

NEPHRITE JADE FROM GUANGXI PROVINCE, CHINA

Zuowei Yin, Cui Jiang, M. Santosh, Yiming Chen, Yi Bao, and Quanli Chen

Nephrite jade with high market value and production potential from the Chinese city of Hechi, in Guangxi Province, was tested by standard gemological methods, polarizing microscopy, scanning electron microscopy (SEM), X-ray diffraction (XRD), Raman spectroscopy, and energy-dispersive spectrometry (EDS). The three samples were mainly white and gray-white (with areas of gray, gray-green, dark green, and black) and had a greasy to waxy luster. Within each of these color varieties, the samples exhibited either “band” or dendritic patterns. The band pattern, composed of tremolite, varied in shape and was either transparent or opaque. Its color, transparency, and distribution were different from the unpatterned areas. The dendritic patterns, which had a brownish yellow and dark brown to black color, were composed of chlorite that formed during metamorphism.

Nephrite is favored by Chinese collectors for its color and luster, as well as its fine texture and outstanding toughness. Primary nephrite deposits are found in more than 20 countries, including China, Russia, Canada, Australia, New Zealand, and South Korea. Chinese deposits are mainly distributed in the areas of Xinjiang, Qinghai, Guizhou, and Liaoning (Liao et al., 2005; Zhang et al., 2011). Research shows that nephrite’s excellent toughness is a product of its fine-grained interlocking structure (Bradt et al., 1973; Dorling and Zussman, 1985; Yang, 2011). Its green color is due mainly to the substitution of Cr^{3+} and Fe^{2+} for Mg^{2+} (Flint, 1990). In principle, nephrite can form in two different ways. One is by contact metasomatism between intermediate-acidic intrusive

rocks and dolomite and/or limestone. The other is by contact metasomatism between serpentine or serpentinizing peridotite and more silicic rocks (Harlow and Sorensen, 2005; Siqin et al., 2012).

The Chinese nephrite samples in this study were recovered in 2012 from Dahua County, in the city of Hechi. There are several mines in the county, worked by independent miners who also farm the area. One farmer estimated production of more than 1,000 tons per year. The local government controls the mining, and the market for this nephrite is growing in Guangxi and Guangdong. In 2013, the pendant shown in figure 1 sold for US\$300, while the bangles in figure 5 brought US\$3,000 each.

This paper introduces the mine at Hechi and characterizes the patterns in these nephrites.

GEOLOGIC BACKGROUND AND LOCATION

The nephrite mining area at Hechi, shown in figure 2, belongs to the west wing of the NNE-striking (15° – 30°) Yangshan-Damingshan anticline. Regional strata dip steeply, and almost all main structural features strike NNE. The wall rocks are marine carbonate rocks deposited from the Upper Devonian to Lower Permian periods (362–290 Ma). Basic intrusive and volcanic rocks were emplaced during the Permian period (approximately 295–250 Ma). The heat gener-

Figure 1. This nephrite pendant, from a mine at Hechi in China’s Guangxi Province, features a dendritic pattern. Photo by Yiming Chen.



See end of article for About the Authors and Acknowledgments.

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Figure 2. This map shows the main locations of China's nephrite deposits (Zhang et al., 2011) and the working area of this study, in Guangxi Province.

ated by the emplacement caused metasomatism between the igneous rocks and the carbonate rocks. Nephrite is the product of this metasomatism (Bureau of Geology and Mineral Resources of Guangxi Province, 1985).

The mining area has a typical karst landscape. It has been severely weathered by the subtropical climate, and slope sediments, fluvial, and alluvial materials are all visible. The ore-bearing country rocks are limestone, in severely weathered layers of varying thickness. Nephrite occurs as bands and veins in these layers. The width of a single vein ranges from tens of centimeters to several meters. The ore body and wall

rock (mainly dolomite marble) are alternately distributed, and the boundary between them is sharp.

The nephrites from these primary and secondary mines are mainly white, gray-white, gray-green, dark green, and black, with a greasy to waxy luster (figure 3). All of these color varieties display either band or dendritic patterns. The band patterns are white and opaque, and their color, transparency, and distribution are different from those of the unpatterned areas. The dendritic patterns are brownish yellow and dark brown to black (figure 4). At Hechi, the dendritic patterns only occur in the nephrites from secondary deposits in river or soil.

Figure 3. The dark green nephrite on the left shows a beautiful green color when illuminated. Black nephrite carvings of the Buddhist goddess Guanyin (center) and necklaces of nephrite beads with various colors (right) are displayed at the local market near the mine. All material shown was mined in Hechi. Photos by Yiming Chen and Zuowei Yin.





Figure 4. A: In the hills near Hechi, nephrite is found in shallow ground, about one meter underground, and belongs to secondary deposits. B: Grayish green rough with a thick weathered surface. C: Nephrites with dendritic patterns and country rock. The country rock is dolomitic marble that has undergone metasomatism. The boundary between marble and nephrite is sharp. D: In the primary deposit, nephrite occurs as bands of dark green, white, and gray. Photos by Yiming Chen.

MATERIALS AND METHODS

Three white and gray-white nephrite samples were examined for this study: the two bangles with dendritic patterns (figure 5, left and center) and a slab with a band pattern (figure 5, right). The dendritic patterns in the two bangles ranged from brownish yellow to black. In the slab, the banded area showed lower transparency than the rest of the sample. The samples were tested by standard gemological methods, polarizing microscopy, scanning electron microscopy (SEM), X-ray diffraction (XRD), Raman spectroscopy, and energy-dispersive spectrometry (EDS). We conducted the tests at the National Key Lab of the China University of Geosciences in Wuhan.

For SEM analysis, the authors fractured the specimens and coated the fracture surfaces with carbon powders using an SCD-005 ion sputter coater. The

specimens were then fastened to a round metal disk for observation. An FEI Quanta 200 scanning electron microscope was used to observe the nephrites' microstructure, especially their dendritic and band patterns. The SEM images are from secondary electrons.

The instrument used for XRD analysis was an X'Pert PRO DY 2198 with Cu K α radiation operating at 40 kV and 40 mA. The instrument was equipped with a small platform and a monocapillary lens with a 100 μ m diameter micro-zone. Dendritic patterns were tested by the micro-area method, since it is difficult to detect very small particles through normal analysis.

To detect the mineral composition of the patterns, we used a Bruker Senterra scanning Raman microscope in the 40–3650 cm^{-1} region. The instrument, which features a 785 nm light source and 50 mW laser energy, was set to approximately 3.5 cm^{-1}



Figure 5. In these photos of the three nephrite samples, the red circles represent the testing points. The two bangles display a dendritic pattern, while the slab contains a band pattern. Photos by Yiming Chen.

resolution and 10 seconds per scan. Dendritic, band, and unpatterned areas were all tested.

For EDS analysis of the dendritic and band patterns, we used an EDAX Genesis 2000. This element-testing method employs back-scattered electrons to obtain chemical composition. Measurement error with the EDS data is 0.1–0.5%.

RESULTS AND DISCUSSION

Gemological Features and Petrographic Study. The samples showed a spot RI of 1.61–1.62 and a hydrostatic SG of 2.88–2.90. The unpatterned and band areas of the nephrite slab were sliced into thin sections. Under polarized light, they displayed different microstructures. The tremolites of the band area (figure 6, left) were fibrous, columnar, of various grain size, and poorly oriented. The individual tremolite crystals ranged from less than 0.05 to 0.2 mm long, occurring in radial beam and fan shapes. The band had a coarser texture than the unpatterned area. The interwoven tremolites of the unpatterned area (figure 6, right) were fine, with a homogeneous grain size. Most of the tremolites were less than 0.05 mm long.

SEM. We performed SEM testing of the dendritic areas in the two bangles, and the band and unpatterned

areas of the slab. The tremolites with a dendritic pattern were magnified 1514 \times and 2840 \times (figure 7). The tremolite grains occurred as long strips, the dendritic pattern grains as tiny dots. At 2840 \times magnification, the tremolite grains were clearly visible, while the grain shape of the dendritic pattern was not.

In Brief

- Nephrite jade in China's Guangxi Province displays different colors and dendritic pattern inclusions.
- Dendritic pattern inclusions composed of chlorite in brownish yellow and dark brown to black color only occur in secondary nephrites found in rivers or soil.
- Since these dendritic patterns have not been found in other Chinese nephrite mines, the pattern may be used in origin determination studies.

The grains in the band areas were unevenly distributed, while those in the unpatterned areas were uniformly distributed at 500 \times magnification. At 2000 \times magnification, the grains in the band were poorly oriented, while those in the unpatterned areas were better oriented (figure 8). Those distinctions led to different appearances between these two areas of the sample.

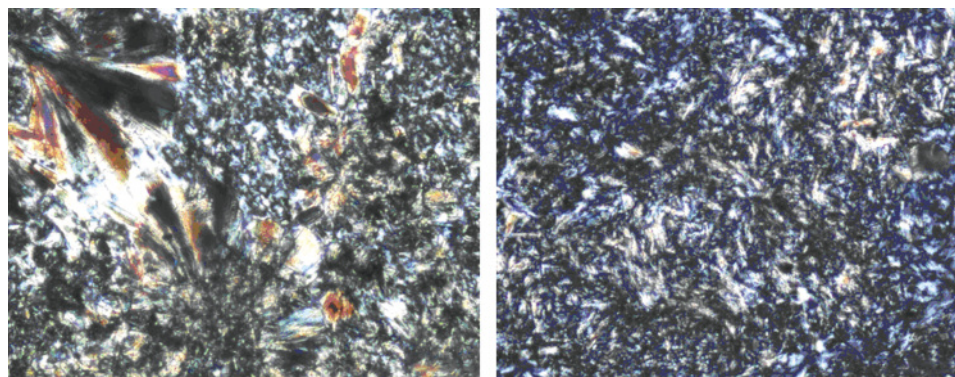


Figure 6. The nephrite slab displays band (left) and unpatterned areas (right). The band's tremolites are fibrous, columnar, of varying particle size, and poorly oriented. The interwoven tremolites of the unpatterned area are fine, with homogeneous particle size. Photomicrographs by Zuowei Yin; image widths 0.57 mm.

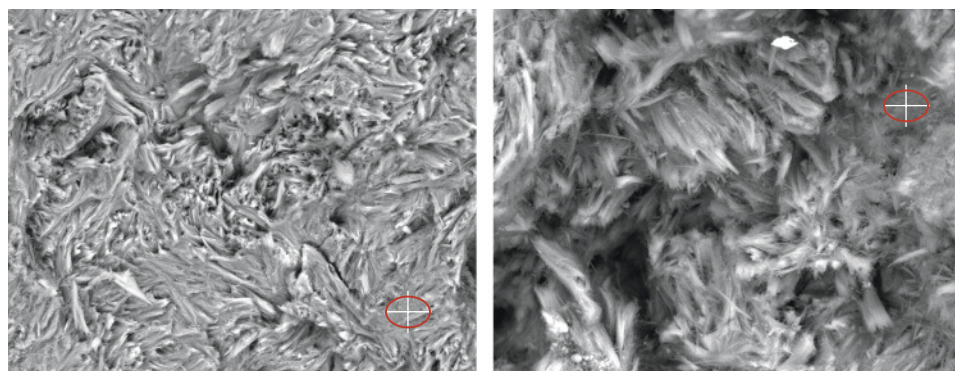


Figure 7. These SEM photos of tremolites with dendritic patterns are magnified 1514 \times (left) and 2840 \times (right). The red circles represent the EDS testing points. Photo by Yi Bao.

Raman Spectroscopy. The grains of the dendritic patterns were too small to detect by Raman, even though the dendritic patterns themselves appeared quite large. Only the spectra of the band and unpatterned areas are provided.

According to the Raman spectra of the slab (figure 9), the mineral constituents of the band and unpatterned portions were all tremolites. Among the nephrite peaks, the 3600–3700 cm^{-1} features represent O-H stretching vibration, and the 900–1150 cm^{-1} features represent the stretching vibration and antisymmetric stretching vibration of the Si-O bond.

The 677 cm^{-1} band designates the symmetric stretching vibration of Si-O-Si. The 100–400 cm^{-1} features may be caused by the deformation vibration induced by the distortion vibration of the silicon oxygen tetrahedron (Zhao and Gan, 2009; Qiu et al., 2010; Yang et al., 2012).

To verify the dendritic patterns by means of their crystal structure and chemical composition, we turned to XRD and EDS.

XRD. To identify the mineral crystal structure of the dendritic pattern, we used the micro-area XRD

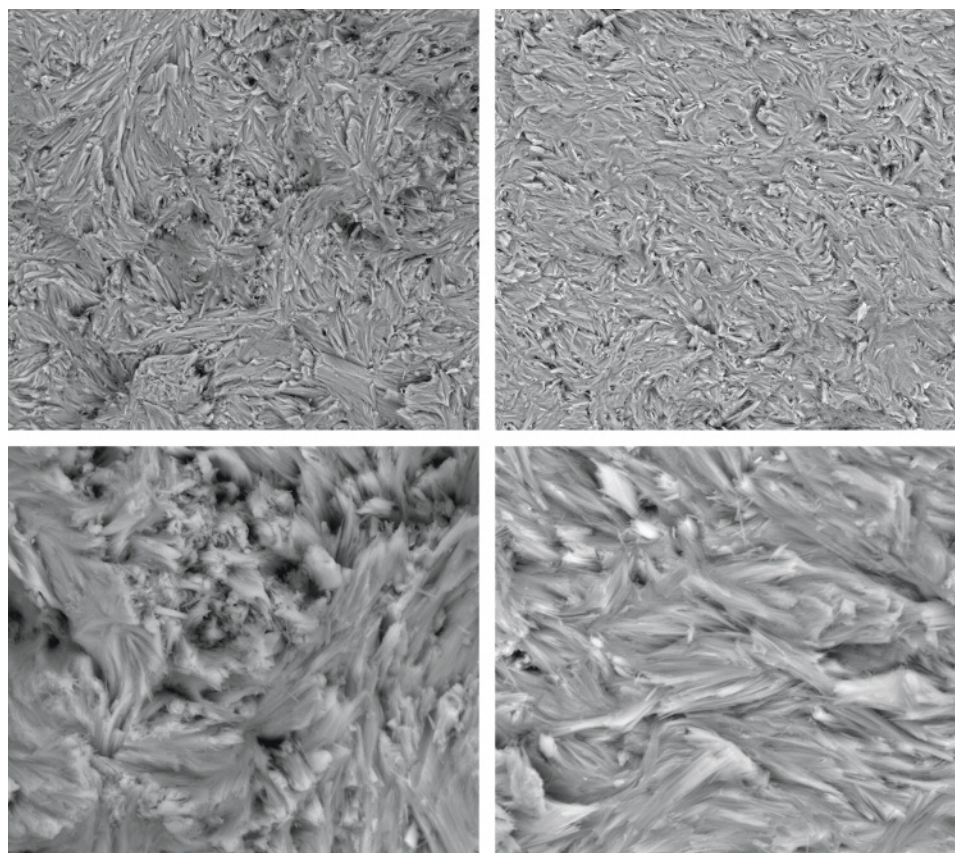


Figure 8. SEM photos of the band (top left) and unpatterned areas (top right) of the nephrite slab are shown at 500 \times magnification. Note the uneven distribution of the grains in the band area. At 2000 \times magnification (bottom left and bottom right), the grains are poorly oriented in the band and better oriented in the unpatterned area. Photomicrographs by Yi Bao.

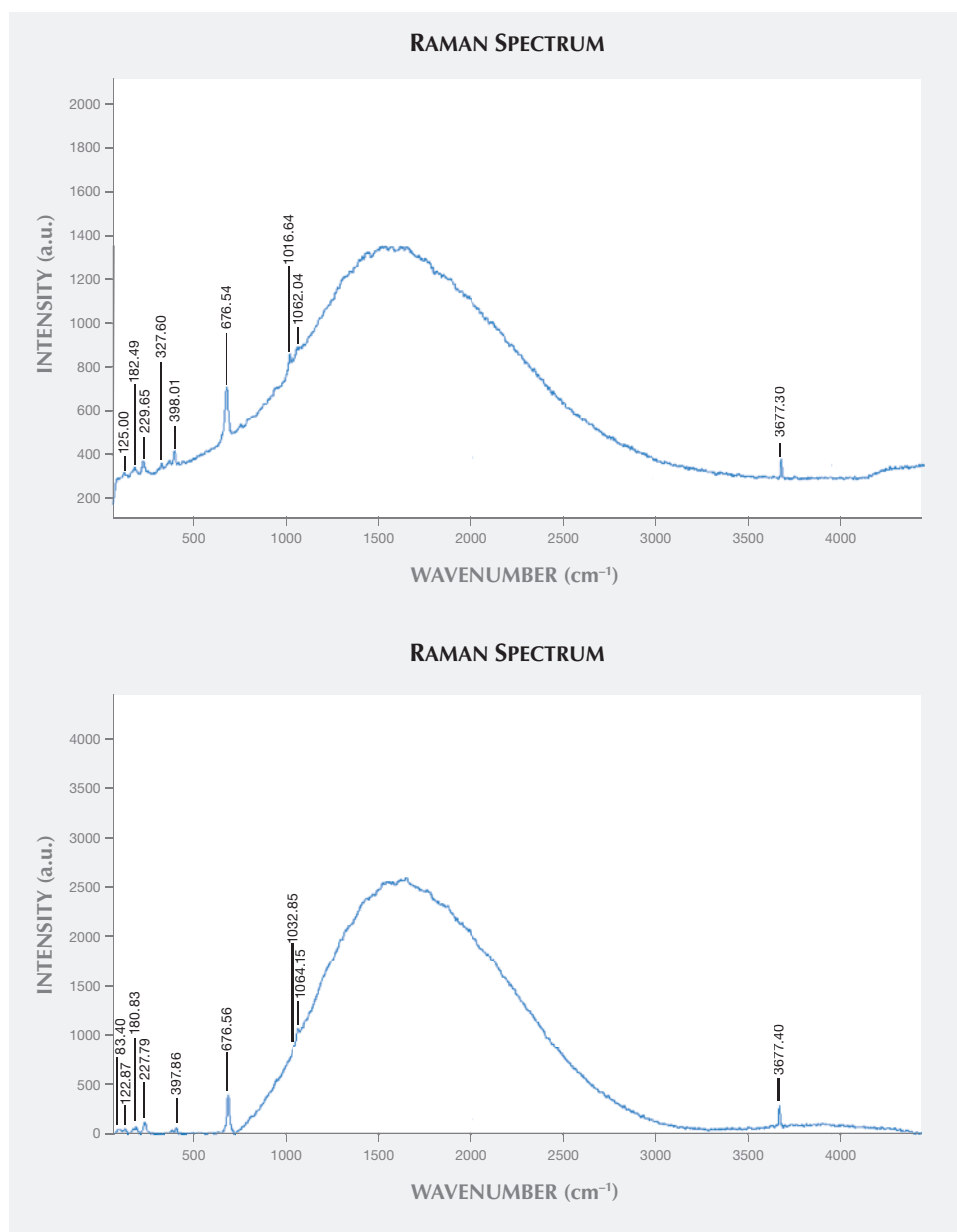


Figure 9. The Raman spectra of the band (top) and unpatterned area (bottom) of the nephrite slab identified them as tremolite.

method, the results of which are shown in figure 10. According to Bragg's law, defined as

$$n\lambda = 2d \sin\theta$$

"d" is the crystal lattice spacing in a certain direction. The dendritic pattern gave d values of 14.4, 7.1, 4.7, 3.5, and 2.8 Å, confirming that the mineral belonged to the chlorite group (Bailey and Lister, 1989; Zhao et al., 2006).

Chemical Composition. The dendritic, band, and unpatterned areas were all tested by EDS. The main composition of the dendritic pattern (table 1) was consistent with chlorite, which has a general chemical

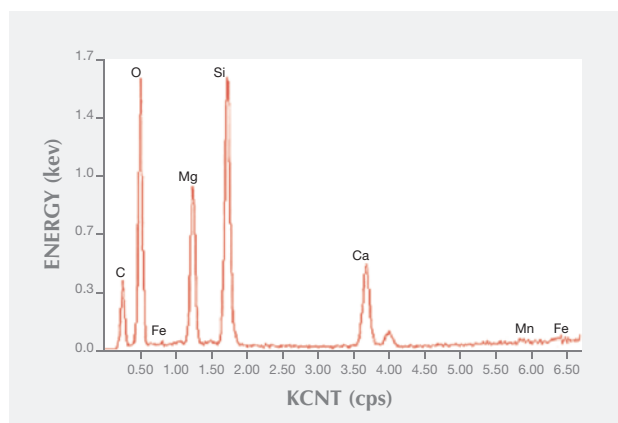
formula of $Y_3[Z_4O_{10}](OH)_2 \cdot Y_3(OH)_6$, where Y can represent Ca, Mg, Fe^{2+} , Al, Fe^{3+} , Cr, Ni, Mn, V, Cu, or Li, and Z is mainly Si and Al. According to table 1, the formula of chlorite here is $(Ca, Mg, Mn, Fe)[Si_4O_{10}](OH)_2(Ca, Mg, Mn, Fe)(OH)_6$. The band (table 2) and unpatterned areas (table 3) were both consistent with tremolite.

CONCLUSION

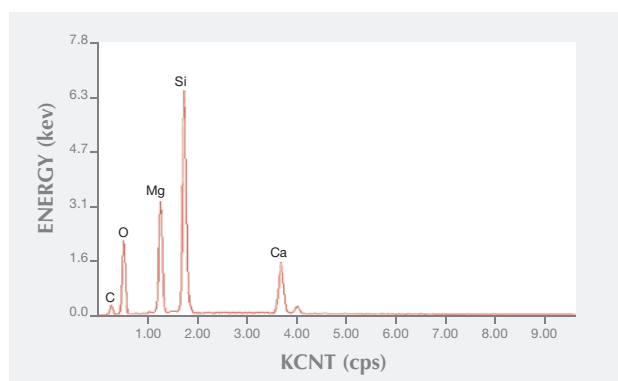
Nephrite jade from primary and secondary deposits at Hechi in China's Guangxi Province displays white, gray-white, gray, gray-green, dark green, and black colors, with a greasy to waxy luster. The white and gray-white samples from this study

TABLE 1. EDS chemical composition of dendritic patterns in nephrite from Guangxi Province, China.

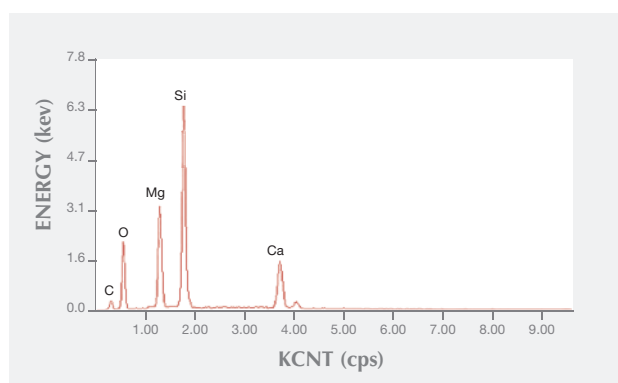
Element	Wt.%	At.%
O	39.16	42.23
Si	14.52	8.92
Mg	9.48	6.73
Ca	7.20	3.10
Fe	1.88	0.58
Mn	1.27	0.40
C	26.49 ^a	38.05 ^a

^a C content is from the carbon-coated surface.**TABLE 2.** EDS chemical composition of band patterns in nephrite from Guangxi Province, China.

Element	Wt.%	At.%
O	33.29	39.19
Si	25.88	17.36
Mg	13.26	10.27
Ca	9.16	4.31
C	18.41 ^a	28.88 ^a

^a C content is from the carbon-coated surface.**TABLE 3.** EDS chemical composition of unpatterned areas in nephrite from Guangxi Province, China.

Element	Wt.%	At.%
O	30.27	37.67
Si	29.91	21.20
Mg	14.05	11.51
Ca	11.28	5.61
C	14.49 ^a	24.02 ^a

^a C content is from the carbon-coated surface.

showed band or dendritic patterns. The transparent or opaque bands contained an irregular arrangement of tremolite, and their color, transparency, and distribution of grains were different from the rest of

the nephrite. The dendritic pattern only occurred in the secondary nephrites found in river or soil. There were also some dendritic patterns with brownish yellow and dark brown to black color. They con-

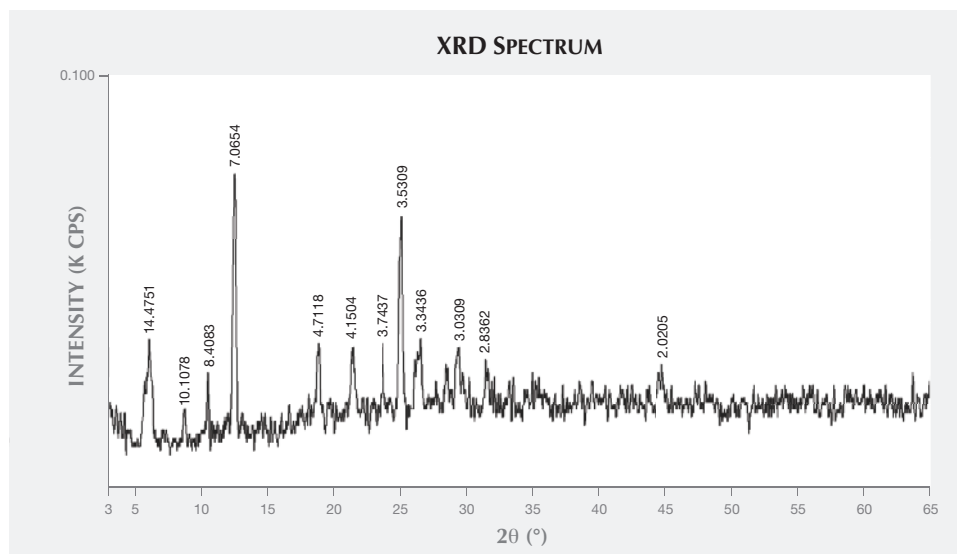


Figure 10. XRD testing of the dendritic patterns gave d values (crystal lattice spacing) characteristic of the chlorite group.

tained very small particles composed of chlorite that occurred during metamorphism. These kinds of dendritic patterns have not been found in other Chinese nephrite mines, making them useful fea-

tures for identifying the locality. The pattern also proves that these nephrites are from secondary deposits, which have a higher value in the Chinese market.

ABOUT THE AUTHORS

Dr. Yin (yinzhouwei1025@163.com) is a professor at the Gemological Institute, China University of Geosciences in Wuhan, where Mr. Chen and Ms. Bao are students and Dr. Chen is a lecturer. Ms. Jiang (jiangcuijane@163.com, corresponding author) is a lecturer at the Foreign Language School, China University of Geosciences in Wuhan. Dr. Santosh is a professor at the School of Earth Sciences and Resources, China University of Geosciences in Beijing.

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