Archaeomineralogy of Taiwan Nephrite: Sourcing Study of Nephritic Artifacts from the Philippines

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ABSTRACT

Green-colored nephritic jade artifacts are commonly found in Neolithic archaeological sites in Taiwan and some regions of the Philippines. Nephrite deposits only occur rarely in nature, and it is widely accepted that chemical analysis is required if nephritic artifacts are to be sourced to specific quarries. In order to define the mineralogical character of the Fengtian nephrite in Taiwan, an electron probe micro analysis (EPMA) was carried out on nephrites from this source and others in East Asia and the Pacific region. Seventeen nephrite specimens were analysed, and found to be composed of tremolite-actinolite amphiboles (Mg/[Mg+Fe] less than 0.93) with fibrous texture, and bearing chromian-spinel inclusions with significant amounts of manganese (Mn: up to 9 wt.%) and zinc (Zn: up to 7 wt.%). These chemical characters can be applied to differentiate the Fengtian nephrite from others.

An EPMA sourcing study was also applied to a series of green- and white-colored nephritic artifacts excavated from the Philippines. These included nine green nephritic ornaments from the Tabon Caves on Palawan Island, a fragment of a green nephritic bracelet from the Nagsabaran site in the Cagayan Valley, northern Luzon, and four white nephritic adzes from Batangas, south-western Luzon. The results indicate that there are at least two kinds of nephrite raw material that were used in the Philippines. The green nephrite, used mostly for the ornaments, was derived from the Fengtian deposits in eastern Taiwan. The white nephrite found in many Batangas sites, not of high quality, was only used for tools such as adzes and chisels and may have been acquired from a local Luzon source. Consequently, this study provides some important evidence about interaction between different prehistoric populations across a large area of Island Southeast Asia.

Key Words: Nephrite, Taiwan, Philippines, EPMA, Neolithic

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INTRODUCTION

In Chinese culture, JADE (nephrite) has been more highly valued for over 8000 years than any other gem stone material. The toughness of nephrite is remarkable. Nephrite has strength greater than most of steel, and was used for axes, adzes, chisels, arrowheads and spearheads in human prehistory. Nephrite was also a highly symbolic stone, used for ornaments and ritual objects since the Neolithic. Nephrite deposits only occur in specific tectonic settings, and it is widely accepted that geochemical characterization of nephrite artifacts is essential for the study of their quarries (Wen & Jing 1992; 1996; Douglas 1996; 2003; Yui *et al*. 2001).

Nephritic artifacts have been found widely distributed in Neolithic archaeological sites in Taiwan and nearby islands such as Penghu, Ludao and Lanyu (*e.g.*, Kano 1946; Sung 1980; Kobubu 1981; Tsang 1992; Chen 1998; Huang & Chou 2001; Lien 2002; Liu 2003; Hung 2004). These nephritic tools and ornaments, mostly green in color, have been reported from more than 108 locations (Hung 2004). Since green nephrite occurs in the Fengtian area in eastern Taiwan, it is generally accepted that this area was a major source for the ancient nephritic artifacts in Taiwan (Wang *et al*. 1996; Lien *et al*. 1996; Tan *et al*. 1997; Huang & Chou 2001; Yui *et al*. 2001; Lien 2002).

In the Philippines, green nephritic ornaments have recently been recognized as being extremely similar in their technology of manufacture, style and texture to those discovered in Taiwan. These green nephritic artifacts have been discovered from the islands of Itbayat (Batanes), northern and south-western Luzon, and Palawan (Hung *et al*. 2004; Hung & Iizuka 2004; Bellwood and Dizon 2005; Hung 2005: *this issue*). On the other hand, a large quantity of nephritic tools (axes, adzes and chisels), which are mostly white in color, were collected by H. Otley Beyer during the 1930s and 1940s from Batangas, Rizal and Laguna Provinces in southwest Luzon (Beyer 1948). These materials are now stored in the Beyer's collection in the National Museum of the Philippines, Manila. During the 1960s and 1970s, green nephrite artifacts were excavated by Robert B. Fox (1970) from the Tabon Caves Complex on Palawan Island. The green nephrite ornaments, such as earrings, bracelets, and beads were found in Leta-Leta Cave near El Nido, and in the Tabon Caves Complex, including the caves of Duyong, Manunggul, Uyaw, Guri, Rito-Fabian and Tadyaw, near Quezon on Palawan (Fox 1970:14-17; Fox 1977a:303-308; Fox 1977b:228-234; Peralta 1977:226). Recently, a fragment of a green nephritic bracelet was excavated from the early Neolithic red-slipped pottery layer at Nagsabaran site, near Lallo in Cagayan Province, northern Luzon (Tsang *et al*. 2002:244). A small bell-shaped green nephrite bead was also found in Kay Daing site in Batangas (Hung *et al*. 2004). As noted by Beyer (1948)(1) and Fox (1970)(2), the sources of both the green and the white

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(1) Beyer stated "where the raw material came from is still uncertain, as no natural source for it has yet been discovered in the Philippines" (Beyer 1948: 44-45).

(2) Fox commented "although there is no question that nephrite was worked extensively elsewhere in the Philippines, notably in Batangas Province where the writer believes a local but still undiscovered source of nephrite was known and worked, the ornaments of jade found in Palawan appear to have been introduced at different periods" (Fox 1970: 131).

nephrites are an important issue in Philippine archaeology. However, mineralogical investigation including sourcing study has not been carried out yet.

In any sourcing study of nephrite artifacts, it is important to be able to compare the chemical signatures of composed minerals with raw material samples, without causing damage to the artifacts as small as possible. Most of geological and mineralogical studies of nephrite artifacts which have been done in last decade are divided into 3-categories; 1st: mineral descriptions based on optical observation by microscope; 2nd: crystallographic studies by X-ray diffraction (XRD) for powdered sample (*e.g.*, S.B. Lin *et al*. 1996; Hung 2000; S.F. Lin *et al.,* 2002) or non-destructive Raman spectroscopy (*e.g.*, Xu *et al*. 1996; Lien *et al*. 1996); and 3rd: bulk-rock chemistry such as major element compositions or limited elemental measurement by X-ray fluorescence analysis (XRF) and oxygen and hydrogen isotopes by mass spectrometers (Douglas 1996; 2003; Wen & Jing 1992; 1996; Yui *et al*. 2001) to understand their forming processes. Recently, advanced analysis methods have been established; combined technique of PIXE and micro-Raman to measure transition elements of nephrite (Chen *et al*. 2004), nephrite Ar-Ar dating (Chou *et al*., 2003; 2004) to understand their geological origin. However, many of methods were not able to identify specific quarry clearly because of similarity of mineralogy and whole rock chemistry(3).

A number of accessary minerals have been reported within nephrites (*e.g.,* Tan *et al*. 1978; Wen & Jing 1996). The chemistry of the accessary minerals is important to understand origin of nephrite deposits, and it should be individually studied from nephrite matrix instate of whole rock analysis. However it has not well investigated yet. An electron probe micro analyzer (EPMA) with wavelength dispersive X-ray spectro-meters (WDS) is powerful equipment for this purpose that needs only a small amount of specimen. Since the 1970s, the use of EPMA has become routine in geology for the study of minerals, because it has a spatial resolution of 1 to a few μm. It performs precise and accurate analysis in weight percentage (wt.%), because the interactions between an electron beam and the atoms in the target materials, are well understood and the target, such as the accessary minerals, can be focused with both the secondary and the back-scattered electron images.

This paper presents the mineral chemistry of nephrites and their accessary minerals from the Fengtian deposits in eastern Taiwan, and several sources in the Asian and Pacific regions. Based on comparison of mineral chemistry in both nephrite matrix and its accessary minerals, we propose criteria for discriminating Fengtian nephrite from the others using EPMA technique. And we present results of sourcing study of green and white nephritic artifacts from Taiwan and the Philippines, and discuss that the green nephrites originated from Fengtian deposit in eastern Taiwan, and that the white ones are probably from a local and missing source on Luzon.

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(3) Recently, study for trace element composition, which is thought to be geochemical fingerprint of their origin, by ICP-MS (Inductively coupled plasma mass spectrometry) and PIXE-PIGME (proton induced x-ray and proton induced gamma-ray emission) have been succeed on pottery and obsidian sourcing study, respectively (Kennett *et al*. 2004; Summerhayes 2004). However these methods have not been applied for nephrite sourcing study yet.

NATURAL NEPHRITES IN TAIWAN AND OTHER LOCATIONS

1. Nature of nephrite

Jade (*yu* in Chinese) is a term applied to the two minerals JADEITE and NEPHRITE in mineralogy, green-colored stones, such as serpentine, talc, diopside (clinopyroxene; Cpx), titanite and some others are called as jade (or Psudojade) occasionally though. Both jadeite and nephrite are similar in appearance, which occur in relatively high-pressure and high-temperature metamorphic rocks, but their crystal structures and chemical compositions are different. Jadeite is a sodium clinopyroxene (Na-CPX: chemical formula $NaAlSi_2O_6$; Density=3.2-3.4; Hardness=6, and nephrite is a calcium amphibole (Ca-amphibole: $Ca_2[Mg,Fe]_5[Si_8O_{22}][OH]_2$; D=2.9-3.5; H=5-6)

Nephrite owes its compactness to its tough fibrous crystalline texture (*also known as* nephrite texture), composed of tremolite-actinolite crystals (Beck 1970; Wen & Jing 1996). Tremolite is an Mg-end member of Ca-amphibole, and is white to grey in color usually. Ferrous iron (Fe^{2+}), which is substituted in the Mg site, is often present in small amounts, and the tremolite gradually becomes green and then grades into actinolite as the Fe content increases. In most of case, Ferric iron (Fe^{3+}) is rarely in nephrite (Tan *et al*. 1978). Tremolite and actinolite can be specified in the plot of Si (atoms per formula unit) vs. Mg# (Atomic ratio of Mg/[Mg+Fe]) (Fig. 1) (Leake *et al*. 1997).

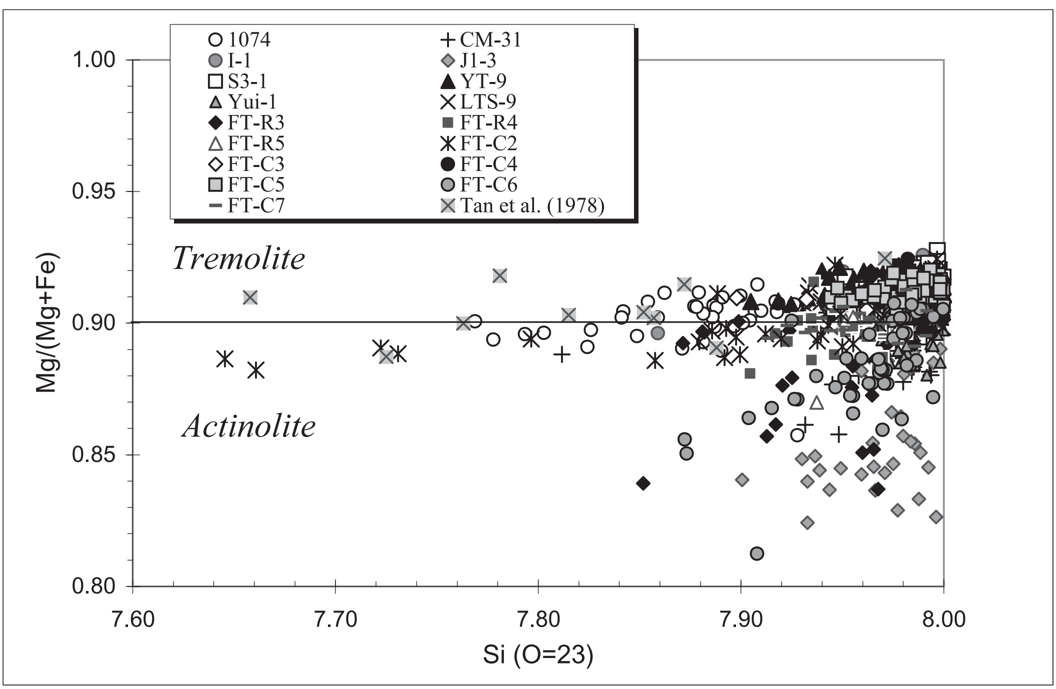

Fig. 1. Si vs. Mg# plot of Fengtian nephrites. The line at Mg# = 0.9 indicates the chemical boundary between tremolite and actinolite. Whole rock chemistry are also plotted (N=10 after Tan *et al*. 1978).

It is generally agreed the process of forming the minerals tremolite-actinolite required that the original rocks prior to metamorphism were either carbonates or serpentinite (Wen & Jing 1992, Tsien *et al*. 1996). Tremolite is derived from carbonate, such as limestone, and marble, which have less iron. Actinolite, on the other hand, is associated with serpentine, which is an alteration product of mantle peridotite (usually Mg# is 0.9), and sedimentary rocks. Share stress should be required to form the fibrous crystalline texture during the metamorphic process.

2. Nephrite deposits in the Fengtian area, Hualien, Taiwan

Nephrite deposits are located west of the town of Fengtian in Hualien County, eastern Taiwan. The nephrite occurs mainly in serpentinite layers between black schists or muscovite-quartz schist in the greenschist facies (Tan *et al*. 1978). The Fengtian area was mined for industrial asbestos (serpentine) in the late 19th century. There were then about a dozen nephrite mines and prospects, and high quality nephrite was mined between the early 1960s and early 1980s. The mining ceased when resources became too depleted. Nowadays, cobbles and boulders of nephrite are occasionally found in the riverbed below the mines(4). Another nephrite deposit occurs west of the town of Wangrong, about 15 km south-southwest of Fengtian. The Wangrong deposit belongs to the same geological sequence as the Fengtian deposits, but was smaller than the Fengtian deposits.

3. Studied natural nephrites

The nephrite samples studied from the Fengtian area are listed in Table 1. There are seven samples from the Fengtian mine field and one from Wangrong. Nine cobble and boulder samples from the riverbed downstream from Fengtian were also studied.

The green nephrites in the comparative study are collected from Xiuyan in Liaoning, Jiuquen and Nanshan in Gansu and Qiemo in Xinjiang in China, Gifu in Japan, near the Lake Baikal, Onot River, and Chara Jelgra River in Yakut in Siberia, Cowell in South Australia, Ouen Island in New Caledonia, Otago area in South Island of New Zealand, British Columbia and Wyoming (Table 2). Although the nephrite from North America is unlikely to occur in the Southeast Asian Neolithic, the mineralogical investigation has been carried out because North American nephrites, especially Canadian nephrite are commonly used for replica artifacts and modern arts. We investigated some other green stones which are so-called "jade" regionally, from several deposits in Taiwan, China, Vietnam and Japan. However, they were not identified as nephrite or Ca-amphibole, so there are not described in this report except the green stones from the Philippines, which describe the later section. White-colored nephrites from known nephrite deposits in provinces of Liaoning, Xinjiang and Jiangsu in China, Chun-cheon in Korea, and Siberia in Russia are also studied (Table 3).

(4) Collection of nephrite in this area is prohibited by law of the Republic of China (Taiwan).

A drilled sampling serpentine (WT-9019), which attached with nephrite deposit in Fengtian, was studied for comparison study of accessary minerals between nephrites and serpentine.

ANALYTICAL PROCEDURE

1. Sample preparation

The natural nephrites were sliced in several small pieces (less than few cm in size with few mm in thickness) by a micro-diamond saw with the distilled water. Cleaned samples were mounted in a cold-mounting epoxy resin and the exposed surfaces were well polished with Alumina paste. Each polished sample was then carbon coated.

2. Electron probe micro analysis

Mineral identification and quantitative chemical analyses were made with a JEOL EPMA JXA-8900R at Institute of Earth Sciences, Academia Sinica at Taipei. An operated beam condition is 15kV, 10 nA, and 2 μm defocused beam for the acceleration voltage, beam current and beam size, respectively. Analysed points were selected within the secondary and the back-scattered electron images to avoid cleavage and weathered areas. The quantitative data were corrected by PRZ method to calculate as oxide compositions, using the standard calibration of synthetic and natural chemical-known standards; Wollastonite for Si and Ca, rutile for Ti, corundum for Al, Chrome-oxide for Cr, fayalite for Fe, tephroite for Mn, pyrope for Mg, Ni-olivine for Ni, albite for Na, adularia for K, apatite for P, and Zinc-oxide for Zn. The relative standard deviations of analysis for all 13-elements are less than 1.0%.

Because Ferric iron (Fe^{3+}) is rarely in nephrite (Tan *et al*. 1978), all analysis data is concerned FeO as total iron. For Ca-amphibole, the number of cations of nephrite is calculated on the basis of 23 oxygen atoms and mineral name were classified based on nomenclature of amphiboles (Leake *et al*. 1997).

MINERALOGY OF NEPHRITE

1. Fengtian nephrites

Mineral descriptions are shown in Table 1 and the EPMA data are listed in Appendix 1 and 2. Although the color of the Fengtian nephrites varies from dark green through yellowish green to opaque white, most is green in color and characterized by a fibrous texture (Fig. 2). Chromian spinel (Cr-spinel), black in color (up to few mm in size), can be observed as an inclusion mineral in the Fengtian nephrite (Fig. 2-c). Chlorite, serpentine and talc are often observed within the fibrous texture as brownish to white impurities. These are secondary products of nephrite-forming metamorphism or hydrothermal alteration.

TABLE 1. List of studied nephrites from Fengtian area, east Taiwan.

sample No.	Locality	mineral name	n.o.a.	Mg/(Mg+Fe)	Al/(Al+Cr)	color	texture	inclusions
OVERALL		**tremolite-actinolite**	**675**	**0.928-0.766**	**1.00-0.43**			
Fengtian (mine field)		*tremolite-actinolite*	*262*	*0.928-0.766*	*1.00-0.43*			Zn-chromite, Al-chromite, Cpx, Cr-gros.
YT-9	YuenTong Mine (South)	tremolite	54	0.921-0.903	0.93-0.57	green	fibrous	Zn-chromite
S3-1	China Mine (North)	tremolite	24	0.928-0.904	0.89-0.58	green	fibrous	Zn-chromite
I-1	China Mine (North)	tremolite-actinolite	23	0.926-0.893	0.70-0.43	pale green-green	fibrous	Zn-chromite, Ni-As, Cr-Gros
#1074	China Mine (North)	tremolite-actinolite	65	0.918-0.857	0.90-0.61	pale green-dark green	fibrous	Zn-chromite, Al-chromite, Cpx, Cr-Gros
CM-31	China Mine (North)	tremolite-actinolite	28	0.916-0.858	1.00-0.60	dark green	fibrous	Zn-chromite
J1-3	China mine (North)	actinolite	39	0.896-0.766	1.00-0.89	white	fibrous	no
Yui-1	China mine (South)	tremolite-actinolite	29	0.910-0.880	1.00-0.84	white	fibrous	no
Fengtian (riverbed)		*tremolite-actinolite*	*385*	*0.924-0.780*	*1.00-0.56*			Zn-chromite, Al-chromite, Cpx, Cr-gros.
FT-C2		tremolite-actinolite	60	0.924-0.873	0.90-0.57	green-pale green	fibrous	Zn-chromite
FT-C3		tremolite	7	0.915-0.905	0.92-0.67	green	fibrous	Zn-chromite, Al-chromite
FT-C4		tremolite-actinolite	42	0.924-0.896	1.00-0.74	green	fibrous	Zn-chromite, Al-chromite, Cpx, Cr-Gros
FT-C5		tremolite	55	0.920-0.905	0.93-0.66	green	fibrous	Zn-chromite
FT-C6		tremolite-actinolite	49	0.907-0.780	0.97-0.56	green	fibrous	Zn-chromite
FT-C7		tremolite-actinolite	21	0.913-0.891	1.00-0.69	green	fibrous	Zn-chromite
FT-R3		tremolite-actinolite	89	0.922-0.837	1.00-0.61	green	fibrous	Zn-chromite
FT-R4		tremolite-actinolite	49	0.916-0.881	0.94-0.65	green	fibrous	Al-chromite, Zn-chromite
FT-R5		tremolite-actinolite	13	0.918-0.870	0.98-0.76	green	fibrous	Zn-chromite, Cr-Gros
Wangrong (mine)								
LTS-9	Lin tian shan	tremolite	28	0.920-0.906	0.76-0.55	dark green	fibrous	Zn-chromite, Cpx, Cr-gross.

n.o.a.: numbers of analyses points.

TABLE 2. List of studied world known green-colored nephrites.

sample No. and locality			mineral name	n.o.a.	Mg/(Mg+Fe)	Al/(Al+Cr)	color	texture	inclusions	group
Asia										
Liao ning, CHINA										
LN-2	Xiu yan		tremolite	28	0.978-0.970	1.00-0.90	green	massive	no	I
LN-6	Xiu yan		tremolite	53	0.988-0.982	1.00-0.88	pale-green	massive	no	I
Xin jiang, CHINA										
XT-1	Qie mo		tremolite	39	0.974-0.958	1.00-0.95	pale green	massive	no	I
Gan su, CHINA										
GS-1	Jiu quen		tremolite	43	0.983-0.976	1.00-0.97	pale-green	massive	rutile in titanite, Ca-garnet (grossular)	I
GS-2	Jiu quen		tremolite	43	1.00-0.995	1.00-0.95	pale green	massive	no	I
GS-6	Nan shan		tremolite-actinolite	45	0.919-0.899	0.95-0.64	greem	massive	allanite, chromite	III
Siberia, RUSSIA										
Yk-1	L. Baikal, Yakut		tremolite	40	0.981-0.965	1.00-0.93	green	massive	apatite	I
Yk-3	L. Baikal, Yakut		tremolite	34	0.995-0.976	1.00-0.92	green-brown	massive	titanite	I
Yk-4	L. Baikal, Yakut		tremolite	48	0.990-0.983	1.00-0.91	green-pale green	massive	no	I
Sb-1	Onot R.		tremolite	38	0.951-0.908	1.00-0.47	light green	fibous	chromite	II
Sb-3	Chara Jelgra R.		tremolite-actinolite	62	0.928-0.759	1.00-0.47	green	fibous	Zn-chromite, Fe-Ni-Cr metal	III
Central JAPAN										
JN-130	Nyu kawa, Gifu		tremolite-actinolite	68	0.977-0.902	1.00-0.68	green	fibous	Cpx	I and II
Oceania										
AUSTRALIA										
AUS-1	Cowell	South Australia	tremolite	36	0.983-0.972	1.00-0.94	light brown-green	fibous	apatite	I
NEW ZEALAND										
NZ-1	C. Otago	South Island	tremolite-actinolite	48	0.914-0.885	0.93-0.62	green	fibous	no	III
NZ-2	Red Mt.	South Island	tremolite	36	0.928-0.908	0.98-0.58	pale green	fibous	Cr-Spinel, Zn-chromite, pentrandite	III
NZ-3	L. Wakatipu	South Island	actinolite	13	0.895-0.875	0.95-0.37	pale green	fibous	Al-chromite, pentrandite, Cr-gros.	III
NEW CALEDONIA										
NC-1*	Ouen Island		(tremolite -actinolite)	29	0.911-0.890	0.98-0.81	green	fibous	(anorthite matrix with Cpx)	
North America										
British Clumbia, CANADA										
BC-1			tremolite	26	0.918-0.903	0.78-0.26	dark green	massive	Cr-gros., Zn-chromite, Pentrandite	III
BC-2	Dease Lake		tremolite-actinolite	54	0.922-0.879	0.83-0.50	dark green	massive	Cr-gros., Chromite	III
BC-3	Shulaps		tremolite-actinolite	40	0.915-0.897	0.92-0.70	dark green	massive	Cr-gros., Chromite	III
BC-4	Mt. Ogden		tremolite-actinolite	38	0.922-0.884	0.96-0.57	dark green	massive	Cr-gros., Chromite	III
Wyoming, USA										
Wy-6		S. Wyoming	tremolite	48	0.949-0.930	1.00-0.82	green	fibous	titanite	II

TABLE 3. List of studied world known white-colored nephrites.

sample No. and locality		mineral name	n.o.a.	Mg/(Mg+Fe)	Al/(Al+Cr)	color	texture	inclusions
Russia								
LB C2	L. Baikal	tremolite	57	1.000-0.996	1.00-0.90	grey-white	massive	no
LB C5	L. Baikal	tremolite	53	0.999-0.995	1.00-0.92	white-brown	massive	no
Sb-7	Onot River	tremolite	39	0.940-0.919	1.00-0.66	white	fibous	no
China								
CD014	Kuan dian, Liao ning	tremolite	55	0.996-0.988	1.00-0.88	yellow-white	massive	no
Trk-1	Kun lun, Xing jian	tremolite	41	0.995-0.964	1.00-0.88	white	fibous	apatite, galena
Trk-2	Kun lun, Xing jian	tremolite	40	0.996-0.982	1.00-0.91	white	fibous	no
MLG1	Hsiao mei lin, Jiang su	tremolite	20	0.995-0.988	1.00-0.92	white	massive	Cpx
Korea								
KN 2-2A	Chun cheon	tremolite	54	0.978-0.957	1.00-0.96	white	massive	Cpx
KN 2-2B	Chun cheon	tremolite	52	0.996-0.992	1.00-0.92	white	massive	no
KN 2-2C	Chun cheon	tremolite	42	0.997-0.993	1.00-0.94	white	massive	no
KN 3	Chun cheon	tremolite	28	0.989-0.984	1.00-0.92	white	massive	no
KN 3-1	Chun cheon	tremolite	73	0.994-0.978	1.00-0.91	white	massive	no

The quantitative analyses of the 17 nephrite samples from the mine areas and the riverbed bed show a rather broad compositional range for Mg# from 0.93 to 0.8 (average of all 675 points is about 0.9 in Mg#), which ranges from tremolite to actinolite (Fig. 1). Results of whole rock chemical analysis of Fengtian nephrites by Tan *et al*. (1978: 10 hand specimens) are also shown in Figure 1. Whole rock major element compositions show that Mg# ranges from 0.887 to 0.924 with SiO_2 ranges from 55.0 to 58.6 wt.% (52.5-59.3 wt.% in EPMA). And other elements show similar range of their variations with EPMA results. Unrelated to their sampling locality and color, the Fengtian nephrites show FeO content between 4 and 6 wt.% (3.5-5.1 wt.% from Tan *et al*. 1978). The range of Mg# from samples Yui-1 (the cat's eye nephrite) and J1-3, white in color, shows between 0.91 and 0.78, and these FeO values seem slightly higher than that of the common (green-colored) nephrites. All samples show also a broad compositional range of Al# (Al/[Al+Cr]) from 1.0 to 0.4, though most have Al_2O_3 and Cr_2O_3 contents less than 1 wt.% (1.9 wt.% in Al_2O_3 and 0.2 wt.% in Cr_2O_3: Tan *et al*. 1978). MnO contents are less than 0.3 wt.% (0.5 wt.%: Tan *et al*. 1978), and Na_2O, K_2O and TiO_2 contents are less than the detection limit of analysis (0.1 wt.%) (these are less than 0.5 wt.%: Tan *et al*. 1978).

Since the analysed points were on unweathered surfaces, and the data were collected from several localities (with 675 analysed points in total), and also the EPMA data are also consistent with the whole rock whole rock chemistry by Tan *et al*. (1978), the range of variation should be accurate for Fengtian nephrite. This chemical range allows discrimination of Fengtian nephrite from the tremolite nephrites.

2. Accessary minerals of Fengtian nephrites

In the Fengtian nephrites, Cr-spinel (chemical formula: $[Mg,Fe][Al,Cr]_2O_4$) is the most abundant and a characteristic accessary mineral. The Cr-spinel can be observed in patches associated with chlorite veins. In the larger Cr-spinel grains (> 1 mm), the cores are enriched in Al and Mg, and the exteriors are enriched in Fe and Cr. As shown in Figure 3, chemical compositions of Cr-spinels are gradually increasing in Fe firstly and increasing in Cr secondary from the cores to the rims. The cores show 0.35-0.40 in

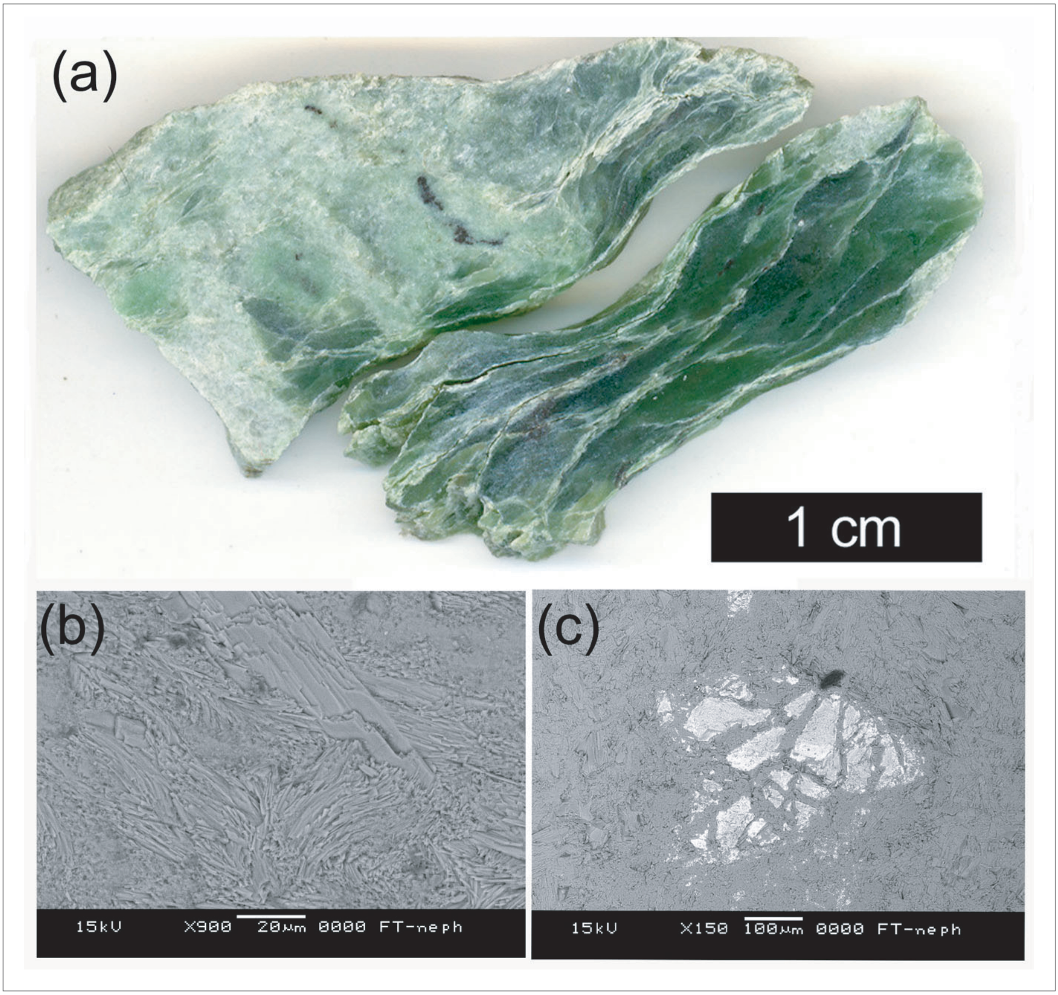

Fig. 2. Fengtian nephrites.

(a) Representative color variation and texture of Fengtian nephrite with Cr-spinel inclusions (black in color).
(b) A back-scattered electron micrograph of the matrix of Fengtian nephrite. The fibrous texture can be observed.
(c) A back-scattered electron micrograph of Cr-spinels (grey to white in color) in Fengtian nephrite.

Fe# (Fe/[Mg+Fe]) and 0.50-0.55 in Cr# (Cr/[Al+Cr]). Most small Cr-spinel grains are the Cr-end members of Cr-spinel (chromite) and are similar to the outer part of the larger grains in chemical composition. Manganese (Mn) and Zinc (Zn) contents in chromites are between 2 and 9 wt.%, and 2 and 7 wt.% respectively (Fig. 4 and Table 4).

As other accessary minerals, Cr bearing Ca-garnet (uvarovitic grossular: $Ca_3[Cr,Al]_2Si_3O_{12}$) is occasionally observed. Grain size of Cr-Ca-garnet is mostly less than

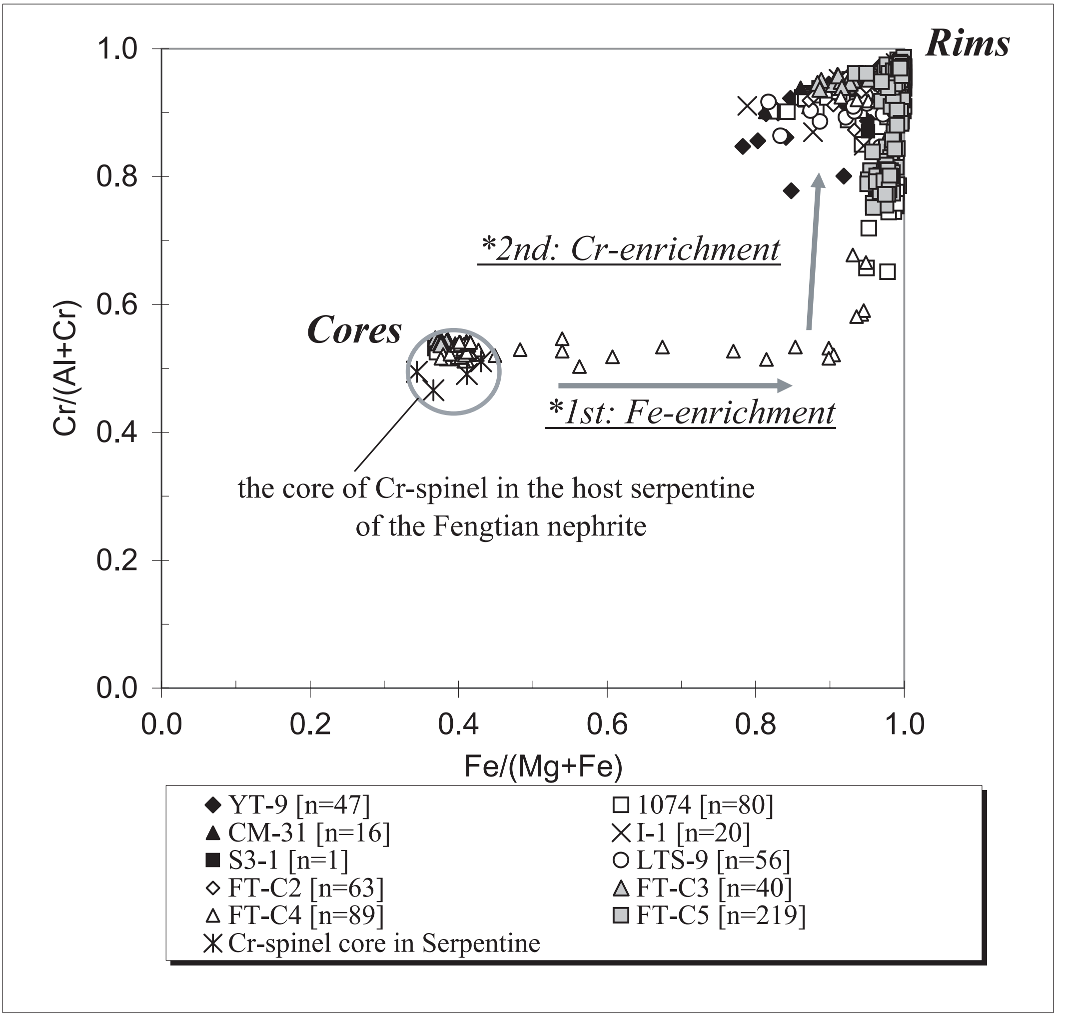

Fig. 3. Fe# vs. Cr# plot of Cr-spinels in Fengtian nephrite. The points at the lower left and at the upper right represent the end-members of spinel ($MgAl_2O_4$) and chromite ($FeCr_2O_4$). Arrows indicate the trajectory of chemical alteration from the cores to the rims. The chemical compositions of cores of Cr-spinel in serpentine (WT-9019), which is the host rock of the Fengtian nephrites, are also shown in the circle.

1mm in size and brilliant green in color. Titanite, diopside (Cpx), allanite and Ni-As sulphides are rarely recognized. Although existing of chalcopyrite and pyrrhotite are reported by Tan *et al*. (1978), there are not identified in this study.

3. Green nephrites from Asia and Pacific region

Mineral descriptions and chemical compositions of the green nephrites are listed in

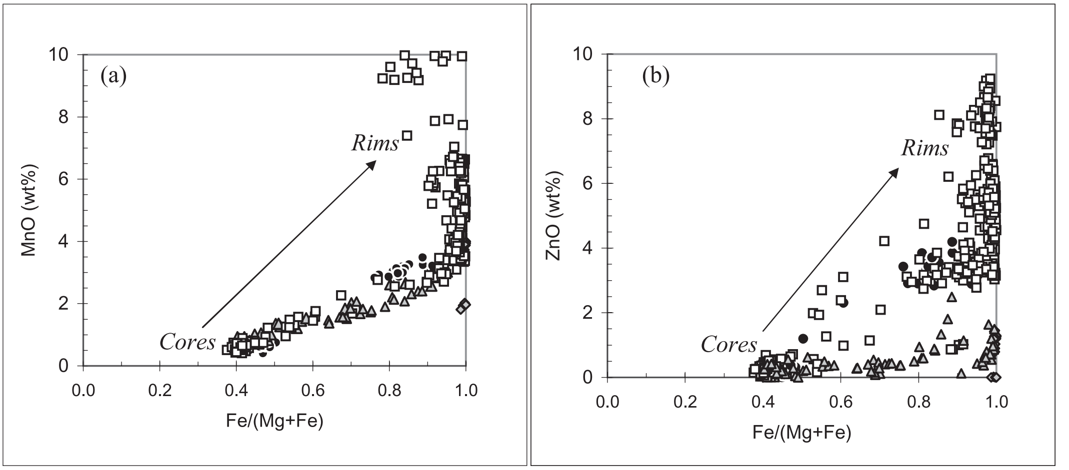

Fig. 4. Chemical compositions of Cr-spinel in green nephrites (Mg#<0.93).
(a) Fe# vs. MnO plot; (b) Fe# vs. ZnO plot. Cores and rims are Al-chromites and Zn-chromites, respectively. Symbols: squares: Fengtian (Taiwan); circles: New Zealand (NZ-2 and NZ-3); triangles: Nanshan, Gansu, China (GS-6); diamonds: Siberia (Sb-1 and Sb-3). Arrows represent alteration trajectories from the cores to the rims.

Table 2 and Appendix 3, respectively. Except New Caledonian Jade, in terms of surface features, the nephrites from China, Canada, and Yakut (Yk-1, 3, 4: Lake Baikal) show massive texture instead of the fibrous texture in the nephrites from Fengtian (Taiwan), Siberia (Sb-1 and Sb-3), Japan (JN-130) and Oceania (Aus-1 and all-NZ).

As shown in Figure 5, the green nephrites are divided into 3 groups in Mg#. Group-I is Mg-rich tremolite (Mg#>0.96: the topmost shaded area in Fig. 5). It consists of Liaoning (LN-2 and LN-6), Jiuquen in Gansu (GS-1 and GS-2), Xinjiang (XT-1), Yakut (Yk-1, Yk-3 and Yk-4), and South Australia (Aus-1). The nephrites in this group are light green in color and have a fairly narrow compositional range for Mg# and Si. There is also a narrow compositional range for Al/[Al+Cr] (Al#), and this group has lower Cr_2O_3, FeO, and MnO contents than the other two.

Group-II is Fe-rich tremolite (Mg# =0.95 to 0.91: at the center in Fig. 5). It includes nephrites from Siberia (Sb-1) and Wyoming (Wy-6), and has a fairly narrow compositional range for Mg#. The nephrites in both groups I and II can be termed tremolite. They have no Cr-spinel inclusions, except for Sb-1. Chemical composition of Japanese nephrite (JN-130) ranges from group-I to II, and Si compositions are also widely scattered.

Group-III is Fe-rich tremolite to actinolite (Mg# < 0.93). It includes nephrites from Nanshan in Gansu (GS-6), Siberia (Sb-3), New Zealand (NZ-1, NZ-2 and NZ-3), and British Columbia (BC-1, BC-2, BC-3 and BC-4). This group shows a spread over the compositional field from tremolite to actinolite that overlaps with the Fengtian nephrites, as shown in Figure 5.

TABLE 4. Mn and Zn contents in chromite inclusions in the green nephrites.

sample No.	Locality	n.o.a.	Mn, wt.%	Zn, wt.%
Natural nephrite				
The Fengtian nephrite (overall)		**267**	**2.0-9.2**	**2.0-7.0**
YT-9	Fengtien, Taiwan	40	6.0-9.2	2.6-3.1
S3-1		2	2.1-2.7	dnd**
I-1		15	4.0-8.7	4.2-5.0
#1074		30	4.3-8.1	2.8-4.5
CM-31		8	7.1-8.2	2.2-2.8
LTS-9		50	3.3-3.9	2.0-4.9
FT-R4		1	3.0	3.8
FT-C2		37	2.2-2.7	2.4-3.6
FT-C3		10	3.0-3.3	dnd*
FT-C4		4	2.9-3.1	2.4-3.8
FT-C5		34	2.3-3.1	3.5-7.0
FT-C6		36	2.9-4.6	3.5-6.9
Green nephrites (Mg#<0.93)				
Sb-1	Siberia, Russia	18	1.4-2.4	< 2.5
Sb-3	Siberia, Russia	16	1.4-3.1	< 1.2
GS-6	Gan su, China	44	0.5-2.9	< 1.3
NZ-2	South Island, New Zealand	5	0.3-2.7	< 3.4
NZ-3	South Island, New Zealand	16	0.3-0.5	< 0.6
BC-1	B.C., Canada	12	< 1.7	< 0.6
BC-2	B.C., Canada	4	< 1.7	< 1.3
BC-3	B.C., Canada	7	< 1.3	< 2.6
BC-4	B.C., Canada	6	< 0.4	**
Nephritic artifacts				
Taiwan				
R17b	Qigu	4	2.3-2.6	2.7-3.2
R9 (R-3H)	Shanyuan	5	2.9-3.4	1.7-2.3
R-00KT	Kending	46	3.9-4.2	2.6-3.3
R-25	Zhishanyan	20	2.0-2.5	1.6-2.2
Philippines				
NL3466-1	Nagsabaran, Cagayan	16	2.9-3.4	1.8-2.3
Duy-1	Tabon Caves, Palawan	8	2.8-3.2	2.0-2.5
M-2	Tabon Caves, Palawan	10	1.9-2.2	2.0-2.8
M-3	Tabon Caves, Palawan	18	2.7-3.3	2.8-3.6
RF-4	Tabon Caves, Palawan	10	2.6-2.7	2.5-2.8
62-2-12	Tabon Caves, Palawan	52	2.0-2.6	2.4-4.3
62-2-31	Tabon Caves, Palawan	20	1.6-2.9	1.3-2.7
P-122	Tabon Caves, Palawan	10	1.4-2.2	1.2-2.7

Mn = [MnO] x 0.7745; Zn = [ZnO] x 0.8035.

*: do not determine but confirmed Zn peak; **: less than the detection limit (0.1 wt.%).

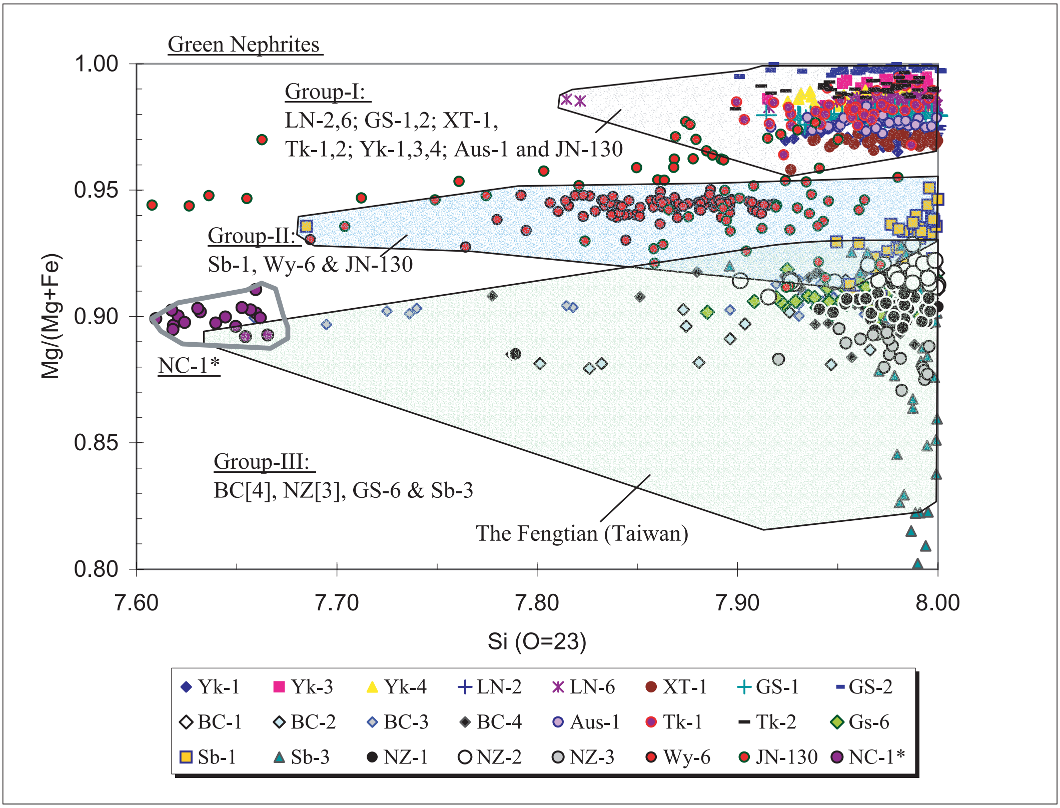

Fig. 5. Si vs. Mg# plot of green nephrites from Asian and Pacific regions. There are three groups in Mg# values (see text). From the top, the shaded areas represent group-I, group-II, and the chemical field of Fengtian nephrite, which almost overlaps with group-III.

Ca-amphibole in New Caledonian Jade (NC-1*) have significantly different chemical composition in Si-Mg# plot. The EPMA results of Ca-amphiboles show that Mg# ranges between 0.91 and 0.89, and low Si contents, which cause by higher abundance of Alumina (2.7-4.1 wt.% in Al_2O_3) in compared with other nephrites (Appendix 3). However, mineralogical investigation indicate that green-colored Ca-amphibole (tremolite and actinolite) and diopside occur as inclusion mineral in anorthite (Ca-feldspar) matrix, and abundance of Ca-amphibole is less than 10 vol.%, as well as diopside. Thus New Caledonian Jade can not be termed as nephrite.

4. Accessary minerals in green nephrites

Cr-spinels can be observed in samples GS-6, Sb-1, Sb-3, NZ-2, NZ-3, and the Canadian nephrites. The large grains (> 1 mm) of Cr-spinel show compositional zoning as same as the Fengtian nephrite (Fig. 6), with Al- and Mg-enriched cores and Cr- and Fe-enriched rims.

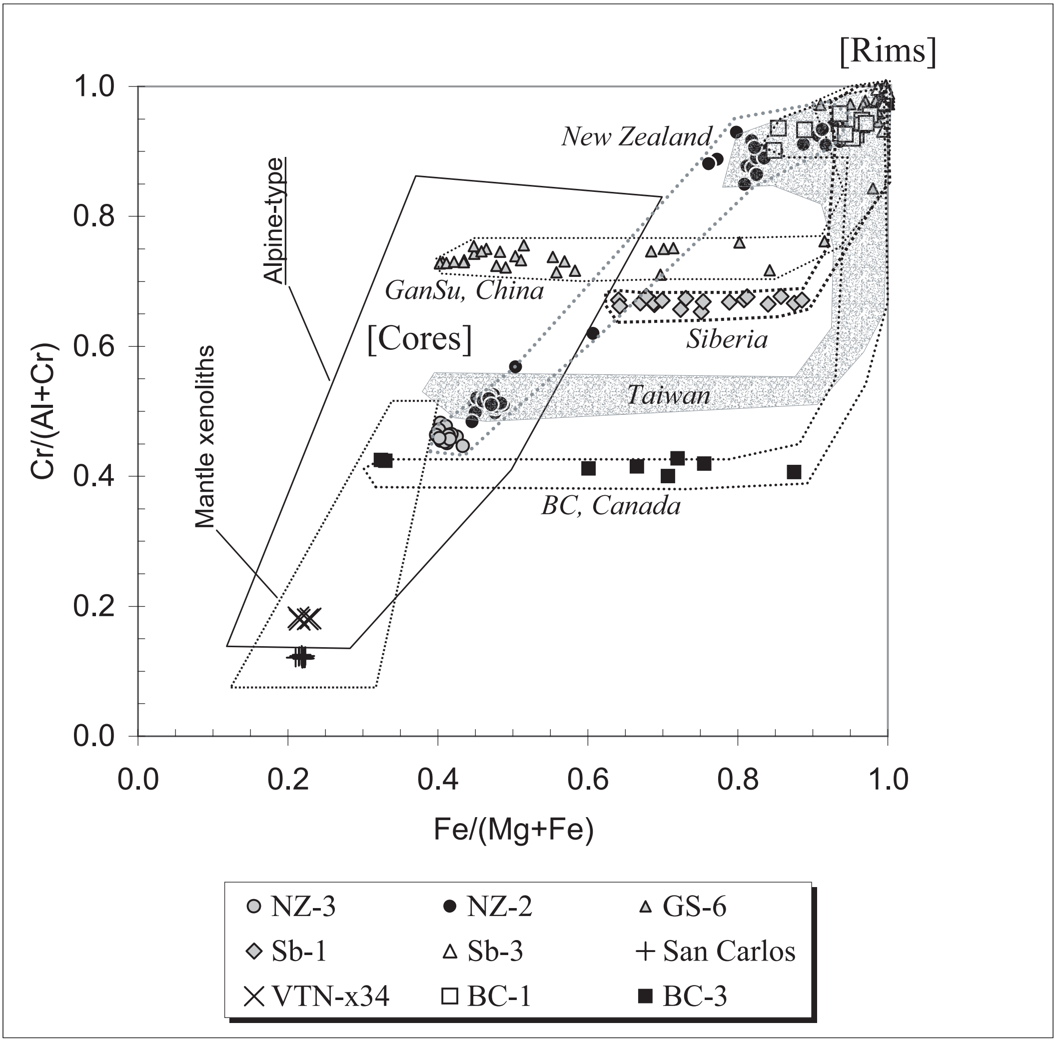

Fig. 6. Fe# vs. Cr# plot of Cr-spinel inclusions in the Group-III green nephrites. For comparison, Cr-spinel compositions in the upper mantle xenoliths (spinel lherzolite) from San Carlos (USA) and Central Vietnam are also plotted (Y. Iizuka unpublished data). Enclosed areas represent the different tectonic settings of peridotite evolution in the upper mantle, Alpine-type and Mantle xenoliths (Irvine & Findley 1972). If the cores still have their original chemistry in the peridotite, all nephrite deposits, shown here, are related with the alpine type peridotite, which is thought be the upper mantle material in the subduction zone, but their original P-T conditions should be different. The shaded zone represents chemical variation of Cr-spinel in the Fengtian nephrite (Taiwan). It shows a different chemical alteration trajectory when compared with other nephrites from China, Siberia, Canada and New Zealand.

The chemical compositions of rims show almost the same as the end member of chromite in the spinel-chromite plot, but the cores have different chemical composition in each nephrite. GS-6 is relatively enriched in Cr# (0.7) compared with NZ-2, NZ-3 (Cr# 0.45), Fengtian (Cr# 0.5), and BC-3 (Cr# 0.4). The compositional ranges of the Cr-spinel are variable in the spinel-chromite plot (Fig. 6). GS-6, Sb-1 and BC-3 (perhaps also BC-1) show the same chemical alteration pattern as Fengtian nephrite, in that Fe increases firstly and then Cr increases to the rim. On the other hand, the chemical trend of NZ-2 seems different from the others.

Both Mn and Zn contents of chromites in GS-6, Sb-1, Sb-3, NZ-2 and NZ-3 are lower (< 3.5 wt.%) than those of Fengtian nephrites, and those in the Canadian nephrites are lower (< 2.5 wt.%) than the other green nephrites.

Cr-Ca garnets can be observed in NZ-3 and the Canadian nephrites. Especially in the Canadian nephrite, Cr-garnets are more abundant than other mineral inclusions. This brilliant green colored garnet is a distinctive feature of the Canadian nephrites. Rutile attached with titanite can be observed in GS-1 and Yk-3, and apatite can be identified in Yk-1 and Aus-1. Titanite can be also observed as an accessary mineral in Wy-6, in the Fe-enriched tremolite group. Fe-Ni sulfide (Pentrandite; $[Fe,Ni]S_2$) can be identified in NZ-2, NZ-3 and BC-1. JP-130 contains significant amount of diopside (more than 20 vol.%) but there is no any other accessary minerals. Chlorite is commonly observed within the vein texture but its chemical composition is not significantly different between samples.

5. Comparison using the accessary minerals within green nephrites

The group-III green nephrites have similar range of chemical compositions to the Fengtian nephrites. However, the inclusion minerals, especially the Cr-spinels, have unique signatures.

5-1. Cr-spinel and its chemistry:

Cr-spinels are common in small amounts in peridotite and related metamorphic rocks. In the peridotite, the Cr-spinel compositions relate to variations in pressure (P) and temperature (T) and melt composition in the upper mantle (*e.g.*, Irvine 1965; Arai 1992; Barnes & Roeder 2001). In metamorphic rocks, on the other hand, Cr-spinel compositions change with regional metamorphic processes with P-T conditions as well (*e.g.*, Evans & Frost 1975, Burkhard 1993; Figueiras & Waerenborgh 1997; Abzalov 1998).

As shown in Figure 3, both core of Cr-spinel in serpentine (WY-9019) and the core of Cr-spinels in nephrites from Fengtian have the similar ratios of Al and Cr, and show low abundances of Zn and Mn in termes of detection limits. Since actinolitic nephrite is commonly considered as the metamorphic products of serpentine (Tsien *et al*. 1996), the Cr-spinel might preserve the original composition. These indicate that the cores of Cr-spinel in nephrites should preserve their original chemical compositions of serpentine, which is an altered upper mantle peridotite. Since the actinolite amphibole (group-III green nephrites in this study) is associated with serpentine (Wen & Jing 1992), the chemical compositions of the cores of Cr-spinels in the nephrites may indicate their peridotite origin.

Alteration patterns from core to rim in Cr-spinel have been well described in many metamorphic fields, and such enrichment patterns for Fe# and Cr# in Cr-spinel (chromite) indicate differences in alteration or metamorphic history (*e.g.*, Kimball 1990; Burkhard 1993). Most chromites in the Fengtian nephrite are enriched in Mn and Zn. Since the ratio of Mn and Zn vs. Fe# is in direct proportion; with Mn and Zn increasing as Fe# increases, the Mn and Zn should substitute into the Fe-Mg site of Cr-spinel. Such geological evidences are reported from several sedimentary and granitic rocks related metamorphic rocks (*e.g.*, Figueiras & Waerenborgh 1997; Abzalov 1998). Because Mn and Zn are not the primary element in spinel in the mantle peridotite, chemical exchange between Mg-Fe and Mn-Zn should be reflected their specific nephrite forming episode.

The Cr-spinel chemistry both of the core and the rims among the group-III green nephrites (Mg#<0.93) from Fengtian (Taiwan), New Zealand, Nanshan in Gansu, Siberia and British Columbia are different (Fig. 6). It implies that there are different origin of serpentine (peridotite) and different metamorphic process during nephrite formation. This indicates, therefore, that such geological and mineralogical fingerprints can be used to trace different geological origins. Although more detailed studies in this regard are needed on the host rocks of nephrites, such as serpentine, the differences in chemical character of the inclusions should be applicable in any sourcing study of nephrites.

5-2. Other accessory minerals:

Ni-bearing iron sulfide (pentlanditic pyrite) is identified as accessory mineral of nephrites from both New Zealand and Canada, but is rare. Although iron sulfide has not been observed in Fengtian nephrite, the Fengtian serpentine (WT-9019) which is the host for the nephrite contains Ni-Fe sulfide. So it is possible that it occurs also in the Fengtian nephrite.

Cr-Ca-garnet, brilliant green in color, is occasionally observed as another accessory mineral in Fengtian, New Zealand and Canadian nephrites. This mineral often occurs in metamorphic rocks such as green nephrite and other serpentine-related deposits. However, substitution between Cr and Al is in rather wide range, so there is no characteristic signature to discriminate specific sources.

6. White nephrites

The chemical compositions of the white nephrites are listed in Appendix 4. The white nephrites from China and Russia are greater than 0.98 in Mg#, and the Korean nephrites are greater than 0.96 in Mg#. These white nephrites can be termed tremolite (Fig. 7). Sample Sb-7 from Siberia has relatively lower Mg# amongst the white nephrites. Their Mg# range is between 0.92 and 0.94, and it shows the fibrous texture.

Accessory minerals are rare in this white nephrite (tremolite) group; most have no inclusion minerals and massive texture. Diopside can be observed in KN2-2A from Korea, and MLG-1 from China. No Cr-spinel was observed.

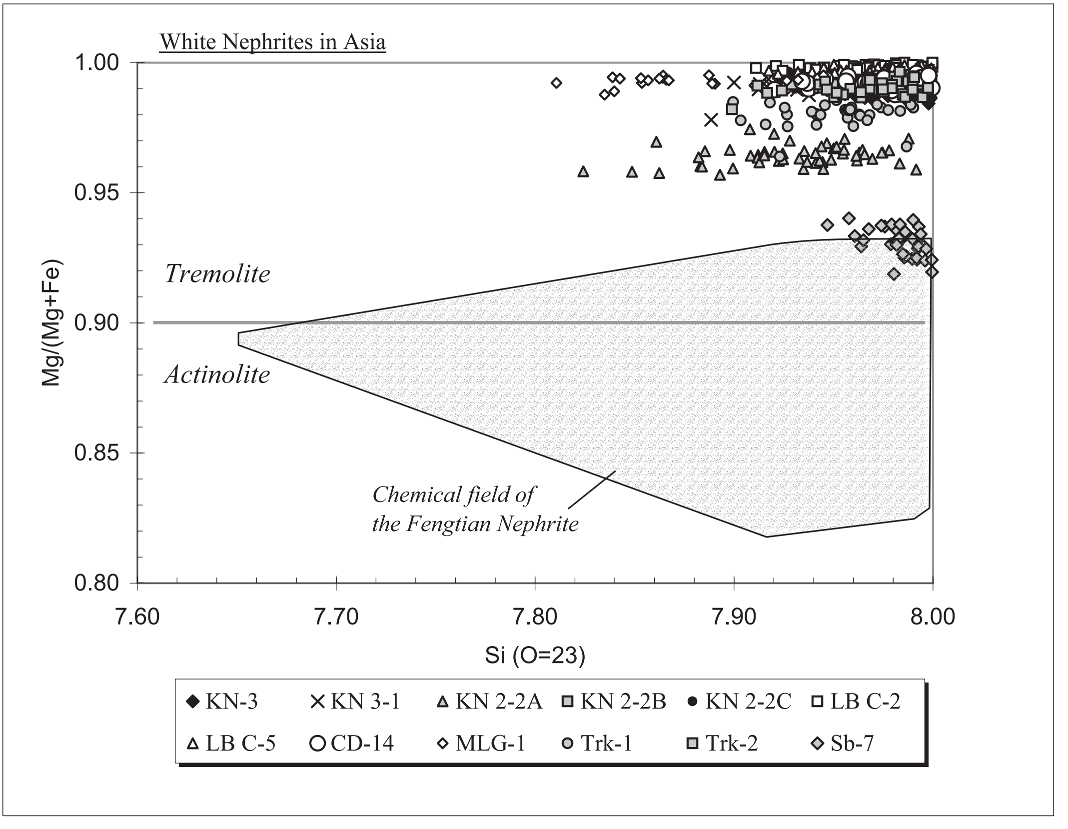

Fig. 7. Si vs. Mg# plot of white nephrites from Asia. The chemical field of the Fengtian nephrites is also shown as a shaded area.

All of white nephrites are clearly discriminated from green nephrite in chemical compositions.

7. Criteria for identifying Fengtian (Taiwan) nephrite

Fengtian nephrites have unique mineral characteristics which have variable color from deep green though light green to white with fibrous texture. The Fengtian nephrites are tremolite-actinolitic amphibole (Mg#<0.93) (Fig. 1), and Mn-Zn bearing chromite occurs commonly as the accessory mineral. The Mn and Zn contents in chromites are between 2 and 9 wt.%, and 2 and 7 wt.%, respectively (Fig. 4). These contents are significantly higher than in other chromite inclusions in the group-III (tremolitic to actinolitic: Mg#<0.93) green nephrites in other parts of the world. On these points, Fengtian nephrite can be distinguished from all others.

Xu *et al*. (1996) demonstrated a numbers of Raman spectrums of minerals, such as tremolite, actinolite, serpentine, jadeite, and others, which are mostly used for stone artifacts and show efficiency of mineral identification among different crystallography.

The Raman spectroscopy is useful and easy to obtain the crystal information in non-destructive. Some Raman spectroscopic studies have been carried out on Fengtian nephrite and Neolithic nephrite artifacts in Taiwan. These studies suggested that chromium (Cr) can be used to characterize Fengtian nephrite (Xu *et al*. 1996; Lien *et al*. 1996). However, the Cr contents in the Fengtian nephrites are mostly less than 1 wt.%, and it is not remarkable to compare with other nephrites. Since the Fengtian nephrite contains many Cr-spinel as accessary minerals, these results were probably caused by mis-shooting the laser beam on to a tiny Cr-spinel inclusion. Because of this, it is unlikely that the Raman peak for Cr in the nephrite matrix can be used to differentiate Fengtian nephrite.

On the other hand, EPMA sourcing is rather difficult to apply for white nephrites which are indistinguishable in mineral chemistry, such as the tremolitic nephrites from China and Korea.

SOURCING STUDY OF NEPHRITE ARTIFACTS

A series of EPMA sourcing study was carried out on green nephritic artifacts from Taiwan, and green and white nephrite artifacts from the Philippines.

A small piece (less than few mm) with spinel grain, if it was available, was sliced out by diamond wafering blade (0.3 mm in thickness) from each artifact, and mounted into epoxy resin before being polished. The quantitative chemical analyses were carried out by EPMA, as the analyses of the natural nephrites in the previous part.

1. Analysis results of green nephrite artifacts in Taiwan

The EPMA analysis was carried out more than a hundred nephrite artifacts from over 20 archaeological sites in Taiwan and near by islands such as islands of Penghu Archipelago and Lanyu. These nephrite artifacts were thought to be originated from Fengtian nephrite deposit in their color and context of design (*e.g.*, Hung 2000:31-32, 34-35; 2004:63). Here, nephrite artifacts from representative different four locations in Taiwan were selected to show: Shanyuan site in Taidong (southeast), Zhishanyan site in Taipei (north), Qigu site in Nantou (central west) and Kending site in Pingtong (south). Fig. 8 shows EPMA results of 4-nephrite artifacts with the former EPMA data of six nephrite artifacts from Beinan site in Taidong (after Wang *et al*. 1996). The results show that chemical compositions of nephrite matrix are comparable to the Fengtian nephrite. The ranges for Mn and Zn content in chromites are 2.0-4.2 wt.% and 1.6-3.3 wt.% respectively (Table 4). Both chemical compositions of nephrite matrix and accessory mineral are consistent with Fengtian nephrite. Thus, it can reliably be concluded that these nephrites are comparable with the Fengtian nephrite. It is suggested that most of nephrite artifacts in Taiwan were originated from the Fengtian deposits. The detail information both in archaeological and mineralogical analysis would be reported (Iizuka and Hung in prep.).

2. Analysis results green nephrite artifacts in the Philippines

The studied nephrite artifacts from the Philippines are listed in Table 5 with mineralogical

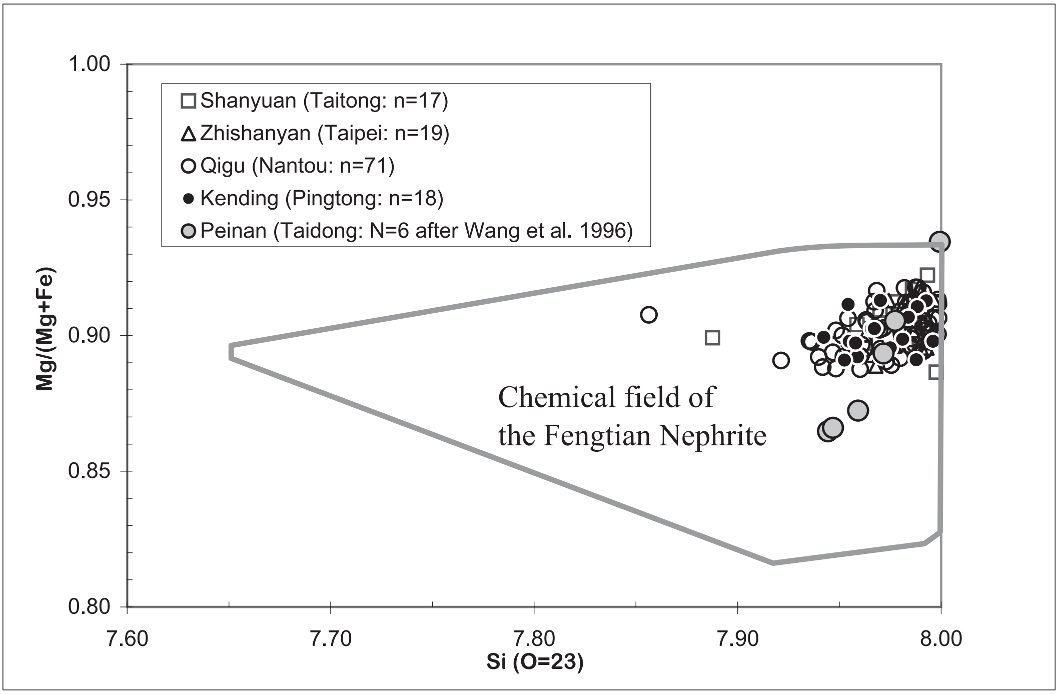

Fig. 8. Comparative plot of Si vs. Mg# for the 4 nephrite artifacts from Neolithic sites in Taiwan with former EPMA data after Wang *et al.* (1996: N: number of specimens) Enclosed area represents chemical field of Fengtian nephrite. (n) is numbers of analysis points on each artifact.

descriptions (Fig. 9). The chemical compositions of the green nephritic ornaments are listed in Appendix 5. The nine green nephrite ornaments were excavated from the Tabon Caves Complex in Palawan (Figs. 9-a to -h), and a broken bracelet was excavated from the Nagsabaran site in Cagayan (Fig. 9-j). The four white nephrite adzes are from the Beyer's collection (Figs. 9-k to -n). Oxygen isotopes analyses have already been carried out on these 4 adzes (Hung 2000:96).

The matrix colors are mostly green to dark green. Both bracelet fragments (NL3644 and Duy-1) are partially brown and white in color on the surface, but the cut sections are green. The fibrous textures can be observed in all specimens. As shown in Fig. 10, the chemical compositions of the analysed green nephrites are tremolite-actinolite (Mg/[Mg+Fe]=0.93-0.85), and the chemical variations are consistent with Fengtian nephrite. Zn and Mn bearing Cr-spinels (chromites) occur in all the studied samples except U-1, and the Zn and Mn contents are equivalent to those of the chromites in Fengtian nephrite (Table 4). Samples 62-2-12 and 62-2-31 have Cr-spinels that show the characteristic chemical zoning from core to rim, and the chemical variation is identical with Fengtian nephrite (Fig. 11). Therefore, the studied green nephritic ornaments from the Philippines are very similar to Fengtian nephrite.

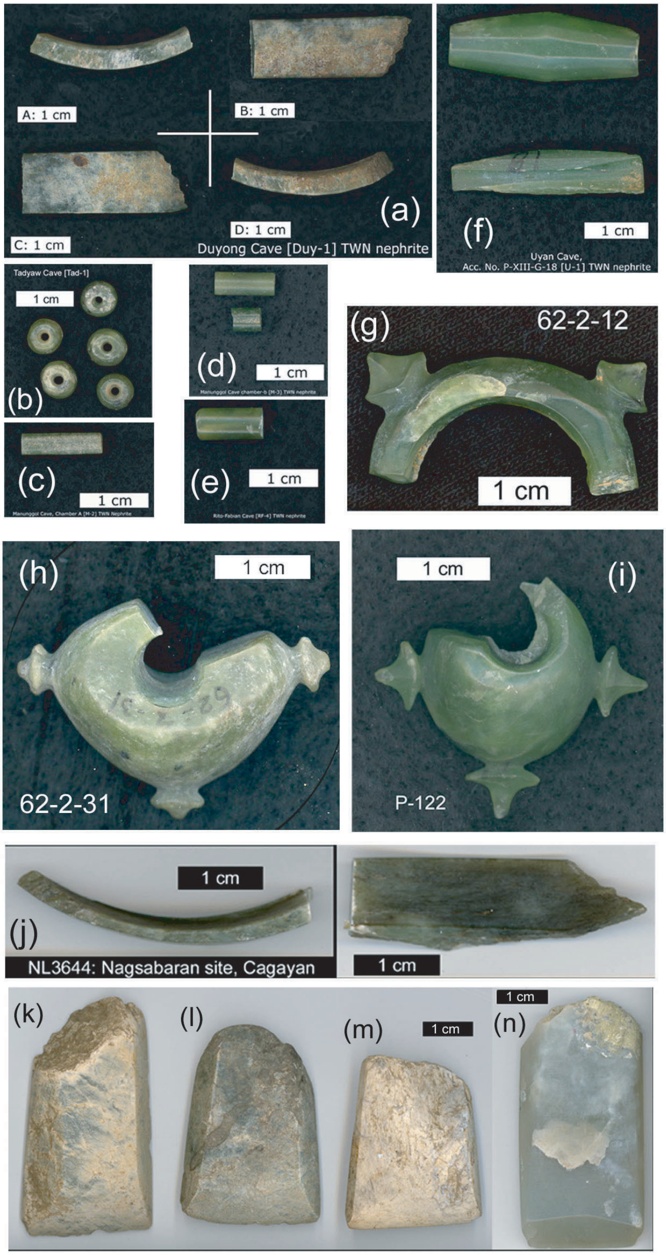

Fig. 9. Nephritic artifacts from the Philippines:

(a) Bracelet fragment from Duyong Cave (Duy-1): views from 4 directions.

(b) Flattened spherical beads from Tadyaw Cave (Tad-1). Diameters of holes: 1-3 mm.

(c) A tubular bead from Manunggul Cave, Chamber-A (M-2). Hole diameter: 0.5-1 mm.

(d) Tubular beads from Manunggul Cave, Chamber-B (M-3). Hole diameter: 1 mm.

(e) Tubular bead from Rito-Fabian Cave (RF-4). Hole diameter: 0.5-1 mm.

(f) Broken hexagonal bead from Uyan Cave (U-1): outside (top) and inside (bottom). The tapered hole is 2 mm diameter at the center, 5 mm at the edges.

(g) A fragment of Hong-Kong type ornament with four circumferential projections (62-2-12) from Uyaw Cave. Outer and inner diameters are 30.5 mm and 19.5 mm respectively; thickness: 5.0 mm.

(h) A broken *lingling-o* (62-2-31) from Uyaw Cave. Width: 33 mm; thickness: 12 mm; the tapered hole is 5.4 mm diameter at the center, 7.3 mm at the surface.

(i) A broken *lingling-o* (P-122) from Duyong Cave. Width: 30.5 mm; thickness: 14.5 mm; the tapered hole is 6.4 mm in diameter at the center, 9.0 mm at the surface.

(j) Fragment of a bracelet from Nagsabaran site (NL3644), viewed from 2 directions.

(k) White nephrite adze from Batangas (Beyer's collection) (P-1) from Pila, Banua: $\delta^{18}O = +14.3‰$

(l) White nephrite adze from Batangas (Beyer's collection) (P-2): from Pila, Banua: $\delta^{18}O = +14.6‰$

(m) White nephrite adze from Batangas (Beyer's collection) (P-3): from Pila, Banua: $\delta^{18}O = +14.3‰$

(n) White nephrite adze from Batangas (Beyer's collection) (C-9): IV-95-Y-22143: from Uilang Bundok site, Kalatagan: $\delta^{18}O = +14.1‰$

TABLE 5. List of studied nephrite artifacts from the Philippines.

sample #	locality	type/ shape	color	texture	n.o.a.	nomenclature	Mg/(Mg+Fe)	Al/(Al+Cr)	inclusions
Green-colored nephritic ornaments									
Cagayan									
NL3644	Nagsabaran, Lal-lo	bracelet	green	fibrous	64	tremolite	0.902-0.926	1.00-0.56	Zn-chromite, Cpx
Palawan (Tabon Caves)									
Tad-1	Tadyaw Cave	bead	dark green	fibrous	49	tremolite-actinolite	0.896-0.935	1.00-0.52	Zn-chromite
Duy-1	Duyong Cave	bracelet	dark green	fibrous	34	tremolite	0.904-0.925	0.93-0.48	Zn-chromite
M-2	Manunggul Cave	tube bead	dark green	fibrous	79	tremolite-actinolite	0.886-0.909	0.89-0.68	Zn-chromite
M-3	Manunggul Cave	tube bead	dark green	fibrous	75	tremolite-actinolite	0.853-0.919	0.79-0.52	Zn-chromite
RF-4	Rito-Fabian Cave	tube bead	dark green	fibrous	57	tremolite-actinolite	0.852-0.909	0.93-0.58	Zn-chromite
U-1	Uyaw Cave	hexagonal tube	dark green	fibrous	6	tremolite	0.898-0.916	0.93-0.57	no
62-2-12	Uyaw Cave	*4-projections*	dark green	fibrous	92	tremolite-actinolite	0.854-0.911	0.96-0.64	Zn-chromite, Al-chromite, Cr-gros.
62-2-31	Uyaw Cave	*lingling-o*	dark green	fibrous	60	tremolite-actinolite	0.884-0.938	0.94-0.44	Zn-chromite, Al-chromite, Cpx
P-122	Duyong Cave	*lingling-o*	dark green	fibrous	41	tremolite-actinolite	0.926-0.886	0.93-0.67	Zn-chromite, Cpx
Batangas (from Hung *et al*. 2004)									
	Kay Daing	bell shaped	green	fibrous	2	tremolite-actinolite	0.91-0.90		Zn-chromite
White-colored nephrite tools									
Batangas									
C-9	Uilang Bundok, Kalatagan	adze	clear white	massive	47	tremolite	0.989-0.976	1.00-0.87	Cpx
P-1	Pila, Bauna	adze	white-brown	massive	30	tremolite	0.985-0.994	1.00-0.91	Cpx
P-2	Pila, Bauna	adze	white-brown	massive	43	tremolite	0.955-0.971	1.00-0.95	Cpx, apatite, titanite
P-3	Pila, Bauna	adze	white-brown	massive	34	tremolite	0.974-0.986	1.00-0.90	Cpx

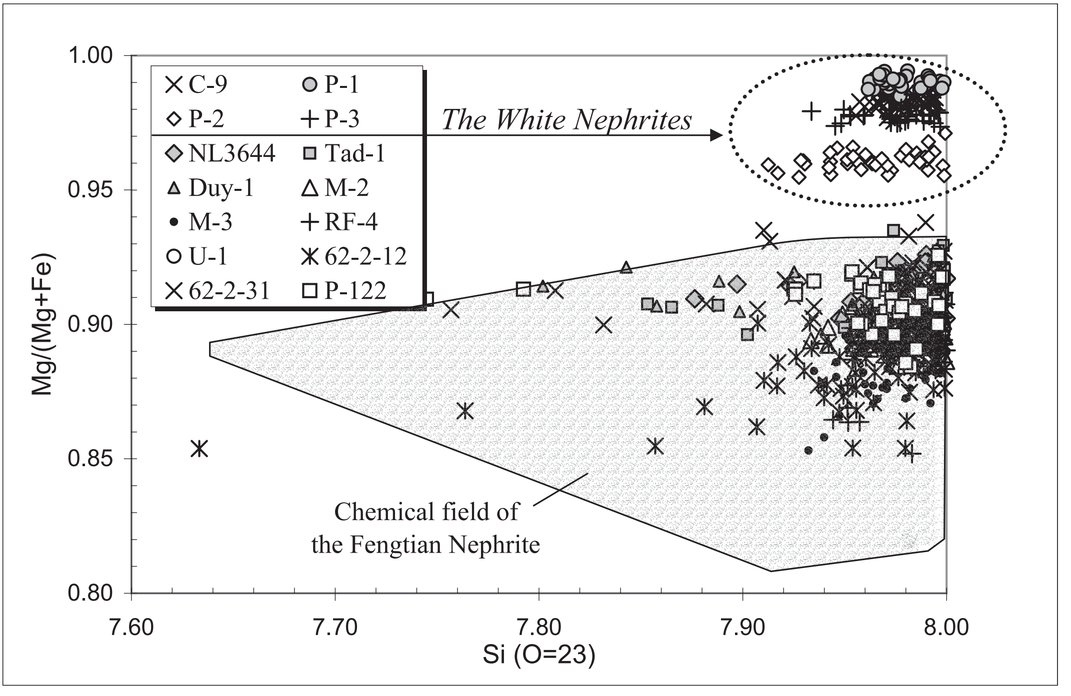

Fig. 10. Chemical compositions of the 10 green nephritic ornaments and the 4 white nephritic artifacts (enclosed by a dashed circle) on Si vs. Mg# plot. The chemical variation of the Fengtian nephrite is shown as a shaded area.

3. Analysis results of white nephrite artifacts in the Philippines

The chemical compositions of the white nephritic artifacts are listed in Appendix 6. The matrix colors vary from brown, grey, milky white to transparent white. The matrix portions of Mg# are greater than 0.96 with a relatively narrow range (Fig. 10), so these white nephrites can be termed tremolite. Inclusion minerals are relatively rich and there are commonly Cpx, and apatite, and a small amount of dolomite. Allanite and titanite are rarely observed. In comparison to the green nephritic ornaments, purity of studied white nephrites are no good. The high Mg# ratios and the existence of dolomite inclusions suggest that those tremolites should be related to a carbonate (marble and/or limestone) origin.

DISCUSSION

This is the first report to demonstrate that the white nephritic stone tools from the Batangas are made of tremolite amphibole. Their chemical compositions clearly differ from the green (actinolite) nephrites, such as the Taiwan nephrite. Although there are similarities with the white nephrites from China and Korea (Fig. 5), the oxygen isotope ratios of the Philippine white nephrites are higher ($\delta^{18}O$ = +14.2 to +14.6; Hung

2001:96) than those for Asian nephrites (Wen & Jing 1996; Wang *et al*. 1996)(5). It can be concluded from these differences that the Philippine white nephrites could not have originated from the known deposits in Asia. Given that so many white nephrite artifacts, including preforms and unworked raw material, have been collected in the Batangas area, it is likely that the source region lies in carbonate fields around southwestern Luzon (Bayer 1948; Geological map of the Philippines 1981).

A workshop of green nephrite manufacturing has recently been found on Itbayat in the Batanes Islands (Bellwood 2005:137; Bellwood & Dizon 2005: *this issue*). However, any workshop site of neither green nor white nephrite has yet been found in the main islands of the Philippines. A numbers of imitation jade ornaments, similar in style to some of the green nephrite ornaments, are stored in the Beyer's collection and have also been found in Palawan and Cagayan (pers. comm.: Mr. Rey Santiago of National Museum of the Philippines, and Dr. Kazuhiko Tanaka of Sofia University, Tokyo). These imitation jades are of green minerals such as mica (so-called "Mindoro jade")(6), talc, serpentine, quartz, and andesitic volcanic rocks (Y. Iizuka unpublished data). Since the white nephrite adzes in the Uilang Bundok site in Batangas date from about 800 BC (Hung *et al*. 2004), the prospective workshop site might have been in existence since the Late Neolithic.

This EPMA sourcing study of nephrites indicates that at least two kinds of nephrite raw materials were used in the Philippines. The white nephrites, not of high quality, found in many Batangas sites were used only for tools such as adzes and chisels. As previous studies suggested (Kano 1946; Bayer 1948), this may have come from a local Luzon source. The green nephrites, on the other hand, were derived from Taiwan and were used mostly for ornaments.

In terms of style and context, the green nephrite ornaments in the Philippines belong to two phases; Neolithic and Early Metal. Most green nephrite ornaments from Philippine Neolithic contexts are similar in style with contemporary ornaments in Taiwan (Hung 2005: Tables 3 and 4: *this issue*). For example, the Neolithic green jade bracelets from Duyong Cave (Fig. 9-a) on Palawan and Nagsabaran in the Cagayan Valley (Fig. 9-j) are identical in size with those from the Beinan site in southeastern Taiwan. The age of these green nephrite ornaments goes back to 1400 BC (early Neolithic) in Nagsabaran (Tsang *et al*. 2002). Moreover, the bell-shaped and tube beads (Fig. 9-c to -e) from both Taiwan and the Philippines are almost identical in style and size (Hung *et al*. 2004:46-47). During the Early Metal Age, the green nephrite ornaments from the Philippines also show similarities with those from Ludao and Lanyu islands off

(5) Oxygen isotope ratios ($\delta^{18}O$) from the white nephrites: Kunlun, Xingjiang, NW China: +1 to +4‰; Kuandian, Liaoning, NE China: +2 to +8‰; Xiaomeiling, Liyang, Jiangsu, SE China: +6 to +10‰: Chun-choen, Korea: -9 to -7‰ (Wen & Jing 1996); Siberia, Yakut, Russia: +6.5 to +7.0‰ (Wang *et al*. 1996).

(6) The Mindoro jade, green in color, from the Mindoro Island, the Philippines, can be termed muscovite (mica) in mineralogy (Y. Iizuka: unpublish data).

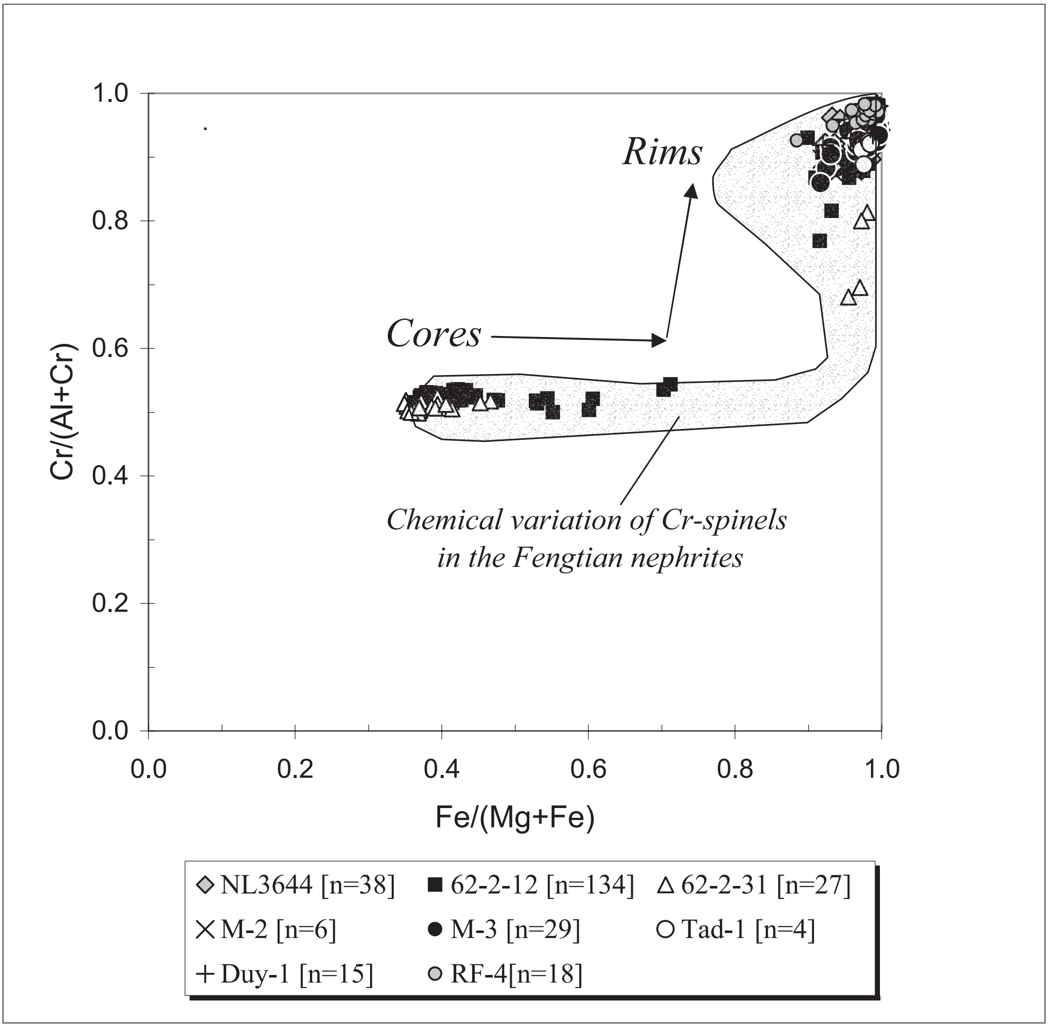

Fig. 11. Cr-spinel inclusions in the green nephritic artifacts from the Philippines on Fe# vs. Cr# plot. Arrows indicate trajectory of chemical alteration from the cores to the rims. The shaded zone represents the chemical variation of Cr-spinels in the Fengtian nephrites.

southeastern Taiwan (Kano 1946). The results of this study imply, therefore, that the green nephrites in the Philippines were made of Fengtian nephrite and were widely distributed in the Philippines from the early Neolithic to the Metal Age.

One remarkable discovery from this study is that the two Palawan *lingling-o* (62-2-31 and P-122) are made of Taiwan nephrite (Figs. 9-h and -i). These *lingling-o* have three circumferential protuberances, and are of the type called by Robert Fox (1970) the "Sa Huynh type *lingling-o*". Such earrings are noticeable amongst the green nephritic

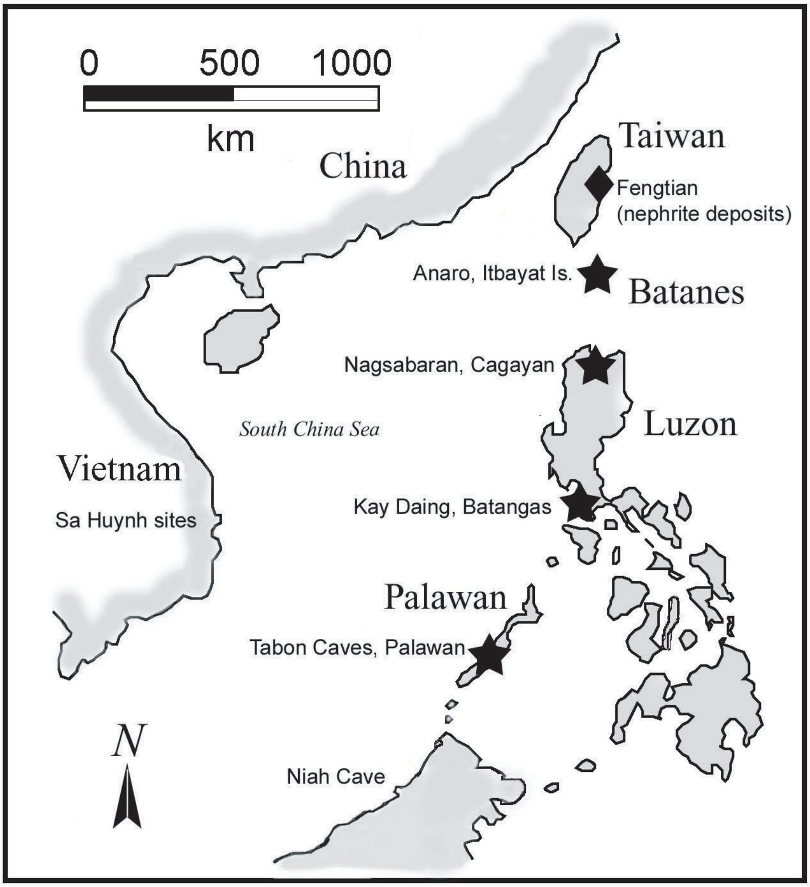

Fig. 12. Map of Taiwan and the Philippines. Stars: Philippine sites with Taiwan nephritic ornaments (Anaro site on Itbayat Island: Iizuka *et al*. 2005: *this issue*; Kay Daing site: Hung *et al*. 2004; Cagayan and Palawan: *this study*).

ornaments that belong to the Southeast Asian Metal Age, and have been found in several locations around the South China Sea, particularly in the Tabon Caves on Palawan, in Sa Huynh sites in south-central Vietnam (Kano 1946; Fox 1970; Sung 1989; Dizon 1998; Ha 1998; Nguyen 1998), and in the Niah Caves in Sarawak (Chin 1980). Although a similar ornament has been reported from Lanyu island (Kano 1946), such have never been found in Taiwan proper. In addition to the above, the discovery of two drilled-out cores from the central perforations in lingling-o type ornaments, made of Taiwan nephrite, from the Anaro site on Itbayat Island is also significant (Bellwood & Dizon 2005: *this issue*; Iizuka *et al*. 2005: *this issue*). These specimens date from the first millennium AD.

The distance between the Fengtian source and the Tabon Caves is more than 1500 km by sea, through the Batanes (*approx*. 350 km), Cagayan (*approx*. 500 km) and Batangas (*approx*. 1000 km) in Luzon to Palawan (Fig. 12). Consequently, this study provides some important evidence for long distance interaction, trade and transport between people living in different regions of Island Southeast Asia in prehistory.

CONCLUSION

In order to define the mineralogical quarry of nephrite artifacts, especially the Fengtian nephrite in Taiwan, electron probe micro analysis (EPMA) was carried out on nephrites from this source and others in East Asia and the Pacific region. The results show that the Fengtian (Taiwan) nephrites can be discriminated from others under the following condition;

(1) The Fengtian nephrites are tremolite-actinolite amphiboles. Although the Si-Mg# range is fairly wide, Mg# is under 0.93 in all cases (the median in Mg# is 0.9).
(2) The Fengtian nephrites have the unique characteristic of Cr-spinel as a major accessory mineral, bearing significant amounts of Zn and Mn.

An EPMA sourcing study was also applied to a series of green- and white- colored nephritic artifacts excavated from the Philippines. The results indicate that there are at least two kinds of nephrite raw material that were used in the Philippines. The green nephrite, used mostly for the ornaments, was derived from the Fengtian deposits in eastern Taiwan. The white nephrite, used mostly for tools, was probably collected from local sources in the Philippines.

It might be noted that more exploration for nephrite deposits and further addition of mineralogical data from nephrite artifacts will be necessary.

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REFERENCES CITED

Abzalov, Marat Z.

1998 Chrome-spinel in gabbro-wehrlite intrusions of the Pechenga area, Kola Peninsula, Russia: Emphasis on alteration features. Lithos 43:109-134.

Arai, Soji

1992 Chemistry of chromian spinel in volcanic rocks as a potential guide to magma chemistry. Mineralogical Magazine 56:173-184.

Beck, Russell J.

1970 New Zealand Jade: The story of greenstone. Wellington: A.H. & A.W. Reed.

Bellwood, Peter

2005 The first farmers: Origins of agricultural societies. Oxford: Blackwell.

Bellwood, Peter and Eusebio Z.

2005 The Batanes Archaeological Project and the "Out of Taiwan" Hypothesis for Austronesian Dispersal. Journal of Austronesian Studies 1(1):1-33.

Bernier, L.R.

1990 Vanadiferous zincian-chromian hercynite in a metamorphosed basalt-hosted alteration zone, Atik Lake, Monitoba. Canadian Mineralogists 28:37-50.

Beyer, H. Otley

1948 Philippine and East Asian Archaeology, and its Relation to the Origin of the Pacific Islands Population. Quezon: National Research Council of the Philippines.

Burkhard, Dorothee J.M.

1993 Accessory chromium spinels: Their coexistence and alteration in serpentinites. Geochimica Cosmochimica Acta 57:1297-1306.

Chen, Chung-yu

1998 Tai wan shi qian de yu qi gong ye (Prehistoric jade industry of Taiwan). *In* East Asian Jade: Symbol of Excellence. Chung Tang, ed. vol. 1, Pp. 336-349. Hong Kong: The Chinese University Hong Kong (in Chinese).

Chen, Tung-ho, T. Callagaro, S. Pages-Camagna and M. Menu

2004 Investigation of Chinese archaic jade by PIXE and μRaman spectrometry. Applied Physics A 79:177-180.

Chin, Lucas

1980 Cultural Heritage of Sarawak. Kuching: Sarawak Museum.

Chou, Su-jung Chou, Chung-ho Lo, Yoshiyuki Iizuka and Kui-lin Tang

2003 A comparative study of the geological formation age of Nephrite artifacts (Yu-Bi) from Fansan site of Liangzhu culture. Paper presented at the 2nd Conference of Jade and Traditional Chinese Culture Study. Hangzhou, Zhejiang, China, April (in Chinese).

Chou, Su-jung Chou, Chung-ho Lo, Yun-au He, Zu-fang Zhang, Yoshiyuki Iizuka and Kui-lin Tang

2004 An Application of Ar-Ar Isotopic Dating for the Jade from Yin-Shang Dynasty. *In* Proceedings of the International Conference of Anyang Yin-Shang Civilization (6). Yu-xin Wang ed. Section 90 (in Chinese).

Dizon, Eusebio Z.

1998 Earrings in Philippine prehistory. *In* East Asian Jade: Symbol of Excellence. Chung Tang, ed. vol. 2, Pp. 377-382. Hong Kong: The Chinese University of Hong Kong.

Douglas, Janet G.

1996 The study of Chinese archaic jades using non-destructive X-ray fluorescence spectroscopy. Acta Geologica Taiwanica 32:43-54.

2003 Exploring issue of geological source for jade worked by ancient Chinese cultures with the aid of X-ray fluorescence spectroscopy. *In* Scientific Research in the Field of Asian Art: Proceedings of the first Forbes symposium at the Freer Gallery of Art, the Smithsonian Institution. Paul Jett, ed. Pp. 192-199. London: Archetype Publications.

Evans, B.W. and B.R. Frost

1975 Chrome-spinel in progressive metamorphism: A preliminary analysis. Geochimica Cosmochimica Acta 39:959-972.

Figueiras, J. and J.C. Waerenborgh

1997 Fullyoxidized chromite in the Serra Alta (South Portugal) quartzites: Chemical and structural characterization and geological implications. Mineralogical Magazine 61: 627-638.

Fox, Robert B.

1970 The Tabon Caves. National Museum Monograph 1. Manila: The National Museum of the Philippines.

1977a The jade mystique: Some evidence of Philippine prehistoric jade. *In* Filipino Heritage: The making of a Nation, vol.2 The Metal Age in the Philippines: The Foundations of the Society: Pp. 303-308. Manila: Lahing Pilipino Publishing, Inc.

1977b Lete-Lete Cave: The science and art of cave archaeology. *In* Filipino Heritage: The making of a Nation, vol.1 The Stone Age in the Philippines: The Search for Early Man: Pp. 228-234. Manila: Lahing Pilipino Publishing, Inc.

Geological map of the Philippines

1981 The Geology and Mineral Resources of the Philippines, vol. 1, geology, 1981 edition. Manila: The Bureau of Mines & Geo-Sciences, the Philippines.

Ha, Van Tan
1998 Nephrite split earrings with projections, in Vietnam. *In* East Asian Jade: Symbol of Excellence. Chung Tang, ed. vol. 2, Pp. 397-401. Hong Kong: The Chinese University Hong Kong.

Huang, Shih-chiang and Su-jung Chou
2001 Lao Fan She yi zhi bu fen chu tu yu qi cai zhi yu gong yi ji shu te zheng (Material and technological characters of the nephrite artifacts from Laofanshe Site). *In* Conference Papers for the Ancient Nephrite Studies from Cross-Strait, X.H. Qian ed. Pp. 421-436. Taipei: Department of Geology, National Taiwan University (in Chinese).

Hung, Hsiao-chun
2000 Comparative studies of stone adzes in Taiwan, South China and the Philippines. Master of Arts Thesis, Department of Anthropology, National Taiwan University (in Chinese).
2003 Study on Taiwan adzes. Journal of Southeast Archaeology 3:71-99. Xia-men University (in Chinese).
2004 A sourcing study of Taiwan stone adzes. Bulletin of the Indo-Pacific Prehistory Association 24:57-70.
2005 Neolithic interaction between Taiwan and northern Luzon. The pottery and jade evidences from the Cagayan Valley. Journal of Austronesian Studies 1(1):109-133.

Hung, Hsiao-chun and Yoshiyuki Iizuka
2004 Taiwan jade in the context of Southeast Asian archaeology. Paper presented at the 10th Conference of European Association of South East Asian Archaeology. British Museum, London, September 16.

Hung, Hsiao-chun, Yoshiyuki Iizuka and Rey A. Santiago
2004 Lost treasure from beyond the sea: A prehistoric jade bell-shaped bead excavated from the Philippines. The National Palace Museum Research Quarterly 21:43-56 (in Chinese with English abstract).

Iizuka, Yoshiyuki, Peter Bellwood, Hsiao-chun Hung and Eusebio Z. Dizon
2005 A Non-Destructive Mineralogical Study of Nephritic Artifacts from Itbayat Island, Batanes, Northern Philippines. Journal of Austronesian Studies 1(1):83-108.

Irvine, T.N.
1965 Chromian spinel as a petrogenetic indicator. Part I. Theory. Canadian Journal of Earth Sciences 2:648-672.

Irvine, T.N. and T.C. Findley
1972 Alpine-type peridotite with particular reference to the Bay of Island igneous Complex. Canadian Dept. Energy, Mines, and Resources, Earth Physics Branch Publ. 42:91-128.

Kano, Tadao

1946 Projected earrings in Southeast Asia. *In* Studies in the Ethnology and Prehistory of Southeast Asia I, Pp. 227-234. Tokyo: Yajima Shobo (in Japanese).

Kennett, D.J., A.J. Anderson, M.J. Cruz, G.R. Clark and Glenn R. Summerhayes

2004 Geochemical Characterization of Lapita Pottery via Inductively Coupled Plasma Mass Spectrometry (ICP-MS). Archaeometry 46:35-46.

Kimball, K.L.

1990 Effects of hydrothermal alteration on the compositions of chronian spinels. Contribution for Mineralogy and Petrology 105:337-346.

Kokubu, Naoichi

1981 Kou-tou-sho hatsugen no sekki oyobi dozoku shiryo (Stone tools and local customs in Lanyu Island in Taiwan) *In* Taiwan Kouko Minzokushi (Taiwan archaeo-ethnology). Pp. 292-302. Tokyo: Kei yu sha (in Japanese).

Leake, Bernard E. with 21 co-authors

1997 Nomenclature of amphiboles: Report of the subcommittee on amphiboles of the international mineralogical association, commission on new minerals and mineral names. American Mineralogist 82:1019-1037.

Lien, Chao-mei

1998 Study of jade artifacts from the Peinan site, Taiwan. *In* East Asian Jade: Symbol of Excellence. Chung Tang, ed. vol. 1, Pp. 350-367. Hong Kong: The Chinese University Hong Kong (in Chinese).

2002 The Jade Industry of Neolithic Taiwan. Bulletin of the Indo-Pacific Prehistory Association 6:55-62.

Lien, Chao-mei, Li-ping Tan and Bing-sheng Yu

1996 A preliminary study on the raw materials for the jade artifacts excavated from the Painan site, Taiwan. Acta Geologica Taiwanica 32:121-129.

Lin, Szu-bin, Hsien-ho Tsien and Li-ping Tan

1996 Mineralogical properties and secondary alterations of serpentine archaic jades. Acta Geologica Taiwanica 32:149-168.

Lin, Shu-fen, Cheng-yi Chu, Cheng-hwa Tsang and Kuang-ti Li

2002 Tai nan xian you xian fang yi zhi yu qi chu bu fen xi yan jiu (Preliminary Results of the jade artifacts from Youxianfang Site, Tainan.). *In* Qian xian he jiao shou luo huan ji jiao shou rong tui yan tao hui lun wen ji (Professor Qian Xian He and Luo Huan Ji Festschrift). National Taiwan University, Taipei (in Chinese).

Liu, Yi-chang

2003 Tai wan yu qi liu xing nian dai ji qi xiang guan wen ti (the prevalent age of Taiwan jade and its related problems) *In* Cheng-hwa Tsang, ed. Prehistory and classical civilization (Papers from the third international conference on sinology. History section). Pp. 1-44. Taipei: Academia Sinica (in Chinese).

Nguyen, Kim Dung

1998 Ancient jade-manufacturing tradition in Vietnam. *In* East Asian Jade: Symbol of Excellence. Chung Tang, ed. vol. 2, Pp. 383-396. Hong Kong: The Chinese University Hong Kong.

Peralta, Jesus T.

1997 Ancient Stone Jewelry. *In* Filipino Heritage: The making of a Nation, vol.1 The Stone Age in the Philippines: The Search for Early Man. Pp. 225-227. Manila: Lahing Pilipino Publishing.

Sung, Wen-hsun

1980 A double-headed nephrite ornament from Botel Tobago Island, Taiwan (translated by Chao-mei Lien). The National Palace Museum Quarterly 14:39-51 (in Chinese).

1989 On the prehistoric split earrings of Taiwan and Circum South China Sea. Proceedings of the Second International Conference on Sinology (vol. History and Archaeology):117-140, Academia Sinica, Taipei (in Chinese).

Summerhayes, Glenn R.

2004 The nature of prehistoric obsidian importation to Anir and the development of a 3,000 year old regional picture of obsidian exchange within the Bismarck Archipelago, Papua New Guinea. *In* A Pacific Odyssey: Archaeology and Anthropology in the Western Pacific. Papers in Honour of Jim Specht. V. Attenbrow & R. Fullagar eds. Pp. 145-156. Records of the Australian Museum (Sydney), Supplement 29.

Tan, Li-ping, Chihming Wang Lee and Pei-lin Tien

1978 Mineralogy of the nephrite in the Fengtian area, Hualien, Taiwan. National Science Council special publication 1: A mineralogical study of the Fengtian nephrite deposits of Hualien, Taiwan:1-28.

Tan, Li-ping, Chao-mei Lien and Bing-sheng Yu

1997 Preliminary study on the source of nephrite in the Beinan site of Taiwan. Bulletin of the Department of Anthropology 52:211-220. Taipei: National Taiwan University (in Chinese).

Tsang, Cheng-hwa

1992 Archaeology of the P'eng-hu Islands. Taipei: Academia Sinica, Institute of History and Philology.

Tsang, Cheng-hwa, Rey A. Santiago and Hsiao-chun Hung

2002 Report on the Archaeological Explorations in Northern Luzon, Philippines, 1996-2002 Academia Sinica: Annual report for the program of Asian and Pacific study (in Chinese).

Tsien, Hsien-ho, Li-ping Tan and Janet G. Douglas

1996 Geology of tremolite rock and petrofabrics of archaic Chinese Yu. Acta Geologica Taiwanica 32:85-101.

Wang Lee, Chihming, Chao-mei Lien, Wen-hung Sung, Tzeng-fu Yu and Cheng-hong Chen

1996 Archaeological and mineral study on the nephrite artifacts from Beinan Site. *In* Handbook of the International Conference for the Mineral Study of Ancient Nephrite:13-18. Taipei: National Taiwan University (in Chinese).

Wen, Guang and Zhichun Jing

1992 Chinese Neolithic jade: A preliminary geoarchaeological study. Geoarchaeology 7:251-275.

1996 Mineralogical studies of Chinese archaic jade. Acta Geologica Taiwanica 32: 55-83.

Xu, Ji-an, Eugene Huang, Cheng-hong Chen, Li-ping Tan and Bing-sheng Yu

1996 A Raman spectroscopic study of archaic jades. Acta Geologica Taiwanica 32: 11-42.

Yui, Tzeng-fu, Hsiao-wen Yeh and Chihming Wang Lee

1988 Stable isotope studies of nephrite deposits from Fengtian, Taiwan. Geochimica Cosmochimica Acta 52:593-602.

Yui, Tzeng-fu, Hsiao-chun Hung, Shu-fen Lin, and Chihming Wang Lee

2001 A preliminary stable isotope study of prehistoric tremolitic jade from Taiwan. Proceeding of Archaic Jades across the Taiwan Strait: 537-542. Taipei: Department of Geology, National Taiwan University.

APPENDIX 1. Chemical compositions of natural nephrite from the Fengtian mine field, eastern Taiwan.

	YT-9				**S3-1**				**I-1**				**#1074**			
No. of analyses	54				24				23				65			
color	green				green				green				green			
wt%	avrg	max	min	sd	avrg	max	min	sd	avrg	max	min	sd	avrg	max	min	sd
SiO2	57.78	58.92	56.99	0.43	58.12	58.72	56.89	0.39	57.97	58.68	56.45	0.54	57.47	58.66	56.17	0.62
TiO2	0.01	0.08	0.00	0.02	0.02	0.11	0.00	0.03	0.01	0.06	0.00	0.02	0.03	0.10	0.00	0.03
Al2O3	0.41	1.00	0.19	0.16	0.34	0.59	0.17	0.10	0.31	0.91	0.11	0.17	1.02	2.02	0.25	0.42
Cr2O3	0.16	0.48	0.04	0.08	0.18	0.56	0.05	0.11	0.32	0.83	0.12	0.16	0.56	1.36	0.10	0.31
FeO	3.70	4.15	3.36	0.19	3.52	4.09	3.14	0.20	3.80	4.58	3.23	0.36	4.04	6.03	3.49	0.36
MnO	0.35	0.52	0.17	0.06	0.18	0.25	0.11	0.04	0.14	0.20	0.05	0.04	0.22	0.33	0.10	0.06
MgO	22.02	22.67	21.39	0.28	22.06	22.55	21.27	0.30	21.96	22.68	21.17	0.39	21.35	22.15	20.31	0.43
CaO	13.01	13.42	12.51	0.23	13.32	13.53	12.97	0.14	13.25	13.53	12.94	0.16	13.18	13.41	12.73	0.16
Na2O	0.03	0.09	0.00	0.02	0.03	0.08	0.00	0.02	0.02	0.05	0.00	0.02	0.06	0.17	0.00	0.03
K2O	0.01	0.05	0.00	0.01	0.02	0.06	0.00	0.02	0.02	0.04	0.00	0.02	0.02	0.08	0.00	0.02
Total	97.49	98.97	96.17	0.64	97.80	98.49	96.30	0.52	97.79	98.60	96.48	0.58	97.94	99.00	96.07	0.64
(O=23)																
Si	7.973	8.000	7.905	0.023	7.986	8.000	7.951	0.013	7.977	7.999	7.859	0.030	7.913	7.999	7.769	0.057
Al (iv)	0.027	0.095	0.000	0.023	0.014	0.049	0.000	0.013	0.023	0.141	0.001	0.030	0.087	0.231	0.001	0.057
Al (vi)	0.039	0.082	0.002	0.021	0.041	0.069	0.007	0.017	0.027	0.092	0.000	0.021	0.079	0.165	0.004	0.036
Ti	0.001	0.008	0.000	0.002	0.002	0.011	0.000	0.004	0.001	0.006	0.000	0.002	0.003	0.011	0.000	0.003
Cr	0.018	0.052	0.004	0.009	0.020	0.062	0.006	0.012	0.035	0.091	0.013	0.017	0.061	0.148	0.011	0.033
Fe	0.428	0.477	0.391	0.022	0.405	0.474	0.357	0.024	0.437	0.524	0.368	0.042	0.465	0.704	0.403	0.042
Mn	0.041	0.062	0.020	0.008	0.020	0.030	0.012	0.005	0.016	0.024	0.006	0.005	0.025	0.039	0.012	0.007
Mg	4.529	4.637	4.441	0.048	4.518	4.590	4.433	0.046	4.504	4.613	4.323	0.071	4.382	4.555	4.153	0.078
Ca	1.923	1.971	1.859	0.031	1.962	1.990	1.901	0.018	1.954	1.996	1.918	0.022	1.945	1.993	1.880	0.025
Na	0.008	0.023	0.000	0.006	0.007	0.023	0.000	0.006	0.005	0.013	0.000	0.004	0.017	0.044	0.000	0.009
K	0.003	0.008	0.000	0.002	0.004	0.011	0.000	0.003	0.003	0.008	0.000	0.003	0.004	0.014	0.000	0.003
cation total	14.989	15.028	14.957	0.017	14.979	15.006	14.961	0.011	14.983	15.029	14.922	0.022	14.981	15.054	14.924	0.027
Mg/(Mg+Fe)	0.914	0.921	0.903	0.004	0.918	0.928	0.904	0.005	0.911	0.926	0.893	0.009	0.904	0.918	0.857	0.009
Al/(Al+Cr)	0.787	0.925	0.573	0.082	0.747	0.886	0.581	0.074	0.580	0.695	0.427	0.056	0.738	0.904	0.607	0.065

	CM-31				**J1-3**				**Yui-1 (cat's eye nephrite)**				**LTS-9 (Wangrong)**			
No. of analyses	28				39				29				28			
color	green				white				white				green			
wt. %	avrg	max	min	sd	avrg	max	min	sd	avrg	max	min	sd	avrg	max	min	sd
SiO2	57.83	58.47	56.97	0.35	57.43	58.31	56.06	0.49	57.79	58.48	57.11	0.37	58.05	58.78	57.13	0.41
TiO2	0.03	0.09	0.00	0.03	0.03	0.11	0.00	0.03	0.02	0.07	0.00	0.02	0.02	0.07	0.00	0.02
Al2O3	0.29	1.75	0.11	0.31	0.64	1.26	0.29	0.25	0.17	0.24	0.11	0.03	0.40	0.60	0.21	0.11
Cr2O3	0.07	0.50	0.00	0.10	0.01	0.08	0.00	0.02	0.01	0.04	0.00	0.01	0.34	0.56	0.10	0.12
FeO	4.72	6.13	3.63	0.62	6.36	9.64	4.52	1.24	4.61	5.25	3.86	0.36	3.70	3.98	3.40	0.16
MnO	0.19	0.30	0.05	0.05	0.37	0.70	0.18	0.13	0.23	0.35	0.14	0.04	0.19	0.28	0.11	0.04
MgO	21.60	22.17	20.75	0.42	20.21	21.84	17.68	1.06	21.87	22.37	21.41	0.25	21.78	22.21	21.30	0.23
CaO	13.21	13.72	12.14	0.27	13.05	13.40	12.57	0.23	12.95	13.28	12.55	0.19	13.33	13.50	13.03	0.13
Na2O	0.02	0.05	0.00	0.02	0.04	0.10	0.00	0.03	0.01	0.04	0.00	0.01	0.02	0.05	0.00	0.01
K2O	0.01	0.03	0.00	0.01	0.02	0.06	0.00	0.02	0.01	0.06	0.00	0.01	0.01	0.04	0.00	0.01
Total	97.96	98.89	97.32	0.46	98.16	98.96	96.51	0.60	97.68	98.85	96.71	0.59	97.83	98.94	96.70	0.68
(O=23)																
Si	7.975	7.998	7.812	0.036	7.965	7.998	7.891	0.025	7.985	8.000	7.969	0.009	7.983	8.000	7.934	0.016
Al (iv)	0.025	0.188	0.002	0.036	0.035	0.109	0.002	0.025	0.015	0.031	0.000	0.009	0.017	0.066	0.000	0.016
Al (vi)	0.023	0.095	0.000	0.020	0.070	0.157	0.013	0.037	0.012	0.030	0.000	0.009	0.047	0.080	0.004	0.018
Ti	0.003	0.009	0.000	0.003	0.003	0.011	0.000	0.003	0.002	0.007	0.000	0.002	0.002	0.007	0.000	0.002
Cr	0.008	0.054	0.000	0.010	0.001	0.008	0.000	0.002	0.001	0.005	0.000	0.002	0.037	0.061	0.011	0.013
Fe	0.545	0.706	0.418	0.072	0.738	1.127	0.518	0.147	0.533	0.607	0.449	0.042	0.426	0.461	0.393	0.017
Mn	0.022	0.035	0.006	0.006	0.044	0.083	0.021	0.015	0.027	0.041	0.017	0.005	0.022	0.032	0.013	0.005
Mg	4.440	4.551	4.255	0.077	4.178	4.456	3.688	0.206	4.504	4.576	4.429	0.036	4.464	4.552	4.371	0.044
Ca	1.951	2.019	1.783	0.040	1.939	1.987	1.873	0.029	1.917	1.961	1.854	0.030	1.963	1.993	1.915	0.017
Na	0.005	0.013	0.000	0.004	0.011	0.026	0.000	0.007	0.002	0.011	0.000	0.003	0.007	0.013	0.000	0.004
K	0.002	0.006	0.000	0.002	0.004	0.011	0.000	0.003	0.002	0.010	0.000	0.002	0.002	0.007	0.000	0.002
cation total	14.998	15.032	14.978	0.013	14.987	15.056	14.940	0.023	15.001	15.017	14.984	0.009	14.969	15.013	14.934	0.017
Mg/(Mg+Fe)	0.891	0.916	0.858	0.014	0.850	0.896	0.766	0.032	0.894	0.910	0.880	0.008	0.913	0.920	0.906	0.003
Al/(Al+Cr)	0.863	1.000	0.598	0.107	0.986	1.000	0.893	0.029	0.962	1.000	0.841	0.051	0.644	0.764	0.549	0.054

avrg, max and min are average, maximum, minimum values respectively; sd: standard deviation.

APPENDIX 2. Chemical compositions of natural nephrite of boulders from the river floor near the Fengtian mine field.

	FT-C2				FT-C3				FT-C4				FT-C5				FT-C6			
No. of analyses	60				7				42				55				49			
wt.%	avrg	max	min	sd	avrg	max	min	sd	avrg	max	min	sd	avrg	max	min	sd	avrg	max	min	sd
SiO2	57.52	58.93	52.46	1.19	57.84	58.34	56.91	0.51	57.92	58.73	57.13	0.35	57.93	58.73	57.08	0.39	57.64	58.48	56.10	0.57
TiO2	0.02	0.09	0.00	0.02	0.00	0.01	0.00	0.00	0.02	0.07	0.00	0.02	0.01	0.09	0.00	0.02	0.02	0.06	0.00	0.02
Al2O3	0.61	4.23	0.10	0.70	0.37	0.79	0.08	0.25	0.19	0.42	0.12	0.05	0.26	0.50	0.13	0.07	0.45	1.09	0.17	0.25
Cr2O3	0.21	0.86	0.02	0.15	0.10	0.15	0.06	0.03	0.02	0.10	0.00	0.02	0.10	0.22	0.02	0.04	0.26	0.97	0.04	0.15
FeO	4.14	5.74	3.30	0.52	3.90	4.14	3.70	0.17	3.93	4.48	3.35	0.26	3.78	4.13	3.45	0.15	5.19	9.13	3.96	1.10
MnO	0.09	0.19	0.01	0.04	0.07	0.11	0.02	0.04	0.11	0.17	0.01	0.04	0.17	0.23	0.09	0.03	0.19	0.60	0.07	0.10
MgO	21.99	22.74	21.14	0.35	22.27	22.53	22.08	0.17	22.04	22.96	21.61	0.24	22.11	22.53	21.67	0.18	21.10	21.98	17.77	0.84
NiO					0.12	0.26	0.04	0.08												
CaO	13.21	13.74	11.27	0.48	13.14	13.27	13.01	0.11	13.40	13.73	12.87	0.15	13.28	13.57	12.79	0.20	13.22	13.67	12.38	0.24
Na2O	0.01	0.04	0.00	0.01	0.01	0.06	0.00	0.02	0.00	0.03	0.00	0.01	0.01	0.03	0.00	0.01	0.01	0.04	0.00	0.01
Total	97.81	99.49	96.19	0.79	97.82	98.59	97.06	0.48	97.63	98.78	96.52	0.57	97.65	98.88	96.13	0.60	98.10	99.49	96.03	0.76
(O=23)																				
Si	7.927	8.000	7.386	0.106	7.958	7.997	7.898	0.034	7.985	8.000	7.949	0.010	7.980	8.000	7.944	0.016	7.960	8.000	7.872	0.030
Al (iv)	0.073	0.614	0.000	0.106	0.042	0.102	0.003	0.034	0.015	0.051	0.000	0.010	0.020	0.056	0.000	0.016	0.040	0.128	0.000	0.030
Al (vi)	0.027	0.138	0.000	0.025	0.018	0.034	0.001	0.013	0.016	0.032	0.000	0.008	0.023	0.047	0.000	0.012	0.035	0.099	0.001	0.024
Ti	0.002	0.009	0.000	0.002	0.000	0.001	0.000	0.000	0.002	0.007	0.000	0.002	0.001	0.009	0.000	0.002	0.002	0.006	0.000	0.002
Cr	0.023	0.096	0.002	0.016	0.011	0.017	0.006	0.004	0.002	0.010	0.000	0.003	0.011	0.024	0.002	0.005	0.029	0.106	0.005	0.016
Fe	0.478	0.676	0.377	0.062	0.449	0.473	0.424	0.020	0.453	0.516	0.381	0.030	0.436	0.477	0.396	0.018	0.599	1.082	0.459	0.132
Mn	0.011	0.022	0.001	0.004	0.008	0.013	0.002	0.004	0.013	0.020	0.001	0.004	0.019	0.027	0.011	0.004	0.023	0.072	0.008	0.012
Mg	4.518	4.677	4.354	0.060	4.568	4.598	4.508	0.032	4.531	4.651	4.463	0.041	4.541	4.602	4.481	0.027	4.342	4.525	3.756	0.154
Ni					0.013	0.028	0.004	0.009												
Ca	1.950	2.003	1.700	0.058	1.937	1.951	1.924	0.011	1.979	2.009	1.918	0.017	1.960	2.002	1.892	0.025	1.956	1.996	1.841	0.031
Na	0.004	0.011	0.000	0.004	0.003	0.015	0.000	0.006	0.001	0.008	0.000	0.002	0.002	0.007	0.000	0.002	0.002	0.011	0.000	0.003
Total	15.012	15.219	14.947	0.045	15.008	15.029	14.994	0.015	14.997	15.013	14.981	0.009	14.993	15.019	14.964	0.013	14.988	15.020	14.940	0.016
Mg/(Mg+Fe)	0.904	0.924	0.873	0.012	0.911	0.915	0.905	0.004	0.909	0.924	0.896	0.006	0.912	0.920	0.905	0.003	0.879	0.907	0.776	0.027
Al/(Al+Cr)	0.770	0.896	0.571	0.071	0.806	0.920	0.667	0.101	0.937	1.000	0.738	0.074	0.802	0.934	0.659	0.063	0.720	0.969	0.562	0.115

	FT-C7				FT-R3				FT-R4				FT-R5				Fengtian nephrites*		
No. of analyses	21				89				49				13				(n=675)		
wt.%	avrg	max	min	sd	avrg	max	min	sd	avrg	max	min	sd	avrg	max	min	sd	avrg	max	min
SiO2	58.15	58.73	57.44	0.39	57.91	59.27	56.22	0.72	57.42	58.46	56.46	0.53	57.80	58.62	56.99	0.55	57.80	58.93	52.46
TiO2	0.03	0.10	0.00	0.03	0.01	0.10	0.00	0.02	0.01	0.07	0.00	0.02	0.01	0.04	0.00	0.01	0.02	0.11	0.00
Al2O3	0.53	0.90	0.08	0.22	0.45	1.09	0.15	0.23	0.47	0.79	0.33	0.10	0.35	0.46	0.24	0.06	0.43	4.23	0.08
Cr2O3	0.08	0.25	0.00	0.06	0.13	0.33	0.00	0.08	0.21	0.58	0.07	0.09	0.09	0.15	0.02	0.04	0.17	1.36	0.00
FeO	4.32	4.70	3.77	0.22	4.42	7.00	3.39	0.89	4.26	5.02	3.58	0.31	4.22	5.58	3.55	0.49	4.27	9.64	3.14
MnO	0.16	0.21	0.09	0.03	0.12	0.32	0.00	0.06	0.16	0.24	0.05	0.04	0.12	0.16	0.06	0.03	0.18	0.70	0.00
MgO	21.69	22.12	21.27	0.20	21.56	23.03	20.12	0.77	21.52	22.17	20.69	0.32	21.86	22.38	20.95	0.41	21.70	23.03	17.68
NiO	0.18	0.29	0.00	0.07	0.21	0.42	0.00	0.09	0.13	0.27	0.00	0.06	0.18	0.30	0.07	0.07	0.17	0.42	0.00
CaO	13.38	13.84	13.00	0.23	13.24	13.74	12.71	0.20	13.17	13.48	12.70	0.18	13.18	13.43	12.79	0.17	13.21	13.84	11.27
Na2O	0.16	0.29	0.00	0.07	0.08	0.29	0.01	0.06	0.03	0.09	0.00	0.02	0.05	0.08	0.01	0.02	0.03	0.29	0.00
K2O					0.01	0.07	0.00	0.02									0.01	0.08	0.00
Total	98.68	99.48	97.54	0.58	98.16	99.94	96.19	0.76	97.37	98.84	96.13	0.77	97.85	98.63	96.64	0.65	97.87	99.94	96.03
(O=23)																			
Si	7.956	7.992	7.913	0.022	7.997	7.999	7.852	0.030	7.960	8.000	7.904	0.021	7.968	7.999	7.937	0.018	7.968	8.000	7.386
Al (iv)	0.044	0.087	0.008	0.022	0.034	0.148	0.001	0.030	0.040	0.096	0.000	0.021	0.032	0.063	0.001	0.018	0.034	0.614	0.000
Al (vi)	0.041	0.114	0.004	0.027	0.040	0.126	0.002	0.025	0.036	0.073	0.002	0.019	0.025	0.056	0.004	0.015	0.035	0.165	0.000
Ti	0.003	0.010	0.000	0.003	0.001	0.010	0.000	0.002	0.002	0.007	0.000	0.002	0.001	0.004	0.000	0.001	0.002	0.011	0.000
Cr	0.009	0.028	0.000	0.007	0.014	0.037	0.000	0.008	0.023	0.064	0.008	0.010	0.010	0.016	0.002	0.004	0.018	0.148	0.000
Fe	0.494	0.539	0.429	0.026	0.509	0.808	0.386	0.105	0.493	0.583	0.416	0.036	0.487	0.648	0.407	0.059	0.493	1.082	0.357
Mn	0.018	0.024	0.011	0.004	0.014	0.037	0.000	0.007	0.018	0.028	0.005	0.005	0.013	0.019	0.007	0.003	0.021	0.083	0.000
Mg	4.424	4.491	4.313	0.040	4.417	4.624	4.148	0.127	4.443	4.526	4.293	0.057	4.489	4.558	4.334	0.060	4.458	4.677	3.756
Ni	0.020	0.032	0.000	0.008	0.023	0.046	0.000	0.010	0.014	0.030	0.000	0.007	0.020	0.033	0.008	0.008	0.019	0.046	0.000
Ca	1.962	2.020	1.915	0.029	1.951	2.000	1.868	0.027	1.955	1.998	1.883	0.025	1.946	1.984	1.913	0.021	1.950	2.020	1.700
Na	0.043	0.078	0.000	0.020	0.020	0.077	0.001	0.015	0.009	0.024	0.000	0.006	0.012	0.022	0.001	0.006	0.009	0.078	0.000
K					0.002	0.013	0.000	0.000									0.002	0.014	0.000
Total	15.015	15.055	14.984	0.019	14.995	15.081	14.969	0.021	14.993	15.027	14.950	0.020	15.003	15.031	14.970	0.017	14.994	15.219	14.922
Mg/(Mg+Fe)	0.900	0.913	0.891	0.005	0.897	0.922	0.837	0.022	0.900	0.916	0.881	0.007	0.902	0.918	0.870	0.012	0.900	0.928	0.766
Al/(Al+Cr)	0.881	1.000	0.687	0.103	0.832	1.000	0.614	0.098	0.770	0.938	0.644	0.058	0.854	0.977	0.759	0.064	0.805	1.000	0.427

*: Fengtian nephrites (all analyses in this study)

APPENDIX 3-1. Chemical compositions of natural green-colored nephrites from Asia.

	GS-1				**GS-2**				**GS-6**	**(USNM32771)**			**XT-1**				**LN-2**				**LN-6**			
No. of analyses	43				43				45				39				28				53			
	avrg	max	min	sd	avrg	max	min	sd	avrg	max	min	sd	avrg	max	min	sd	avrg	max	min	sd	avrg	max	min	sd
SiO2	58.67	59.48	57.67	0.40	59.10	59.80	57.43	0.44	57.40	58.43	56.61	0.43	58.83	59.57	57.83	0.45	58.71	59.47	57.56	0.54	58.78	59.52	56.79	0.50
TiO2	0.02	0.08	0.00	0.02	0.02	0.10	0.00	0.03	0.02	0.12	0.00	0.03	0.04	0.10	0.00	0.03	0.01	0.05	0.00	0.01	0.02	0.09	0.00	0.03
Al2O3	0.71	0.90	0.55	0.08	0.79	0.90	0.67	0.06	0.48	0.91	0.29	0.13	0.62	0.98	0.52	0.08	0.29	0.37	0.24	0.04	0.50	1.63	0.28	0.23
Cr2O3	0.00	0.04	0.00	0.01	0.01	0.06	0.00	0.02	0.20	0.55	0.04	0.10	0.01	0.06	0.00	0.02	0.01	0.04	0.00	0.01	0.02	0.09	0.00	0.02
FeO	0.91	1.06	0.77	0.06	0.11	0.23	0.02	0.05	3.90	4.22	3.44	0.20	1.33	1.81	1.15	0.11	1.20	1.39	0.98	0.09	0.66	0.79	0.52	0.07
MnO	0.07	0.19	0.00	0.05	0.03	0.12	0.00	0.03	0.13	0.23	0.02	0.06	0.15	0.44	0.07	0.06	0.09	1.02	0.00	0.18	0.08	0.19	0.00	0.04
MgO	23.96	24.32	23.26	0.23	24.62	24.90	24.24	0.17	21.55	22.10	20.97	0.27	23.84	24.39	23.18	0.25	24.54	25.00	23.71	0.30	24.52	24.97	23.83	0.28
NiO									0.22	0.40	0.00	0.08												
CaO	13.12	13.46	12.48	0.24	13.15	13.62	12.47	0.22	13.26	13.71	12.53	0.21	13.07	13.43	12.57	0.18	12.57	13.10	11.92	0.30	12.97	13.56	12.24	0.31
Na2O	0.15	0.21	0.09	0.03	0.07	0.13	0.04	0.02	0.05	0.13	0.00	0.03	0.08	0.12	0.04	0.02	0.03	0.07	0.01	0.01	0.02	0.06	0.00	0.02
K2O	0.09	0.23	0.03	0.03	0.06	0.17	0.00	0.03	0.02	0.11	0.00	0.02	0.04	0.07	0.00	0.02	0.02	0.05	0.00	0.01	0.03	0.08	0.00	0.02
Total	97.70	98.88	96.70	0.56	97.96	98.85	96.10	0.58	97.23	98.46	96.09	0.53	98.02	99.23	96.14	0.63	97.47	98.82	95.45	0.79	97.59	98.62	96.12	0.59
(O=23)																								
Si	7.965	8.000	7.914	0.024	7.965	8.000	7.899	0.023	7.962	7.999	7.885	0.027	7.972	8.000	7.927	0.020	7.984	8.000	7.959	0.014	7.971	8.000	7.815	0.035
Al (iv)	0.035	0.086	0.000	0.024	0.035	0.101	0.000	0.023	0.038	0.115	0.001	0.027	0.028	0.073	0.000	0.020	0.016	0.041	0.000	0.014	0.029	0.185	0.000	0.035
Al (vi)	0.077	0.115	0.031	0.023	0.091	0.130	0.025	0.022	0.041	0.082	0.001	0.022	0.071	0.101	0.032	0.019	0.031	0.050	0.003	0.016	0.051	0.099	0.003	0.021
Ti	0.002	0.009	0.000	0.003	0.002	0.010	0.000	0.003	0.002	0.012	0.000	0.003	0.005	0.011	0.000	0.003	0.001	0.005	0.000	0.001	0.002	0.009	0.000	0.003
Cr	0.000	0.005	0.000	0.001	0.001	0.007	0.000	0.002	0.021	0.060	0.005	0.011	0.001	0.006	0.000	0.002	0.001	0.005	0.000	0.001	0.002	0.010	0.000	0.002
Fe	0.103	0.120	0.088	0.007	0.012	0.026	0.002	0.005	0.452	0.492	0.400	0.024	0.151	0.207	0.130	0.013	0.136	0.158	0.113	0.010	0.075	0.090	0.060	0.008
Mn	0.008	0.022	0.000	0.005	0.004	0.013	0.000	0.004	0.015	0.027	0.003	0.007	0.018	0.051	0.008	0.007	0.011	0.117	0.000	0.021	0.009	0.022	0.000	0.005
Mg	4.849	4.941	4.740	0.045	4.946	5.106	4.878	0.039	4.451	4.560	4.351	0.045	4.816	4.864	4.733	0.036	4.975	5.079	4.869	0.051	4.957	5.098	4.861	0.047
Ni									0.024	0.045	0.000	0.009												
Ca	1.909	1.952	1.816	0.035	1.898	1.955	1.819	0.027	1.969	2.018	1.851	0.031	1.898	1.940	1.818	0.027	1.832	1.915	1.734	0.043	1.884	1.953	1.776	0.047
Na	0.040	0.056	0.023	0.008	0.018	0.033	0.010	0.006	0.015	0.034	0.000	0.009	0.020	0.031	0.010	0.006	0.008	0.018	0.002	0.004	0.006	0.016	0.000	0.004
K	0.016	0.039	0.005	0.006	0.011	0.030	0.000	0.004	0.003	0.018	0.000	0.004	0.006	0.012	0.000	0.003	0.003	0.009	0.000	0.002	0.005	0.014	0.000	0.003
cation total	15.005	15.051	14.968	0.023	14.983	15.045	14.944	0.022	14.995	15.052	14.963	0.023	14.987	15.027	14.958	0.019	14.997	15.023	14.978	0.015	14.991	15.082	14.959	0.022
Mg/(Mg+Fe)	0.979	0.982	0.976	0.001	0.998	1.000	0.995	0.001	0.908	0.919	0.899	0.005	0.970	0.974	0.958	0.003	0.973	0.978	0.970	0.002	0.985	0.988	0.982	0.002
Al/(Al+Cr)	0.996	1.000	0.969	0.008	0.991	1.000	0.951	0.014	0.789	0.950	0.639	0.077	0.990	1.000	0.948	0.017	0.982	1.000	0.898	0.030	0.977	1.000	0.881	0.031

	Yk-3				**Yk-1**				**Yk-4**				**Sb-1 (USNM 84590)**				**Sb-3**				**JN-130 (NMJ 37130)**			
No. of analyses	34				40				48				38				62				67			
	avrg	max	min	sd	avrg	max	min	sd	avrg	max	min	sd	avrg	max	min	sd	avrg	max	min	sd	avrg	max	min	sd
SiO2	59.17	59.72	58.45	0.38	58.84	59.89	57.38	0.48	58.77	59.97	57.34	0.54	58.05	58.92	55.50	0.58	57.37	58.40	56.41	0.49	57.12	58.89	54.53	0.87
TiO2	0.03	0.14	0.00	0.03	0.02	0.10	0.00	0.03	0.03	0.13	0.00	0.03	0.02	0.15	0.00	0.03	0.02	0.11	0.00	0.03	0.02	0.12	0.00	0.03
Al2O3	0.57	0.83	0.30	0.11	0.70	0.81	0.53	0.06	0.60	0.79	0.42	0.08	0.28	2.82	0.08	0.43	0.21	0.92	0.08	0.11	1.07	2.70	0.47	0.57
Cr2O3	0.02	0.07	0.00	0.02	0.01	0.07	0.00	0.02	0.02	0.11	0.00	0.03	0.12	0.29	0.00	0.07	0.13	0.30	0.00	0.06	0.35	1.99	0.00	0.44
FeO	0.52	1.05	0.24	0.19	1.15	1.56	0.87	0.20	0.61	0.75	0.47	0.07	3.06	3.94	2.13	0.44	5.41	10.14	3.06	2.11	2.22	4.21	0.98	0.74
MnO	0.03	0.09	0.00	0.03	0.19	0.34	0.08	0.06	0.08	0.17	0.00	0.04	0.14	0.25	0.03	0.05	0.08	0.15	0.00	0.04	0.09	0.26	0.00	0.06
MgO	24.82	25.68	24.30	0.28	24.32	24.76	23.58	0.27	24.66	25.38	23.79	0.33	22.51	24.51	21.28	0.57	20.82	22.58	17.93	1.28	22.62	23.83	21.32	0.56
NiO													0.11	0.28	0.00	0.07	0.23	0.50	0.00	0.13				
CaO	12.73	13.60	11.45	0.41	12.42	12.78	11.67	0.24	12.64	13.24	11.98	0.35	13.33	13.88	9.90	0.64	13.19	13.60	12.35	0.25	13.50	14.14	12.56	0.27
Na2O	0.08	0.15	0.03	0.03	0.08	0.12	0.04	0.02	0.08	0.15	0.03	0.02	0.03	0.10	0.00	0.03	0.03	0.12	0.00	0.03	0.21	0.57	0.09	0.11
K2O	0.06	0.10	0.02	0.02	0.07	0.12	0.03	0.02	0.06	0.10	0.02	0.02	0.01	0.05	0.00	0.01	0.02	0.09	0.00	0.02	0.03	0.10	0.00	0.03
Total	98.02	98.82	96.88	0.57	97.79	99.36	96.26	0.67	97.53	99.38	95.60	0.75	97.68	98.98	96.22	0.64	97.49	98.90	96.03	0.70	97.24	99.11	96.28	0.54
(O=23)																								
Si	7.976	7.997	7.915	0.019	7.972	8.000	7.924	0.018	7.968	7.999	7.925	0.020	7.975	8.000	7.685	0.050	7.986	8.000	7.896	0.016	7.871	7.980	7.608	0.088
Al (iv)	0.024	0.085	0.003	0.019	0.028	0.076	0.000	0.018	0.032	0.075	0.001	0.020	0.025	0.315	0.000	0.050	0.014	0.104	0.000	0.016	0.129	0.392	0.020	0.088
Al (vi)	0.066	0.126	0.009	0.025	0.084	0.116	0.031	0.019	0.064	0.111	0.018	0.021	0.022	0.145	0.000	0.024	0.020	0.047	0.000	0.012	0.045	0.112	0.000	0.028
Ti	0.003	0.015	0.000	0.003	0.002	0.010	0.000	0.003	0.003	0.013	0.000	0.003	0.003	0.015	0.000	0.003	0.002	0.012	0.000	0.003	0.002	0.013	0.000	0.003
Cr	0.002	0.007	0.000	0.002	0.002	0.008	0.000	0.002	0.002	0.011	0.000	0.003	0.014	0.032	0.000	0.008	0.014	0.033	0.000	0.006	0.038	0.219	0.000	0.048
Fe	0.059	0.118	0.027	0.022	0.130	0.176	0.098	0.022	0.069	0.085	0.053	0.008	0.352	0.456	0.247	0.050	0.631	1.196	0.356	0.250	0.256	0.488	0.112	0.086
Mn	0.004	0.010	0.000	0.003	0.022	0.039	0.009	0.007	0.009	0.020	0.000	0.005	0.017	0.029	0.004	0.006	0.009	0.018	0.000	0.005	0.011	0.030	0.000	0.007
Mg	4.987	5.182	4.883	0.058	4.911	4.986	4.812	0.050	4.983	5.097	4.869	0.051	4.608	5.055	4.399	0.113	4.316	4.661	3.769	0.242	4.644	4.845	4.421	0.095
Ni													0.013	0.030	0.000	0.008	0.025	0.055	0.000	0.014				
Ca	1.839	1.964	1.661	0.058	1.803	1.852	1.705	0.035	1.836	1.920	1.740	0.051	1.962	2.043	1.468	0.093	1.966	2.027	1.842	0.034	1.993	2.067	1.866	0.036
Na	0.021	0.039	0.008	0.007	0.020	0.031	0.011	0.005	0.020	0.040	0.009	0.006	0.007	0.026	0.000	0.008	0.009	0.033	0.000	0.008	0.057	0.153	0.023	0.029
K	0.009	0.018	0.003	0.004	0.012	0.020	0.004	0.004	0.011	0.017	0.004	0.003	0.002	0.009	0.000	0.002	0.003	0.016	0.000	0.003	0.006	0.017	0.000	0.005
cation total	14.990	15.045	14.959	0.019	14.986	15.035	14.955	0.019	14.996	15.037	14.958	0.019	14.997	15.076	14.974	0.017	14.994	15.020	14.975	0.011	15.052	15.168	14.969	0.038
Mg/(Mg+Fe)	0.988	0.995	0.976	0.004	0.974	0.981	0.965	0.004	0.986	0.990	0.983	0.001	0.929	0.951	0.908	0.011	0.873	0.928	0.759	0.050	0.948	0.977	0.902	0.017
Al/(Al+Cr)	0.982	1.000	0.917	0.022	0.986	1.000	0.929	0.019	0.976	1.000	0.906	0.029	0.739	1.000	0.474	0.130	0.704	1.000	0.473	0.108	0.857	1.000	0.668	0.087

APPENDIX 3-2. Chemical compositions of natural green-colored nephrites from the Pacific region.

	Wy-6				BC-1				BC-2				BC-3				BC-4			
No. of analyses	48				26				54				40				38			
wt. %	avrg	max	min	sd	avrg	max	min	sd	avrg	max	min	sd	avrg	max	min	sd	avrg	max	min	sd
SiO2	57.13	58.18	55.51	0.53	58.17	59.27	57.38	0.44	57.30	58.25	55.49	0.71	57.15	58.59	54.63	0.95	57.39	58.04	56.20	0.49
TiO2	0.06	0.25	0.00	0.04	0.02	0.06	0.00	0.02	0.01	0.05	0.00	0.01	0.01	0.08	0.00	0.02	0.02	0.08	0.00	0.02
Al2O3	1.42	3.23	1.00	0.31	0.13	0.24	0.06	0.04	0.46	1.57	0.10	0.40	0.84	2.48	0.35	0.64	0.53	1.38	0.26	0.24
Cr2O3	0.31	0.42	0.11	0.06	0.14	0.33	0.04	0.07	0.34	0.98	0.06	0.27	0.21	0.62	0.11	0.10	0.15	0.29	0.05	0.06
FeO	2.34	2.85	2.15	0.13	3.77	4.26	3.51	0.17	3.88	4.96	3.34	0.44	4.02	4.52	3.60	0.23	3.90	4.90	3.30	0.39
MnO	0.03	0.10	0.00	0.03	0.05	0.11	0.00	0.03	0.12	0.20	0.03	0.04	0.05	0.13	0.00	0.03	0.05	0.13	0.00	0.03
MgO	22.15	22.69	21.35	0.30	22.25	22.53	21.90	0.15	21.50	22.22	19.70	0.62	21.67	22.20	21.15	0.28	21.66	22.45	20.94	0.31
NiO	0.15	0.30	0.04	0.05					0.20	0.38	0.01	0.08	0.19	0.33	0.06	0.05	0.18	0.36	0.00	0.07
CaO	13.56	13.98	13.05	0.17	13.31	13.52	12.99	0.15	13.21	13.58	12.77	0.18	13.04	13.65	11.80	0.49	13.29	13.73	12.85	0.22
Na2O	0.11	0.24	0.05	0.03	0.02	0.05	0.00	0.01	0.06	0.17	0.00	0.04	0.07	0.11	0.02	0.02	0.06	0.11	0.01	0.02
K2O																				
Total	97.25	98.42	96.07	0.55	97.87	99.62	96.58	0.71	97.07	98.16	95.73	0.61	97.25	98.70	96.00	0.63	97.23	98.12	95.66	0.60
(O = 23)																				
Si	7.871	7.918	7.687	0.038	7.993	8.000	7.977	0.007	7.960	8.000	7.787	0.054	7.922	8.000	7.659	0.091	7.955	7.998	7.778	0.042
Al (iv)	0.129	0.313	0.082	0.038	0.007	0.023	0.000	0.007	0.040	0.213	0.000	0.054	0.078	0.341	0.000	0.091	0.045	0.222	0.002	0.042
Al (vi)	0.101	0.213	0.032	0.035	0.013	0.031	0.000	0.009	0.035	0.133	0.000	0.029	0.059	0.128	0.002	0.032	0.042	0.084	0.003	0.020
Ti	0.006	0.026	0.000	0.004	0.002	0.006	0.000	0.002	0.001	0.005	0.000	0.001	0.002	0.008	0.000	0.002	0.002	0.009	0.000	0.002
Cr	0.033	0.046	0.012	0.006	0.015	0.036	0.004	0.008	0.037	0.109	0.006	0.030	0.023	0.069	0.012	0.011	0.016	0.031	0.005	0.006
Fe	0.270	0.329	0.248	0.015	0.434	0.488	0.406	0.018	0.451	0.584	0.388	0.052	0.466	0.528	0.414	0.028	0.452	0.571	0.382	0.045
Mn	0.004	0.012	0.000	0.003	0.005	0.012	0.000	0.003	0.014	0.023	0.003	0.004	0.005	0.015	0.000	0.004	0.006	0.015	0.000	0.004
Mg	4.545	4.658	4.403	0.059	4.555	4.620	4.510	0.030	4.448	4.572	4.118	0.111	4.475	4.609	4.340	0.066	4.473	4.627	4.340	0.062
Ni	0.017	0.034	0.004	0.006	0.000	0.006	0.000	0.001	0.022	0.043	0.001	0.009	0.022	0.037	0.006	0.006	0.020	0.040	0.000	0.007
Ca	2.001	2.066	1.923	0.028	1.959	1.989	1.923	0.019	1.966	2.017	1.910	0.023	1.936	2.011	1.766	0.068	1.972	2.033	1.909	0.033
Na	0.029	0.063	0.014	0.009	0.006	0.014	0.000	0.004	0.016	0.047	0.000	0.010	0.019	0.030	0.006	0.005	0.016	0.028	0.003	0.005
K	0.000	0.000	0.000	0.000	0.000	0.005	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
cation total	15.006	15.057	14.958	0.026	14.990	15.007	14.975	0.009	14.991	15.055	14.931	0.025	15.006	15.114	14.947	0.041	15.000	15.103	14.962	0.025
Mg/(Mg+Fe)	0.944	0.949	0.930	0.003	0.913	0.918	0.903	0.004	0.908	0.922	0.879	0.012	0.906	0.915	0.897	0.005	0.908	0.922	0.884	0.009
Al/(Al+Cr)	0.870	0.978	0.821	0.030	0.592	0.784	0.261	0.134	0.672	0.832	0.496	0.070	0.833	0.922	0.699	0.054	0.830	0.958	0.573	0.074

	NZ-1				NZ-2				NZ-3				Aus-1				NC-1 (not nephrite)			
No. of analyses	48				36				13				36				29			
	avrg	max	min	sd	avrg	max	min	sd	avrg	max	min	sd	avrg	max	min	sd	avrg	max	min	sd
SiO2	57.74	58.68	54.97	0.57	57.73	58.62	57.15	0.45	57.18	57.89	56.38	0.47	58.39	59.44	57.59	0.45	54.50	55.40	52.63	0.56
TiO2	0.02	0.08	0.00	0.02	0.02	0.09	0.00	0.02	0.01	0.06	0.00	0.02	0.01	0.10	0.00	0.02	0.06	0.16	0.00	0.04
Al2O3	0.34	1.81	0.15	0.23	0.32	1.00	0.09	0.26	0.37	0.98	0.04	0.31	0.85	1.00	0.61	0.08	3.23	4.11	2.69	0.35
Cr2O3	0.16	0.30	0.03	0.06	0.08	0.17	0.01	0.04	0.15	0.23	0.03	0.06	0.01	0.07	0.00	0.02	0.83	1.17	0.58	0.15
FeO	4.11	4.87	3.60	0.22	3.63	4.06	3.07	0.17	5.04	5.53	4.65	0.28	1.03	1.20	0.73	0.09	4.15	4.51	3.64	0.19
MnO	0.09	0.15	0.03	0.03	0.08	0.14	0.00	0.04	0.14	0.27	0.02	0.07	0.08	0.14	0.02	0.03	0.06	0.13	0.00	0.04
MgO	21.70	22.07	21.05	0.24	22.24	22.63	21.79	0.20	21.72	22.40	20.72	0.43	23.69	24.08	23.25	0.19	20.52	21.20	19.78	0.34
NiO	0.15	0.28	0.05	0.05	0.12	0.24	0.04	0.05					0.02	0.10	0.00	0.03				
CaO	13.29	13.69	12.23	0.25	13.01	13.54	12.00	0.38	12.13	13.13	11.27	0.53	13.07	13.59	12.71	0.22	13.47	13.91	12.87	0.31
Na2O	0.04	0.09	0.00	0.02	0.06	0.11	0.02	0.02	0.04	0.08	0.00	0.03	0.06	0.11	0.01	0.02	0.33	0.46	0.25	0.05
K2O									0.02	0.07	0.00	0.02					0.03	0.09	0.00	0.02
Total	97.63	98.81	95.59	0.65	97.29	98.55	96.11	0.66	96.79	98.07	96.06	0.70	97.22	98.63	95.99	0.62	97.18	98.42	94.16	0.92
O = 23																				
Si	7.975	8.000	7.789	0.032	7.976	8.000	7.901	0.026	7.975	7.996	7.921	0.022	7.965	7.999	7.917	0.020	7.614	7.666	7.533	0.039
Al (iv)	0.025	0.211	0.000	0.032	0.024	0.099	0.000	0.026	0.025	0.079	0.004	0.022	0.035	0.083	0.001	0.020	0.386	0.467	0.334	0.039
Al (vi)	0.031	0.092	0.000	0.018	0.028	0.078	0.003	0.021	0.035	0.134	0.000	0.039	0.102	0.134	0.054	0.020	0.145	0.228	0.054	0.043
Ti	0.002	0.009	0.000	0.002	0.002	0.009	0.000	0.002	0.001	0.006	0.000	0.002	0.001	0.010	0.000	0.002	0.006	0.017	0.000	0.004
Cr	0.017	0.033	0.003	0.007	0.008	0.018	0.001	0.004	0.016	0.026	0.003	0.007	0.001	0.007	0.000	0.002	0.091	0.128	0.064	0.016
Fe	0.475	0.576	0.418	0.026	0.420	0.468	0.357	0.020	0.587	0.638	0.544	0.031	0.117	0.135	0.084	0.010	0.485	0.523	0.428	0.021
Mn	0.010	0.017	0.004	0.003	0.009	0.016	0.000	0.004	0.017	0.032	0.003	0.008	0.009	0.015	0.002	0.003	0.008	0.016	0.000	0.005
Mg	4.464	4.542	4.377	0.038	4.578	4.660	4.499	0.040	4.511	4.653	4.345	0.081	4.814	4.911	4.723	0.041	4.271	4.443	4.142	0.077
Ni	0.017	0.031	0.006	0.006	0.014	0.027	0.004	0.006					0.002	0.011	0.000	0.003				
Ca	1.965	2.018	1.856	0.031	1.925	1.989	1.782	0.054	1.811	1.980	1.689	0.083	1.910	1.970	1.857	0.030	2.015	2.070	1.953	0.042
Na	0.011	0.024	0.000	0.006	0.017	0.030	0.005	0.006	0.010	0.020	0.000	0.007	0.017	0.028	0.002	0.006	0.089	0.123	0.066	0.015
K	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.012	0.000	0.003	0.000	0.000	0.000	0.000	0.006	0.016	0.000	0.004
cation total	14.992	15.047	14.957	0.018	15.001	15.028	14.977	0.012	14.992	15.014	14.943	0.019	14.973	15.029	14.943	0.021	15.116	15.194	15.061	0.033
Mg/(Mg+Fe)	0.904	0.914	0.885	0.005	0.916	0.928	0.908	0.004	0.885	0.895	0.875	0.007	0.976	0.983	0.972	0.002	0.898	0.911	0.890	0.004
Al/(Al+Cr)	0.759	0.932	0.619	0.076	0.828	0.978	0.582	0.097	0.697	0.945	0.369	0.179	0.991	1.000	0.944	0.014	0.853	0.894	0.810	0.021

APPENDIX 4. Chemical compositions of natural white-colored nephrites from Asia.

	MLG-1				**CD-14**				**LB C-2**				**LB C-5**			
No. of analyses	20				55				57				53			
	avrg	max	min	sd	avrg	max	min	sd	avrg	max	min	sd	avrg	max	min	sd
SiO2	57.99	58.72	57.34	0.39	58.98	59.89	57.87	0.53	58.98	59.83	57.66	0.51	58.81	59.66	57.23	0.51
TiO2	0.06	0.11	0.00	0.03	0.02	0.10	0.00	0.03	0.02	0.09	0.00	0.02	0.01	0.08	0.00	0.02
Al2O3	1.03	1.30	0.59	0.20	0.44	0.98	0.07	0.13	0.51	0.64	0.40	0.06	0.60	0.87	0.43	0.08
Cr2O3	0.02	0.08	0.00	0.02	0.01	0.07	0.00	0.02	0.01	0.08	0.00	0.02	0.01	0.08	0.00	0.02
FeO	0.31	0.53	0.21	0.08	0.33	0.54	0.19	0.08	0.08	0.18	0.00	0.04	0.14	0.22	0.03	0.05
MnO	0.12	0.30	0.02	0.09	0.07	0.18	0.01	0.05	0.03	0.44	0.00	0.06	0.05	0.13	0.00	0.03
MgO	24.24	24.73	23.57	0.28	24.82	25.50	24.01	0.30	24.99	25.45	24.11	0.26	25.01	25.56	24.41	0.25
CaO	13.20	13.45	12.72	0.18	13.05	13.71	12.02	0.33	12.85	13.47	12.32	0.26	12.49	13.17	11.17	0.37
Na2O	0.74	0.96	0.56	0.09	0.03	0.10	0.00	0.02	0.07	0.11	0.02	0.02	0.08	0.11	0.03	0.02
K2O	0.27	0.40	0.19	0.05	0.04	0.09	0.00	0.02	0.06	0.08	0.02	0.02	0.07	0.15	0.03	0.03
Total	97.98	99.15	96.69	0.62	97.79	98.93	96.08	0.73	97.60	99.30	95.82	0.73	97.27	98.63	95.50	0.70
(O=23)																
Si	7.872	7.945	7.811	0.035	7.972	8.000	7.921	0.020	7.973	8.000	7.911	0.022	7.972	8.000	7.918	0.019
Al (iv)	0.128	0.189	0.055	0.035	0.028	0.080	0.000	0.020	0.027	0.089	0.000	0.022	0.028	0.082	0.000	0.019
Al (vi)	0.036	0.080	0.001	0.023	0.042	0.076	0.001	0.022	0.055	0.097	0.002	0.020	0.069	0.126	0.013	0.025
Ti	0.006	0.011	0.000	0.003	0.002	0.010	0.000	0.003	0.002	0.010	0.000	0.003	0.001	0.008	0.000	0.002
Cr	0.002	0.008	0.000	0.002	0.001	0.007	0.000	0.002	0.001	0.008	0.000	0.002	0.001	0.009	0.000	0.002
Fe	0.035	0.060	0.024	0.009	0.037	0.061	0.021	0.009	0.009	0.020	0.000	0.004	0.016	0.025	0.004	0.005
Mn	0.014	0.034	0.002	0.010	0.008	0.021	0.001	0.005	0.004	0.050	0.000	0.007	0.006	0.015	0.000	0.004
Mg	4.905	4.989	4.827	0.046	5.001	5.134	4.871	0.053	5.037	5.133	4.916	0.044	5.054	5.154	4.973	0.043
Ca	1.920	1.959	1.861	0.025	1.890	1.976	1.753	0.046	1.861	1.959	1.772	0.037	1.815	1.914	1.622	0.054
Na	0.196	0.253	0.147	0.024	0.009	0.026	0.000	0.005	0.019	0.029	0.006	0.004	0.020	0.030	0.009	0.004
K	0.047	0.069	0.033	0.009	0.007	0.015	0.000	0.004	0.010	0.015	0.004	0.003	0.012	0.025	0.005	0.004
cation total	15.161	15.201	15.102	0.028	14.998	15.035	14.973	0.018	14.998	15.057	14.966	0.021	14.994	15.048	14.957	0.021
Mg/(Mg+Fe)	0.993	0.995	0.988	0.002	0.993	0.996	0.988	0.002	0.998	1.000	0.996	0.001	0.997	0.999	0.995	0.001
Al/(Al+Cr)	0.988	1.000	0.920	0.020	0.979	1.000	0.878	0.030	0.983	1.000	0.896	0.026	0.985	1.000	0.920	0.021

	Tk-1				**Tk-2**				**Sb-7**				**KN 2-2B**			
No. of analyses	41				40				39				52			
	avrg	max	min	sd	avrg	max	min	sd	avrg	max	min	sd	avrg	max	min	sd
SiO2	58.36	59.14	57.17	0.44	58.23	59.02	57.27	0.42	57.99	59.08	56.47	0.50	58.40	59.25	57.33	0.39
TiO2	0.02	0.10	0.00	0.03	0.02	0.09	0.00	0.02	0.02	0.08	0.00	0.02	0.02	0.08	0.00	0.02
Al2O3	0.65	0.88	0.42	0.11	0.61	0.84	0.35	0.12	0.21	0.49	0.08	0.09	0.46	0.60	0.39	0.04
Cr2O3	0.02	0.13	0.00	0.03	0.01	0.12	0.00	0.03	0.02	0.11	0.00	0.03	0.01	0.05	0.00	0.01
FeO	0.76	1.54	0.23	0.26	0.42	0.77	0.15	0.11	2.99	3.61	2.63	0.24	0.27	0.37	0.17	0.05
MnO	0.04	0.16	0.00	0.05	0.08	0.20	0.00	0.05	0.22	0.36	0.08	0.06	0.07	0.13	0.01	0.02
MgO	23.50	24.35	21.38	0.54	23.94	24.46	23.24	0.30	22.64	23.21	22.05	0.26	24.64	25.08	24.05	0.23
NiO	0.03	0.23	0.00	0.06	0.05	0.23	0.00	0.06	0.03	0.16	0.00	0.04	0.02	0.13	0.00	0.03
CaO	13.93	16.52	13.15	0.68	13.36	13.81	12.80	0.22	13.26	13.62	12.75	0.19	13.10	13.73	12.61	0.25
Na2O	0.08	0.15	0.00	0.04	0.06	0.12	0.00	0.03	0.02	0.09	0.00	0.02	0.00	0.03	0.00	0.01
K2O	0.06	0.13	0.01	0.03	0.07	0.19	0.01	0.04	0.03	0.11	0.00	0.02	0.03	0.10	0.00	0.02
P2O5													0.01	0.08	0.00	0.02
Total	97.46	98.44	96.28	0.51	96.85	98.15	96.02	0.59	97.44	99.55	94.72	0.82	97.03	98.15	95.33	0.65

(O=23)																
Si	7.958	7.998	7.900	0.026	7.967	7.998	7.899	0.024	7.983	8.000	7.947	0.012	7.961	7.999	7.929	0.017
Al (iv)	0.042	0.100	0.002	0.026	0.033	0.101	0.002	0.024	0.017	0.053	0.000	0.012	0.039	0.071	0.001	0.017
Al (vi)	0.063	0.119	0.006	0.027	0.065	0.121	0.018	0.028	0.016	0.045	0.000	0.010	0.035	0.071	0.009	0.017
Ti	0.002	0.011	0.000	0.003	0.002	0.009	0.000	0.002	0.002	0.008	0.000	0.002	0.002	0.008	0.000	0.002
Cr	0.002	0.014	0.000	0.003	0.002	0.013	0.000	0.003	0.002	0.012	0.000	0.003	0.001	0.006	0.000	0.002
Fe	0.087	0.177	0.026	0.029	0.048	0.089	0.017	0.013	0.344	0.408	0.300	0.027	0.030	0.043	0.019	0.005
Mn	0.005	0.018	0.000	0.006	0.009	0.023	0.000	0.006	0.026	0.041	0.009	0.007	0.008	0.015	0.001	0.003
Mg	4.774	4.942	4.371	0.104	4.878	4.977	4.763	0.052	4.643	4.725	4.596	0.033	5.003	5.087	4.895	0.040
Ni	0.004	0.025	0.000	0.007	0.005	0.025	0.000	0.007	0.003	0.018	0.000	0.005	0.002	0.014	0.000	0.003
Ca	2.035	2.428	1.912	0.101	1.958	2.035	1.887	0.031	1.955	2.008	1.887	0.025	1.912	1.990	1.841	0.031
Na	0.021	0.039	0.000	0.010	0.017	0.032	0.000	0.008	0.005	0.024	0.000	0.006	0.001	0.008	0.000	0.002
K	0.010	0.023	0.001	0.005	0.012	0.034	0.001	0.007	0.005	0.018	0.000	0.004	0.005	0.017	0.000	0.003
P	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.010	0.000	0.002
cation total	15.002	15.065	14.953	0.025	14.996	15.056	14.948	0.025	15.003	15.021	14.982	0.010	15.001	15.031	14.961	0.018
Mg/(Mg+Fe)	0.982	0.995	0.964	0.006	0.990	0.996	0.982	0.003	0.931	0.940	0.919	0.005	0.994	0.996	0.992	0.001
Al/(Al+Cr)	0.981	1.000	0.876	0.027	0.985	1.000	0.908	0.024	0.928	1.000	0.663	0.093	0.987	1.000	0.922	0.021

	KN 3				**KN 3-1**				**KN 2-2C**				**KN 2-2A**			
No. of analyses	28				73				42				54			
	avrg	max	min	sd	avrg	max	min	sd	avrg	max	min	sd	avrg	max	min	sd
SiO2	58.89	59.65	58.35	0.38	58.74	59.99	57.57	0.41	58.24	59.35	57.09	0.47	57.94	58.81	56.57	0.47
TiO2	0.02	0.08	0.00	0.03	0.02	0.08	0.00	0.02	0.02	0.07	0.00	0.02	0.02	0.10	0.00	0.02
Al2O3	0.45	0.53	0.36	0.04	0.65	1.57	0.51	0.12	0.51	0.59	0.42	0.04	0.94	1.38	0.68	0.14
Cr2O3	0.01	0.04	0.00	0.01	0.01	0.08	0.00	0.01	0.01	0.06	0.00	0.02	0.01	0.05	0.00	0.01
FeO	0.57	0.70	0.49	0.05	0.39	0.93	0.25	0.09	0.20	0.32	0.11	0.05	1.53	1.85	0.94	0.19
MnO	0.08	0.14	0.02	0.03	0.12	0.65	0.01	0.08	0.06	0.15	0.01	0.03	0.18	0.28	0.10	0.04
MgO	24.74	25.06	24.24	0.20	24.64	25.15	23.35	0.25	24.65	25.03	24.21	0.20	23.27	23.83	22.13	0.32
NiO	0.02	0.11	0.00	0.03	0.02	0.16	0.00	0.03	0.03	0.16	0.00	0.04	0.02	0.14	0.00	0.03
CaO	12.78	13.24	12.23	0.23	13.11	13.61	12.49	0.27	12.97	13.42	12.35	0.24	13.33	14.39	12.24	0.47
Na2O	0.00	0.02	0.00	0.01	0.01	0.04	0.00	0.01	0.01	0.03	0.00	0.01	0.01	0.05	0.00	0.01
K2O	0.04	0.07	0.01	0.02	0.05	0.10	0.01	0.02	0.03	0.06	0.00	0.01	0.05	0.10	0.01	0.02
P2O5	0.02	0.08	0.00	0.02	0.01	0.07	0.00	0.02	0.02	0.06	0.00	0.02	0.02	0.09	0.00	0.02
Total	97.63	98.83	96.63	0.57	97.78	99.44	96.27	0.59	96.74	98.43	94.95	0.69	97.31	98.41	95.67	0.63
(O=23)																
Si	7.977	7.999	7.956	0.015	7.951	7.996	7.888	0.023	7.957	7.992	7.923	0.021	7.930	7.992	7.824	0.036
Al (iv)	0.023	0.044	0.001	0.015	0.049	0.112	0.004	0.023	0.043	0.077	0.008	0.021	0.070	0.176	0.008	0.036
Al (vi)	0.049	0.077	0.017	0.017	0.054	0.138	0.004	0.024	0.039	0.076	0.005	0.022	0.082	0.153	0.027	0.031
Ti	0.002	0.008	0.000	0.003	0.002	0.008	0.000	0.002	0.002	0.007	0.000	0.002	0.002	0.011	0.000	0.002
Cr	0.001	0.005	0.000	0.001	0.001	0.009	0.000	0.001	0.001	0.006	0.000	0.002	0.001	0.005	0.000	0.001
Fe	0.064	0.079	0.055	0.005	0.045	0.105	0.028	0.010	0.023	0.036	0.013	0.005	0.175	0.212	0.107	0.022
Mn	0.009	0.016	0.002	0.004	0.014	0.074	0.001	0.010	0.007	0.017	0.001	0.004	0.021	0.032	0.012	0.005
Mg	4.993	5.030	4.907	0.026	4.968	5.052	4.700	0.051	5.017	5.076	4.927	0.039	4.743	4.830	4.557	0.054
Ni	0.002	0.012	0.000	0.003	0.003	0.017	0.000	0.004	0.003	0.017	0.000	0.004	0.003	0.015	0.000	0.003
Ca	1.855	1.928	1.789	0.034	1.900	1.980	1.812	0.036	1.898	1.945	1.829	0.029	1.954	2.098	1.791	0.070
Na	0.001	0.006	0.000	0.002	0.002	0.010	0.000	0.002	0.001	0.009	0.000	0.002	0.002	0.012	0.000	0.003
K	0.006	0.012	0.002	0.003	0.009	0.017	0.001	0.004	0.006	0.011	0.000	0.002	0.008	0.018	0.002	0.003
P	0.003	0.009	0.000	0.003	0.002	0.008	0.000	0.002	0.002	0.007	0.000	0.002	0.003	0.010	0.000	0.003
cation total	14.984	15.007	14.961	0.015	14.998	15.049	14.953	0.022	15.000	15.039	14.966	0.021	14.993	15.072	14.929	0.032
Mg/(Mg+Fe)	0.987	0.989	0.984	0.001	0.991	0.994	0.978	0.002	0.995	0.997	0.993	0.001	0.964	0.978	0.957	0.004
Al/(Al+Cr)	0.992	1.000	0.924	0.016	0.993	1.000	0.909	0.014	0.987	1.000	0.935	0.019	0.995	1.000	0.964	0.010

APPENDIX 5. Chemical compositions of the green nephirite ornament from the Philippines.

	62-2-12				62-2-31				P-122				Tad-1				Duy-1			
No. of analyses	92				60				41				49				34			
wt.%	avrg	max	min	sd	avrg	max	min	sd	avrg	max	min	sd	avrg	max	min	sd	avrg	max	min	sd
SiO2	57.81	58.77	54.66	0.60	57.92	59.23	55.69	0.64	58.02	58.83	55.51	0.61	57.91	59.28	56.05	0.58	58.20	59.30	53.77	1.07
TiO2	0.02	0.09	0.00	0.02	0.02	0.06	0.00	0.02	0.02	0.06	0.00	0.02	0.01	0.08	0.00	0.02	0.02	0.07	0.00	0.02
Al2O3	0.44	2.44	0.18	0.34	0.42	1.92	0.05	0.45	0.38	1.72	0.17	0.31	0.23	0.89	0.08	0.18	0.53	2.85	0.14	0.59
Cr2O3	0.21	0.53	0.01	0.11	0.18	0.42	0.03	0.08	0.13	0.30	0.03	0.06	0.11	0.29	0.00	0.07	0.22	0.55	0.09	0.11
FeO	4.84	6.47	4.15	0.52	3.85	4.94	2.65	0.45	3.97	5.03	3.19	0.38	3.84	4.54	2.80	0.35	3.82	4.34	3.25	0.26
MnO	0.12	0.20	0.04	0.04	0.08	0.15	0.02	0.03	0.08	0.14	0.02	0.03	0.07	0.17	0.00	0.04	0.09	0.17	0.04	0.03
MgO	21.34	22.18	20.66	0.45	22.26	23.02	21.09	0.45	22.09	22.59	21.16	0.36	22.17	22.79	21.56	0.27	22.38	23.46	21.65	0.38
NiO	0.19	0.40	0.02	0.07	0.14	0.32	0.00	0.07	0.16	0.27	0.01	0.07								
CaO	13.29	13.65	12.12	0.29	12.94	15.22	11.43	0.57	13.38	13.70	12.33	0.26	13.31	13.59	12.60	0.20	13.27	13.81	11.50	0.47
Na2O	0.01	0.08	0.00	0.01	0.02	0.06	0.00	0.02	0.00	0.02	0.00	0.01	0.01	0.04	0.00	0.01	0.01	0.03	0.00	0.01
K2O													0.00	0.02	0.00	0.01				
Total	98.28	99.53	97.42	0.59	97.84	99.58	96.24	0.73	98.24	99.42	96.73	0.65	97.66	99.55	96.30	0.68	98.53	99.60	96.30	0.81
(O=23)																				
Si	7.962	8.000	7.633	0.049	7.964	7.999	7.757	0.048	7.959	7.998	7.745	0.048	7.978	8.000	7.853	0.031	7.944	7.999	7.549	0.095
Al (iv)	0.038	0.367	0.003	0.049	0.036	0.243	0.001	0.048	0.041	0.255	0.002	0.048	0.022	0.147	0.000	0.031	0.056	0.451	0.002	0.095
Al (vi)	0.033	0.120	0.000	0.024	0.033	0.136	0.001	0.036	0.021	0.063	0.000	0.017	0.014	0.056	0.000	0.013	0.030	0.070	0.002	0.018
Ti	0.002	0.009	0.000	0.002	0.002	0.007	0.000	0.002	0.002	0.006	0.000	0.002	0.001	0.009	0.000	0.002	0.002	0.008	0.000	0.002
Cr	0.023	0.058	0.001	0.012	0.019	0.046	0.004	0.009	0.014	0.033	0.003	0.006	0.012	0.032	0.000	0.007	0.024	0.061	0.009	0.012
Fe	0.558	0.755	0.473	0.061	0.443	0.567	0.308	0.053	0.455	0.576	0.368	0.044	0.443	0.529	0.323	0.041	0.436	0.509	0.368	0.030
Mn	0.014	0.024	0.005	0.005	0.010	0.017	0.002	0.004	0.009	0.016	0.003	0.003	0.009	0.020	0.000	0.005	0.011	0.019	0.004	0.003
Mg	4.377	4.538	4.226	0.080	4.559	4.738	4.326	0.081	4.515	4.695	4.344	0.068	4.552	4.639	4.451	0.040	4.554	4.846	4.413	0.086
Ni	0.021	0.045	0.002	0.008	0.016	0.035	0.000	0.008	0.017	0.030	0.001	0.007								
Ca	1.960	2.010	1.813	0.039	1.905	2.252	1.691	0.082	1.965	2.016	1.843	0.033	1.964	2.006	1.876	0.027	1.941	2.007	1.730	0.060
Na	0.002	0.022	0.000	0.004	0.004	0.017	0.000	0.005	0.001	0.005	0.000	0.002	0.002	0.010	0.000	0.002	0.002	0.009	0.000	0.002
K	0.000	0.008	0.000	0.001	0.000	0.004	0.000	0.001					0.001	0.004	0.000	0.001				
cation total	14.991	15.142	14.963	0.026	14.992	15.071	14.948	0.021	15.001	15.097	14.965	0.024	14.997	15.061	14.974	0.016	15.000	15.183	14.957	0.044

Mg/(Mg+Fe)	0.887	0.911	0.854	0.012	0.911	0.938	0.884	0.010	0.908	0.926	0.884	0.009	0.911	0.935	0.896	0.008	0.913	0.925	0.904	0.006
Al/(Al+Cr)	0.746	0.956	0.639	0.069	0.702	0.935	0.441	0.131	0.794	0.928	0.665	0.067	0.735	1.000	0.516	0.124	0.724	0.932	0.480	0.100

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	U-1				**RF-4**				**M-3**				**M-2**				**NL3644**			
No. of analyses	6				57				73				79				64			
wt.%	avrg	max	min	sd	avrg	max	min	sd	avrg	max	min	sd	avrg	max	min	sd	avrg	max	min	sd
SiO2	57.29	57.63	56.92	0.25	57.48	58.44	56.30	0.52	57.44	58.72	56.42	0.47	57.64	58.72	56.65	0.46	58.02	59.07	56.25	0.54
TiO2	0.02	0.05	0.00	0.02	0.02	0.06	0.00	0.02	0.01	0.06	0.00	0.02	0.01	0.09	0.00	0.02	0.01	0.09	0.00	0.02
Al2O3	0.16	0.24	0.11	0.05	0.25	0.58	0.17	0.08	0.36	0.65	0.13	0.11	0.40	0.62	0.29	0.07	0.23	0.92	0.09	0.14
Cr2O3	0.08	0.21	0.01	0.08	0.10	0.37	0.02	0.06	0.25	0.52	0.11	0.08	0.16	0.31	0.05	0.05	0.07	0.39	0.00	0.06
FeO	3.91	4.33	3.63	0.24	4.63	6.09	3.91	0.46	4.57	6.20	3.48	0.57	4.31	4.84	3.92	0.22	3.68	4.20	3.24	0.20
MnO	0.15	0.20	0.10	0.04	0.12	0.18	0.04	0.03	0.12	0.22	0.01	0.04	0.10	0.20	0.01	0.04	0.11	0.22	0.01	0.04
MgO	21.77	22.15	21.37	0.28	21.39	22.05	19.65	0.39	21.29	22.34	20.20	0.48	21.52	22.06	20.65	0.26	22.27	22.77	21.72	0.25
CaO	13.20	13.40	12.94	0.15	13.24	13.62	12.89	0.19	13.19	13.59	12.59	0.21	13.29	13.66	12.88	0.19	13.37	13.74	12.72	0.20
Na2O	0.02	0.04	0.00	0.02	0.01	0.05	0.00	0.01	0.01	0.06	0.00	0.01	0.01	0.03	0.00	0.01	0.01	0.04	0.00	0.01
Total	96.60	97.18	96.14	0.42	97.24	98.97	96.12	0.78	97.24	98.78	96.00	0.67	97.45	98.93	96.13	0.74	97.81	99.27	96.17	0.77
(O=23)																				
Si	7.985	7.999	7.974	0.010	7.983	8.000	7.944	0.015	7.976	8.000	7.932	0.017	7.976	8.000	7.934	0.017	7.978	8.000	7.876	0.021
Al (iv)	0.015	0.027	0.002	0.010	0.017	0.056	0.000	0.015	0.024	0.068	0.000	0.017	0.024	0.066	0.000	0.017	0.022	0.124	0.000	0.021
Al (vi)	0.012	0.038	0.000	0.014	0.023	0.079	0.002	0.014	0.036	0.098	0.001	0.019	0.040	0.094	0.004	0.020	0.016	0.047	0.000	0.011
Ti	0.002	0.006	0.000	0.002	0.002	0.007	0.000	0.002	0.001	0.006	0.000	0.002	0.001	0.009	0.000	0.002	0.001	0.009	0.000	0.002
Cr	0.009	0.023	0.001	0.009	0.011	0.040	0.002	0.007	0.027	0.057	0.012	0.009	0.018	0.033	0.006	0.006	0.008	0.043	0.000	0.006
Fe	0.456	0.503	0.424	0.026	0.538	0.717	0.456	0.055	0.531	0.721	0.404	0.068	0.499	0.559	0.450	0.025	0.423	0.485	0.369	0.024
Mn	0.017	0.023	0.012	0.005	0.014	0.022	0.005	0.004	0.014	0.026	0.001	0.004	0.011	0.023	0.001	0.004	0.013	0.025	0.002	0.004
Mg	4.524	4.613	4.420	0.065	4.429	4.538	4.126	0.069	4.406	4.569	4.188	0.083	4.440	4.517	4.312	0.043	4.564	4.634	4.458	0.036
Ca	1.972	1.997	1.938	0.020	1.971	2.005	1.931	0.023	1.963	2.005	1.898	0.027	1.971	2.010	1.916	0.023	1.969	2.009	1.897	0.027
Na	0.006	0.010	0.000	0.004	0.002	0.013	0.000	0.003	0.003	0.017	0.000	0.004	0.002	0.009	0.000	0.003	0.002	0.011	0.000	0.003
cation total	14.998	15.012	14.976	0.012	14.991	15.019	14.967	0.013	14.981	15.020	14.940	0.016	14.983	15.018	14.945	0.018	14.999	15.044	14.973	0.012
Mg/(Mg+Fe)	0.908	0.916	0.898	0.006	0.892	0.909	0.852	0.011	0.892	0.919	0.853	0.014	0.899	0.909	0.886	0.005	0.915	0.926	0.902	0.005
Al/(Al+Cr)	0.784	0.931	0.566	0.136	0.789	0.932	0.580	0.074	0.686	0.789	0.524	0.054	0.788	0.893	0.677	0.048	0.826	1.000	0.562	0.097

APPENDIX 6. Chemical compositions of the white colored nephirite artifacts from Batangas, the Philippines.

	C-9				P-1				P-2				P-3			
No. of analyses	47				30				43				34			
wt.%	avrg	max	min	sd	avrg	max	min	sd	avrg	max	min	sd	avrg	max	min	sd
SiO2	58.42	59.20	57.82	0.31	58.54	59.59	57.94	0.49	58.69	59.76	57.63	0.54	58.82	60.01	58.08	0.39
TiO2	0.02	0.10	0.00	0.02	0.02	0.05	0.00	0.02	0.03	0.14	0.00	0.03	0.03	0.10	0.00	0.02
Al2O3	0.30	0.39	0.19	0.03	0.25	0.32	0.19	0.03	0.63	1.40	0.44	0.17	0.42	0.57	0.22	0.08
Cr2O3	0.01	0.07	0.00	0.02	0.00	0.05	0.00	0.01	0.01	0.04	0.00	0.01	0.01	0.07	0.00	0.02
FeO	0.74	1.06	0.50	0.13	0.43	0.67	0.25	0.09	1.70	1.97	1.29	0.14	0.98	1.16	0.64	0.11
MnO	0.10	0.17	0.02	0.03	0.18	0.32	0.11	0.05	0.44	0.93	0.25	0.13	0.16	0.30	0.08	0.05
MgO	24.12	24.68	23.73	0.18	24.56	25.32	24.00	0.32	23.39	24.27	22.77	0.29	24.06	24.36	23.55	0.20
NiO					0.02	0.06	0.00	0.03	0.02	0.11	0.00	0.03	0.02	0.10	0.00	0.03
CaO	13.29	13.59	12.91	0.15	13.01	13.66	12.00	0.41	12.54	12.94	11.42	0.29	12.91	13.33	12.58	0.21
Na2O	0.06	0.10	0.02	0.02	0.07	0.17	0.00	0.03	0.09	0.16	0.05	0.02	0.06	0.10	0.02	0.02
K2O					0.04	0.08	0.02	0.02	0.09	0.42	0.01	0.07	0.04	0.09	0.00	0.02
Total	97.06	98.08	96.25	0.41	97.07	98.46	96.06	0.80	97.63	98.91	95.98	0.64	97.50	99.18	96.55	0.58
(O=23)																
Si	7.980	8.000	7.956	0.012	7.977	7.999	7.962	0.011	7.965	7.999	7.913	0.024	7.976	7.997	7.934	0.017
Al (iv)	0.020	0.045	0.000	0.012	0.023	0.038	0.001	0.011	0.035	0.088	0.001	0.024	0.024	0.066	0.003	0.017
Al (vi)	0.029	0.053	0.004	0.013	0.018	0.040	0.001	0.012	0.065	0.140	0.000	0.029	0.043	0.079	0.009	0.019
Ti	0.002	0.010	0.000	0.002	0.002	0.005	0.000	0.002	0.004	0.014	0.000	0.003	0.003	0.010	0.000	0.003
Cr	0.001	0.007	0.000	0.002	0.000	0.005	0.000	0.001	0.001	0.004	0.000	0.001	0.001	0.008	0.000	0.002
Fe	0.085	0.121	0.057	0.015	0.049	0.075	0.029	0.010	0.193	0.224	0.145	0.016	0.111	0.131	0.072	0.012
Mn	0.011	0.020	0.002	0.004	0.020	0.037	0.012	0.006	0.051	0.106	0.029	0.014	0.019	0.035	0.009	0.005
Mg	4.911	5.003	4.844	0.033	4.988	5.128	4.882	0.060	4.731	4.876	4.615	0.054	4.863	4.954	4.789	0.042
Ni					0.002	0.007	0.000	0.003	0.002	0.012	0.000	0.003	0.002	0.011	0.000	0.003
Ca	1.946	1.984	1.893	0.022	1.899	2.000	1.761	0.056	1.824	1.897	1.649	0.046	1.876	1.937	1.831	0.029
Na	0.015	0.025	0.006	0.005	0.018	0.045	0.001	0.009	0.025	0.041	0.012	0.006	0.015	0.026	0.005	0.004
K					0.008	0.014	0.003	0.004	0.016	0.072	0.002	0.013	0.007	0.016	0.000	0.003
cation total	15.000	15.018	14.981	0.012	14.997	15.027	14.895	0.030	14.911	14.989	14.835	0.034	14.939	14.993	14.890	0.030
Mg/(Mg+Fe)	0.983	0.989	0.976	0.003	0.990	0.994	0.985	0.002	0.961	0.971	0.955	0.003	0.978	0.986	0.974	0.003
Al/(Al+Cr)	0.981	1.000	0.871	0.032	0.989	1.000	0.913	0.023	0.990	1.000	0.951	0.013	0.988	1.000	0.898	0.022

台灣閃玉之考古礦物學研究：兼論菲律賓群島出土玉器之溯源分析

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不論在台灣或是菲律賓群島，在新石器時代的考古遺址經常可以發現綠色閃玉製的器物。由於在自然界中閃玉的礦脈極為稀少，因此對於史前閃玉製器物的溯源就必須採用化學成份分析以為辨識不同的玉料來源。為了明確定義台灣所產的豐田閃玉之礦物特徵，本文使用了電子微探儀（electron probe micro analyzer，或簡稱EPMA）對台灣豐田的閃玉進行化學成份分析以和生產於東亞及太平洋等其他地區的軟玉進行區辨。在本文中總計分析了17件採自花蓮豐田的玉料，從而確定它們是由透閃石－陽起石所組成的角閃石礦物（鎂/[鎂+鐵] 的比值低於 0.93）、為纖維狀組織，而且其鉻鐵礦包裹體中含有具指標性意義的錳元素（含量可達 9 wt.%）以及鋅元素（含量可達 7 wt.%）。上述幾項礦物特徵都可做為區辨花蓮豐田玉料與他地玉料間的差異。

同時，本文也利用電子微探儀針對菲律賓群島所出土的白色玉器和綠色玉器進行分析，其中包括了9件出土於Palawan島Tabon Caves遺址群的綠色玉飾、1件出土於呂宋島北部Cagayan河谷Nagsabaran遺址的綠色玉環，以及4件採集自呂宋島南部Batangas地區的白色玉錛。本文的分析結果顯示，在菲律賓史前時代至少有兩類的玉料被廣泛的使用，其中可知綠色玉料多用於製造裝飾品，主要來自台灣東部的豐田玉礦，至於大量出土於Batangas地區的白色玉器，主要是錛和鑿這類的日常工具，很可能是來自呂宋島的某處未知礦源。因此，本文的研究結果讓我們對於史前族群在東南亞島嶼之間的互動往來有了更多、更確切的瞭解。

關鍵字：閃玉 (軟玉)，台灣，菲律賓，電子微探儀分析，新石器時代。