A Noninvasive Mineralogical Study of Nephrite Artifacts from the Philippines and Surroundings: The Distribution of Taiwan Nephrite and Implications for Island Southeast Asian Archaeology

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ABSTRACT Jade artifacts composed of nephrite are found in China, Taiwan, and some regions of Southeast Asia, commencing in Neolithic times. Nephrite deposits are rare in nature, and it is widely accepted that chemical analysis is required if nephrite artifacts are to be sourced to specific quarries. Most analytical methods, however, require object sampling to obtain the chemical compositions of materials. A low-vacuum scanning electron microscope with an energy-dispersive x-ray spectrometer is a powerful and completely noninvasive method of analysis. It requires no conventional sampling, apart from surface cleaning of the artifact. This system has been used for noninvasive mineral studies of nephrite ornaments (Sa Huynh type lingling-o earrings) from Iron Age sites in the Tabon Caves on Palawan Island in the Philippines and in Niah Cave in Sarawak, western Borneo, Malaysia. These ornaments were found to be composed of nephrite (tremolite-actinolite amphiboles) with zinc-bearing chromite inclusions. The mineralogical characteristics of these nephrite ornaments are comparable to those of native rock from the Fengtian nephrite deposit in eastern Taiwan. The results suggest that the original materials for these artifacts were collected in eastern Taiwan and offer important information about long-distance cultural interaction among ancient Austronesian societies, commencing around 2000 B.C.E. and continuing until after 500 C.E.

Introduction

Starting 8,000 years ago in China, nephrite was a symbolic material used for ornaments and ritual objects as well as tools such as axes, adzes, chisels, and spearheads (Huang 1975; Zhang 1995; Tang 1998). Commencing in the Neolithic period, nephrite artifacts, including ornaments and tools, became more abundant, especially in Taiwan (Chen 1998; Lien 1998, 2002; Liu 2003; Hung 2000, 2004) as well as in Southeast Asia around the South China Sea, including the Philippines, East Malaysia, and Vietnam (Kano 1946a; Beyer 1948; Fox 1970; Chin 1980; Sung 1989; Dizon 1998; Ha 1998; Nguyen 1998; Tang and Nguyen 2004; Hung et al. 2004; Hung and Iizuka 2004).

In prehistoric Taiwan, green nephrite was commonly used to make ornaments. Nephrite objects have been found in Taiwan, where they have been exchanged since the Middle Neolithic, both on the main island and on nearby satellite islands such as Penghu, Ludao (Green Island), and Lanyu (Orchid Island, formerly known as Botel Tobago). In Taiwan, at least 108 sites so far have been found associated with nephrite artifacts. Most of these jade artifacts occur in contexts dated between 2500 B.C.E. and 1 C.E. (Hung 2005).1

Geological sources of nephrite in Taiwan were not identified until the last three decades, when archaeologists and geologists began to conduct investigations. Some green nephrite ornaments from Beinan2 on the southeast coast of Taiwan have been analyzed by petrographic microscopy and chemical methods (Wang Lee et al. 1996; Tan et al. 1997; Lien 2002). The results indicate that the Fengtian nephrite source near Hualien in eastern Taiwan was the most probable source for the nephrite used for ornaments found at Beinan. Analyses of more than thirty nephrite artifacts from prehistoric sites throughout Taiwan have been carried out by x-ray diffraction (Hung 2000), oxygen isotope analysis (Yui et al. 2001), Raman spectroscopy (Huang and Chou 2001), and electron probe microanalysis (EPMA) (Iizuka and Hung 2005; Hung et al. 2006). The artifacts and the Fengtian nephrite source material exhibit the same chemical composition and mineral inclusions. It is now the general consensus that the Fengtian area was a major source for the ancient nephrite artifacts found in Taiwan.

In the Philippines, green nephrite ornaments have recently been recognized as being extremely similar in their technology of manufacture, style, and texture to those discovered in Taiwan. These green nephrite objects have been discovered from Palawan Island, Cagayan, and Batangas provinces on Luzon, and on Itbayat Island (Batanex) (Hung et al. 2004;...
Hung and Iizuka 2004; Bellwood and Dizon 2005; Hung 2005). On Palawan, during the 1960s and 1970s a number of green nephrite ornaments such as earrings, bracelets, and beads were found in Leta-Leta Cave near El Nido and in some of the Tabon Caves (Fox 1970, 1977a, 1977b; Peralta 1977). On Luzon, a fragment of a green nephrite bracelet was excavated from the early Neolithic red-slipped pottery layer at Nagsabaran, near Lal-lo in Cagayan province, northern Luzon (Tsang et al. 2002). A small bell-shaped green nephrite bead was also found at Kay Daing in Batangas province, southwestern Luzon (Hung et al. 2004).

A type of jade penannular earring with three-pointed circumferential projections is the most celebrated form of green nephrite ornament in the Island Southeast Asian Iron Age (fig. 1). This type of ear ornament was initially reported from the Sa Huynh (ca. 500 B.C.E.–500 C.E.) jar burial site in south-central Vietnam by Henri Parmentier (1924). In the Philippines, several earrings of this type were recovered from the Tabon Caves on Palawan, and these were referred to as the Sa Huynh type lingling-o earrings (Fox 1970). The term lingling-o means “earring” in the Ifugao language of northern Luzon. These Sa Huynh type lingling-o earrings are also reported from elsewhere in the South China Sea region, the West Mouth of the Niah Cave in Sarawak, West Malaysia, and now many sites in central and southern Vietnam (Chin 1980; Fontaine 1983; Aoyagi 1987; Yokokura 1987) (fig. 2). As shown in figure 1, all are similar in style, manufacturing technology, and size, being about 3 cm in ring diameter. Recently, drilled cores, possibly remains from the central holes of Sa Huynh type lingling-o earrings, have been excavated from contexts dated to about 500 C.E. in the site of Anaro on Itbayat, Batanes Islands, halfway between Taiwan and Luzon (see figs. 1 f and g) (Bellwood and Dizon 2005).
No local nephrite sources have been found to date for jade artifacts unearthed in the Philippines (Beyer 1948; Fox 1970), so more distant sources of nephrite may have been used. Tracing the sources of these nephrite artifacts and identifying the quarries and workshops in which they were made will allow us to reconstruct trade networks as well as cultural relations and interactions among various societies. Chemical analysis can often determine specific geological sources or quarries, as nephrite deposits are not numerous (Wen and Jing 1992, 1996; Douglas 1996, 2003; Yui et al. 2001).

In any sourcing study of nephrite artifacts, it is important to compare their chemical signatures with those of raw material samples, but without causing damage to the artifacts. For precious nephrite artifacts, some nondestructive analytical methods have been applied, such as Raman spectroscopy (Xu et al. 1996; Lien et al. 1996), x-ray fluorescence spectroscopy (XRF) (Douglas 1996, 2003), and a combination of proton induced x-ray emission (PIXE) and micro-Raman spectroscopy (Chen et al. 2004). Unfortunately, many of these methods are not useful in the unambiguous identification of specific quarries because of overlaps in the mineralogy and whole rock chemistry of different nephrite sources.

EPMA has the advantage of being noninvasive, and it is possible to analyze micrometer-sized areas to obtain the chemical composition of both the nephrite matrix and the associated accessory minerals. Elemental analyses obtained by EPMA sourcing have been compiled in a mineralogical database for several nephrite deposits, including Fengtian (Taiwan) nephrite (Iizuka and Hung 2005).

The newly developed low-vacuum type scanning electron microscope (LVSEM) equipped with an energy-dispersive x-ray spectrometer (EDX) is a completely noninvasive technique. Quantitative analysis of elements that occur at more than 1% by weight can easily be undertaken using this method (Iizuka et al. 2005), and it is an effective method for analyzing jade artifacts without causing damage. Using this new method, the mineralogical characteristics of five selected nephrite lingling-o earrings from Tabon and Niah were studied.

The Term Nephrite and Its Geological Meaning

The term “jade” is typically applied to two different fine-grained, massive rock materials composed called nephrite and jadeite (sometimes soft jade and hard jade, respectively). Nephrite owes its compactness to its tough, interwoven fibrous texture. It is composed of more than 90% by volume of tremolite-actinolite, Ca_{	ext{MgFe}}[(SiO_3)_2](OH), with some mineral inclusions (Beck 1970; Wen and Jing 1996). Tremolite is the magnesium end-member of calcium amphibole and is usually white to gray in color. Ferrous iron (Fe^{2+}), which is substituted in the magnesium site, is often present in small amounts. With the addition of Fe^{2+}, tremolite gradually becomes green in color. With higher amounts of iron, it becomes actinolite, the iron-rich end-member of the calcium amphiboles. In most cases, ferric iron (Fe^{3+}) is rare in nephrite (Tan et al. 1978). Tremolite and actinolite can be differentiated by the atomic ratio of Mg/(Mg+Fe) or Mg#, where tremolite is greater than 0.9 in Mg#, and actinolite is smaller than 0.9 in Mg# (Leake et al. 1997).

Formation of nephrite (tremolite and actinolite) usually occurs when the host rocks, prior to metamorphism, were either magnesium-rich carbonate rocks such as limestone, marble, or serpentinite (Wen and Jing 1992; Tsien et al. 1996; Harlow and Sorensen 2005). Tremolite is typically derived from magnesium-containing carbonates such as dolomite, CaMg(CO_3)_2, with no or little iron. Actinolite is typically associated with serpentine, a rock composed primarily of serpentine, (Mg,Fe)_2[Si_2O_5](OH)_4, that occurs as an alteration product of mantle peridotite (usually Mg# is 0.9). A number of accessory minerals have been reported within nephrites (Tan et al. 1978; Wen and Jing 1996). Chemical composition of the accessory minerals is important for understanding the origin of nephrite deposits and should be studied separately from the nephrite matrix (Iizuka and Hung 2005).

In the study of prehistory, the term “jade” usually refers to nephrite, and most “jade” artifacts in Southeast Asia during this period were made of nephrite. Jadeite, which is a rock composed primarily of the mineral jadeite, a sodium clinopyroxene, NaAl(Si_2O_6), occurs rarely in nature and has not been reported to have been used in prehistoric times of Southeast Asia.

Mineralogy of Fengtian Nephrite (Taiwan Jade)

A major nephrite deposit is located west of the town of Fengtian, in Hualien county in eastern Taiwan (Tan et al. 1978). Fengtian nephrite, characteristically green in color, occurs mainly in association with serpentinite layers intercalated in black schist or muscovite-quartz schist of the greenschist facies. After this nephrite deposit was rediscovered in the nineteenth century, research has shown that Fengtian was the most likely source for prehistoric nephrite artifacts in Taiwan (Tan et al. 1997; Lien et al. 1996; Wang Lee et al. 1996; Huang and Chou 2001; Yui et al. 2001; Lien 2002).

Iizuka and Hung (2005) report a comparative study of green-colored nephrite deposits, including Fengtian and others from East Asia and the circum-Pacific region. These include Xiuyan in Liaoning province, Jiucken and Nanshan in Gansu province, and Qiemo in Xinjiang province in China; Gifu prefecture in Japan; Onot River; Chara Jelgra River in Yakut in Siberia; Cowell in South Australia; Ouen Island in New Caledonia, Australia; southern New Zealand; and British Columbia in Canada. With the aid of chemical analysis of seventeen specimens of nephrite and its associated accessory minerals (eight samples are from in situ deposits and nine are riverbed pebbles from the minefields: total 675 analyses, and 267 analyses of nephrite matrix and chromite, respectively), they conclude that Fengtian (Taiwan) nephrite can be discriminated from the others on the following criteria.
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1. The Fengtian nephrites are mostly green in color (but occasionally vary from white to gray), with a fibrous texture.

2. The Fengtian nephrites are tremolite-actinolite. Although the Mg# (Mg/[Mg+Fe] ratio) is fairly wide, Mg# is under 0.93 in any color (the median is 0.9). Most tremolitic or white-colored nephrites (most of Chinese nephrites) have a Mg# >0.96 and therefore do not meet this criterion.

3. Black chromite (FeCr\(_2\)O\(_4\)) is the most common accessory mineral in the Fengtian nephrite. The light green garnet, uvarovitic-grossular Ca\(_3\)(Cr,Al)\(_2\)Si\(_3\)O\(_{12}\), chlorite (Mg,Al,Fe)\(_{12}\)[(Si,Al)\(_8\)O\(_{20}\)](OH)\(_{16}\), and serpentine (Mg\(_{0.9}\),Fe\(_{0.1}\))\(_3\)[Si\(_2\)O\(_5\)](OH)\(_4\) are observed occasionally. Nephrites that do not originate from serpentinite usually do not meet this criterion. So far, nephrites from the Fengtian (Taiwan), New Zealand, Gansu in China, and British Columbia do meet this criterion.

4. The chromite bears significant amounts of zinc (up to 7 wt.%) and manganese (up to 9 wt.%). Nephrites that contain less (< 1 wt.%) in chromite inclusions do not meet this criterion and include those from New Zealand, Gansu in China, and British Columbia.

Noninvasive Analysis of the Sa Huynh Type Lingling-o Earrings by LVSEM-EDX

Analytical Procedure

Five Sa Huynh type lingling-o earrings were studied (see figs. 1 a–e). Before SEM observation, the earrings were cleaned with distilled water for several hours in an ultrasonic bath to remove dust and soil from their surfaces. Each object was then rinsed in ethanol and dried in an oven overnight at 75°C.

A JEOL JSM-6360LV SEM equipped with an EDX (Oxford Instruments, INCA-300) was used with an acceleration voltage of 15 kV and beam current of 0.18 nA under low-vacuum conditions (25 Pascal). The analyzed points were selected on relatively flat and well-polished surfaces of each earring. Minerals were identified based on comparisons of the x-ray spectra with those of chemically known minerals (Iizuka et al. 2005). Chemical composition of elements present in amounts greater than 1% by weight in both the nephrite matrix and mineral inclusions were analyzed with a 1 μm electron beam spot for 100 seconds. The quantitative data were corrected as oxide compositions, using the x-ray intensities of synthetic minerals as standards, as follows: wollastonite for silicon and calcium, corundum for aluminum, fayalite for iron, pyrope for magnesium, chromium oxide for chromium, and zinc oxide for zinc. The number of cations was calculated into the atoms per formula unit (apfu) on the basis of 23 oxygen, and minerals were classified according to the nomenclature of amphiboles (Leake et al. 1997). The corrected data in the cation ratios are based on the ideal chemical formula of calcium amphibole, Ca\(_2\)(Mg,Fe)\(_{12}\)Si\(_8\)O\(_{22}\)(OH)\(_{2}\). All iron is calculated as ferrous iron (Fe\(^{2+}\)) because ferric iron (Fe\(^{3+}\)) is rare in nephrite (Tan et al. 1978).

Analytical Results

Most surfaces on the earrings were worked by ancient craftsmen and are therefore well polished and suitable for analysis. The fibrous textures observed on the surface of all earrings indicate that they have a typical fine-grained nephrite matrix (fig. 3). The quantitative compositional data of the nephrite matrix for each earring are shown in table 1, and the results are shown in a discrimination diagram of calcium amphiboles (fig. 4). Based on chemical composition, the matrix of all earrings can be termed tremolite and actinolite. Their chemical variations are comparable to that of the sample of Fengtian nephrite (Mg/[Mg+Fe]=0.93-0.85), which is shown as an enclosed area in figure 4. Based on their chemistry and the surface texture, they can be termed nephrite.

Opaque minerals exposed on the surface of all earrings can be identified as chromite (fig. 5). The sizes of these inclusions vary from less than a few μm to 3 mm. A repre-
Table 1. Chemical composition of studied lingling-o earrings.

<table>
<thead>
<tr>
<th></th>
<th>NC-J6 (n = 14)</th>
<th>PBP-203 (n = 6)</th>
<th>P-122 (n = 5)</th>
<th>62-2-61 (n = 9)</th>
<th>62-2-31 (n = 8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>58.13 av. 59.32 max 56.51 min</td>
<td>57.78 av. 58.74 max 57.27 min</td>
<td>57.71 av. 58.93 max 56.52 min</td>
<td>57.68 av. 58.84 max 56.41 min</td>
<td>57.94 av. 59.14 max 56.42 min</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>0.82 av. 1.75 max 0.30 min</td>
<td>0.31 av. 0.56 max 0.03 min</td>
<td>0.47 av. 0.71 max 0.31 min</td>
<td>0.64 av. 0.86 max 0.41 min</td>
<td>0.37 av. 0.58 max 0.19 min</td>
</tr>
<tr>
<td>FeO</td>
<td>3.82 av. 4.45 max 3.09 min</td>
<td>3.35 av. 3.86 max 2.89 min</td>
<td>4.65 av. 5.08 max 3.88 min</td>
<td>4.54 av. 5.06 max 3.80 min</td>
<td>4.56 av. 5.17 max 4.28 min</td>
</tr>
<tr>
<td>MgO</td>
<td>22.21 av. 23.44 max 21.21 min</td>
<td>22.13 av. 22.84 max 21.91 min</td>
<td>21.59 av. 22.38 max 20.88 min</td>
<td>21.47 av. 23.18 max 20.27 min</td>
<td>21.59 av. 22.88 max 20.52 min</td>
</tr>
<tr>
<td>CaO</td>
<td>13.20 av. 14.07 max 12.29 min</td>
<td>13.77 av. 14.31 max 13.36 min</td>
<td>13.22 av. 13.48 max 12.83 min</td>
<td>13.29 av. 13.90 max 12.61 min</td>
<td>13.68 av. 15.07 max 12.71 min</td>
</tr>
<tr>
<td>Total</td>
<td>98.19 av. 99.98 max 95.58 min</td>
<td>97.34 av. 98.55 max 96.22 min</td>
<td>97.64 av. 99.76 max 96.41 min</td>
<td>97.62 av. 99.52 max 95.40 min</td>
<td>98.13 av. 99.88 max 95.83 min</td>
</tr>
<tr>
<td>(O = 23)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Si</td>
<td>7.952 av. 7.995 max 7.894 min</td>
<td>7.976 av. 7.994 max 7.954 min</td>
<td>7.974 av. 7.995 max 7.945 min</td>
<td>7.968 av. 7.990 max 7.912 min</td>
<td>7.973 av. 7.993 max 7.940 min</td>
</tr>
<tr>
<td>Al (iv)</td>
<td>0.048 av. 0.106 max 0.005 min</td>
<td>0.024 av. 0.046 max 0.006 min</td>
<td>0.026 av. 0.055 max 0.005 min</td>
<td>0.032 av. 0.088 max 0.010 min</td>
<td>0.027 av. 0.060 max 0.007 min</td>
</tr>
<tr>
<td>Al (vi)</td>
<td>0.085 av. 0.208 max 0.013 min</td>
<td>0.026 av. 0.048 max 0.009 min</td>
<td>0.050 av. 0.100 max 0.019 min</td>
<td>0.072 av. 0.113 max 0.022 min</td>
<td>0.033 av. 0.070 max 0.002 min</td>
</tr>
<tr>
<td>Fe²⁺</td>
<td>0.437 av. 0.509 max 0.351 min</td>
<td>0.387 av. 0.447 max 0.331 min</td>
<td>0.537 av. 0.597 max 0.446 min</td>
<td>0.525 av. 0.579 max 0.429 min</td>
<td>0.525 av. 0.611 max 0.485 min</td>
</tr>
<tr>
<td>Mg</td>
<td>4.525 av. 4.710 max 4.386 min</td>
<td>4.550 av. 4.631 max 4.516 min</td>
<td>4.443 av. 4.523 max 4.361 min</td>
<td>4.416 av. 4.660 max 4.276 min</td>
<td>4.424 av. 4.635 max 4.306 min</td>
</tr>
<tr>
<td>Ca</td>
<td>1.935 av. 2.058 max 1.775 min</td>
<td>2.036 av. 2.102 max 1.997 min</td>
<td>1.957 av. 2.029 max 1.889 min</td>
<td>1.967 av. 2.064 max 1.856 min</td>
<td>2.016 av. 2.210 max 1.863 min</td>
</tr>
<tr>
<td>cation total</td>
<td>14.981 av. 15.026 max 14.936 min</td>
<td>14.999 av. 15.014 max 14.984 min</td>
<td>14.988 av. 15.018 max 14.958 min</td>
<td>14.980 av. 15.019 max 14.955 min</td>
<td>14.997 av. 15.026 max 14.974 min</td>
</tr>
<tr>
<td>Mg/[Fe=Mg]</td>
<td>0.912 av. 0.929 max 0.896 min</td>
<td>0.922 av. 0.932 max 0.910 min</td>
<td>0.892 av. 0.910 max 0.880 min</td>
<td>0.894 av. 0.916 max 0.882 min</td>
<td>0.894 av. 0.905 max 0.876 min</td>
</tr>
<tr>
<td>ZnO, wt%</td>
<td>0.4 av. 2.9 max 3.4 min</td>
<td>3.4 av. 5.3 max 5.3 min</td>
<td>5.3 av. 5.3 max 5.3 min</td>
<td>5.3 av. 5.3 max 5.3 min</td>
<td>5.3 av. 5.3 max 5.3 min</td>
</tr>
</tbody>
</table>

n = numbers of analyses points on LVSEM-EDS

* maximum value of ZnO from zinc chromite.

Discussion

In terms of style and context, the archaeological nephrite ornaments in the Philippines belong to two phases: Neolithic and Early Iron Age. Most of the ornaments from Neolithic contexts are similar in style with contemporaneous ornaments in the Taiwan Middle and Late Neolithic. An example is the Neolithic nephrite bracelets without surface decoration that occur at Nagsabaran in the Cagayan valley and in Duyong Cave in the Tabon Caves Complex on Palawan (Iizuka and Hung 2005, figs. 8 a and j). Both bracelets have dimensions (diameter, thickness, and width) similar to those of the lingling-o earrings from Fengtian in eastern Taiwan.
of a large number of bracelets from contemporaneous sites in Taiwan, indicating a close relationship in style and manufacturing technology (Hung et al. 2004). Moreover, the nephrite bell-shaped beads (Hung et al. 2004) and tube beads from both the Philippines and Taiwan are almost identical in dimension and material (Hung 2005). During the Early Iron Age in the Philippines, green nephrite lingling-o earrings and bracelets with surface decoration also show many similarities with similar objects from Ludao and Lanyu Island, southeast of the island of Taiwan (Hung 2005). The results of this study suggest that four Sa Huynh type lingling-o earrings from Tabon and the one from Niah were made of nephrite that is similar in mineralogy with the Fengtian nephrite. All have zinc-chromite inclusions, which occur only in the Fengtian nephrite source and in no other source (at least among known nephrite deposits in East Asia and Southeast Asia) (Iizuka and Hung 2005). Although an ornament similar in shape to the lingling-o earrings, but without typical three pointed projections, has been reported from Lanyu Island (Kano 1946c). No lingling-o earring has ever been found in Taiwan proper. However, the discovery of two drilled-out cores from the central perforations in lingling-o earrings from the Anaro site on Itbayat Island is very significant. These drilled-out cores suggest that lingling-o earrings, also consistent with the Taiwan nephrite source, were likely made at this site from Fengtian nephrite during the first millennium C.E. (Bellwood and Dizon 2005; Iizuka et al. 2005).

Several nephrite ornaments and other worked fragments have also been unearthed since the 1940s from both Ludao and Lanyu, southeast of the island of Taiwan (Kano 1946a, 1946c) and north of Batanes (Kōmoto 1983; Bellwood and Dizon 2005). Fourteen waste pieces of nephrite, including nine drilled-out cores from annular objects, were collected from the site of Lanyu High School between 1978 and 1982 (Shu 2003). Several of these have also been identified as Fengtian nephrite by LVSEM-EDX (Hung et al. 2006). From the associated pottery, these nephrite materials belong to the Early Iron Age, like those from the Anaro site on Itbayat (Shu 2003). Fragments of worked nephrite are very common on the surface of the Pinglin site in eastern Taiwan (Kano 1946b) as well as at the Qubing site in central Taiwan (Chen 1998) and the Beinan site in southeast Taiwan (Lien 1998). All of these sites are thought to be prehistoric nephrite workshops. Several knives and points also found at Anaro are composed of slate, which is thought to originate in Taiwan because slate is common in the Central Mountain Range in Taiwan and absent in the volcanic islands such as Batanes, Babuyan, and Luzon in the northern Philippines. These knives and points were probably used to work nephrite, as sometimes appears to have been the case in the Taiwan workshops (Bellwood and Dixon 2005). As shown in figure 7, the working techniques applied to Fengtian nephrite on Itbayat and Lanyu were identical.

According to similarities on Lanyu and Itbayat, including pottery decoration, nephrite ornaments, and jar burial practices (de Beauclair 1972; Dizon 1996; Bellwood and Dixon 2005; Hung 2005), the Early Iron Age inhabitants of these islands probably possessed closely related cultures and created similar new styles of ornamentation, such as the lingling-o earrings, that spread into the Philippines, Borneo, and perhaps to the Austronesian-speaking regions of central and southern Vietnam.

Conclusions

Noninvasive chemical analysis was performed on five Sa Huynh type lingling-o earrings, using LVSEM with an EDX. The ornaments, all lingling-o earrings from Palawan and Borneo, were found to be composed of nephrite (tremolite-actinolite) with zinc-bearing chromite as an accessory mineral. The mineralogical characteristics of these nephrite earrings are comparable to the Fengtian (Taiwan) nephrite and suggest that the original raw materials were collected in the Fengtian area in eastern Taiwan.

So far, nephrite sourcing studies show that Taiwan nephrite was widely distributed in the Philippines and Borneo. The distance between the Fengtian source in Taiwan and Niah on Borneo is more than 2,000 km by sea. Lanyu Island is 90 km from Taiwan, Batanes 150 km, the Cagayan valley 500 km, Batangas 1,000 km, and Palawan 1,500 km. In addition to the trade in nephrite, cultural interaction between eastern Taiwan and northern Luzon commencing in the Neolithic period is suggested by similarities in pottery (Hung 2005). The results of this study also suggest that cultural interactions by sea from Taiwan to the south, against the normal south-to-north flow of the Kuroshio Current (also called the Japan Current) across the Bashi Channel, were already occurring between Taiwan and the Philippines about 3,500 years ago. In the future, more detailed research on this topic is needed and should include analysis of additional jade ornaments from Taiwan, the Philippines, and Vietnam.

![Figure 7. Waste pieces of the Fengtian nephrites, identified by LVSEM-EDX. a. LY-12 from Lanyu High School site on Lanyu Island. b. Q-69. c. I-2901 from Anaro site on Itbayat Island. d. 05D-01 from Pinglin site in eastern Taiwan, near the Fengtian source area.](image-url)
Acknowledgments

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Notes

1. Chronology in Eastern Taiwan: Early Neolithic; 3500–2500 B.C.E.; Middle Neolithic, 2500–1500 B.C.E.; Late Neolithic, 1500 B.C.E.–1 C.E., after which the Iron Age began. In northern Luzon, Neolithic started around 2000 B.C.E. and closed around 1 C.E.; after 1 C.E. the Iron Age began (Hung 2005).

2. This article uses the standard Mandarin pinyin spelling instead of the Taiwanese method. Localities such as Beinan, Fengtien, and Qubing in Taiwan have been spelled as Peinan, Fengtien, and Chiping, respectively, in the previous reports.

3. In East Asia, jadeitite was used in the Late Paleolithic, also known as the Jōmon period (10,500–400 B.C.E.), in Japan (Kawasaki 2004; Suzuki 2004), but was not used until the Qing dynasty (1644–1912) in China (Valdes 2004).

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