

Gemmological Characterization of Precious Serpentine from Booyo, Korea

부여산 귀사문석의 보석학적 특성 연구

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ABSTRACT : The precious serpentine, referring to a rare and highly valuable gem variety of serpentine group minerals, is found to occur in serpentinite from Booyo Green Jade Mine which is located in Oesan-myun, Booyo-gun of Chungchungnam-do. Gemmological properties of the precious serpentine have been investigated by use of polarizing microscope, specific gravity balance, refractometer, hardness pencils, X-ray diffractometer, XRF, ICP-MS analyser, and infrared absorption spectroscope.

The precious serpentine from Booyo is colored deep green with oily luster and semi-transparent. It is highly tough and Mohs's scale of hardness is measured to be 5-6. Specific gravity is determined to be 2.67, and a single refractive index $N_b=1.56$ is observed by a spot method, using sodium light source. X-ray powder diffraction data is represented by the reflection lines at 7.40 (100), 4.64(25), 3.68(68), 2.757(69), 2.530(49), 2.459(32), 2.113(32), and 1.710(21)Å, which compares very well with that of antigorite of serpentine group minerals. The major chemical compositions of the precious serpentine are SiO_2 42.49%, MgO 39.08%, Fe_2O_3 3.85%, and H_2O 11.87%. Besides, trace elements such as Cr (2188ppm), Ni (1110ppm), Co (58ppm), and Ta (108ppm) are relatively concentrated when compared with similar materials from other sources. Infrared absorption spectrum shows peaks at 3670, 1190, 1070, 980 and 610cm^{-1} . Strong absorption at 3670cm^{-1} is due to OH stretching, and 1190, 1070 and 980cm^{-1} due to SiO stretching. The absorption 610cm^{-1} is responsible to OH bending vibration. The serpentinite in the mine area is assumed to have formed by alteration of pre-existing ultramafic rock, namely peridotite, with an introduction of fluid with very little content of CO_2 , under 400°C environment. Magnetite inclusions, finely disseminated in the precious serpentine, may be a result of Fe precipitation, during serpentinization of olivine-bearing country rock.

요약 : 귀사문석(貴蛇紋石)은 사문석군에 속하는 매우 희소하고 값진 보석원석을 일컫는 보석학적 변종명(變種名)으로서, 충남 부여군 외산면에 소재한 부여록옥광산에서 모암인 사문암내에서 산출됨이 처음 발견되었다. 귀사문석에 대한 보석학적 특징을 편광현미경, 비중저울, 굴절율, 경도심, X선 분말회절기, X선 형광분석기, ICP-MS 분석기, 적외선분광분석기 등을 사용하여 연구하였다.

부여산 귀사문석은 색이 짙은 녹색을 띠며, 연마 표면에서는 지방광택을 나타낸다. 투명도는 아투명하다. 모스 경도는 약 5-6이며, 인성이 매우 강하다. 비중은 2.56로 측정되었다. 굴절율은 나트륨광원을 사용하여 전반사법을 이용한 스포트법으로 측정한 결과 1.56인 하나의 굴절율을

얻었다. X선 분말회절 실험 결과, 7.40(100), 4.64(25), 3.68(68), 2.757(69), 2.530(49), 2.459(32), 2.113(32), 1.710(21) Å 등의 회절선이 관찰되었으며, 이 분말회절 양상은 사문석군 광물 중 안티고라이트와 일치함을 알 수 있다. 귀사문석의 주요 화학성분은 SiO₂ 42.49%, MgO 39.08%, Fe₂O₃ 3.85, H₂O 11.87%이며, 미량원소는 Cr (2188ppm), Ni (1110ppm), Co (58ppm), Ta (108ppm) 등이 비교적 많이 함유되어 있다. 적외선흡수분광분석 실험 결과, 3670, 1190, 1070, 980, 610cm⁻¹에서 흡수현상이 일어났다. 가장 예리한 흡수 피크인 3670cm⁻¹은 OH stretching에 의한 것이며, 1190, 1070, 980cm⁻¹의 흡수선은 SiO stretching에 의한 것으로 해석된다. 그리고 610cm⁻¹에서의 흡수띠는 OH bending vibration에 의해 기록된 것이다. 광산에 산출하고 있는 사문암은 기존에 있던 시대미상의 초염기성암인 페리도타이트가 400°C이하의 온도조건에서 탄산가스를 거의 함유하지 않은 유체가 유입될 때변질작용을 일으켜 형성된 것으로 판단되며, 귀사문석내에 있는 자철석은 이 과정에서 모암을 구성하고 있던 감람석내에 들어 있던 철분이 추출되어 결정화된 산화물로 해석된다.

INTRODUCTION

The Booyo Green Jade Mine, located in Oesan-myun, Booyo-gun, Chungchungnamdo-Province (Fig. 1), had originally been begun in 1940's for production of asbestos and been left abandoned for many years. It has recently re-opened, after discovery of precious serpentine from the mine dumps. The precious serpentine is a highly valuable gem variety of serpentine minerals and

is one of the three green jade materials which are distinct in mineralogical sense, i. e., jadeite, nephrite and serpentine. Jadeite (NaAlSi₃O₆) is a member of the pyroxene group minerals and nephrite a member of the tremolite-actinolite series of the amphibole family. Serpentine group includes three polymorphs, such as lizardite, antigorite and chrysotile (Deer et al., 1980). However, these mineral names have not been used in gemmology. Instead, bowenite, williamsite, and precious serpentine have been applied (Webster and Anderson, 1983). In general, serpentine is a hydrated silicate of magnesium [Mg₃Si₂O₇(OH)₂] and crystallises in the monoclinic system, but the mineral is almost always massive and is never encountered as single crystals. Typical serpentine is about 2½ on Mohs's hardness scale, except for the varieties of the above three gem species whose hardness value goes up to 5 or more, and is too soft to be fashioned.

The precious serpentine refers to purer semi-transparent to translucent variety having an oil-green color and has been regarded to be superior to yellow or yellowish-green serpentine varieties called 'bowenite'. The so-called 'Chosun jade', designating yellowish colored bowenite and mainly from Danchon, Hamkyungnam-do, North Korea, is inferior in color to those from the Booyo Green Jade mine. A translucent deep green or bluish-green variety of bowenite, very much similar to the Booyo material, had been reported from the



Fig. 1. Location map of Booyo Green Jade Mine.

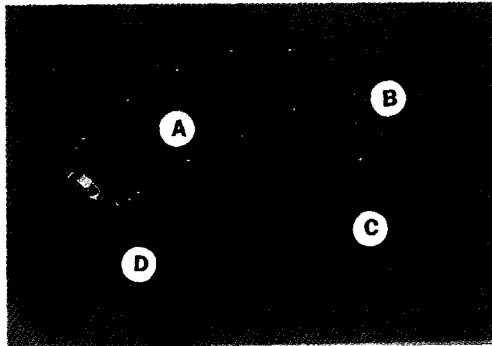


Fig. 2. Fashioned precious serpentine from Booyo. Bracelet(a), button(b), pendant(c), and ring(d).

South Island of New Zealand, the Delaware river, Pennsylvania, and at Smithfield, Rhode Island. Some fashioned precious serpentine is shown in Fig. 2.

Previous works on serpentinite or serpentine material were mainly confined to those in the area of Ulsan Iron Mine, Korea and conducted by Choi et al. (1990), Kim et al. (1993), and Park et al. (1995). According to their mineralogical, petrological and geochemical results, the so-called 'Ulsan serpentinite' is composed of essentially of lizardite, one of the three serpentine polymorphs.

In this paper gemmological properties of the precious serpentine, together with general geology of the Booyo Green Jade Mine area and a brief description of ore deposit will be given.

GENERAL GEOLOGY AND ORE DEPOSIT

Geology of the Booyo Green Jade Mine area consists of Pre-cambrian schist and granitic gneiss, Jurassic Chogyeri conglomerate and Baekwunsa Formation which overly the Pre-cambrian rocks unconformably, and age-unknown serpentinite which intruded the schist of Pre-cambrian age (Fig. 3). Time relationship between the serpentinite and Jurassic sediments is not certain because no direct contact between them is seen in

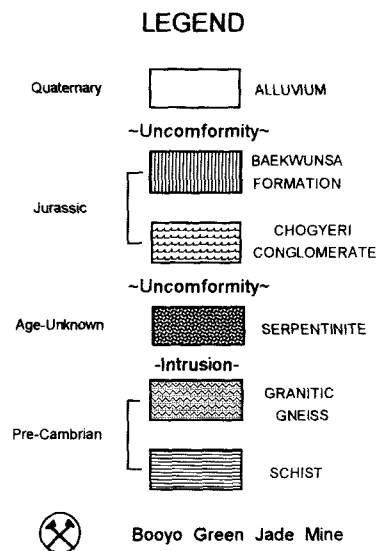
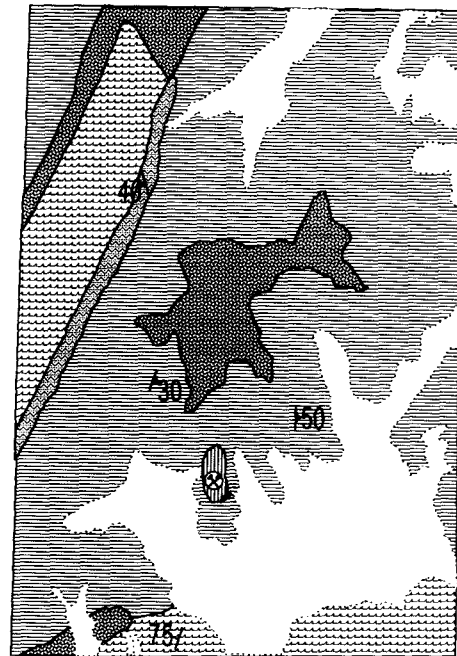


Fig. 3. Geological map of Booyo Green Jade Mine area (modified from Daechon Geologic map, 1930).

the area. Weathered surface of the schist shows yellowish brown to greyish brown depending on the degree of alteration, but light grey to grey



Fig. 4. Layered serpentinite in the mine area.

color on a fresh surface. Schistosity gives a strike of NS to N30°E and a dip of 50°E or 20°SE in dip. The schist consists mainly of quartz and biotite of fine to medium-grain size, and minor amount of opaque minerals are also accompanied. Granitic gneiss occurs as thin stripe in the area northwest side of the serpentinite mine and is of medium to coarse-grained one. The gneiss is marked by distinct lineation with parallelly oriented hornblende and biotite crystals in the rock.

The Chogyeri conglomerate occupies in the area including the crest of Mt. Sungtae and overlies unconformably the underlying Pre-cambrian schist. Composite clasts of the conglomerate are largely of quartzite and sandstone, with average dimension of 3~5cm, although the maximum size attains 20cm in length. Roundness of the clasts is relatively good. The Baekwunsa Formation is distributed in the area northwest and southwest sides of the mine and consisted of repeating layers of conglomerate and sandstone. Bedding planes strike N30°~75°E and dip 50°~75°NW. Clasts of the conglomerate of Baekwunsa Formation are mostly quartzite and 0.5~1.5cm in size. However, they show very poor roundness. In general, roundness and size of clasts forming the Chogyeri conglomerate are far better than that of the Baekwunsa Formation. Sandstone layers are composed of medium-grained sized quartz, feldspar, and other rock fragments.

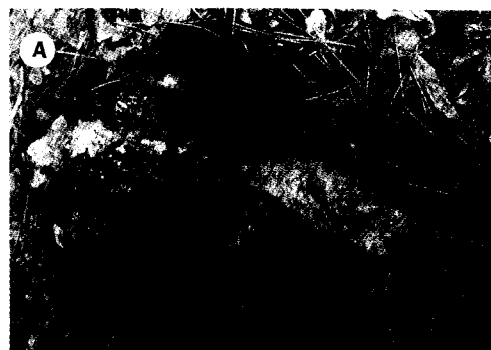


Fig. 5. Garnet vein intruding the serpentinite(A, B). Precious serpentinite develops along the contact between garnet vein and serpentinite.

Serpentinite occurs as elongate body of about 100m in length, yet its intrusion age is unknown. The rock is massive and dark green in color. Some portion of the rock is characterized by well-developed layers (Fig. 4) which are assumed to be of igneous origin. The attitude of the igneous layers is measured to be N18°W in strike and 50° SW in dip. Small veinlets of chrysotile, approximately 5mm in thickness, cut through serpentinite. The precious serpentinite is developed along the both contacts between grossular garnet vein and the stratiform serpentinite (Fig. 5). The grossular garnet vein shows light brownish color and attains max. width of 10cm on the outcrop. It runs EW direction with a dip of 66°N.

The mine comprises 2 adits of different levels at about 10m vertical interval (Fig. 6). The old

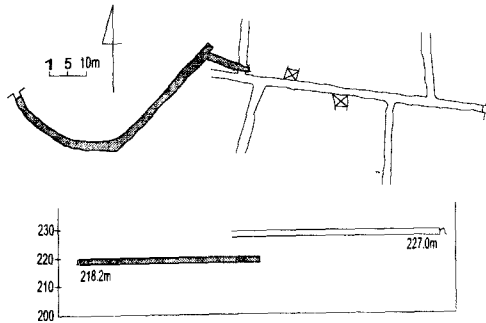


Fig. 6. Distribution of tunnels. Two adits at approximately 10m vertical interval.



Fig. 7. Entrance of the new tunnel. It is temporary closed during heavy rainy season.



Fig. 8. Mine dump site.

one, opened approximately 50 years ago, runs approximately 75m from east to west direction, whereas the new one, situated at 10m below it, 80m from west to east. The entrance of new horizontal tunnel and mine foreground is shown in Fig. 7 and 8, respectively.

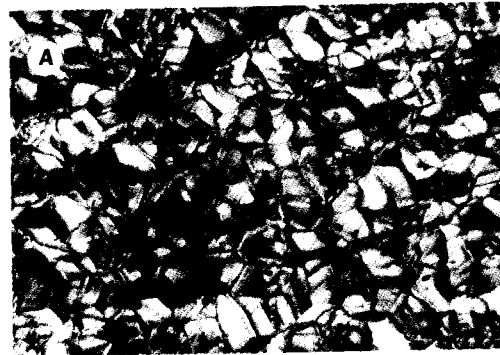


Fig. 9. Photomicrographs of precious serpentine. 40X. Fibrous antigorite crystals at random orientation, seen under crossed nicols (A), and the same position (B) but seen under open nicol. Magnetite (black) concentrates between round crystals.

It is very interesting to find that the grossular garnet vein carries pinkish clinozoisite in the forms of dissemination and massive aggregate. The maximum dimension of clinozoisite aggregates collected from mine dumps is $10 \times 14 \times 8$ cm, which indicates thickening of the grossular garnet vein in depth. The color of grossular garnet coexisting with clinozoisite appears greenish, contrary to that, light brown, when free from clinozoisite.

PRECIOUS SERPENTINE

Color and Texture

Good gem-quality precious serpentine shows

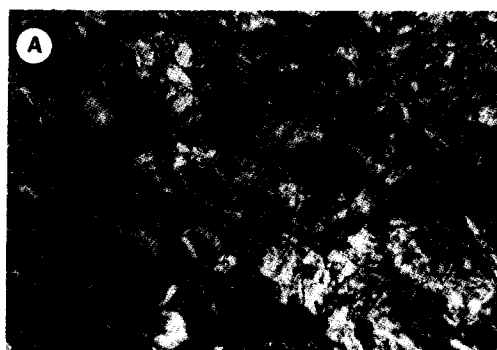


Fig. 10. Photomicrographs showing difference in texture between the precious serpentine (lower left) and serpentinite (right). 40X. Flakes or blades of antigorite in the serpentinite differ from fibrous form of the precious serpentine (A), crossed nicols. In the serpentinite magnetite are finely disseminated within antigorite grains (B), open nicol.

deep green color with oily luster. Diaphaneity varies from semi-transparent to translucent, when observed through 0.3cm thick, doubly polished slab. As the gem-quality of the rough becomes poorer, the color of precious serpentine changes to deeper green, until to almost opaque. Under polarizing microscope, mineral texture of serpentine between gem-quality and ordinary serpentinite varies significantly. In gem-quality portion felted nature of fibrous serpentine, oriented randomly within the original grains of round-shape, is clearly seen at crossed-nicols and open-nicol positions (Figs. 9a, 9b). However, elongate

blades, flakes, or plates are prevailing in the ordinary serpentinite part (Fig. 10), which is very similar to the 'interpenetrating texture' described by Wicks and Whittaker (1977). No indication of pre-existing mineral shape is preserved in this part.

Although antigorite serpentine is of monoclinic symmetry and thus anisotropic nature, no pleochroism is seen through a dichroscope, which is due to polycrystalline nature of the fibrous mineral aggregates.

Refractive Index

When antigorite is a single crystal form, three refractive indices of it, $\alpha=1.558\sim1.567$, $\beta=1.566$, $\gamma=1.562\sim1.574$, may be measured by immersion method. However, precious serpentine occurs always as microscopically small polycrystalline aggregated nature, determination of its three refractive indices is practically impossible. Owing to this fact only a single reading of it may be obtained on a standard gemmological refractometer by spot method or distant vision method. For this test curved and polished surface of precious serpentine is placed on the glass prism of the Duplex II refractometer. A drop of immersion oil with a refractive index of 1.81 is applied. Image of a circle, inside of the refractometer, may be seen when looking through an opening, after removing eye piece, approximately 30cm apart from it. Sodium light, giving 589.3nm wavelength, is employed as a light source. The single reading, 1.56, is well within the range of three refractive indices of antigorite. In contrast, it is considerably larger than those of other two serpentine polymorphs: $\alpha=1.532\sim1.549$, $\gamma=1.545\sim1.556$ for chrysotile, and $\alpha=1.538\sim1.554$, $\gamma=1.546\sim1.560$ for lizardite.

Hardness

Mohs' scale of hardness for ordinary antigorite, chrysotile and lizardite is known to be 2.5 ~ 3.5, 2.5, and 2.5, respectively (Deer et al., 1980),

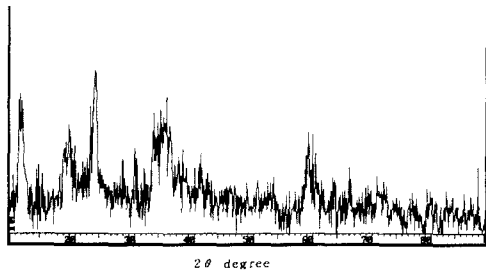


Fig. 11. X-ray powder diffractogram of precious serpentine.

which is too soft to be fashioned as a gemstone or ornaments. This weakness is the main reason why serpentine material is considered inadequate for cutting. However, precious serpentine is harder, giving a hardness of 5~6 on Moh's scale, when determined by use of hardness testing pencils. It is also found to have very high toughness, probably directly related to polycrystalline and felted nature of the constituent materials. Due to these exceptional physical properties, precious serpentine has long been treated as valuable gem rough.

Specific Gravity

Specific gravity of precious serpentine is determined by the hydrostatic weighing technique by use of an electronic chemical balance (AND ER-182A), which is equipped with specific gravity kit. Repeated tests give values of 2.57~2.58 for ten measurements. The material is again tested by immersing it into bottles with heavy liquid of different specific gravity values. It sinks in 2.52 liquid, and floats in 2.62 liquid. Heavy liquid of 2.56 is prepared by adding Benzyl Benzoate (S.G. 1.11) into Bromoform (S.G. 2.88), with an aid of amazonite indicator. When precious serpentine is immersed in the liquid, it moves near horizontally and then gradually floats with time. This phenomenon is interpreted to be resulted from gradual increase of specific gravity of the heavy liquid used, probably due to evaporation of diluting material.

Table 1. Comparison of X-ray powder data of precious serpentine and antigorite.

1		2		
d _o (Å)	I/I _o	d _o (Å)	I/I _o	H K L
7.40	100	7.29	100	0 0 1
		6.43	40	—
		5.82	40	$\bar{6}$ 1 0
		5.15	40	3 1 1
4.64	25	4.64	40	0 2 0
		4.26	20	$\bar{4}$ 20, 711
		3.99	5	9 0 1
3.68	68	3.61	80	12 0 0
2.757	69	2.794	20	$\bar{1}$ 121, 331
		2.667	5	$\bar{1}$ 501, 722
		2.596	20	$\bar{1}$ 202, 731
2.530	49	2.525	100	$\bar{1}$ 6 0 1
2.459	32	2.458	60	9 3 $\bar{1}$
		2.429	20	$\bar{1}$ 701, $\bar{2}$ 03
		2.386	20	14 0 2
		2.210	20	141, $\bar{1}$ 41
2.113	32	2.172	60	83 $\bar{2}$, 901
		1.833	20	$\bar{1}$ 822, 842
		1.812	20	$\bar{1}$ 513, 151
		1.742	20	751, $\bar{2}$ 022
1.710	21	1.709	5	$\bar{2}$ 321, $\bar{9}$ 51

- 1. Precious serpentine from Booyo Green Jade Mine.
- 2. Antigorite, JCPDS 21-963.

Specific gravity of precious serpentine, 2.57~2.58, also compares better with that of antigorite (2.6), rather than that of chrysotile (2.55) and lizardite (2.55 or lower). The specific gravity value (2.57~2.58) of Booyo precious serpentine is slightly smaller than that (2.58~2.59) of ordinary bowenite and far smaller than that (2.617) of precious serpentine from South Island, New Zealand.

X-Ray Powder Diffraction Data

X-ray powder diffraction analysis was performed for the precious serpentine by use of a Rigaku D/Max-IIIB diffractometer. X-ray powder diffractogram using Ni-filtered CuK α radiation ($\lambda=1.5418 \text{ \AA}$) and X-ray powder data de-

Table 2. Chemical data of precious serpentine and other serpentine minerals for comparison.

element	1	2	3	4	5
SiO ₂	42.49	43.1	43.60	38.04	39.45
Al ₂ O ₃	1.30	1.3	1.03	0.86	1.07
Fe ₂ O ₃	3.85	3.4	1.71	7.62	7.72
MgO	39.08	39.8	41.00	37.47	38.48
MnO	0.12		0.04	0.11	0.10
CaO	0.68		0.05	0.24	0.63
K ₂ O	0.06		0.03	0.01	0.02
Na ₂ O	N.D.		0.01	0.01	0.25
TiO ₂	0.01		0.01	0.01	0.02
Cr ₂ O ₃			0.02		
NiO			0.16		
P ₂ O ₅	0.06			0.01	0.11
LOI	11.87				11.30
H ₂ O		11.97	12.26		
Total	99.52	99.57	99.92	84.38	99.13
Li	2717.50	Nb	12925.19	Tb	35.92
Be	321.10	Mo	2858.60	Dy	291.25
Sc	5409.16	Cd	n. d.	Ho	47.37
Cr	2188503.91	Te	2022.68	Er	135.69
Co	58426.31	Cs	1450.91	Tm	70.57
Ni	1110853.28	Ba	22816.11	Yb	254.40
Cu	5929.28	La	1941.50	Lu	n. d.
Zn	96669.14	Ce	4302.41	Hf	n. d.
Ga	2193.34	Pr	396.02	Ta	108501.11
Rb	19809.42	Nd	1242.18	Pb	4264.71
Sr	7097.00	Sm	450.36	Bi	675.74
Y	2897.50	Eu	26.83	Th	1894.58
Zr	8995.92	Gd	601.57	U	991.02

1. Precious serpentine (antigorite) from Booyo Green Jade Mine, Korea. Trace elements in ppb.
2. Antigorite, JCPDS 21-963.
3. Antigorite, Venezuela (Hess, 1952).
4. Lizardite from Ulsan serpentinite (Park et al., 1995).
5. Lizardite from Ulsan serpentinite (Choi et al., 1990).

rived from it is shown in Fig. 11 and Table 1, respectively. The X-ray powder data of precious serpentine compares well with that of antigorite,

given in the same Table (JCPDS card 21-963). It is noted that antigorite of JCPDS card, originated from Griffin Range, Westland of New Zealand, have two strongest X-ray reflections, 7.29(100) and 2.525Å(100), whereas precious serpentine from Booyo gives only one strongest line at 7.40Å. This discrepancy may be due to different radiation or recording system being used. However, it cannot be explained at this stage, because no such data for the antigorite of JCPDS card 21-963 is given.

X-ray powder data of precious serpentine from Booyo does not compare with that of chrysotile and lizardite. That is, reflections 2.75(69), 2.530(49), 2.459(32), 2.113(32) and 1.710(21)Å recorded from precious serpentine do not belong to both chrysotile and lizardite. It is also interesting to note that the serpentinite in Booyo Green Jade mine is made up of antigorite, contrary to the fact that in Ulsan area, Kyungnam Province, is composed essentially of lizardite (Choi et al., 1990; Kim et al., 1993; Park et al., 1995). The difference in mineralogy of those two serpentinites may illustrate unequal condition during the serpentinization of the pre-existing ultramafic rock in the areas.

Chemical Composition

Chemical composition of the precious serpentine is analysed by XRF and ICP-MS method. Major and trace elements analysed are shown in Table 2. Amounts of SiO₂ (43.36%), MgO (43.64%), and H₂O (13.0%) compare well with ideal composition of serpentine, Mg₃Si₂O₇(OH)₂. Elemental substitution of Al⁺³ for Si⁺⁴, and Al⁺³, Fe⁺³, and Fe⁻² for Mg⁺² are reported (Deer et al., 1980). Mg is sometimes replaced by Ni. Surprisingly, amounts of SiO₂ (42.48%) and MgO (39.08%) of precious serpentine from Booyo are very close to those of antigorite from Griffin Range, New Zealand (Table 2, 2) and Caracas, Venezuela (Table 2, 3). In addition, amount of Al₂O₃ (1.30%) is identical between the antigorite from Booyo and Griffin

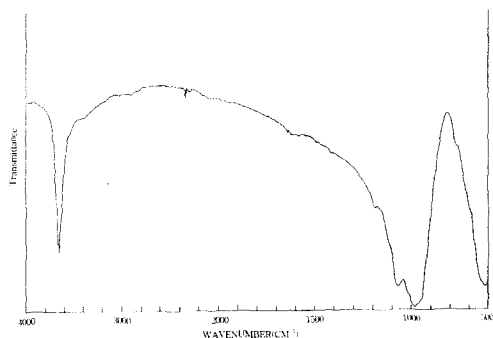


Fig. 12. Infrared absorption spectrum of precious.

Range. It is noted that amount of Fe substituting for Mg in antigorite from Venezuela is smaller than those from Booyo and Griffin Range. Ni is, although very minor amount, found to replace Mg in antigorite from Venezuela. It is very interesting to note that amount of SiO₂ (38.04, 39.45 %) in lizardite from Ulsan serpentinite is considerably lower, when comparing with that of antigorite, which illustrates that nearly all the amount of Al is used up to replace Si, and that high amount of Fe are expecting in the data (Table 2, 4-5).

Characteristic trace elements contained in the precious serpentine from Booyo are Cr (2188 ppm), Ni (1110ppm), Co (58ppm), and Ta (108 ppm) (Table 2). Large concentration of such elements is expected in serpentinite which had been altered from pre-existing peridotite. This fact may postulate the origin of the Booyo precious serpentine. Amounts of Cr (979-3582ppm), Ni (1185-2042) and Co (47-67ppm) reported from Ulsan serpentinite by Kim et al. (1993), and Cr (1150-2749ppm), Ni (1246-2967ppm) and Co (6-78ppm) reported from the same rock by Park et al. (1995) show slight discrepancy between the data, but both data compare very well with those of the Booyo precious serpentine.

Infrared Spectrum

Infrared absorption spectrum (Fig. 12) of pre-

vious serpentine was recorded by JASCO IRA-1 spectrophotometer. Characteristic absorptions occur at 3670, 1190, 980, and 610cm⁻¹. The presence of strong peak at 3670cm⁻¹ is due to OH stretching, and 1190, 1170, and 980cm⁻¹ due to SiO stretching. The 610cm⁻¹ band is resulted from OH bending vibration (Farmer, 1974), which is consistent with the appearance of absorption at 600~660cm⁻¹ by hydroxyls of the hydroxide sheet in the serpentine minerals (Pampuch and Ptak, 1970). The sharpness of OH absorptions at 3670 and 610cm⁻¹ may suggest this precious serpentine making antigorite, which has trioctahedral 1:1 layer silicate structure, have a complex but relatively ordered structure.

Genesis

Ultramafic rocks are composed largely of olivine, orthopyroxene, and/or clinopyroxene, and the MgO/FeO ratio of the rocks is very high. CaO is another component present in clinopyroxene. However, its content in the precious serpentine is very small (0.68% in Table 2), thus the amount of clinopyroxene, if any, may be considered to be minimal. Metamorphism of ultramafic rocks requires the access of H₂O and/or CO₂. Particularly H₂O is commonly available and the introduction of H₂O converts ultramafic rocks into serpentinites, consisting mainly of antigorite, minor amounts of talc or quartz, or brucite, and some magnetite (Winkler, 1974). The transition from lizardite or chrysotile to antigorite in serpentinite rocks has been observed to take place in the Swiss Alps close to the upper limit of pumpellyite (Dietrich and Peters, 1971): i.e., close to the beginning of low grade (greenschist facies) metamorphism. The phase diagram (Johannes, 1969) for the system MgO-SiO₂-H₂O-CO₂ at P_f=2kb (Fig. 13) shows that serpentine, either alone or associated with another mineral, is stable only at very small values of X_{CO₂}, as represented by reactions (1), (3), (5), (6), (7), and (8). In fact the presence of

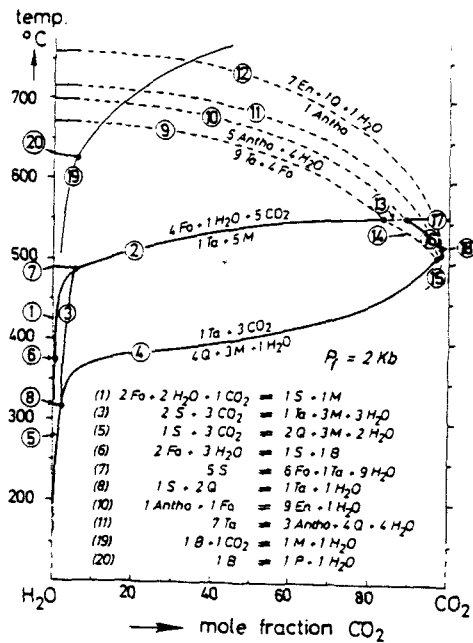


Fig. 13. Isobaric equilibrium curves of reactions in the system $MgO-SiO_2-H_2O-CO_2$ (after Johannes, 1969). Abbreviations: Fo=forsterite, S=serpentine, M=magnesite, Ta=talc, Q=quartz, B=brucite.

serpentine in a rock is a very good indicator that the fluid phase present during rock alteration contained very little CO_2 or none at all. According to experimental data, X_{CO_2} must have been less than 10 mole percent, otherwise serpentine would have been altered to magnesite + quartz or to magnesite + talc. Without the introduction of reagents other than water, serpentinization of olivine has been achieved only at temperatures below $400^\circ C$, and for iron-bearing olivines serpentinization requires still lower temperatures, and is accompanied by the formation of either magnetite or hematite (Bowen and Tuttle, 1949). According to Wicks and Whittaker (1977), the most common accessory mineral produced by the serpentinization of olivine is magnetite. They also reported that there is often a correlation between the distribution of the magnetite and both the degree of serpentinization. In the early stages, magnetite forms very fine discrete grains distributed

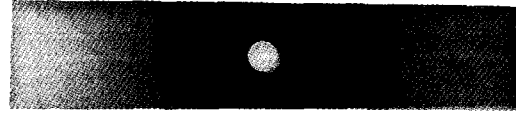


Fig. 14. X-ray Gandolfi powder camera film for magnetite within precious serpentine. Ni-filtered $CuK\alpha$ radiation used.

throughout the serpentine. As serpentinization progresses the magnetite forms coarser grains and concentrates in mesh centers. At later stages the magnetite migrates out of the mesh textural units into cross-cutting lenses and veinlets. In the Booyo precious serpentine fine grains of magnetite, whose identity was verified by a 114.6mm Gandolfi X-ray diffraction camera method (Fig. 14), are concentrated, especially in the interstices between former olivine crystals (Fig. 9b). However, in the neighboring serpentinite portion, magnetite forms very fine grains and distributed throughout (Fig. 10b). It is therefore assumed that magnetite in the precious serpentine might have been remobilized out from the antigorite when a garnet forming fluid was introduced, and then concentrated in the space between the former crystals.

CONCLUSIONS

1. Gem-quality precious serpentine occurs in the Booyo Green Jade Mine located at Oesanmyun, Booyo-gun in Chungnam-do. The host rock of the gem material is serpentinite which had formed from alteration of pre-existing ultramafic rock, possibly a peridotite, of unknown age.

2. Precious serpentine consists of antigorite fibers and develops along the contact between serpentinite and grossular garnet vein which intruded it.

3. Precious serpentine is deep green in color and semi-transparent with oily luster. Hardness of it reaches to $H=5-6$, specific gravity 2.57, and

refractive index 1.567. Major components are SiO₂ 42.49%, MgO 39.08%, Fe₂O₃ 3.85%, and H₂O 11.87%. Important trace elements are Cr (2188 ppm), Ni (1110 ppm), Co (58 ppm), and Ta (108 ppm).

4. Magnetite occurs as inclusion within the precious serpentine and is interpreted to have formed by the reaction of Fe-bearing olivine and orthopyroxene in the presence of water.

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