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Talc Mineralization in the Middle Ogcheon Metamorphic Belt (I): with Emphasis of the Stable Isotope Studies of the Dongyang Talc Deposit

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ABSTRACT: Mineralized zone in the Dongyang talc deposits occurs on the lowest dolomite member of the Hyangsanri Dolomite belonging to the Ogcheon Supergroup. Ore bodies are emplaced as pipe-like body along the axis of minor folds plunging 40° to the west developed in these dolomite layers. Amphibolite and chlorite schist are found along the upper or lower contact of all ore bodies (Kim *et al.*, 1963; Park and Kim, 1966). Following the recrystallization and silicification of dolomite, tremolite and tabular and leafy talc(I) of the earlier stage formed, and microcrystalline talc(II) formed in the later stage. Talc(I) and tremolite formed by the reaction between dolomite and the fluid. Whereas talc(II) formed by the reaction between dolomite and fluid, or by the reaction between early formed tremolite and fluid. During the early stage of mineralization, the fluid was the H_2O-CO_2 system dominant in CO_2. In the later stage, the composition of the fluid changed to H_2O-NaCl-CO_2 system, and finally to the H_2O-NaCl system. The pressure and temperature conditions of the formation of tremolite associated with talc(I) were 1,640~2,530 bar, and 440~480℃, respectively. The pressure and temperature condition of talc(II) ore formation was 1,400~2,200 bar, and 360~390℃, respectively. These conditions are much lower than the metamorphic pressure and temperature of the rocks from the Munjuri Formation located about 5 km to the north of Dongyang talc deposit. $\delta^{13}C$ and $\delta^{18}O$ values of dolomite which is the host rock of the talc ore deposit are 2.9~5.7‰ (PDB), and −7.4~16.8‰ (PDB), respectively. These values are little higher than those from the Cambro-Ordovician limestones of the Taebaeksan region, but belong to the range of the unaltered sedimentary dolomite. $\delta^{18}O$ and δD values of the talc from Dongyang deposit are 8.6~15.8‰ (vs SMOW), and −65~−90‰ (vs SMOW), respectively, belonging to the range of magmatic origin. These values are quite different from those measured in the metamorphic rocks of Munjuri and Kyemyungsan Formation. $\delta^{34}S$ value of anhydrite is 22.4‰ (CDT), which is much lower than $\delta^{34}S$ (30‰ vs CDT) of sulfate of early Paleozoic period, and indicates the possibility of the addition of magmatic sulfur to the system. Talc ores show the textures of weak foliation and well developed crenulation cleavages. Talc ore deposit in the area is concluded as hydrothermal replacement deposit formed before the latest phase of the deformations that Ogcheon Belt has undergone.

INTRODUCTION

Dongyang talc deposit emplaced in dolomite is most important talc deposit in Korea in its quality and production as well as its exploration history. Many researches for this deposit has been performed since the work of Choi (1956), Kim *et al.* (1963) has carried out detailed geologic mapping (1/10,000, 1/1, 200) and underground geologic mapping (1/500) in the deposit and surrounding areas and revealed that the talc deposit was emplaced within the lowest dolomite member of the Hyangsanri Dolomite. Talc ore bodies have close spatial relationship with amphibolite and was emplaced being controlled by bedding and fault. Ore shoots were formed along the fold axis and show pipe-like ore bodies. Kim *et al.* (1963) provided that talc deposits were formed as hydrothermal replacement deposits by the ascending residual fluid following the intrusion of amphibolite, and the exploration guide was proposed based on the result of research shown above. Reedman *et al.* (1973) reported that this deposit was formed by regional metamorphism and the related hydrothermal solution was associated with the intrusion of Jurassic granodioritic complex. About the kind and origin of the host rock of this deposit, Lee (1987) reported that dolomite was formed by the Penecontemporaneous dolomitization related to submarine volcanic activity and diagenesis, and the chlorite schist and amphibolite is mafic rocks of the igneous origin, and the talc deposit was formed through the telethermal solutions. On the other hand, Park and Chon (1988) revealed that dolomite is from sedimentary origin, amphibolite and chlorite schist are of igneous origin, and the talc ore

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deposit is genetically related to the regional metamorphism based on the carbon and oxygen isotope and petrochemical studies of the host rocks of the deposit. Moon and Kim (1988) interpreted the origin of this deposit as hydrothermal replacement deposit unrelated to contact metasomatism or regional metamorphism mainly based on the mineralogic and chemical data.

Despite of many researches in this area, the timing of mineralization and the origin of the ore fluid has never been clearly revealed. In this study, the mineral occurrence and ore texture at Dongyang and at adjacent mines were examined, stable isotopes (C, O, H, S) from the talc, tremolite, anhydrite, and other country rocks were analyzed, and fluid inclusion of the ore and gangue minerals were studied. Based on these results, the origin and the nature of the ore fluid and the temperature and pressure conditions of the talc mineralization were estimated and finally, discussed on the genesis of the talc deposit.

GEOLOGY

Geology of Dongyang talc mine area consists of metamorphic rocks of the Ogcheon Supergroup and intruded amphibolite of unknown age, and the granitoids of the Mesozoic era. Many scholars has been studied the age and stratigraphy of the Ogcheon Supergroup, but they could not reach the agreement for these subject.

In the area of the Dongyang talc deposit, from the bottom to top, the Ogcheon Supergroup consists of Munjuri Formation, Daehyangsan Quartzite, Hyangsanri Dolomite, and Kyemyeongsan Formation (Fig. 1). Lee and Park (1965), Son (1976), and Kim (1970) interpreted the sequence of the formations as reversed and proposed that the Kyemyeongsan Formation is the lowest one in this area. However, Reedman *et al.* (1973), Choi and Kim (1981), Ihm *et al.* (1991) proposed that the stratigraphic sequence is normal based on the cross bedding, graded bedding, the relationship between bedding plane and slaty cleavage. Lee (1987) reported that Munjuri Formation is the upper layer than the Daehyangsan Quartzite and contacted by thrust fault. But Ihm *et al.* (1991) reported that the evidence of thrust could not recognized in the field. Stratigraphic sequence proposed by Reedman *et al.*(1973) is adapted in this report.

Munjuri Formation consists of phyllite, chlorite schist, and frequently shows well developed wavy crenulation. Daehyangsan Quartzite consists of white quartzite and intercalated with dolomite lamella near the contact with upper Hyangsanri Dolomite. Hyangsanri Dolomite consists of lower dolomite (D1), middle pink banded limestone (L), and upper dolomite (D2). The thickness of Hyangsanri Dolomite is 300~400 m. Lower dolomite composed of white dolomite and the thickness is 100~200 m. Developed talc ore bodies in the Dongyang and in adjacent mines are all emplaced in the lower dolomite layer. Middle limestone mainly consists of pink banded limestone with thin bed of grey limestone, quartz-sericite schist, white dolomite, quartzite, and calcareous phyllite. Upper dolomite consists of white dolomite and quartzite, and the total thickness ranges from 8 to 28 m.

Kyemyeongsan Formation consists of biotite schist, sericite chlorite schist, quartz sericite schist, amphibolite, and limestone. Park and Kim (1966) reported that the original rocks of the metamorphic rocks consisting the Kyemyeongsan Formation were volcanic rocks of rhyolite-rhyodacitic composition and amygdaloid-bearing andesitic rocks intercalated in places.

Amphibolites occur along the bedding of dolomite or occur as dikes irregularly cutting the bedding. Within the talc mineralized zone, ore bodies occur along the upper or lower contact of the amphibolite showing close spatial relationship between ore body and amphibolite. Amphibolite parallel to the bedding plane of dolomite commonly altered to chlorite schist or chlorite-talc schist. Lee (1987) and Park and Chon (1988) studied the mineral composition and geochemical characteristic of chlorite schist and amphibolite and concluded as the alteration product of mafic igneous rocks, or metabasite.

As for the granitic rocks, Cretaceous Bulguksa Granite and Jurassic Daebo Granite are exposed about 3 km north east and north of talc deposit respectively. No skarn zone is reported in the contact between Hyangsanri Dolomite and the Bulguksa Granite. In addition to the intrusions described above, lamprophyre dikes are cutting all of the above rocks in the area.

The bedding of the Ogcheon Supergroup in this area shows the strike of N20°~55°E and the dip of 40°~60°NW. Axis of minor folds plunges 40° to the west and lineation parallel to the axis of the folds are dominant in this area. In dolomite linear structure parallel to the fold axis are clearly developed. Reedman *et al.* (1973) proposed that Ogcheon Supergroup were deformed at least three phases, and the first and second were the strong folding event in the Hwanggangri area. Linear structures in the Dongyang talc deposit are those (L1 and L3) parallel to the fold axis formed in the first and third phases of defo-

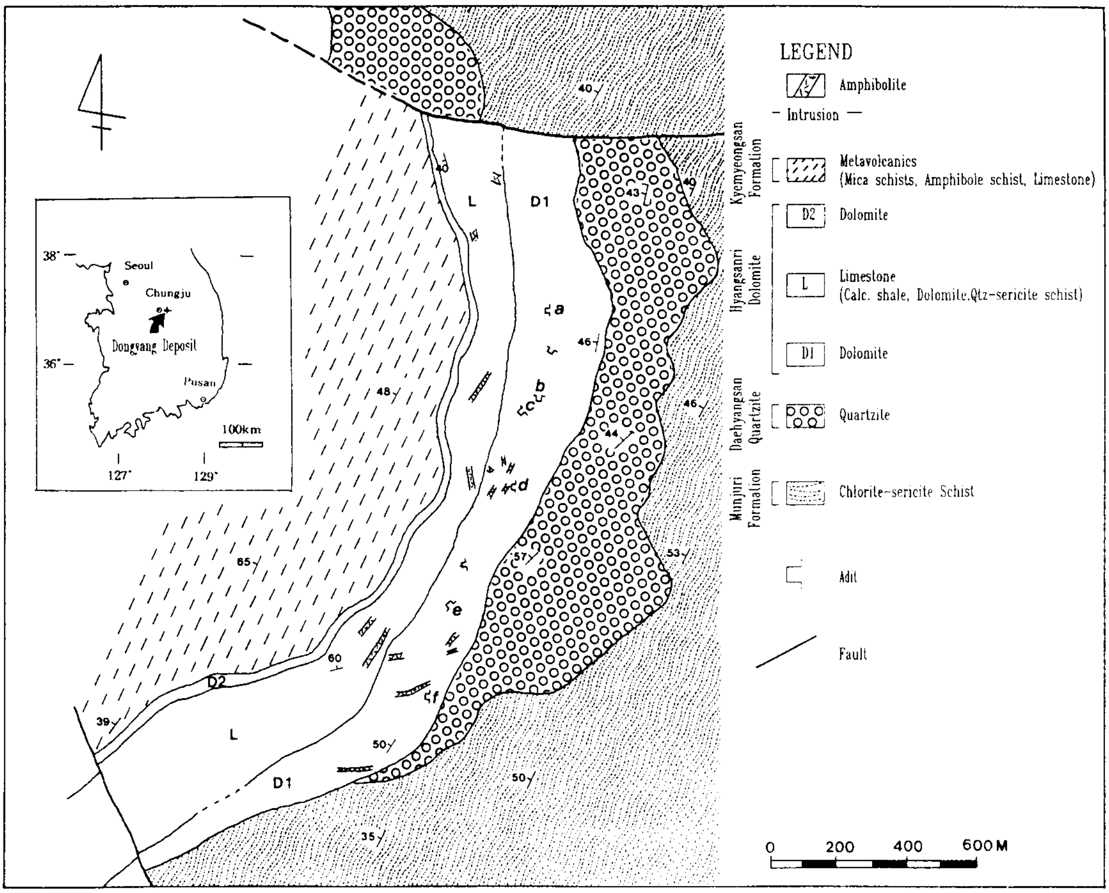

Fig. 1. Geology and location of Dongyang Talc deposit. a; Chosun adit, b; Bongang (Main adit), c; Jungweon adit, d; Shinhung adit, e; Dondaemi adit, f; Hanugol adit.

rmation.

ORE DEPOSITS

Major ore bodies developed in Dongyang talc deposit are six bodies distributed within 1200 m distance: Chosun, Jungweon, Bongang (main), Shinhung, Dondaemi, and Hanugol ore body from north to south. These ore bodies were emplaced within Lower dolomite about 40~80 m above the boundary between Lower dolomite (D1) and Daehyangsan Quartzite. In most cases amphibolite or chlorite schist is in contact with ore bodies. But in general, ore bodies are located directly above the chlorite schist. Ore bodies occur as lense shape in a plane view, and steeply dipping rod-shaped bodies. The pipe-shaped ore shoot are emplaced along the fold axis plunging at approximately 40° to the west, or occur along the intersection of bedding plane and cleavage or fracture zone. These ore bodies are emplaced replacing host rock. The size of the ore bodies are 20~140 m in long diameter, and 5~20 m in short diameter in a plane view, extending more than 800 m vertically (Korea Mining Promotion Corporation, 1988). In the mineralized zone, based on the relative ratio of remained dolomite and talc, ore shoot consists of almost pure talc, and the grade of ore becomes poor as remained dolomite ratio increases.

Host rock of talc ore consists of dolomite and chlorite schist. Of these two, ore bodies within dolomitic host rock are more important in quality and production of the ore. Therefore major ore bodies developed are from host rock of dolomite. Dolomite recrystallized and silicified along the contact with talc ore, consequently quartz grains aligned along recrystallized dolomite grain boundaries. Pure talc was formed from dolomite; many residual lenses of recrystallized and silicified dolomites are present in the ore.

Talc ores originated from dolomite consist of talc, tremolite, dolomite, calcite, and quartz with occasional anhydrite. There are two generations of talc in the ore. An older generation of talc is tabular or leafy crystal habit and occurs in massive foliated or fibrous aggregates. Tabular flakes disseminated in recrystallized dolomite in places. On the other hand younger generation of talc is fibrous and microcrystalline aggregates and occurs as irregular shaped mass and veins cutting through early formed talc, tremolite and host rock. Older and younger generations of talc will hereafter be called talc(I) and talc(II) respectively.

Talc(I) was formed from dolomite by following reaction

$$3CaMg(CO_3)_2 + 4SiO_2 + H_2O = Mg_3Si_4O_{10}(OH)_2 + 3CaCO_3 + 3CO_2 \quad (1)$$

dolomite, fluid, fluid = talc, calcite, fluid

Talc(II) occur with fine calcite grains and form rim around the tremolite crystal outline which is in contact with dolomite. Fine talc(II) and calcite associations also occur as alteration product along the cracks within the tremolite crystals. These textures indicate that talc(II) and calcite are formed as the product of two reactions shown below.

$$3Ca_2Mg_5Si_8O_{22}(OH)_2 + 2H_2O + 6CO_2 = 5Mg_3Si_4O_{10}(OH)_2 + 4SiO_2 + 6CaCO_3 \quad (2)$$

tremolite, fluid, fluid = talc, fluid, calcite

$$Ca_2Mg_5Si_8O_{22}(OH)_2 + CaMg(CO_3)_2 + H_2O + CO_2 = 2Mg_3Si_4O_{10}(OH)_2 + 3CaCO_3 \quad (3)$$

tremolite, dolomite, fluid, fluid = talc, calcite

Talc(II) ores were formed by not only reaction (2) and (3) but also reaction (1).

Tremolite occurs in long prismatic crystal bundles and columnar to fibrous. This tremolite can be ascribed to the following reaction at an earlier stage

$$5CaMg(CO_3)_2 + 8SiO_2 + H_2O = Ca_2Mg_5Si_8O_{22}(OH)_2 + 3CaCO_3 + 7CO_2 \quad (4)$$

dolomite, fluid, fluid = tremolite, calcite, fluid

It can sometimes be seen that fresh and unaltered tremolite associate with leafy, tabular talc(I) and form five mineral association (tremolite + talc + calcite + dolomite + quartz) in the early stage ore. In view of the results so far obtained, talc ores were generated in early and late stages during mineralization.

Fig. 2 is T-XCO_2 diagram showing isobaric univariant curves for four stable reactions radiate from an isobaric invariant points, at which the six phases assemblage, tremolite, talc, calcite, dolomite, quartz and fluid is stable. These facts reveal that early stage ores are the product of reactions around the invariant point of the Fig. 2.

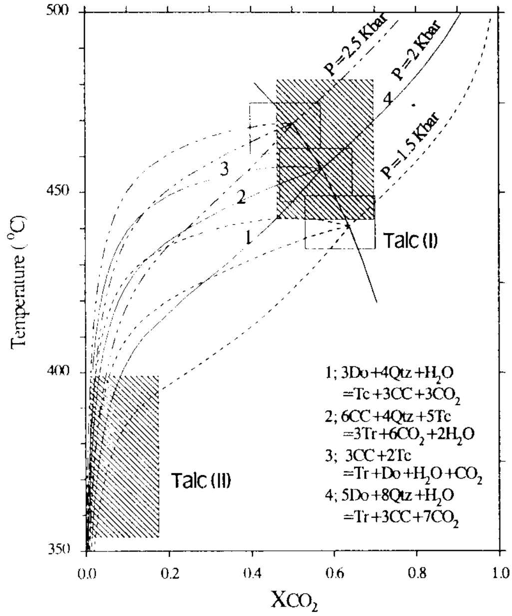

Fig. 2. Pressure and XCO_2 diagram showing condition of talc(I) and talc(II) ore formation. Hatched boxes are obtained from fluid inclusion study at 2 Kbar, dots boxes are obtained from coexisting mineral assemblages.

Based on ore texture and related reactions described above, simplified paragenetic sequence can be summarized as follows,

1. Recrystallization and silicification of host rock
2. Formation of tremolite and talc(I) from dolomite
3. Formation of talc(II) from dolomite and tremolite

Weakly foliated structure or crenulation cleavage developed in talc ore. In particular, tremolite bearing talc ores are folded and long prismatic tremolite crystals are broken at the axial part of the fold and fibrous talcs are complicatedly twisted. Therefor, talc mineralization have occurred before latest phase of the deformations that Ogcheon Belt experienced. Reedman *et al.* (1973) reported that Ogcheon Belt has undergone three phases of deformation and talc deposits formed during the main pulse of regional metamorphism which post-dated F1 folding.

FLUID INCLUSION STUDY

For the fluid inclusion study, quartz, tremolite, anhydrite, and dolomite were examined. However, Tremolite and anhydrite are lack or rare in fluid inclusion and commonly too small for study in size. Therefore heating and freezing experiments were performed mainly for the inclusions in quartz and carbonate mineral. For the heating and freezing experiments, gas flow heating/freezing stage of the Fluid Inc. product was used. Computer program of Brown (1989) was used to calculate the salinity, density, and isochore of the fluid inclusions. Fluid inclusions can be classified as follows according to the phases observed at the room temperature (20℃). The result of heating and freezing experiments were summarized for each type.

Type I inclusion: This type of inclusion consists of liquid and vapor phase. Filling degree is 70~85 and homogenizes to liquid phase in heating experiment. CO_2 hydrate was not recognized in the freezing experiment. This type of fluid inclusion is commonly observed in quartz, dolomite, and tremolite, and mainly occurs in linear alignment implying secondary in origin. Homogenization temperature is 212~275℃, and salinity is 1.8~5.8 wt.% equivalent to NaCl.

Type II-A inclusion: This type of inclusion consists of liquid H_2O, liquid CO_2, and gas CO_2. The volume % of CO_2 is 33~65%. Gas CO_2 is not observed in some inclusions at room temperature. In freezing experiment, CO_2 hydrate formed, and the CO_2 homogenizes to liquid phase and finally homogenized to liquid water. This type of inclusion in quartz is secondary in origin. The melting point of CO_2 was −56.4~−57.5℃, and the homogenization temperature of CO_2 was 21.8~30.8℃. Homogenization temperature is 300~418℃, and the salinity is 1.3~4.7 wt.% equivalent to NaCl. The density of CO_2 is 0.61~0.75 g/cc.

Type II-B inclusion: This type of inclusion consists of CO_2 inclusion. The separation of the phases into liquid CO_2 and gas CO_2 are observed in the freezing experiment. Sometimes, water phase was recognized around CO_2 phase. Formation of CO_2 clathrate can not be recognized during cooling experiment and also precise homogenization temperature of CO_2-H_2O can not be obtained because of too small amount of water phase contained. Volume % of CO_2 is approximated above 80%. This type of inclusion is found in quartz as primary or secondary in origin. The melting point of CO_2 is −56.9~−57.6℃, the homogenization temperature of CO_2 is 9.1~25℃, and the density of CO_2 is 0.71~0.86 g/cc.

Trapping temperature and pressure of type I and II inclusions described above will be locate on the isochore in P-V-T diagram of H_2O-NaCl and H_2O-CO_2 system. Therefore after isochore is acquired from the data of heating and freezing experiment for the fluid inclusions, and equilibrium curves of reaction equation of the host minerals are gained, formation temperature and pressure can be estimated from the intersection of these two curves. As described above, type II-B inclusion is primary or secondary in quartz. Type I and type II-A inclusions are secondary in quartz in contact with talc(II). Therefore, based on the paragenetic sequence of the minerals, type II-B represent the early stage of mineralization characterized by silicification and the formation of talc(I) associated with tremolite. Type I and type II-A inclusions are considered to represent the stage of talc(II) ore formation. The formation pressure and temperature of talc(I) associated with tremolite estimated from the isochore of type II-B inclusion and the reaction equation (2) and (3) are 1,640~2,530 bar, 440~480℃, respectively. The formation pressure and temperature of talc(II) estimated from the isochore of type I inclusion and reaction equation (1) are 1,400~2,200 bar, 360~390 ℃, respectively.

As mentioned above formation temperature and XCO_2 of talc(I) ore are around the invariant point at the pressures between 1.5~2.5 Kbar shown in Fig. 2. Temperature and XCO_2 data obtained from fluid inclusion studies are accord with the data deduced from invariant point at the 2 Kbar shown in Fig. 2.

STABLE ISOTOPE STUDIES

Sampling and Analytical Methods

For this research, geology in the Dongyang deposit and its surrounding areas were examined in the field and the samples were collected in the outcrops and from the underground. Samples from the underground mainly from R3 and R4 of Main adit level (+170 L) and Shinhungmaek of 20 level (−209 L). Sample locations are shown in Fig. 3. Several samples are from the ore refinery site of the mine and sampling location is not known for those samples. All stable isotopic analyses were performed in the stable isotope laboratory of the Korea Basic Science Institute.

For the oxygen isotope analysis of talc and other silicate minerals, gas samples were prepared following the method of Clayton and Mayeda (1963). After samples were dried in the vacuum oven, mineral powders were reacted with F_2 gas to produce oxygen gas. O_2 produced was converted to CO_2 and collected

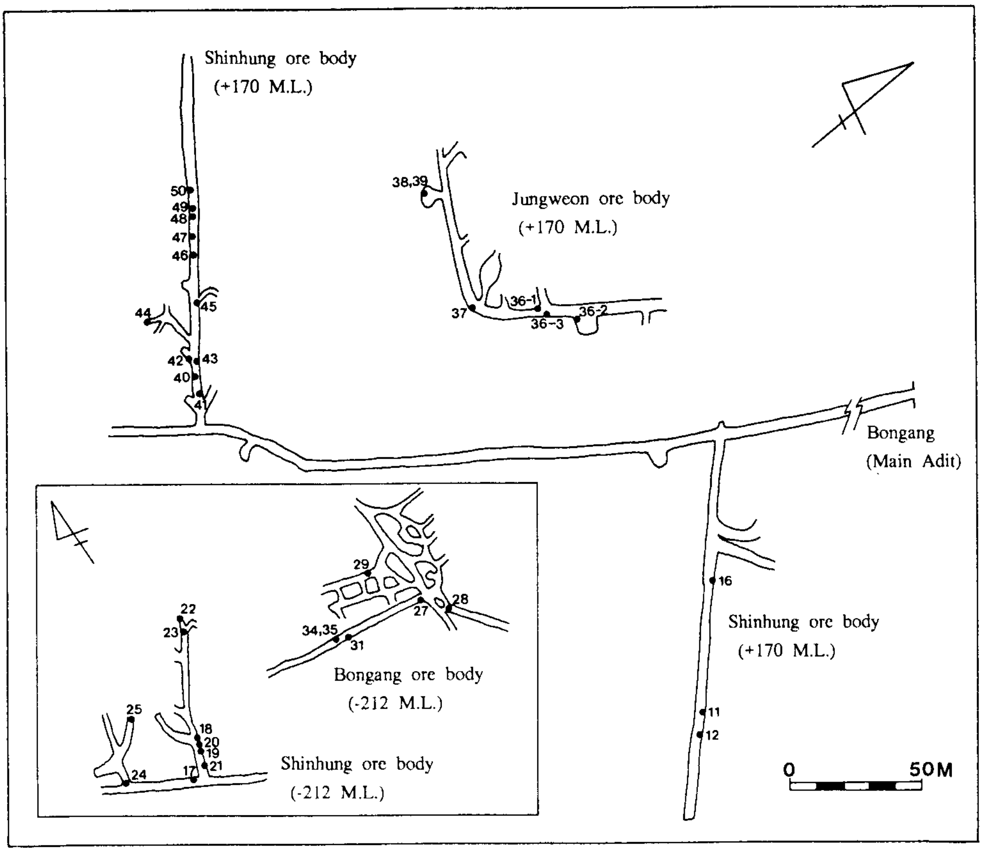

Fig. 3. Location of samples in Dongyang Talc deposit.

in the sealed glass tube, and the CO_2 gas was analyzed on a VG Prism II stable isotope ratio mass spectrometer of the FISON company product.

For hydrogen isotope analysis of the minerals, Kendall and Coplen (1985), and Vennemann and O' Neil (1993)'s method was followed. Water was extracted from whole rock and minerals by melting powder samples in vacuum, and the H_2O was converted to H_2 by reaction with heated zinc in a sealed vycor tube. Water yield were measured by monitoring mass-2 intensity on the mass spectrometer. For carbon and oxygen isotope analyses of carbonate minerals, carbonate powder was reacted with supersaturated phosphoric acid following the method of MaCrea (1950). ISOCARB automated device attached to VG Prism II was used for the carbonate analyses.

In this study, 30 samples were analyzed for oxygen isotope of mineral and whole rock samples (silicate preparation line used), 28 samples were analyzed for hydrogen isotopes, 29 carbonate minerals were analyzed for carbon and oxygen isotopes, and 1 anhydrite was analyzed for sulfur isotope.

The result of isotope analysis are reported in δ-notation as followings.

$$\delta = \left[\frac{R_{sample}}{R_{standard}} \right] \times 1000$$

R_{sample} denotes $^{18}O/^{16}O$, D/H, $^{34}S/^{32}S$, and $^{13}C/^{12}C$. SMOW (Standard Mean Ocean Water) was used for both oxygen and hydrogen standard. PDB (Pee Dee formation Belemnite) was used for carbon and oxygen isotope standard of carbonate minerals. CDT (Canyon Diablo Troilite) was used for sulfur standard. Analytical precision of measured $\delta^{18}O$, δD, $\delta^{13}C$, and $\delta^{34}S$ is ± 0.05, ± 1.0, ± 0.05, and ± 0.2‰ respectively.

Result

Result of oxygen isotope analyses using silicate line is shown in Table 1.

$\delta^{18}O$ values of talc ranges from 8.6 to 15.8‰ (vs.

Table 1. Oxygen isotope analyses of rock and mineral separates from the Dongyang deposit area.

Sample #	$\delta^{18}O$ per mil (SMOW)	Rock Type	Comment
DY1	11.4	Talc	Dy
DY1-1	14.2	Talc	Dy
DY3-1	11.4	Chl. Sch.	Dy
DY4	14.3	Talc	Dy
DY5	13.4	Talc	Dy
DY6	13.7	Talc	Dy
DY7	12.1	Talc	Dy
DY19	5.6	Amp	Dy
DY20-17	7.4	Chl. Sch.	Dy
DY21	5.5	Amp	Dy
DY22-1	11.4	Talc	Dy
DY23	12.9	Talc	Dy
DY25	9.3	Talc	Dy
DY27	7.2	Amp	Dy
DY29	10.3	Talc	Dy
DY30	13.2	Talc	Dy
DY31	15.4	Chl. Sch.+Dol	Dy
DY34	15.1	Talc	Dy
DY39	8.6	Talc+Dol.	Dy
DY40	12.3	Talc	Dy
DY41	12.5	Talc+Dol.	Dy
DY42-16	8.1	Amp.+Chl. Sch.	Dy
DY43sch	12.4	Schist	Dy
DY44	15.8	Talc	Dy
Chungju 5	12.9	Talc	CJ
Hanugol Talc	12.5	Talc	HNG
Hanugol Trem.	10.4	Tremolite	HNG
Kyemyeongsan	4.2	W.R.	KMS
Munjuri #1	1.7	W.R.	MJR
Munjuri #2	0.9	W.R.	MJR

DY; Dongyang deposit, CJ; Chungju deposit area, W.R.; whole rock, HNG; Hanugol area, KMS; Kyemyeongsan Fm, MJR; Munjuri Fm.

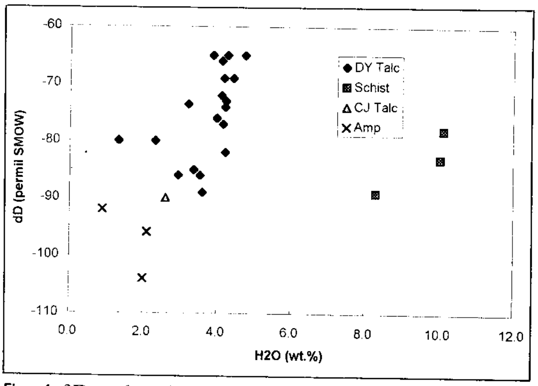

Fig. 4. δD and H_2O content cross plot in Dongyang deposit area.

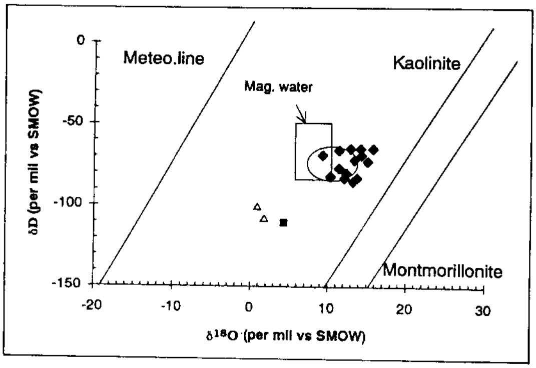

Fig. 5. δD and $\delta^{18}O$ cross plot with meteoric water line, Kaolinite, Montmorillonite line, and a box of magmatic water. Solid diamond denotes talc. Solid rectangle and open triangle denote Kyemyeongsan Formation and Munjuri Formation respectively. Oval shape represent the isotopic composition of the fluid in equilibrium with talc (only oxygen shift was considered).

SMOW). Talc and tremolite of the Hanugol area in the Dongyang deposit also show similar range of oxygen isotope values. $\delta^{18}O$ value of chlorite schist is 12.4‰ and fall within the range of talc. Average and standard deviation of $\delta^{18}O$ value of standard sample (NBS28) are 9.59‰ and 0.13 respectively. Comparing with reference values of 9.6, the result shows very good reproducibility and precision.

The result of hydrogen isotope analyses for minerals and whole rocks in the study area are shown in Table 2. δD values of the talc samples ranges from −65 to −90‰ (vs. SMOW). H_2O content in general is near 4.0 wt% and agree with the amount of water calculated from the chemical formula (Fig. 4). Several samples of very high water content or relatively low water content also show similar δD values to those of major group of talc. This is because those samples contain other hydrous minerals or silicates except talc. δD values of Hanugol tremolite or chlorite schist show similar range to those of talc. δD values of amphibolite whole rock samples ranges from −92 to −104‰ (vs. SMOW), a little lower than those of talc.

Fig. 5 shows plotting of oxygen and hydrogen isotope values of talc and chlorite schist with meteoric water line, kaolinite, and montmorillonite. At present, oxygen and hydrogen isotope data of talc is not abundant yet, and the fractionation factors for talc are not well known. However, fractionation factor of talc is frequently considered to be similar to those of clay minerals (Blount and Vassiliou, 1980; Noack *et al.*, 1986). Isotope values of talc plotted in Fig. 5 are higher in δD values and lower in $\delta^{18}O$ than those of

Table 2. Oxygen isotope analyses of rock and mineral separates from the Dongyang deposit area.

Sample No.	$\delta^{18}O$ per mil (SMOW)	H_2O wt.%	Rock Type	Comment
DY1	−77	4.1	Talc	DY
DY1-1	−65	4.7	Talc	DY
DY3-1	−78	10.1	Chl. Sch.	DY
DY4	−69	4.4	Talc	DY
DY5	−72	4.1	Talc	DY
DY7	−83	10.0	Talc+Chl. Sch.	DY
DY20-17	−86	3.5	Talc	DY
DY22-1	−66	4.1	Talc	DY
DY23	−65	3.9	Talc	DY
DY25	−69	4.2	Talc	DY
DY29	−82	4.2	Talc	DY
DY30	−85	3.4	Talc	DY
DY31	−76	4.0	Talc	DY
DY34	−73	4.2	Talc	DY
DY40	−80	2.3	Talc	DY
DY41	−74	3.2	Talc	DY
DY42-16	−89	3.6	Talc	DY
DY43sch	−89	8.3	Schist	DY
DY44	−65	4.3	Talc	DY
Chungju 5	−90	2.6	Talc	CJ
Hanugol Talc	−74	4.2	Talc	HNG
Hanugol Trem	−86	2.9	Tremolite	HNG
DY21 Amp	−104	2.0	Amphibolite	DY
DY27 Amp	−96	2.1	Amphibolite	DY
DY42 Amp	−92	0.9	Amphibolite	DY
Kyemyeongsan	−111	1.0	W.R.	KMS
Munjuri ♯1	−110	2.4	W.R.	MJR
Munjuri ♯2	−102	2.3	W.R.	MJR

DY; Dongyang deposit, CJ; Chungju deposit area, HNG; Hanugol area, W.R.; whole rock, KMS; Kyemyeongsan Fm, MJR; Munjuri Fm.

Table 3. Carbon and oxygen isotope data in Dongyang Talc Deposit.

Sample	$\delta^{13}C$ per mil vs. PDB	$\delta^{18}O$ per mil vs. PDB	$\delta^{18}O$ per mil vs. SMOW	Rock type
DY8	2.9	−12.7	17.7	dolomite (dol)
DY11	5.5	−7.9	22.7	dolomite (dol)
DY12	5.2	−9.1	21.5	dolomite (dol)
DY16	5.0	−7.5	23.1	dolomite (dol)
DY17	4.0	−11.4	19.0	dolomite (dol)
DY23	4.5	−14.1	16.2	dol. partly Talc
DY24	4.7	−11.9	18.5	dolomite
DY28	5.7	−7.0	23.6	dolomite
DY29	5.1	−11.2	19.2	dol-talc intergrowth
DY35	4.9	−12.6	17.9	dolomite
DY36	5.1	−10.3	20.2	dolomite
DY36-1 cc	−1.9	−22.3	7.7	calcite
DY37	5.4	−9.6	21.0	dolomite
DY45	4.8	−9.6	20.9	dolomite
DY46	3.7	−10.4	21.1	dolomite
DY47	4.6	−16.8	13.4	limestone(Ls)
DY48	5.3	−11.9	18.5	limestone(Ls)
DY49	5.1	−12.1	18.3	pink Ls
DY50	5.0	−12.2	18.3	dolomite
DY52	1.9	−11.8	18.6	dolomite
DY53	5.1	−10.0	20.5	dolomite
Hanugol	4.9	−12.2	18.2	dolomite
Hyangsanri 1	4.5	−8.0	22.6	dolomite
Hyangsanri 2	4.9	−7.4	23.2	dolomite
Hyangsanri 3	4.4	−7.7	22.9	dolomite
Chungju Adit 5-1	3.6	−13.1	17.3	dolomite
Chungju Adit 5-2	5.3	−12.9	17.5	dolomite
Chungju Adit 5-3	2.8	−13.6	16.7	dolomite
Daerim quarry	4.2	−7.8	22.8	dolomite

DY; Dongyang deposit, CJ; Chungju deposit area, HNG; Hanugol area, DR; Daerim deposit.

kaolinite or montmorillonite formed on the surface temperature of the earth.

Park and Chon. (1988) reported oxygen and carbon isotope data of dolomite which is the host rock in this area. Kim (1980), and Park and Woo (1986) studied the oxygen and carbon isotopes of domestic limestone. Carbon and oxygen isotope data analyzed in Dongyang deposit area shows that the $\delta^{13}C$ and $\delta^{18}O$ of dolomite ranges from 2.9 to 5.7‰ (PDB), from −7.4 to −16.8‰ (PDB) respectively (Table 3). Calcite sample (DY36-1) has $\delta^{13}C$ of −1.9 and $\delta^{18}O$ of −22.3‰ (PDB). Samples from Chungju deposit has the similar range of carbon and oxygen isotope values to those of Dongyang deposit as shown in Fig. 6. These isotope values are similar to those reported in Park and Chon (1988). These carbon and oxygen isotope values are much heavier than those reported in other limestone in Korea. In case of oxygen isotope, it is known that $\delta^{18}O$ of dolomite is heavier by 5~7‰ than limestone formed at the same temperature (25℃)(O'Neil and Epstein, 1966; Sheppard & Schwarcz, 1970).

One anhydrite was analyzed for sulfur isotope, giving the $\delta^{34}S$ value of 22.4‰ vs. CDT.

DISCUSSIONS

The genetic model proposed for the Dongyang talc deposit can be grouped into two types: hydrothermal replacement deposit (Kim *et al.*, 1963; Park and Kim, 1966; Lee, 1987; Moon *et al.*, 1988) and regional metamorphic deposit (Reedman *et al.*, 1983; Park and Chon, 1988). It is generally agreed that talc in this deposit was formed as the result of the reaction between the SiO_2-rich fluid and the country rock of dolomite. One of the important problems still unsolved is whether the fluid related to talc mineralization is magmatic, metamorphic, meteoric, or mix of various origin.

Hydrogen isotope data of talc is very rare. But oxygen isotope data of talc has been accumulated by Blount and Vassiliou (1980), Noack *et al.* (1986), Zheng *et al.* (1995), Tennie *et al.* (1995), although still we need more data to be used for full range of temperature. Blount and Vassiliou (1980) and Noack *et al.* (1986) estimated the isotopic composition of talc assuming that the fractionation factor between water and talc is similar to those between water and clay minerals. Fig. 5 shows the results of estimated isotopic composition of the fluid in equilibrium with talc. The oval shape is the composition of the fluid in equilibrium with talc assuming the same oxygen isotope fractionation factor for the talc and montmorillonite. Only oxygen isotope was considered for the shift of the composition of the fluid in equilibrium with talc. Considering the relationships between meteoric water and the clay minerals, the isotopic composition of fluid shown as an oval could move more upward when hydrogen isotope fractionation is considered. In general, isotope values of hydrothermal alteration type clay minerals are plotted near the isotope values of related fluid. Isotope values of talc from Dongyang deposit are far from those of low temperature clay mineral lines, implying much higher formation temperature. The plotting of talc shows quite narrow area and range near or overlapping the magmatic water values (δD: −50∼−85‰; $\delta^{18}O$: 5.5∼9.0‰). The oxygen and hydrogen isotope values of the metamorphic rocks around the talc deposit (Munjuri and Kyemyeongsan Formation) forms distinct plottings apart from talc values (Fig. 5). Calculated isotopic values of the fluid even more agree well with magmatic water rectangle. Oxygen and hydrogen isotope ratios of the talc and related fluid indicates that the source fluid was from the hydrothermal fluid of the igneous origin, and formed at the much higher temperature than the clay minerals of the surface environment.

The sulfur isotope values from anhydrite (22.4‰ vs. CDT) in this area is very similar to those of present sea water. However, the sulfur isotope values of sulfate in early Paleozoic is known to be near 30‰ vs. CDT. Although more analyses are required to get any conclusions for the source of sulfur, the sulfur isotopic value of anhydrite in the area is much lower than those of early Paleozoic and indicates the possibility of the addition of sulfur of the igneous origin.

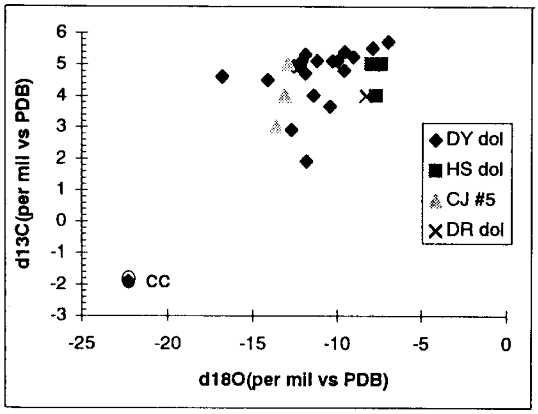

Fig. 6. C and O isotopes of carbonate rocks in the Dongyang deposit area.

The textural evidence for history of mineralization in Dongyang mine indicate as following sequence; 1) recrystallization and silicification of host rock dolomite. 2) Formation of tremolite and talc(I) ore from dolomite. 3) Formation of talc(II) ore from dolomite and tremolite.

Temperature and pressure condition during formation of talc(I) and talc(II) ore are 440∼480℃, 1,640∼2,530 bar and 360∼390℃, 1,400∼2,200 bar, respectively based on fluid inclusion data and condition of reaction forming host minerals. Talc(I) ore was formed around the invariant point in Fig. 2 which represents the intersection of isobaric unvariant PT curve four reactions (1), (2), (3) and (4) in Fig. 2 at earlier stage. When some of talc(II) formed by reaction (2) and (3) shows reverse age relation of talc and tremolite. Therefore these talc(II) ores are the products of reverse reaction after temperature and XCO_2 decreased.

Data of fluid inclusion indicate that nature of fluid related talc(I) ore was H_2O-CO_2 system dominant in CO_2 but in the late period of talc(II) ore formation fluid becomes that of H_2O-NaCl-(CO_2) system.

Based on the calcite-dolomite geothermometer, Moon and Kim (1988) reported that the temperature far from the talc ore was 360∼470℃, and the peak metamorphic temperature of this area was 470± 30℃, and the temperature near the talc ore belongs to the range of temperature lower than those of regular applicable T-calculation of Sheppard and Schwarcz (1970). The temperature differences with distance from the ore body was suggested to indicate that the talc ore was formed as a product of local hydrothermal activity rather than regional metamorphism.

Cho *et al.* (1994) reported the metamorphic temperature and pressure as 500~600℃, and 6~7 kb based on the geobarometer and geothermometer of the metamorphic minerals included in the schist of the Munjuri formation located about 5 km to the north of the Dongyang talc deposit. The condition of this temperature and pressure is quite different from those of Dongyang talc deposit. So far, Dongyang talc deposit is considered as hydrothermal replacement deposit by the fluid of the magmatic origin based on the isotope data of ore fluid, and temperature – pressure condition of mineralization. If the fluid involved in the formation of Dongyang talc deposit was of magmatic origin, what kind of magma would be related to the production of hydrothermal fluid? And among the igneous rocks in this area, which one is the igneous rock related to the formation of talc ore?

To solve this problems the age of talc formation and the age of amphibolite need to be determined in the first hand.

CONCLUSIONS

The results of petrographic, fluid inclusion, and stable isotope study of the Dongyang talc deposit can be summarized as follows:

1. In the talc mineralization of the Dongyang talc deposit, following the recrystallization and silicification of dolomite, tremolite, and tabular and leafy talc (I) of the earlier stage formed, and microcrystalline talc(II) formed in the later stage. Talc(I) formed as a result of the reaction between dolomite and fluid. Talc(II) formed as a result of the reaction between dolomite and fluid, or the reaction between early formed tremolite and fluid.

2. During the early stage of mineralization, the fluid was dominant in CO_2 and belonged to the H_2O-CO_2 system. In the later stage, the composition of the fluid changed to H_2O-NaCl-CO_2 system, and finally to the H_2O-NaCl system.

3. The pressure and temperature conditions of silicification of dolomite and the formation of tremolite associated with talc(I) were 1,640~2,530 bar, and 440~480℃, respectively. The P-T condition of talc(II) formation was 1,400~2,200 bar, and 360~390℃, respectively. These conditions are much lower than the metamorphic pressure and temperatures of the schists from the Munjuri Formation located about 5 km to the north of Dongyang talc deposit.

4. $\delta^{13}C$ and $\delta^{18}O$ values of dolomite which is the host rock of the deposit are 2.9~5.7‰ (PDB), and −7.4~16.8‰ (PDB), respectively. These values are a little higher than those from the Cambro-Ordovician limestones of the Taebaeksan region, but belong to the range of unaltered sedimentary dolomite.

5. $\delta^{18}O$ and δD values of the talc from Dongyang deposit are +8.6~15.8‰ (vs SMOW), and −65~−90‰ (vs SMOW), respectively, belonging to the range of magmatic origin. These values are quite different from those measured in the metamorphic rocks of Munjuri and Kyemyungsan Formation. $\delta^{34}S$ value of anhydrite is 22.4‰ (vs CDT), which is much lower than $\delta^{34}S$ (30‰ vs CDT) of sulfate of early Paleozoic period, and indicates the possibility of the addition of magmatic sulfur to the system.

6. Talc ores show the textures of weak foliation and well developed crenulation cleavages. Talc ore deposit in the area is concluded as hydrothermal replacement deposit formed before the latest phase of the deformations that Ogcheon Belt has undergone.

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REFERENCES

Blount, A. M. and Vassiliou, A. H. (1980) The mineralogy and origin of the talc deposits near Winterboro, Alabama. Economic Geology, v. 75, p. 107-116.

Brown, P. E. (1989) FLINCOR: A microcomputer program for the reduction and investigation of fluid inclusion data. American Mineralogist, v. 74, p. 1390-1393.

Cho, M. S., Min, K. W. and Kim, H. C. (1994) Metamorphism in the central Ogcheon Belt. Field trip guidebook; Structure and Metamorphism of the Ogcheon Belt, IGCP 321 Forth International Symposium and Field Excursion, Han Lim, Seoul, p. 97-120.

Choi, S. I. (1956) Geology and Ore deposits of the Dongyang Talc Mine. Correction of Papers, Seoul National Univ. Graduate School, p. 1-42.

Choi, W. C. and Kim, D. H. (1981) The Study of the Ogcheon Geosynclinal Belt (1). Report on Geoscience

and Mineral Resources, KIGAM, v. 11, p. 19-44.
Clayton, R. N. and Mayeda, T. K. (1963) The use of bromine pentafluoride in the extraction of oxygen from oxides and silicates for isotopic analysis. Geochim. Cosmochim. Acta, v. 27, p. 43-52.
Ihm, M. H., Kim, Y. E. and Chang, T. W. (1991) Deformation History and Strain Analysis of Daehyangsan Quartzite in Chungju Area, Korea. Jour. Geol.Soc. Korea, v. 27, p. 191-199.
Kendall, C. and Coplen, T. B. (1985) Multisample conversion of water to hydrogen by zinc for stable isotopic determination. Anal. Chem., v. 57, p. 1438-1440.
Kim, O. J. (1970) Geology and Tectonics of the Mid-Central Region of South Korea. J. Korean Inst. Mining Geology, v. 2, p. 73-90.
Kim, K. H. (1980) Carbon and Oxygen Isotope Studies of the Paleozoic Limestones from the Taebaegsan Region, South Korea. J. Korean Inst. Mining Geol., v. 13, p. 21-27.
Kim, O. J., Park, H. I. and Kim, K. T. (1963) Report on geologic investigation of Dongyang talc deposit. Ilshin Industrial Co. Ltd. (Unpublished), 40p.
Korea Mining Promotion Corporation (1987) Dongyang Mine, Ore Deposits of Korea, v. 11, p. 23-24.
Lee, J. H. (1987) Origin of Talc Deposit in the Chungju Area; Origin and Types of Initial Rocks and their Origin. J. Geol. Soc. Korea, v. 23, p. 173-188.
Lee, M. S. and Park, B. S. (1965) Geologic map of Korea, Hwanggangni Sheet (1 : 50,000). Geol. Surv. Korea.
McCrea, J. M. (1950) The isotopic chemistry of carbonates and a paleotemperature scale. J. Chem. Phys., v. 18, p. 849.
Moon, H. S. and Kim, S. T. (1988) The Origin and Mineralization of the Dongyang Talc Deposit. J. Korean Inst. Mining Geol., v. 21, p. 235-255.
Noack, Y., Decarreau; A. and Manceau, A. (1986) Spectroscopic and oxygen isotopic evidence for low and high temperature origin of talc. Bull. Mineral, v. 109, p. 253-263.
O'Neil, J. R. and Epstein, S. (1966) Oxygen isotope fractionation in the system dolomite-calcite-carbon dioxide. Science, v. 152, p. 198-201.
Park, B. K. and Woo, K. S. (1986) Carbon and Oxygen Isotopic Composition of the Middle Cambrian Pungchon Limestone Formation, Korea. J. Geol. Soc. Korea, v. 22, p. 40-52.
Park, C. Y. and Chon, H. T. (1988) A Geochemical Study of Metabasites and Dolomites associated with the Dongyang Talc Ore Deposits. J. Korean Inst. Mineral and Mining Eng., v. 25, p. 135-147.
Park, H. I. and Kim, K. T. (1966) Report on geologic investigation of talc deposit in Dongmag area. Ilshin Industrial Co. Ltd. (Unpublished), 55p.
Reedman, H. H., Fletcher, C. J. N., Evans, R. B., Workman, D. R., Yoon, K. S., Rhyu, H. S., Jeong, S. W. and Park, J. N. (1973) Geology of the Hwanggangni mining district, Republic of Korea. Geol. Min. Inst. Korea, p. 1-118.
Sheppard, S. M. F. and Schwarcz, H. P. (1970) Fractionation of carbon and oxygen isotopes and magnesium between coexisting metamorphic calcite and dolomite. Contrib. Mineral. and Petrol., v. 26, p. 161-198.
Son, C. M. (1976) A Historical Review of Geology of Korea. Jour. of Geol.Soc. Korea, v. 12, p. 144-150.
Tennie, A., Hoffbauer, R. and Hoernes, S. (1995) Experimental determination of the oxygen isotope fractionations in the systems kyanite-calcite and talc-carbonate-water. Mineralogical Magazine, v. 58, p. 893-894.
Vennemann, T. W. and O'Neil, J. R. (1993) A simple and inexpensive method of hydrogen iso tope and water analyses of minerals and rocks based on zinc reagent. Chem. Geol. (Isot. Geo sci. Sect.), v. 103, p. 227-234.
Zheng Y.-F., Metz, P. and Satir, M. (1995) Experimental calibration of oxygen isotope fractionation between calcite and tremolite in the presence of a CO_2-H_2O fluid and a new data processing method for three phase systems. Mineralogical Magazine, v. 58, p. 1002-1003.

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중부 옥천변성대내의 활석광화작용 (I): 동양활석광상의 안정동위원소연구를 중심으로

박희인 · 이인성 · 허순도

요 약: 동양활석광상의 광화대는 옥천누층군에 속하는 향산리 돌로마이트의 최하부 돌로마이트층준에 발달하며 광체는 이 지역 지층 중에 발달하는 N85°~90°W에 40°로 플란지하는 작은 습곡축에 따라 파이프상으로 배태되어 있다. 이 광상의 모든 광체들의 상반이나 하반에 각섬질암이나 녹니석편암을 수반한다(김옥준 등, 1963; 박희인과 김기태, 1966). 동양활석 광상의 활석광화작용은 돌로마이트의 재결정작용과 규화작용에 이어 투각섬석과, 판상, 엽편상활석(I), 미립질 활석(II)의 생성 순으로 이루어졌다. 활석(I)은 돌로마이트와 SiO_2 성분이 풍부한 유체와의 반응으로 생성되었고 활석(II)는 돌로마이트와 유체와의 반응과 이미 생성된 투각섬석과 유체와의 반응으로 생성되었다. 광화기간중 유체는 초기에는 H_2O-CO_2계의 것으로 CO_2가 풍부한 것이었으나, 말기로 가며 H_2O-NaCl-CO_2계를 거쳐 H_2O-NaCl계의 것으로 변하였다. 투각섬석과 활석(I) 생성기의 온도 및 압력조건은 각각 1,640~2,530 bar, 440~480℃였고, 활석(II) 생성기의 온도 및 압력조건은 1,400~2,200 bar와 360~390℃였다. 이 값은 동양활석광상 북쪽 약 5 km에 분포하는 문주리층 구성암석의 변성온도 및 압력값에 비하여 현저하게 낮다. 활석광상의 모암인 돌로마이트의 $\delta^{13}C$과 $\delta^{18}O$값은 각각 2.9~5.7‰ (PDB)과 −7.4~16.8‰ (PDB)로서 기보고된 태백산지역의 석회암의 값에 비하여 높으나 변질받지 않은 퇴적원 돌로마이트가 갖는 값의 범위내에 든다. 동양활석광상의 활석의 $\delta^{18}O$와 δD값은 각각 +8.6~15.8‰ (vs SMOW)와 −65~−90‰ (vs SMOW)로서 마그마 기원의 물의 값을 갖는다. 이 값은 이 지역의 문주리층과 계명산층을 구성하는 변성암류의 $\delta^{18}O$과 δD값과는 판이하다. 경석고의 $\delta^{34}S$ 값은 22.4‰ (CDT)로서 고생대초의 황산염의 $\delta^{34}S$의 값(30‰ vs CDT)보다 낮아 화성기원의 S가 첨가되었을 가능성이 있다. 활석광석에는 약하게 엽리와 파랑벽개 등이 발달하고 있어 활석광상은 옥천대가 겪은 여러 차례의 변형작용중 최후기상이 적어도 끝나기 이전에 마그마 기원의 유체에 의하여 생성된 열수교대 광상이라 사료된다.