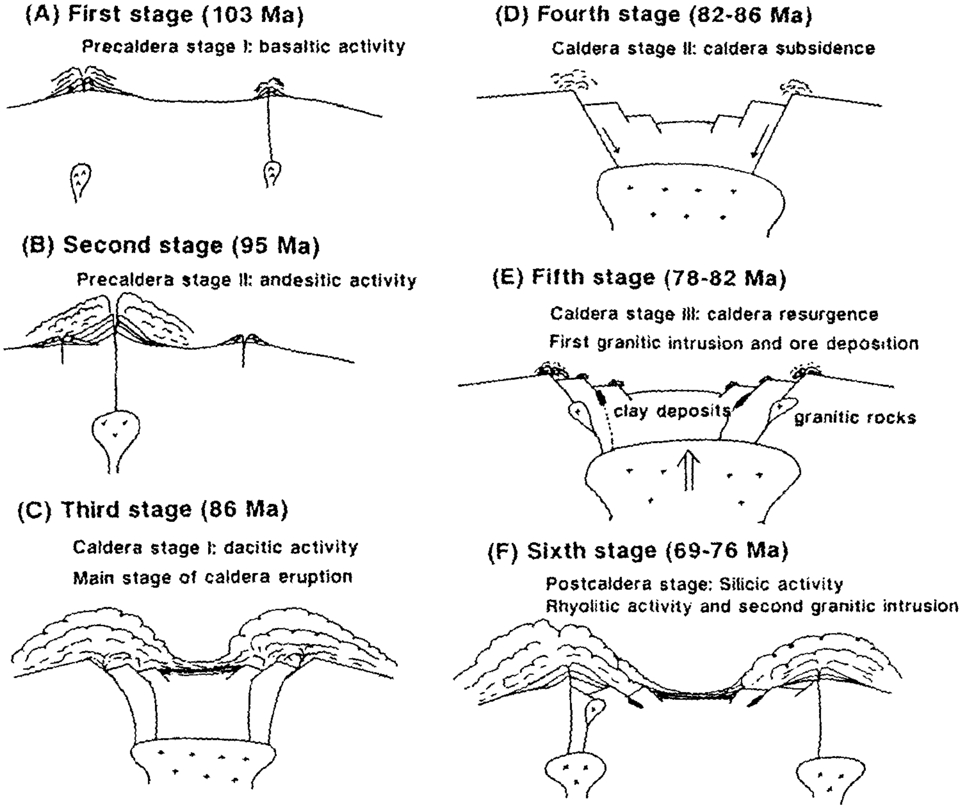

Fig. 6. Schematic diagrams of caldera formation and ore deposition in the Haenam area.

hydrothermal stages of granite, the close relationship of K-Ar ages between the clay deposits and Cretaceous granitic rocks suggests that the clay deposits were formed through the hydrothermal alterations caused by the thermal effects of the granitic intrusions rather than of volcanic activities.

Cha *et al.* (1987) and Cha and Yun (1988) considered that the area has a cauldron structure called "Mogpo Cauldron", which is called "Haenam Caldera" in the present study (Fig. 1). They thought that Weolgagsan granite distributed in the Sanyi peninsula is Cretaceous one, and represents the resurgent pluton in later stage of caldera formation. But the lithologic characteristic of Weolgagsan granite is very similar to that of Jurassic granites in Korea. The K-Ar age determination of this study clarifies that Weolgagsan granite is a Jurassic one, and has no relation to caldera-forming process of late Cretaceous.

Results of the age determination suggest that volcanism of the study area can be divided into six stages on the basis of caldera-forming process as shown in Fig. 6.

In the first stage (Fig. 6(A)), precaldera basaltic activity (Hwawon Basalt) occurred at about 103 Ma. In late stage of basaltic activity, chert, red- and black-shale was deposited in the limited area of the basaltic volcanic field. In the second stage (Fig. 6(B)), andesitic activity (Inji Andesite) followed basaltic volcanism at about 95 Ma. Black- and oily-shale was sedimented in late stage of andesitic activity. In the third stage (Fig. 6(C)), explosive dacitic flow (Hwangsan Dacite) with large volume pyroclastics erupted in most parts of the area. These activities occurred at about 86 Ma. In the fourth stage (Fig. 6(D)), probably, Haenam Caldera was collapsed because of eruption of large volume of acidic compositions (mostly Hwangsan dacite). In the fifth stage (Fig. 6(E)), rhyolitic activities (Weolho Rhyolite) occurred at about 81 Ma. The rhyolitic activity was followed by Cretaceous granitic intrusions (first intrusion) such as Jiyoungsan granite (81.5 Ma), Weolchulsan granite (81.2 Ma) and Weolgangdu quartz porphyry (77.1 and 77.9 Ma). Then, the rising of granitic magma after caldera subsidence has resurgently uplifted to the inner part of the Haenam Caldera. Presumably at the same time, clay deposits were formed around the ring fractures of the caldera. The rising of granitic magma could come with the magmatic fluid generation due to the decrease of water solubility associated with pressure decreasing (Burnham, 1979). In the sixth stage (Fig. 6(F)), pyroclastic rocks (Samji Tuff) were erupted during 76 to 74 Ma. Small volume of rhyolite (Jindo Rhyolite) forming numerous small domes intruded in the southern part of the area (73 to 75 Ma). Silicic pyroclastic activities occurred in 74 to 69 Ma. Finally, felsic magma of Jangseong granite porphyry (71.8 Ma) intruded as a small stock.

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REFERENCES

Burnham, C.W., 1979, Magmas and hydrothermal fluids. in Geochemistry of Hydrothermal Ore deposits, ed., Barnes, H.L., John Wiley, New York, 71-136p.

Cha, M.S. and Yun, S.H., 1988, Cretaceous volcanic cauldrons and ring complexes in Korea. J. Geol. Soc. Korea, Volume in memory of Professor Lee, Dae Sung, 24, 67-86, in Korean.

Cha, M.S., Yun, S.H. and Hwang, I.H., 1987, Cretaceous Mogpo cauldron, southwest Korea. J. Col. of Ed. Busan Nat. Univ., 14, 197-206 (in Korean).

Cho, H.G. and Kim, S.J., 1989, Mineralogical study of the alunite from the Seongsan mine. J. Mineral. Soc. Korea, 2, 81-89.

Choo, S.H., 1987, Rb-Sr age determinations on the Ryeongnam Massif (IV): Granitic gneisses in Mokpo, Yulli Group in Taebacksan and granites in both areas. KIER, KR-87-27, 1-50, in Korean.

Kim, I.J., 1989, Hydrothermal alteration of the felsic volcanic rocks in the southwestern part of Korean Peninsula. M.Sc. Thesis of University of Tokyo, 144 p.

Kim, I.J., 1991, Geochemistry of hydrothermal alteration and clay deposits in the Haenam area, Southwestern Korea. D.Sc. Thesis of University of Tokyo, 238p.

Kim, I.J., 1992a, Hydrothermal Alteration Related to Cretaceous Felsic Magmatism in the Seongsan Dickite deposits, Korea -Estimation of Ore Forming Temperature and aNa^+/aK^+ Ratio of the Hydrothermal Fluid-. J. Korean Inst. Min. Geol. 25, 259-273.

Kim, I.J., 1992b, Alteration zoning, mineral assemblages and geochemistry of the hydrothermal clay deposits related to Cretaceous felsic magmatism in the Haenam area, southwest Korea. J. Korean Inst. Min. Geol. 25, 397-416.

Kim, Y.H., Moon, H.S., Kim, J.H., You, J.H. and Kim, I.J., 1990, Hydrothermal alteration and mineralogy of alunite and kaolinite in Ogmae deposits, southwest Jeonnam. J. Korean Ins. Min. Geol., 23, 207-308 (in Korean).

Kinosaki, Y., 1935, Alunite deposits in Kimhae, Haenam, Jindo and Muan districts in Korea. The Government-General of Korea, Investigate of Mining, Korea, 8, 17-99, in Japanese.

Lanphere, M.A. and Dalrymple, G.B., 1965, P-207-An interlaboratory standard muscovite for argon and potassium analyseis. J. Geophys. Res., 70, 3497-3503.

Lee, D.S., 1987, Geology of Korea. The Kyohak-sa Publishing Co. Seoul, 1st ed., 514p.

Lee, D.S. and Lee, H.Y., 1976, Geological and geological study on the rock sequences containing oily materials in southern coast area of Korea. J. Korean Inst. Min Geol., 9, 45-74, in Korean.

Moon, H.S., Kim, Y.H., Kim, J.H. and You, J.H., 1990, K-Ar ages of alunite and sericite in altered rocks, and volcanic rocks around the Haenam area, Southwest Korea. J. Korean Inst. Min. Geol., 23, 135-141, in Korean.

Nagao, K. and Itaya, T., 1988, K-Ar age determination. Mem. Geol. Soc. Japan, 29, 5-21, in Japanese.

Nagao, K., Nishido, H., Itaya, T. and Ogata, A., 1984, An age determination by K-Ar method. Bull. Hiruzen Res. Inst., 9, 19-38, in Japanese.

Nier, A.O., 1950, A redetermination of the relative abundances of the isotopes of carbon, nitrogen, oxygen, argon and potassium. Phys. Rev., 77, 789-793.

Shibata, K., 1968, K-Ar age determination on granitic and metamorphic rocks in Japan. Rep. Geol. Surv. Japan, 227, 1-73.

Silberman, M.L. and Ashley, R.P., 1970, Age of ore deposition at Goldfield, Nevada, from potassium-argon dating of alunite. Econ. Geol., 65, 352-354.

Steiger, R.H. and Jäger, E., 1977, Subcommission on geochronology convection on the use of decay constants in geo- and cosmo-chronology. Earth Planet. Sci. Lett., 36, 359-362.

Wasserburg, G.J. and Hayden, R.J., 1955, ^{40}K-^{40}Ar dating. Geochim. Cosmochim. Acta, 7, 51-60.

(책임편집 : 좌용주)

韓國 南西部의 熱水粘土鑛床과 周邊岩에 대한 K-Ar 年代 測定

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요 약 : 韓國 南西部의 粘土鑛床들과 周邊岩에 대한 K-Ar 年代測定 結果, 粘土鑛物이 78.1～81.4 Ma, 白堊期 火山岩類(黃山層)가 81.4～86.4 Ma, 白堊期 花崗岩類는 77.1～81.5 Ma의 年代로 나타났다. 이 結果는 粘土鑛床들이 白堊期 後期의 酸性마그마티즘과 成因的으로 密接한 關係가 있음을 指示한다. 月角山 花崗岩은 K-Ar 黑雲母의 年齡이 140.9～144.8 Ma로 밝혀져, 이의 貫入年代는 쥬라기로 判明되었다. 이곳의 粘土鑛床들과 白堊期 花崗岩類의 密接한 關係는 粘土鑛床들이 火山活動에 隨伴된 熱水作用에 의한 것이 아니라 花崗岩類의 貫入에 따른 熱的 效果(熱水 循環)에 起因된 熱水變質作用으로 形成되었다.

핵심어 : K-Ar 年代測定, 粘土鑛床, 白堊期 後期의 酸性 화성활동

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