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Mineral Chemistry of Talc from Different Origins in the Dongyang Talc Deposit

동양활석광상에서 산출되는 서로 다른 기원의 활석에 대한 광물화학

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ABSTRACT : Mineral chemistry of talc from the Dongyang talc deposits was studied to characterize the differences between dolomite-origin talc (talc I) and tremolite-origin talc (talc II). Average iron and aluminum contents are higher in talc II, 2.18 wt% FeO and 0.31 wt% Al_2O_3, than in talc I, 1.48 wt% FeO and 0.08 wt% Al_2O_3. Consistently lower Mg/(Mg+Fe+Mn) ratios and higher Al concentrations with uniform values of talc II compared to talc I seem to reflect the compositional differences of the original materials, tremolite and dolomite, respectively. Relative enrichment of Al as well as Fe in talc II compared to tremolite can be attributed to their immobile behaviors during alteration process and the rapid diffusion of hydrothermal fluids, which can accelerate instantaneous nucleation with immaturity growth of talc II. Increase in the concentrations of talc II can lower the ore grade by increasing concentrations of impure components such as Al and Fe, and by abundant presence of tremolite as well.

Key words : talc, tremolite, mineral chemistry, Dongyang talc deposit

요약 : 동양활석광상에서 산출되는 백운석기원 활석(활석 I)과 투각섬석기원 활석(활석 II)의 차이를 밝히기 위해 광물조성을 연구하였다. 활석 II의 철과 알루미늄 평균 함량이 각각 2.18 wt%와 0.31 wt%이고, 활석 I은 각각 1.48 wt%와 0.08 wt%로서 전자의 경우가 높다. 활석 I보다 활석 II에서 Mg/(Mg+Fe+Mn)비가 일정한 값으로 꾸준히 낮고, 마찬가지로 Al 함량이 높은 것은 이들의 근원물질인 투각섬석과 백운석의 조성의 차이에서 기인된 것으로 보인다. 활석 II에서의 Al과 Fe가 투각섬석 경우보다 부화된 것은 변질작용 중에 이들 원소의 불유동성과 열수용액의 급격한 확산에 기인된 것으로 해석되며, 후자의 경우 활석 II의 불완전성장과 함께 순간적인 성핵을 촉진시키게 된다. 광석 중에 투각섬석기원 활석의 양이 증가하면 투각섬석 자체의 함량과 Al과 Fe 등의 불순물 증가로 인해 광석의 품위는 저하된다.

주요어 : 활석, 투각섬석, 광물화학, 동양 활석광상

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Introduction

Dongyang talc deposit, which is emplaced within the Hyangsanri Dolomite near the Chungju area, is one of the most important talc deposits in its quality, production, and exploration history in Korea, and it has been investigated by many workers on its genesis (Kim *et al.*, 1963; Reedman *et al.*, 1973; Lee, 1987; Moon and Kim, 1988; Kim and Cho, 1993; Park *et al.*, 1995; Ahn *et al.*, 2000).

Kim *et al.* (1963) reported that Dongyang talc deposit was formed by hydrothermal replacement with ascending residual fluid following the intrusion of amphibolite. Reedman *et al.* (1973) concluded that the deposit formed by regional metamorphism and the related hydrothermal solution was associated with the intrusion of Jurassic granodioritic complex. Moon and Kim (1988), mainly based on the mineralogic and geochemical data, interpreted the origin of this deposit as hydrothermal replacement deposit unrelated to contact metamorphism or regional metamorphism. Park *et al.* (1995) regarded the deposit as a hydrothermal replacement type which was formed before the latest phase of the deformation event of the Ogcheon Metamorphic Belt. They interpreted that talc has two different origins; dolomite-origin and tremolite-origin, and provided stable isotope data, which suggest the genetic contribution of magmatic fluids to talc mineralization in the deposit. Using high-resolution transmission electron microscopy (HRTEM), Ahn *et al.* (2000) explained the variation of microstructures regarding tremolite-to-talc reaction, and demonstrated that part of talc of the deposit, beside talc formed directly from dolomite, was produced from tremolite that was formed by dolomite during an early stage metamorphism.

Though previous studies identified two different origins of talc in terms of petrography (Park *et al.*, 1995) and microstructures (Ahn *et al.*, 2000), the differences in their chemical compositions have not been evaluated, which will be helpful to better understanding of talc mineralization process. Especially this study focuses on the variations of talc compositions in association with paragenetic sequence as well as genetic environments.

Geology and Ore Deposits

The study area of the Dongyang talc deposit consists of metamorphic rocks of the Ogcheon Group and intrusive amphibolite of unknown age. From the bottom to the top, the Ogcheon Group consists of Munjuri Formation, Daehyangsan Quartzite, Hyangsanri Dolomite, and Kyemyeongsan Formation in the study area. Munjuri Formation consists of phyllite and chlorite schist, and frequently shows well developed wavy crenulation. Daehyangsan Quartzite includes not only white quartzite but also intercalated dolomite lamella near the contact with Hyangsanri Dolomite. Hyangsanri Dolomite mainly consists of lower dolomite, middle pink banded limestone, and upper dolomite. Talc ore bodies are typically emplaced in the lower dolomite formation, consisting of white dolomite with the thickness of 100 to 200 m. Kyemyeongsan Formation consists of biotite schist, sericite-chlorite schist, quartz-sericite schist, amphibolite and limestone. Amphibolite occur along the bedding of dolomite or occur as dykes irregularly cutting the bedding. Within the zone of talc mineralization, ore bodies occur along the upper or lower contact of the amphibolite, showing close spatial relationship between them (Park *et al.*, 1995).

Talc ores generally consist of talc, tremolite, dolomite, calcite, and quartz with anhydrite as accessory phase. In the deposits two types of talc are identified based on crystallization stage and texture (Fig. 1). Talc I, which was formed by the reaction between dolomite and infiltrated siliceous fluids in early stage, shows tabular or leafy crystal habit and occurs in massive foliated aggregates. In places tabular flakes are disseminated in recrystallized dolomite. This type of talc occupies the majority of talc ore in the deposits. Talc II, which was formed by the reaction between early formed tremolite and fluids in later stage, occurs as microcrystalline aggregates, accompanying fine

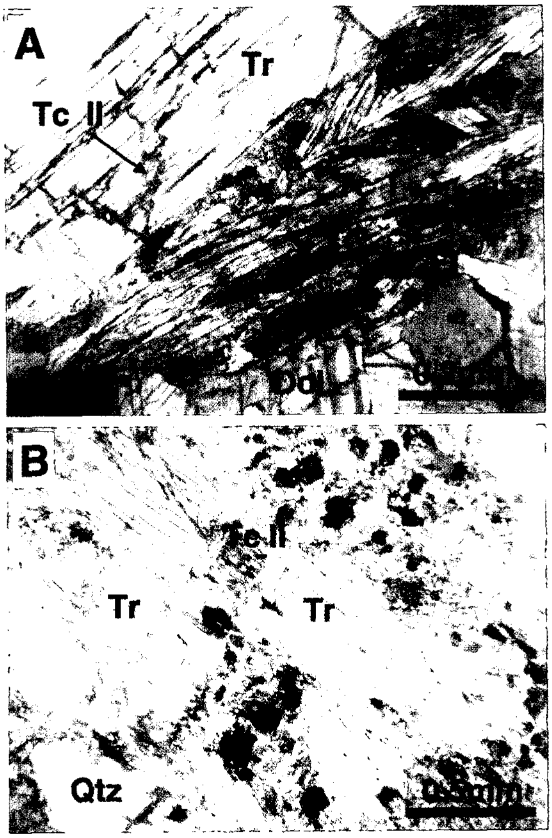

Fig. 1. Photomicrographs of talc ore from the Dongyang deposits. (A) Tremolite + talc + dolomite assemblage. Talc I altered from dolomite shows leafy and fibrous crystal habit. Talc II occurs as veinlets cutting through tremolite. (B) Tremolite + talc + quartz assemblage. Talc II altered from tremolite occurs as microcrystalline aggregates and shows irregular shape. Abbreviations: Tr = tremolite, Tc = talc, Dol = dolomite, Qtz = quartz.

grains of calcite, and sometimes forms veins cutting through the early formed talc, tremolite, or dolomite.

Experimental Methods

Talc-tremolite ore specimens were studied by polarized microscopy in order to characterize the mode of occurrence and phase associations, and two different types of talc with associated tremolite and dolomite were carefully selected. The quantitative chemical analyses of minerals were performed by a JXA 8900R electron microprobe analyzer (EPMA) at Seoul National University.

Results and Discussions

Talc is the trioctahedral mineral of the phyllosilicate group consisting of 2:1 layers. The incorporation of impurity elements in talc is minor. In ideal case, no interlayer ions exist because the 2:1 layers are electrostatically neutral. There is only very weak interlayer bonding, which leads to very low cohesion. Representative talc analyses are presented in Table 1. Most of the talc have typically near end-member compositions, although major Fe, minor Al, and trace Ti, Cr, Mn, Ca, Na, and K have been analyzed. There is little or no replacement of Si^{4+} in tetrahedral sites by Al^{3+} ions, and octahedral occupancy is close to six. Mg^{2+} is the overwhelmingly dominant octahedral cation, and alkali or alkaline earth cations are negligible. The microprobe analyses of talc reveal only small amounts of FeO in addition to the end-member components.

Iron contents of talc show different compositional ranges depending on their types; from 1.31 to 1.63 wt% (avg. 1.48 wt%) for talc I and from 1.87 to 2.46 wt% (avg. 2.18 wt%) for talc II. Thus, slight decrease in Mg/(Mg+Fe+Mn) ratios from talc I of early stage to talc II of later stage is recognized as shown in Fig. 2. Similar variations are also noticed in aluminium concentrations, though minor in their bulk contents, from 0.05 to 0.14 wt% (avg. 0.08 wt%) for talc I, and from 0.12 to 0.54 wt% (avg. 0.31 wt%) for talc II.

The relative enrichment of Al and Fe concentrations in talc II of tremolite-origin than in talc I of dolomite-origin seems to reflect the compositional differences of the original materials; higher FeO concentrations in tremolite from 1.23 to 1.81 wt% (avg. 1.62 wt%) than in dolomite from 0.23 to 0.41 wt% (avg. 0.33 wt%), and higher Al_2O_3 concentrations in tremolite from 0.15 to 0.31 wt% (avg. 0.23 wt%) than in dolomite below 0.04 wt% (avg. 0.01 wt%) (Table 2, 3; Fig. 3). Likewise near absence of Ti concentration in talc

Table 1. Representative microprobe analyses of talc

Type	Talc I (dolomite-origin)										Talc II (tremolite-origin)									
Sample#	HN3	HN3	HN3	HN3	HN4	HN4	HN4	HN7	HN7	HN7	HN3	HN3	HN3	HN3	HN8	HN8	HN8	HN8	HN10	HN10
SiO_2	63.00	63.12	62.92	63.42	62.80	63.02	63.28	62.89	63.07	62.95	62.59	62.63	61.93	62.11	61.73	61.91	62.64	62.99	62.73	61.77
Al_2O_3	0.09	0.09	0.05	0.06	0.08	0.05	0.05	0.08	0.14	0.10	0.29	0.34	0.39	0.23	0.54	0.29	0.31	0.29	0.12	0.34
TiO_2	0.01	0.01	0.01	0.00	0.01	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.02	0.00	0.00	0.00	0.01
Cr_2O_3	0.00	0.02	0.00	0.00	0.02	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.00	0.00	0.02	0.02	0.00
FeO	1.50	1.44	1.63	1.43	1.46	1.31	1.52	1.53	1.47	1.51	2.04	1.87	2.12	2.29	2.39	2.46	1.99	2.32	2.11	2.26
MgO	30.82	30.99	30.61	30.72	30.82	30.81	30.76	30.65	30.81	30.74	30.43	30.26	29.85	30.16	29.79	29.62	30.18	30.39	30.53	29.57
MnO	0.07	0.00	0.02	0.00	0.00	0.01	0.00	0.01	0.02	0.00	0.01	0.00	0.00	0.09	0.00	0.00	0.01	0.03	0.00	0.06
CaO	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.01	0.00	0.05	0.04	0.02	0.01	0.05	0.06	0.02	0.11	0.02	0.03
Na_2O	0.04	0.04	0.02	0.05	0.03	0.02	0.00	0.02	0.04	0.02	0.09	0.06	0.15	0.08	0.21	0.07	0.14	0.08	0.03	0.11
K_2O	0.02	0.00	0.00	0.00	0.03	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.02	0.02
Total	95.54	95.70	95.25	95.69	95.24	95.23	95.62	95.23	95.56	95.32	95.51	95.20	94.46	94.99	94.73	94.42	95.29	96.22	95.58	94.16
	cations per 22 oxygens																			
Si	7.99	7.99	8.01	8.04	7.99	8.01	8.02	8.01	8.00	8.00	7.97	7.99	7.98	7.95	7.94	7.99	8.00	7.97	7.97	7.99
Al(IV)	0.01	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.03	0.01	0.02	0.04	0.06	0.01	0.00	0.03	0.02	0.01
sum	8.00	8.00	8.01	8.04	8.00	8.01	8.02	8.01	8.00	8.00	8.00	8.00	8.00	7.99	8.00	8.00	8.00	8.00	7.99	8.00
Al(VI)	0.01	0.00	0.02	0.04	0.00	0.02	0.03	0.02	0.02	0.02	0.01	0.04	0.04	0.00	0.02	0.03	0.04	0.01	0.00	0.04
Ti	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cr	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fe*	0.16	0.15	0.17	0.15	0.16	0.14	0.16	0.16	0.16	0.16	0.22	0.20	0.23	0.24	0.26	0.27	0.21	0.25	0.22	0.24
Mg	5.83	5.85	5.81	5.80	5.84	5.84	5.81	5.82	5.82	5.82	5.77	5.76	5.73	5.76	5.72	5.70	5.74	5.73	5.78	5.70
Mn	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01
sum	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.01	6.00	6.00	6.00	6.00	6.01	6.00
Ca	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.01	0.00	0.01	0.00	0.00
Na	0.01	0.01	0.00	0.01	0.01	0.00	0.00	0.01	0.01	0.01	0.02	0.01	0.04	0.02	0.05	0.02	0.03	0.02	0.01	0.03
K	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
sum	0.01	0.01	0.00	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.03	0.02	0.04	0.02	0.06	0.03	0.04	0.03	0.01	0.04
Mg/(Mg+Fe+Mn)	0.97	0.97	0.97	0.97	0.97	0.98	0.97	0.97	0.97	0.97	0.96	0.97	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96

*All Fe calcuated as Fe^{2+}

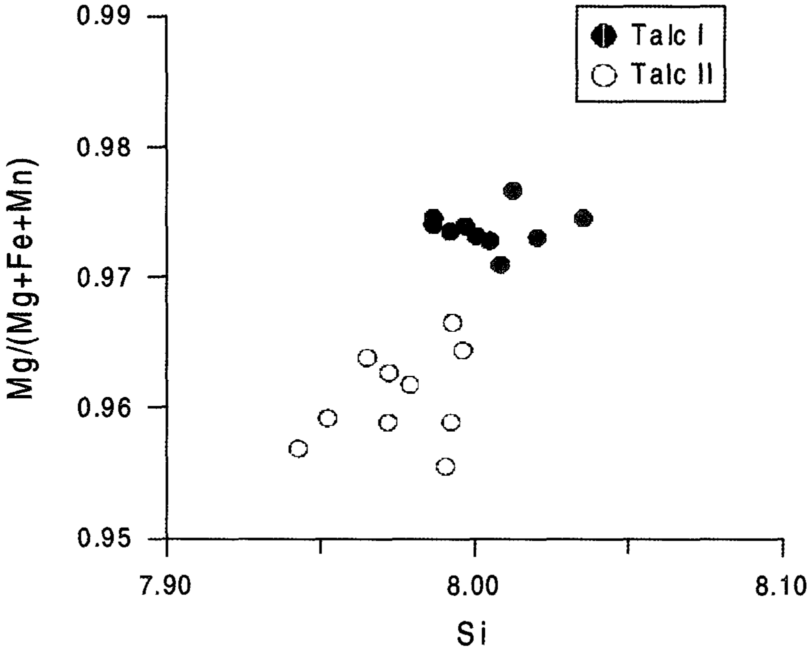

Fig. 2. Variations of talc compositions in molecular proportion Si versus Mg/(Mg+Fe+Mn).

II would be derived from the originally poor concentration in primary tremolite.

It has been reported that the chemical compositions of talc produced from hydrothermal alteration can be affected by their parental minerals or rocks (Kim, 1997; El-Sharkawy, 2000). Especially a quasi-inert behavior of Al at low pressure is important in its enrichment in alteration products (Moine *et al.*, 1989). The relative enrichment of Al as well as Fe in talc compared to tremolite in the Dongyang deposits can be attributed to their immobile behaviors during hydrothermal process. One might ascribe the relative increase of Al and Fe concentrations in talc II of tremolite-origin than in talc I of dolomite-origin to the overlapping analyses both of talc and tremolite, which may be present as tiny inclusions in talc crystals. However, the consistent differences of Mg/(Mg+Fe+Mn) ratios (Fig. 2) and Al concentrations (Fig. 3) with uniform values between the two types of talc strongly reflect the characteristics of their mineral chemistry.

These mineral chemistry data are in agreement with the results of HRTEM study for microstructures (Ahn *et al.*, 2000), which showed tremolite crystals containing holes that are filled with sheet silicates, talc, of which layers are partly extended from the tremolite "I-beam" units and thus indicated that such talc layers formed directly from tremolite during alteration.

Park *et al.* (1995) demonstrated that formation of talc I occurred around the invariant point conditions of temperatures between 440 and 480 ℃ and of XCO_2 between 0.5 and 0.7, while talc II was generated at temperatures between 360 and 390℃ and at XCO_2 below 0.2. Increased permeability in the dolomite induced by decarbonation reactions during prograde metamorphism would have promoted the infiltration of hydrothermal fluids in the retrograde stage. The rapid diffusion of mineralized fluids during the retrograde stage can accelerate the instantaneous nucleation compared with growth of crystals, and nucleation occurs rapidly thereby limiting the spread of crystal sizes (Kerrick *et al.*, 1991; Shin and Lee, 2002). This can explain the occurrence of talc II as microcrystalline aggregates. The immaturity growth as well as the increased concentration of

Table 2. Representative microprobe analyses of tremolite

Sample #	HN3	HN3	HN8	HN8	HN8	HN8	HNB2-1	HNB2-1	HNB2-1
SiO_2	58.50	58.41	58.04	58.59	58.23	58.47	58.08	58.08	58.00
Al_2O_3	0.16	0.28	0.26	0.23	0.25	0.20	0.15	0.31	0.27
TiO_2	0.00	0.00	0.01	0.01	0.03	0.00	0.00	0.04	0.00
Cr_2O_3	0.03	0.04	0.04	0.00	0.00	0.00	0.01	0.00	0.00
FeO	1.68	1.73	1.81	1.75	1.80	1.75	1.23	1.33	1.48
MgO	23.68	23.74	23.59	23.65	23.45	23.53	23.74	23.87	23.56
MnO	0.00	0.02	0.08	0.03	0.00	0.03	0.00	0.00	0.00
CaO	13.53	13.81	13.44	13.59	13.61	13.62	13.55	13.75	13.53
Na_2O	0.10	0.12	0.10	0.10	0.10	0.09	0.06	0.09	0.06
K_2O	0.02	0.01	0.00	0.00	0.00	0.01	0.00	0.03	0.01
Total	97.71	98.14	97.37	97.95	97.45	97.70	96.81	97.49	96.90
	cations per 23 oxygens								
Si	7.97	7.94	7.93	7.97	7.97	7.98	7.98	7.93	7.96
Al(IV)	0.03	0.04	0.04	0.03	0.03	0.02	0.02	0.05	0.04
sum	8.00	7.99	7.97	8.00	8.00	8.00	8.00	7.98	8.00
Al(VI)	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.01
Fe^{3+}	0.03	0.01	0.06	0.02	0.00	0.00	0.01	0.01	0.02
Ti	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cr	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fe^{2+}	0.17	0.19	0.14	0.18	0.20	0.20	0.13	0.14	0.15
Mg	4.81	4.81	4.81	4.79	4.78	4.79	4.86	4.86	4.82
Mn	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
sum	5.00	5.01	5.03	5.00	5.00	5.00	5.00	5.02	5.00
Ca	1.97	2.00	1.97	1.98	1.99	1.99	1.99	2.00	1.99
Na(M4)	0.03	0.00	0.03	0.02	0.01	0.01	0.01	0.00	0.01
sum	2.00	2.00	1.99	2.00	2.00	2.00	2.00	2.00	2.00
Na(A)	0.00	0.03	0.00	0.01	0.02	0.01	0.01	0.02	0.01
K	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
sum	0.00	0.03	0.00	0.01	0.02	0.02	0.01	0.03	0.01
Mg/(Mg+Fe+Mn)	0.96	0.96	0.96	0.96	0.96	0.96	0.97	0.97	0.97

Fe^{3+} calculated on the basis of 13eCNK (Robinson *et al.*, 1982)

Table 3. Representative microprobe analyses of dolomite

Sample #	HN1	HN1	HN3	HN3	HN4	HN4
Al_2O_3	0.01	0.00	0.00	0.04	0.01	0.01
FeO	0.33	0.41	0.30	0.23	0.40	0.32
MgO	22.91	22.32	22.23	23.51	22.08	21.34
MnO	0.11	0.00	0.02	0.04	0.13	0.16
CaO	31.49	32.63	31.76	32.21	32.00	33.01
Total	54.85	55.35	54.32	55.98	54.61	54.83

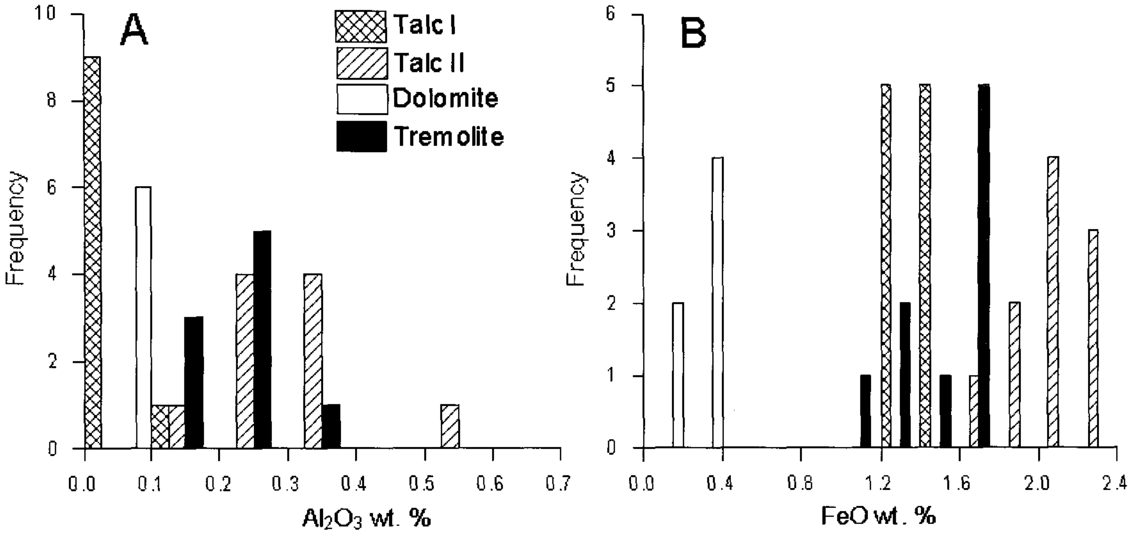

Fig. 3. Histograms of microprobe analyses for (A) Al_2O_3 and (B) FeO of talc, dolomite, and tremolite.

impure elements such as Al and Fe in talc II compared to tremolite may also have been affected by such metastable persistence. On the other hand, the large crystalline leafy crystals of talc I could have formed in a prolonged period of nucleation under comparatively limited diffusion during the prograde stage thereby allowing a large spread of crystal size.

This study reveals that tremolite-origin talc in the Dongyang deposit is distinguished from dolomite-origin talc not only by their textural (Park *et al.*, 1995) and microstructural features (Ahn *et al.*, 2000) but also by different chemical compositions. It can also be stated that the increasing talc concentrations of tremolite-origin can decrease the ore grade by increasing concentrations of impure components such as Al and Fe, and by abundant occurrence of tremolite as well.

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