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Mineralogy of Chinese Stone Carvings.

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Constituent minerals of Chinese stone carvings are determined by orthodox methods. The minerals or rocks of the stone carvings examined are classified into five groups. Those are fluolite, pyrophyllite, serpeninite, calcite and jade. Two flower vases of fluolite crystals are purple and moss green in color, and exhibit distinct fluorescence of characteristic nature of fluorite. Pyrophyllite which is relatively soft is used for skillful fine carvings. The mineral of these fine carvings introduced here is only pyrophyllite and no other mineral is detected. Materials for seals were also pyrophyllite. Serpentine is used for noble carvings. Most of the minerals examined are antigorite, one kind of serpentine minerals, and some of them include talc and other small amount minerals besides antigorite. Two calcite carvings which look the appearance of nephrite are beautiful but soft. One of jade products is the jadeite bracelet and another is the seal carving of tremolite, one of nephrite.

Introduction

There are so many kinds of ornamental or artistic stone carvings in China. Materials used for stone carvings ranging from hard ones such as jadeite to soft ones such as talc. Mineral names of materials are not clear in many cases, because vernacular names are usually used.

A set of stone carvings with a display shelf of 210 cm in height is obtained from Dalian Natural History Museum, China [a)]. In this paper, mineral names of materials used for stone carvings are examined mainly on the carvings from the Museum. One of authors (B. W.) stays at our department as a postdoctoral researcher from China, and it is a good opportunity making this joint research.

History and innovation of Chinese stone carvings are reported by Zhou and He (2008), and jade is described in books (Zhao, 2005; Zhou, 2005). Recently, Sudo (2008) reported stones for seal engraving. There exists no complete report treating mineralogically many kinds of Chinese stone carvings.

Method

Determination of mineral species was performed by the X-ray powder diffraction, Mohs' hardness, specific gravity and microscopic observation of thin sections.

A used X-ray diffractometer is Rigaku-RINT 2500 of the rotating anode type belonging to Chiba

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Institute of Science. Analytical conditions are as follows: Cu Kα 40KV, 200mA, Slits 1°－1°－0.15, Scanning angle 2°～70°, Scanning speed 2°/min. The Mohs' scale of hardness is determined by scratchability using the ten standard minerals selected by Mohs (Mason and Berry, 1968). Specific gravity was measured using pycnometers of 25 cc and 100 cc, or a balance with handmade tools. A part of stone carvings were cut with a diamond cutter and/or an electric hand drill to obtain small test pieces and fine powders for experiments.

The general description of minerals treated in this paper is shown Appendix Ⅰ.

Carvings

1. Fluorite

Big fluorite crystals or their aggregations are used for flower vases.

[A] Purple vase of fluorite.
Fluorite is favorable for the bringing of good fortune in China. As seen in Photo A of p. 87, the vase of 21 cm height is made of purple fluorite. The width of field is given as 25 cm. Bands developing from the bottom to the top resulted from crystal growth are seen. It seems to be the fluorite crystal over 20 cm.

The Mohs' scale of hardness is 4. The specific gravity is 3.13. The X-ray powder diffraction pattern is shown in Figure 1, and indicates the pure mono-mineralic composition of fluorite. The vase exhibits distinct fluorescence in purple and pale blue color during expose to ultraviolet light. Fluorescence observed on fluorite and a few other minerals is the characteristic nature resulted from the light emission of the absorbed invisible radiation energy.

[B] Moss green vase of fluorite.
The vase of 23 cm height is moss green or radiantly white (Photo B of p. 87). It looks the mixture of fluorite crystals of several centimeters. The boundaries and small cracks result in white illumination.

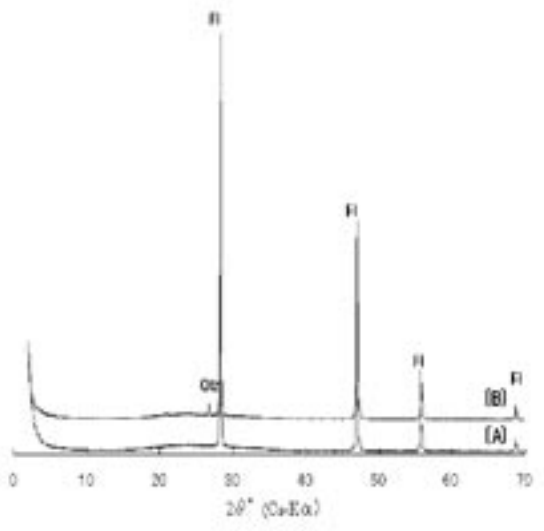

Figure 1. X-ray diffraction pattern of fluorite.
[A] Purple vase of fluorite. [B] Moss green vase of fluorite.
Fl; fluorite Otz; quartz

The Mohs' scale of hardness is 4. The specific gravity is 3.16. The X-ray analysis shows the large amounts of minerals are fluorite and the small amount of mineral is quartz (Fig. 1). The fluorescence of whitish celadon in color is observable in the whole parts of the vase. A photograph in Appendix Ⅱ represents the phenomenon of fluorescence of the moss green fluorite vase [B] during exposed to ultraviolet light.

2. Pyrophyllite

Pyrophillite is markedly refractory as its name implies from the Greek *Pur* meaning fine and *Phullon* meaning leaf.

Following three carvings [C], [D] and [E] are labeled sa Qingtian stone[b] by the museum. The Qingtian stone occurs in Qingtian Country[c], Zhejiang Province[d] (Gavernment of Qingtian Country, 2008) and is known to have been pyrophyllite as a main constituent mineral. Pyrophillite deposits occur in southeastern part of China including Qingtian Country.

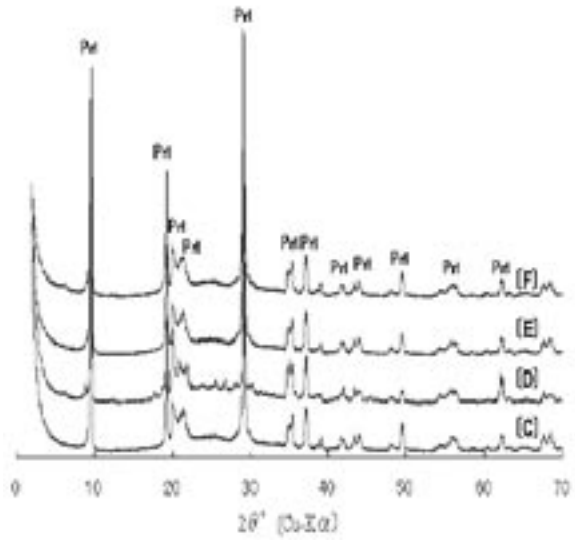

Figure 2. X-ray diffraction pattern of pyrophyllite.
[C] Lion playing ball. [D] Landscape. [E] Turtle's egg. [F] Angular seal carving.
Prl; pyrophyllite

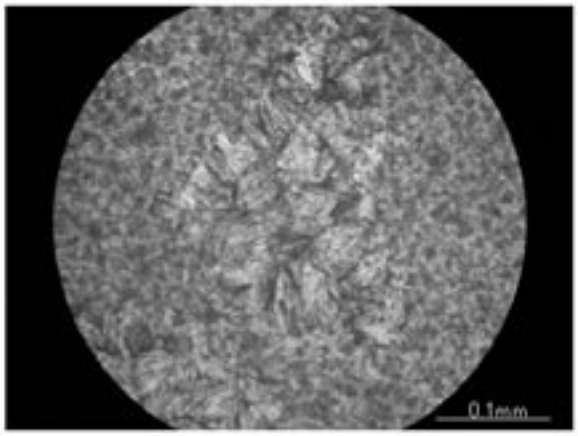

Figure 3. Photomicrograph of pyrophyllite in the thin section from the landscape carving [D]. Open nicol. Detailed explanations are in the text.

［C］Lion playing ball.
The sculpture is very fine. Especially the inside of the ball is vacant without a big hall for chisels. The carving of 20 cm height has two colors. The upper is grayish color, and the lower is dark brown (Photo C of p. 88). Both portions are pyrophyllite as shown by X-ray charts in Figure 2.
The Mohs' scale of hardness is 2.5, and the specific gravity is 2.78.

［D］Landscape.
The fine carving of 25 cm height show the landscape including mountains and rivers of Eternal Youth, old Chinese legend (Photo D of p. 90).

The powder X-ray analysis reveals whole parts of the carving consist of pure pyrophyllite (Fig. 2). Figure 3 shows the photomicrograph of the thin section from this carving. All the parts are pyrophyllite under the microscope and relatively large crystals are observed at the center part. The Mohs' scale of hardness is 2.5. The specific gravity is 2.68.

[E] Turtle's egg.
Ten thousand year's turtle represents the long life. The inside of the egg whose length is 25 cm is excavated from a massive block. Photo E of p. 90 shows this carving on a wooden stage.

The materials of the block is determined also as mono-mineral pyrophyllite by X-ray pattern, hardness of 2.5, and gravity of 2.72 (Fig. 2).

[F] Angular seal carving.
Two rectangular prisms for making angular seal of 14 mm square are put on the market (Photo F of p. 92). One of them (F1) has an indication of Qingtin stone on the case. The X-ray analysis shows pyrophyllite (Fig. 2).

The Mohs' scale of hardness of 2.5 and specific gravity of 2.83 are correspond to pyrophyllite. F2 has mostly the same appearance. The Mohs' hardness and specific gravity are 2.5 and 2.71 respectively, and the result of X-ray diffraction shows the main mineral is pyrophyllite, and the small amount of kaolinite is included.

Both F1 and F2 have the waxy feel.

3. Serpentinite

The Xiu stone[e] occurs in Xiuan Country[f], Liaoning Province[g] used as Xiu Yu[h] (precious material) for making knives and others since 6,800-7,200 years ago of the New Stone Age of China. Xiu Yu is used to be divided into many types according to constituent minerals; serpentine type, tremolite type and mixed type (Zhou and He, 2008). [G] and [H] are labeled as Xiu Yu by the Museum.

In general serpentine is a group of minerals having the formula $Mg_3Si_2O_5(OH)_4$. Those minerals are platy *antigorite*, cylindrical *chrysotile* and flat *lizardite*. Serpentine-group minerals derived by hydrothermal alteration of olivine, pyroxene and amphibole in ultramafic rocks. They are compact, granular or fibrous, and are green, greenish yellow or greenish gray. A rock consisting almost of serpentine-group minerals is called serpentinite.

[G] Carp.

The main part imitating carps and lotus is 20 cm height, and is semitransparent pale bluish green. The base part of mottled yellow green in color is designed as leaves of lotus on its front portion. Photo G of p. 88 shows this carving. The main part is composed simply of antigorite (Fig. 4). Antigorite is confirmed by the difference the Cu Kα diffraction 2 θ angle around 35° introduced by Kohyama (2007) ; 35.6° (2.53 Å) for antigorite and 35.9° (2.50 Å) for lizardite. Chrysotile has no clear peak there. This analogy was applied for following [H], [I] and [J]. The minerals of the base part are mainly antigorite and a small amount of brucite with or without forsterite.

The Mohs' scale of hardness of main and base parts are 3.5 and 3, respectively. The specific gravity of main and base parts are 2.72 and 2.61, respectively.

[H] Vase of serpentinite.

The vase of 36 cm height has mottled color and top and bottom parts are shining as seen in Photo H of p. 89. It may be used for festivals.

Talc and antigorite are detected as constituent minerals of this serpentinite by X-ray analysis (Fig.4). From this chart, the ratio of talc and antigorite is estimated as fifty-fifty. The Mohs' scale of hardness is 2.5. The specific gravity is 2.65.

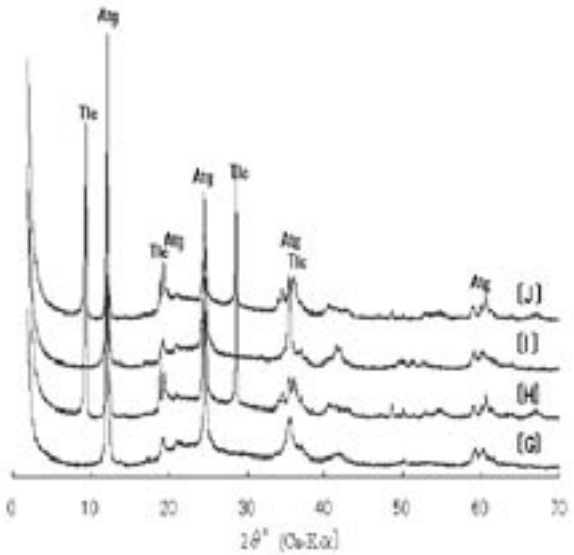

Figure 4. X-ray diffraction pattern of serpentinite.
[G] Carp. [H] Vase of serpentine. [I] Incense burner. [J] Small lion.
Atg; antigorite Tlc; talc

[I] Incense burner.

The noble carving of 14 cm width is composed of a tripodal body and a lid. Both are made of the same materials of pale gray olive color. It has a characteristic decoration imitate a dragon on the top of the lid (Photo I of p. 91), and is used to incense.

The X-ray analysis reveals that the material is antigorite (Fig. 4). The Mohs' scale of hardness and specific gravity are 3.5 and 2.59 respectively, and just fit those of antigorite (Appendix Ⅰ).

[J] Small lion.

The small carving of 10 cm height has also mottled pattern in color and exhibits lofty lucky omen (Photo J of p. 91)

The X-ray analysis reveals that stone materials are talc and antigorite (Fig. 4). The Mohs' scale of hardness is 2.5, and its value is concordant to talc rich materials. The specific gravity is 2.65.

Photo B. Moss green vase of fluorite. (Width 21cm)

Photo A. Purple vase of fluorite. (Width 25cm)

Photo G. Carp. (Width 25cm)

Photo C. Lion playing ball. (Width 21cm)

Photo K. Gold fish. (Width 30cm)

Photo H. Vase of serperitine. (Width 32cm)

Photo D. Landscape. (Width 46cm)

Photo E. Turtle's egg. (Width 45cm)

Photo I. Incense burner. (Width 24cm)

Photo J. Small lion. (Width 25cm)

Photo L. Chinese cabbage. (Width 38cm)

Photo F, N and M. Materials for angular seal (F) and round seal (N), and bracelet of jadeite(M).
From left; F1, F2, N and M. (Width 33cm)

4. Calcite

[K] Gold fish.
The carving of 28 cm height in platy shape of thickness 4 cm or less is brownish yellow in color, and images gold fishes and a peach (Photo K of p. 89). The Chinese pronunciation of fish is same as that of rich. The peach means the long life. Therefore, this carving shows rich and long life.

The mineral identified by the X-ray analysis is calcite (Fig. 5). The Mohs' scale of hardness is 3. The specific gravity is 2.72.

[L] Chinese cabbage.
The fine carving of semitransparent white color is a platy shape of 25 cm length with minute decoration of Chinese cabbage. It reflects the purity of young girls. Photo L of p. 92 shows this carving.

The X-ray and Mohs' scale of hardness of 3 prove to be mineral calcite (Fig. 5). The specific gravity of 2.71 is fit to calcite.

It looks Hetianyu[i] (Zhou and He, 2008) of Ruanyu[l] as the nephrite explained in detail below. It is sure that the carving imitates the production of the Heitiayu.

5. Jade

The word jade, Fei Cui[j] in Chinese, is used as many categories. The most strict one is mineral jadeite. On the other hand, jade includes whole hard stone materials in some cases. There is a reason for this confusion. The derivation of the word jade is from Spanish *ijada*, shortened from *piedra de ijada*, stone of the frank, because it was believed to be a care for renal colic (Morris, 1975). Then, this word was used for many kinds of stones and minerals.

We believe the common usage of jade is a genetic name of both the pyroxene mineral jadeite whose Chinese is Yugyu[k], and the amphibole mineral group nepherite whose Chinese is Ruanyu[l]. Therefore this modality takes over hereafter.

[M] Bracelet of jadeite
The ring shape bracelet of 7 cm in outside diameter is seacrest color with sap green color patch as shown in Photo M of p. 92. The Mohs' scale of hardness is 6.5, and its value is the highest among the collection. The specific gravity is also the highest of 3.30. These values are compatible with jadeite (Appendix Ⅰ). The X-ray diffraction pattern fits to that of jadeite (Fig. 6).

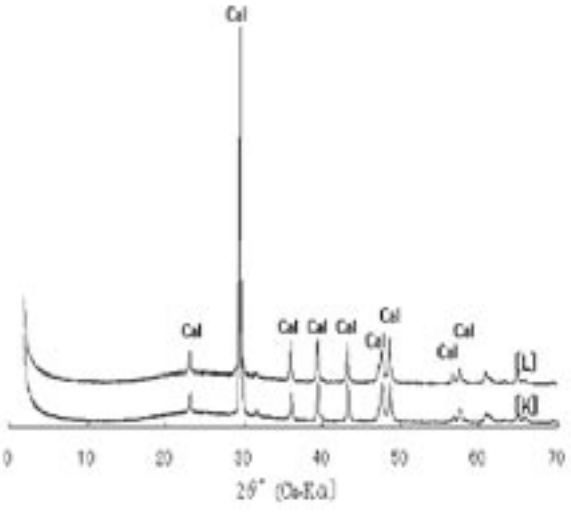

Figure 5. X-ray diffraction pattern of calcite.
[K] Gold fish. [L] Chinese cabbage.
Cal; calcite

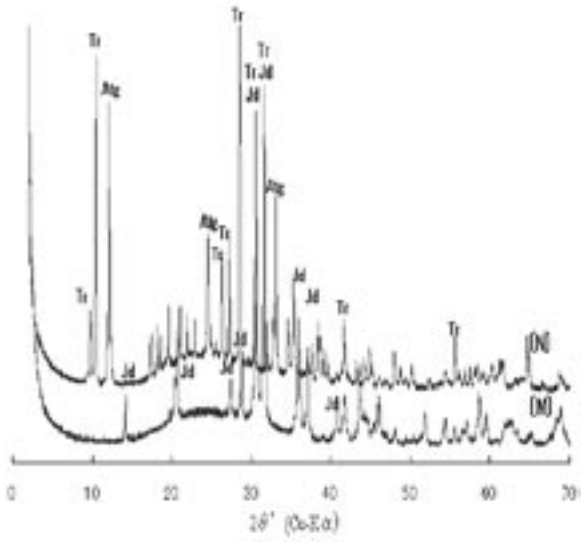

Figure 6. X-ray diffraction pattern of jade.
[M] Bracelet of jadeite. [N] Round seal carving.
Jd; jadeite Tr; tremolite Atg; antigorite

[N] Round seal carving
The cylindrical material for making the round seal of 1.5 cm. The height is 6.5 cm, and the color is gray olive and partly lighter (Photo N of p. 92). The X-ray analysis indicates this mineral is actinolite-tremolite series mineral (Fig. 6), and it is assumed tremolite from the iron content by semi-quantitative analysis. Moderate amounts of antigorite exist as shown in Figure 6. The value 6 of hardness is very high and concordant to that of nephrite. The specific gravity is 2.75.

Summary

The Chinese stone carvings obtained from China were examined mineralogically. Minerals found are mainly fluorite, pyrophyllite, antigorite of serpentine minerals, calcite, jadeite, and tremolite of nephrite. It is easy and accurate to determine the minerals, because whole carving materials being crystalline nor amorphous are suitable for X-ray diffraction. The hardness, specific gravity and microscopic observation on thin section were also effective to determine minerals. Whole minerals occurred in the carvings are completely identified. We believe this is a first attempt to determine the almost whole of the minerals of Chinese stone carvings. Unfortunately, the number of jade is not enough, then, more studies on jade will be continued.

It is shown the properties of minerals or rocks were used to be well fit for the purpose as follows:
Big fluorite crystals for flower vases; Massive and waxy pyrophyllite for fine and excavated carvings; Semi-transparent serpentine for noble decoration; Soft calcite for pretty carvings; precious jade for polished beautiful personal ornament.

Acknowledgments

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Appendix Ⅰ General description of minerals.

Mineral Name	Color	Chem. Composition	Hardness	Sp. Gravity
Antigorite	Green	$Mg_3Si_2O_5(OH)_4$	2.5-4	2.4-2.79
Brucite	Colorless to white	$Mg(OH)_2$	2	2.39
Calcite	Colorless to white	$CaCO_3$	3	2.96
Dolomite	White to reddish white	$CaMg(CO_3)_2$	3.5-4	2.85
Fluorite	White to purple	CaF_2	4	3.18
Forsterite	Pale yellow	Mg_2SiO_4	6.5-7	3.24
Jadeite	Pale green	$NaAlSi_2O_6$	6-7	3.24-3.43
Kaolinite	White	$Al_2Si_2O_5(OH)_4$	2-2.5	2.60-2.68
Pyrophyllite	White to apple-green	$Al_2Si_4O_{10}(OH)_2$	1-2	2.7-2.9
Quartz	Colorless to white	SiO_2	7	2.65-2.66
Talc	White	$Mg_3Si_4O_{10}(OH)_2$	1	2.58-2.83
Tremolite	Bright green	$Ca_2Mg_5Si_8O_{22}(OH)_2$	5-6	2.89-3.44

Compiled from Dana and Ford (1959) and Gaines et al.(1997)

Appendix Ⅱ Fluorescence.

Fluorescence image of the moss green fluorite vase [B] which has been shown in Photo B of p 87.

Appendix Ⅲ Chinese letter.

Expression by Chinese letters on words of proper nouns and others used in the text.

a)	Dailin Natural History Museum, China	中国大連自然博物館
b)	Qingtin stone	青田石
c)	Qingtin Country	青田県
d)	Zhejian Province	折江省
e)	Xiu stone	岫岩
f)	Xiuyang Country	岫岩県
g)	Liaoning Province	遼寧省
h)	Xiu Yu	岫玉
i)	Hetianyu	和田玉
j)	Fei Cui	翡翠
k)	Ruanyu	硬玉, 翡翠輝石
l)	Rauanya	軟玉