A COMPOSITIONAL STUDY OF A SELECTION OF SONG DYNASTY CHINESE CERAMICS FROM THE *JAVA SEA SHIPWRECK*: RESULTS FROM LA-ICP-MS ANALYSIS

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ABSTRACT

This paper presents the findings of compositional analysis using a number of Chinese ceramics of different styles from the twelfth-thirteenth-century Java Sea Shipwreck. Specifically discussed are the results of laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS) analysis conducted at The Field Museum of Natural History in Chicago on a selection of high-fired ceramics from the shipwreck, including qingbai (light whitish-blue glazed), green-glazed, and painted wares. This project was undertaken in order to assess correlations between style and material and to begin to identify potential kiln sites where the pieces were manufactured. By doing so, we can better understand the organization, intensity, and scale of ceramic production in China at the time and how these commodities linked Chinese producers to consumers throughout East and Southeast Asia and the Indian Ocean World.

INTRODUCTION

Based on archaeological research and historical records (e.g., Dreyer 2007; Dunn 1989; Rockhill 1913, 1914, 1915a, b; Zhao 2012 [1911]), it is clear that, during the early to mid-second millennium AD, East and Southeast Asia were part of large, complex maritime trading systems, which included societies living in the South China Sea region as well as the coastal areas along the Indian Ocean and parts of the Middle East. Through these trade networks, China's elite acquired exotic items such as spices, beeswax, aromatic resin, ivory, rhinoceros horn, tortoise shell, coral, pearls, crystal, birds' nests, tropical hardwoods, cotton, and marine delicacies as prestige items. The Southeast Asian political elite procured gold, lead, tin, iron, copper cash, silk, beads, and high-fired ceramics from China, India, the Middle East, and East Africa (Hall 1985, 1999, 2011; Kauz 2010; Miksic, et al. 1994; Reid 1988a, b; Scott 1989; Wade 2009; Wheatley 1959; Wu 1959). During this time, China's ceramic export industry flourished, and high-fired Chinese stoneware and porcelain from this period have been found as far away as South and Southwest Asia and East Africa (Chaudhuri 1985; Hall and Whitmore 1976; Kauz 2010; Kusimba 1999; Oka, et al. 2009).

In order to promote trade and ensure a stable flow of exotic goods, China's Northern Song dynasty (AD 960–1126) instituted a tributary system through which foreign leaders and merchants could gain favored trade status and engage in regular exchange with China (Junker 1999, 2004; Wu 1959). This system thrived for a time; however, trade between China and Southeast Asia became so vigorous that China's own supply of copper cash was depleted (Flecker 2003; Guy 1986). To address this growing deficit, merchants were encouraged to trade ceramics and silk instead, and they found ready markets especially in Southeast Asia and the Middle East.

During the Southern Song dynasty (AD 1126–1279), the Chinese court was forced to relocate south to Hangzhou in Zhejiang province to evade attacks from northern invaders. Consequently, China lost much of its access to the overland routes to the west, and maritime trade ports became increasingly important (Deng 1997; So 2000). During this period, Quanzhou, which was close to Hangzhou, replaced Guangzhou as China's largest port (Figure 1). Also during this period, for the first time ever, private traders from China were allowed and encouraged to engage directly in overseas trade. As a result of this free trade, the tribute system waned and Southeast Asian ports flourished and continued to do so into the Yuan dynasty (AD 1271–1368). Traditionally, scholars have relied largely on historical records and finds from terrestrial archaeological sites to shed light on this history; however, more recently, shipwrecks and other maritime sites have proven to be critical for a more nuanced understanding of trade relationships and commodity production in East and Southeast Asia and the Indian Ocean World (e.g., Descantes, et al. 2002; Dizon 2011; Flecker 2001; Krahl, et al. 2010; Li 2009; Manguin 1993, 2004; Miksic 2011; Miksic and Yap 1992).

THE JAVA SEA SHIPWRECK

In 1998, the Field Museum of Natural History in Chicago received a donation of more than 7,500 artifacts that had lain 27 meters below the water in the Java Sea for almost eight centuries. Now known as the *Java Sea Shipwreck*

Figure 1: Map of China showing the port of Quanzhou and the kiln sites of Dehua and Jingdezhen

(JSW), this twelfth-thirteenth-century vessel was discovered by fishermen in Indonesian waters between Sumatra and Java in the late 1980s (Flecker 2005-2006) (Figure 2). In 1996, Pacific Sea Resources, a U.S.-based salvage company, worked with Indonesian partners to systematically and legally recover the wreck. Half of the collected material was given to the Indonesian government; the other half was donated to The Field Museum. Some research was undertaken soon after the site was excavated (Bronson 1997; Brown 1997b; Flecker 2003, 2005-2006; Mathers and Flecker 1997); more in-depth analysis began on the wreck material at the Museum in 2012.

The ship, which was likely built in Indonesia, carried an international cargo, including more than 200 tons of iron and 30 tons of ceramics and may have been bound for central Java (Flecker 2005-2006; Mathers and Flecker 1997). Most of the iron would have been in the form of trapezoidal ingots and was likely from China (Bronson 1997), but there are also cauldrons, a small axe head, and scale weights and bars. The majority of ceramics are high-fired pieces from China, discussed in more detail below. The collection also includes fine earthenware kendis thought to have been manufactured in Thailand and storage vessels that would have been used to transport organic products, small pieces of pottery, and provisions for the crew (Flecker 2003, 2005-2006; Krahl 2010).

Other items were found onboard in smaller quantities (Mathers and Flecker 1997). These include ivory, aromatic resin, several pieces of glass, and used sharpening stones and scale sets that were likely possessions of the crew and merchants. Tin ingots and portions of copper alloy trays and gongs (likely Chinese), conical and bar ingots of copper, as well as hook-shaped metal pieces also were found. More unique finds made of metal include a stooped, cross-legged figure that was a support for a small table or altar and a figure of a woman riding a mythical sea creature (Flecker 2005-2006; Miksic 1997). Two finials also were recovered, similar to those found in Java that would have been mounted atop wooden staffs carried by mendicants (Singapore National Heritage Board and National Museum (Singapore) 1995:142–143).

Evidence of the mass production of ceramics abounds in China in the form of massive kiln complexes such as those found at Jingdezhen, Changsha, and Foshan (Ho 1994b; Hughes-Stanton and Kerr 2000; Mino 1992; Mino and Wilson 1973; Phillips 1956; Scott 1993; Wood 2011; Ye 1994). Terrestrial archaeological sites throughout Southeast Asia bear witness to frequent trade with China and, in the Philippines, for instance, large quantities of Chinese trade ceramics, and later Vietnamese and Thai pottery, are the result of large-scale foreign trade (Fox and Legaspi 1977; Junker 1999; Nishimura 1992;

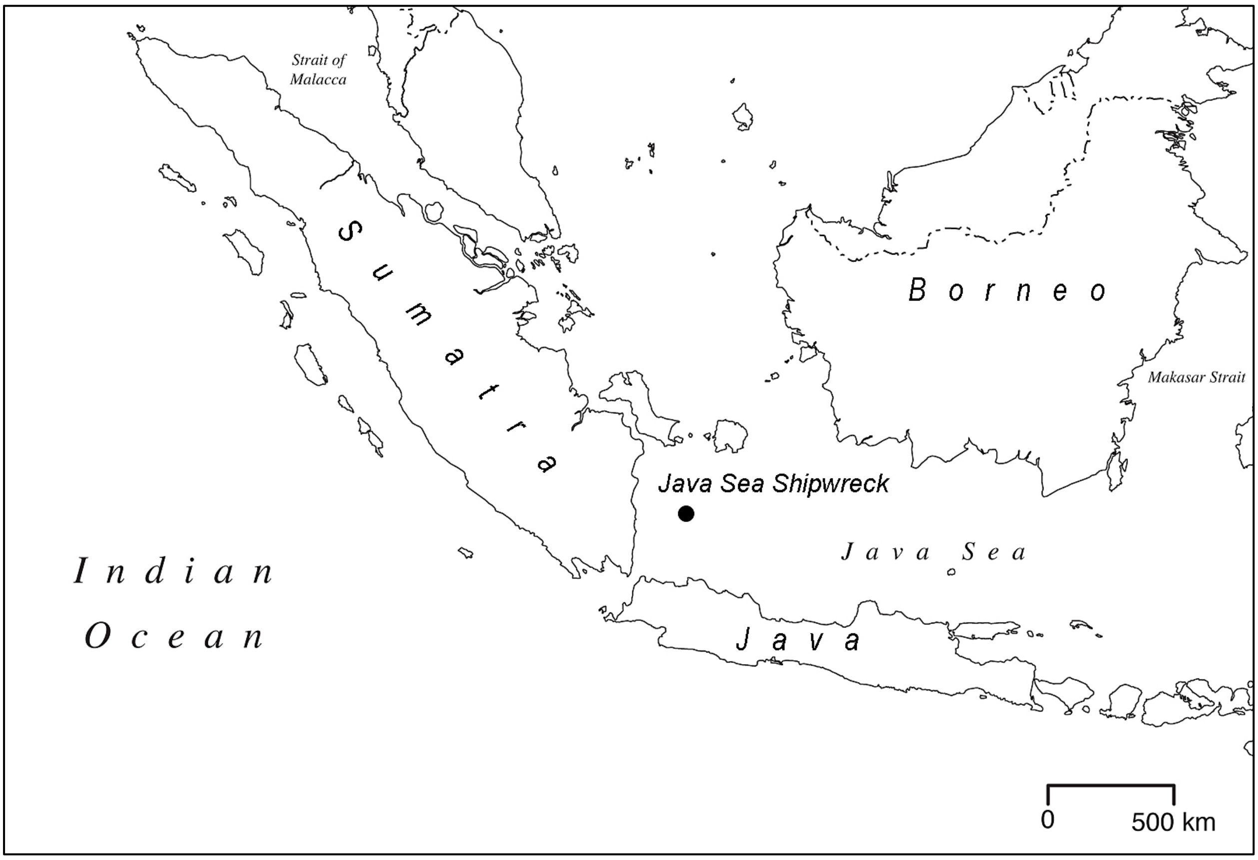

Figure 2: Location of the Java Sea Shipwreck

Tenazas and Hutterer 1968; Wong 2010). Shipwrecks carrying cargos of mostly Chinese export ceramics—but some transporting items from Southeast Asia and elsewhere to China—also indicate vigorous overseas trade (Diem 2004; Dupoizat 1995; Flecker 2001; Grave, et al. 2005; Krahl, et al. 2010; Li 2009; Wade 2003).

Most of the high-fired ceramics from the *JSW* have been identified as Song dynasty Chinese wares and include fine bowls, dishes, vases, bottles, boxes, and jars ranging from small covered boxes with light blue glaze to celadon bowls incised with floral motifs to graceful pitchers with intricate black and white designs that were once covered with bright green glaze. While it is certain that the majority of these ceramics originated in China and it has been hypothesized at which kiln areas certain ware types were manufactured, provenance research based on style and form is complicated by the fact that certain ceramic types were made at multiple production centers (Dupoizat 1995; Ho 1994b; Ye 1994). For example, it is suspected that finely made *qingbai* ceramics were made at the famous Jingdezhen kilns in Jiangxi province whereas other ceramics copying the *qingbai* style were made at Dehua or Anxi in Fujian province (Brown 1997a; Dupoizat 1995; Flecker 2003, 2005, 2005-2006; Guy 1986; Hughes-Stanton and Kerr 2000). Geochemical analysis, then, can aid in the identification and confirmation of the locales (or kiln complexes) where this diverse cargo was produced.

LA-ICP-MS ANALYSIS OF HIGH-FIRED CERAMICS FROM THE *JAVA SEA SHIPWRECK*

Compositional analysis is now frequently employed in archaeology to address questions of origin, production, and distribution, especially with regards to pottery, and can be used to identify ceramic pieces in the *JSW* collection that were made at the same production areas. In turn, this knowledge can be used to reconstruct the organization of production and develop hypotheses regarding exchange networks in East and Southeast Asia during the early to mid-second millennium AD. These regional exchange networks, then, fed into larger transregional systems that spanned half the globe and included diverse political, economic, and social organizations.

The analytical method used most frequently to examine the elemental composition of Chinese ceramics has been x-ray fluorescence (XRF) (e.g., Bao, et al. 2006; Leung and Luo 2000; Yap 1991; Yu and Miao 1996, 1997, 1998; Zhang, et al. 2009; Zhu, et al. 2011). More recently, though, researchers (e.g., Oka, et al. 2009; Zhu, et al. 2012) have applied LA-ICP-MS to geochemical studies of Chinese ceramics with great success, and this is one of the best methods for determining the elemental makeup of ceramic materials. LA-ICP-MS is a semi-nondestructive method that is capable of determining the concentrations of 50–60 elements, many of which are trace elements critical to distinguishing chemical groups represented in ceramic assemblages from China (Li, et al.

2005; Li, et al. 2003; Li, et al. 2006; Zhu, et al. 2010) and elsewhere. The detection limits of LA-ICP-MS also are excellent, reading elements present in the parts per million (Dussubieux, et al. 2007). Its rapid analytical time, low cost, high sample throughput, semi-nondestructive nature (marks left behind are barely visible to the naked eye), and the limited chance of contamination during preparation procedures (done *in situ*), makes LA-ICP-MS attractive to archaeologists and other researchers (Speakman, et al. 2007). Because it can target specific materials in the sample, such as glaze, slip, temper, or clay, through spot or line analysis, it is a good option for ceramic compositional studies.

Sample and Methods

The current project, undertaken using LA-ICP-MS at the Elemental Analysis Facility (EAF) at The Field Museum, had two main goals: (1) to determine if ceramics of different styles in the *JSW* collection could be differentiated chemically and (2) whether or not more than one production area was represented by *JSW* ceramics made in the *qingbai* tradition. The pastes, or bodies, of 58 samples were analyzed, while the glazes of 31 samples were tested (Table 1). The majority of these pieces were suspected to be authentic *qingbai* ceramics made at Jingdezhen in Jiangxi province (Figure 1); however, a number of pieces in the *JSW* collection, while resembling *qingbai*, were hypothesized to have been imitations of it based on visual assessment of glazes (clearer, glassier, and more evenly applied in *qingbai* pieces) and pastes (finer and purer white in color). The pastes of the *qingbai* and *qingbai*-style ceramics are fine or fine-medium in texture and sugary-white or cream. The glazes include translucent aqua, light blue-aqua, and milky blue (Figures 3 and 4). Several green-glazed bowls (Figure 5) also were sampled as well as Cizhou-style pieces (referred to as "painted ware") (Figure 6). All of the green-glazed bowls sampled have incised and combed cloud designs. Their pastes range from lavender-gray to cream to white and their glazes from light olive green to pale gray-green to light blue. The pastes of the painted ware vessels are all fine textured but range in color from white to cream to gray. All of them have designs executed in underglaze black covered by a lead-based, bright green glaze, which is badly weathered in many cases. Appendix 1 provides basic descriptive information for each of the samples.

Table 1: Frequencies of ceramic paste and glaze samples by style analyzed using LA-ICP-MS.

	Paste		Glaze	
Ware	**Frequency**	**%**	**Frequency**	**%**
Qingbai	25	43%	11	35%
Qingbai-style	8	14%	17	55%
Green-glazed	12	21%	3	10%
Painted	13	22%	0	0%
Total	**58**	100%	**31**	100%

Figure 3: Qingbai ewer from the Java Sea Shipwreck (Photo © The Field Museum, Catalog #350385)

Figure 4: Qingbai-style covered box from the Java Sea Shipwreck (Photo © The Field Museum, Catalog #344284)

The EAF houses an Analytik Jena quadrupole ICP-MS with a New Wave UP213 laser that uses a 213 nm wavelength laser. The ablation chamber is six centimeters in diameter and five centimeters deep and can hold several small samples at once. Additional technical details can be found in Dussubieux, et al. (2007). The spectrometer was set to measure 58 elemental isotopes for each sample: ^{7}Li, ^{9}Be, ^{11}B, ^{23}Na, ^{24}Mg, ^{27}Al, ^{29}Si, ^{31}P, ^{35}Cl, ^{39}K, ^{44}Ca, ^{45}Sc, ^{49}Ti, ^{51}V, ^{53}Cr, ^{55}Mn, ^{57}Fe, ^{59}Co, ^{60}Ni, ^{65}Cu, ^{66}Zn, ^{75}As, ^{78}Se, ^{85}Rb, ^{88}Sr, ^{89}Y, ^{90}Zr, ^{93}Nb, ^{98}Mo, ^{107}Ag, ^{111}Cd, ^{115}In, ^{118}Sn, ^{121}Sb, ^{133}Cs, ^{137}Ba, ^{139}La, ^{140}Ce, ^{141}Pr, ^{146}Nd, ^{147}Sm, ^{153}Eu, ^{157}Gd, ^{159}Tb, ^{163}Dy, ^{165}Ho, ^{166}Er, ^{169}Tm, ^{172}Yb, ^{175}Lu, ^{178}Hf, ^{181}Ta, ^{182}W, ^{197}Au, $^{206, 207, 208}$Pb, ^{209}Bi, ^{232}Th, and ^{238}U. The laser was set to operate at 70 percent energy (0.2 mJ) with a pulse frequency of 15 Hz.

For the paste analysis, a total of 10 locations on each sample were chosen for a 100-µm spot ablation (with a brief pre-ablation to remove surface contamination). Standard reference materials (SRM) with known ranges of elemental concentrations—n610 (glass) and n679 (Brick Clay)—were run every five to 10 samples to correct for instrument drift over time (Speakman, et al. 2007). Ohio Red Clay served as a measure of quality control. For the glaze analysis, procedures outlined in Oka, et al. (2009) were followed. Following a pre-ablation pass, a line 55 µm wide by 500 µm long by five µm deep was used to ablate the material of interest (e.g., glaze). A total of four readings were taken for each sample and glass standards n612, n610, Corning B, and Corning D were used. (In cases where high lead content was suspected, as with the painted ware glazes, SRM Corning C was included as well.) After analysis, data was processed per EAF protocols using Microsoft Excel. Statistical analysis was performed on the dataset using Microsoft Excel and GAUSS, an Aptech Systems, Inc. program with routines developed by Hector Neff and Michael Glascock at the University of Missouri Research Reactor Center (MURR).

Figure 5: Green-glazed bowl from the Java Sea Shipwreck (Photo © The Field Museum, Catalog #349352)

Figure 6: Painted (Cizhou-style) ewer from the Java Sea Shipwreck (Photo © The Field Museum, Catalog #350392)

Results and Discussion of the Paste Analysis

Of the original 58 elements measured by LA-ICP-MS, 45 were retained for statistical analysis: Li, Be, B, Na, Mg, Al, Si, K, Sc, Ti, V, Cr, Mn, Fe, Ni, Cu, Zn, Rb, Sr, Y, Zr, Nb, Sn, Sb, Cs, Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Hf, Ta, Bi, Th, and U. Because of questionable readings on the rare earth elements for JSW164, this sample was removed from further analysis. This piece, from a painted ewer, was badly weathered, which may account for anomalous elemental concentrations. All results were converted from parts-per-million to log base-10 values and were processed using well-established statistical routines for ceramic compositional data (Baxter 2001; Dussubieux, et al. 2007; Eerkens, et al. 2002; Glascock, et al. 2004; Kennett, et al. 2004; Neff 1994; Niziolek 2013a, b).

The first step in statistical analysis was to identify potential outliers to the dataset. This was done by inspecting an elemental biplot of Si and Al and a dendrogram using hierarchical cluster analysis of logged elemental values and calculating Mahalanobis distance probabilities of group membership. JSW125 had a low probability of group membership (0.005) and was an outlier on the dendrogram and biplot, so it was removed from subsequent statistical analysis. Compared to other samples, it has higher concentrations of Ca and Sr and lower concentrations of Fe. Other samples removed based on low Mahalanobis distance probabilities (less than one percent) include JSW158, JSW160, JSW170, and JSW193 (see Table 2). JSW158 has higher concentrations of Mg; JSW 160 has lower concentrations of Na and Ba; JSW170 has higher concentrations of Ti; and JSW193 has lower concentrations of Ba. The remaining samples all have Mahalanobis distance membership probabilities greater than one percent and form the core paste dataset.

Next, principal components analysis (PCA) was performed on the correlation matrix in order to compress the 45 elemental variables into a more manageable number. Because many statistical procedures require a larger number of samples than variables, PCA enables this assumption to be met while retaining a high expression of variability. The first five principal components (PCs) all have eigenvalues greater than one and account for almost 90 percent of the elemental variance in the dataset. Mahalanobis distance probabilities were again calculated using the PC values and confirmed that none of the core group samples have a probability of less than one percent.

After PCA, samples were split into four groups based on style: painted, green-glazed, *qingbai*-style, and *qingbai*. Mahalanobis distance probabilities using PCs 1–5 were calculated for these four groups to see if any sample had a higher probability of being in a group other than its suspected style group. Hierarchical cluster analysis also was run on the PC values. Based on the results of these techniques and inspection of PC biplots, it was decided to combine the green-glazed and *qingbai*-style samples into one group. Table 3 shows that many of the samples in these two groups have relatively high probabilities of group membership in both groups based on Mahalanobis distance calculations using the first four principal components. Furthermore, in some instances, different forms and styles may have been manufactured at the same production site (Qin Dashu, personal communication, October 24, 2015). Additional calculations of Mahalanobis distance probabilities using the PC values of the different style groups suggested a number of samples should be removed (JSW121, JSW197, JSW134, and JSW122). After these samples were removed, no additional samples had Mahalanobis distance membership probabilities of less than one percent in their respective style groups (Table 4).

Table 2: Group membership probabilities of paste samples based on Mahalanobis distance calculations using logged elemental values of the 45 elements retained for statistical analysis. Samples that are in bold and italicized have a less than one percent probability of group membership.

Sample ID	% Probability	Sample ID	% Probability
JSW121	5.708	***JSW170***	***0.459***
JSW122	1.516	JSW171	20.301
JSW123	37.507	JSW173	27.660
JSW124	8.065	JSW174	65.254
JSW125	***0.003***	JSW188	31.356
JSW126	86.826	JSW189	47.996
JSW127	24.426	JSW190	82.849
JSW129	87.804	JSW191	91.390
JSW131	7.684	JSW192	99.943
JSW133	89.216	***JSW193***	***0.731***
JSW134	1.143	JSW194	91.800
JSW135	29.177	JSW195	59.974
JSW136	37.783	JSW196	85.939
JSW137	66.127	JSW197	12.451
JSW138	2.499	JSW198	99.031
JSW139	32.546	JSW199	35.241
JSW151	36.278	JSW200	79.491
JSW152	51.728	JSW201	4.834
JSW153	93.199	JSW202	3.549
JSW154	41.121	JSW203	89.969
JSW156	42.472	JSW204	99.855
JSW157	68.157	JSW205	13.722
JSW158	***0.128***	JSW206	4.663
JSW159	91.514	JSW207	17.108
JSW160	***0.004***	JSW208	98.193
JSW161	59.807	JSW900	10.704
JSW163	38.245	JSW902	96.310
JSW165	57.144	JSW901	98.660
JSW168	95.524	JSW904	98.788
JSW169	63.774		

LA-ICP-MS analysis of the ceramic pastes indicates that there are at least three chemical groups, which correspond closely with style (Figure 7). Table 5 lists the average elemental concentrations of the different chemical groups. Group 1 is made up of painted ware samples and can be split into two subgroups based on paste color and form [bowls with white paste (Figure 8) and ewers with gray paste (Figure 9)]. This group is characterized by higher concentrations of Ti, Mg, Sc, V, Cr, Ni, Cu, Zr, Sn, Hf, Ta, and Bi. Group 2 is comprised of green-glazed and *qingbai*-style pieces and has higher amounts of Y and Th and lower concentrations of Rb. Group 3 is significantly different chemically from Groups 2 and 3 and has higher concentrations of Ca, Na, Li, Be, B, Mn, Sb, Cs, and U and lower quantities of the rare earth elements. After these main chemical groups were established, samples that had been taken out throughout the analysis were reprojected back into these main groups. Only JSW158 could be convincingly reassigned (to Group 1, painted ware). The other samples all had very low probabilities of belonging to the established compositional groups. The reasons for this are uncertain since these samples do not appear to be different in terms of style or paste appearance.

Table 3: Group membership probabilities of green-glazed and *qingbai*-style paste samples based on Mahalanobis distance calculations using the first four principal components values.

	Ware Type			
Sample ID	Painted	Green-glazed	Qingbai-style	Qingbai
Green-glazed group				
JSW135	0.050	1.801	20.946	0.000
JSW154	0.002	10.327	55.457	0.000
JSW196	0.010	96.942	93.973	0.000
JSW198	0.005	88.104	55.398	0.000
JSW199	0.034	82.774	90.986	0.000
JSW200	0.050	43.817	74.332	0.000
JSW202	0.003	4.299	73.406	0.000
JSW203	0.004	92.016	88.029	0.000
JSW204	0.006	91.772	94.756	0.000
JSW205	0.006	10.889	77.099	0.000
JSW206	0.059	46.555	64.507	0.000
JSW208	0.071	62.826	86.690	0.000
Qingbai-style group				
JSW122	1.954	0.000	59.416	0.000
JSW123	0.016	70.155	94.146	0.000
JSW124	0.063	2.550	26.875	0.000
JSW134	1.465	0.000	56.854	0.000
JSW188	0.011	81.234	28.851	0.000
JSW207	0.005	59.403	56.656	0.000

Based on the elemental concentrations of some of the major, minor, and trace elements it is possible to offer some preliminary production area assignments for some of the chemical groups. In 2000, Leung and Luo published a paper in which they present criteria that are helpful for distinguishing not only production regions (i.e., northern China vs. southern China) but also different kiln sites in the south. Specifically, they compare porcelain samples from Hebei in the north to samples from Jingdezhen (Jiangxi province) and Dehua (Fujian province) in the south (Figure 1), the two main kiln areas known to have produced ceramics in the *qingbai* tradition. Kilns in both of these areas produced ceramics that are visually similar to those found in the *JSW* cargo and, because data is available for them, provide a good starting point for comparisons—although it must be acknowledged that this comparison is limited in scope, larger scale and more in-depth analysis is planned for the future. Pieces made at Jingdezhen or Dehua have Zr/Rb ratios less than 1.29

while those from Hebei have Zr/Rb ratios higher than 1.29. For the *JSW* samples used in this project, almost all of the samples have Zr/Rb ratios significantly less than 1.29, with the exception of some of the samples from Subgroup 1B (JSW129, JSW169, JSW174, JSW901, and JSW904) (Table 6). Another criterion Leung and Luo (2000) look at is the value of 0.79(Rb/Y + Zr/Y). If this value is greater six, Jingdezhen may be the production site; if it is less than six, then Dehua might be the source. (Yap, et al. 1987 also identify Rb, Zr, and Y among some of the main elements important for discerning ceramic production sites in China.) Based on this criterion, the *JSW* samples in Group 2 appear to have been made at Dehua whereas those in Group 3 and Subgroup 1A were possibly made at the famous kilns of Jingdezhen (Table 6).

Table 4: Mahalanobis distance probabilities of group membership for the three main paste groups based on style

Sample	Group 1 (1A & 1B)	Group 2	Group 3	Best Group
JSW129	45.65	0.00	0.00	Painted ware (Group 1)
JSW159	68.12	0.00	0.00	Painted ware (Group 1)
JSW165	11.32	0.00	0.00	Painted ware (Group 1)
JSW169	50.92	0.00	0.00	Painted ware (Group 1)
JSW171	29.48	0.00	0.00	Painted ware (Group 1)
JSW173	23.17	0.00	0.00	Painted ware (Group 1)
JSW174	40.92	0.01	0.00	Painted ware (Group 1)
JSW901	95.40	0.00	0.00	Painted ware (Group 1)
JSW904	84.64	0.00	0.00	Painted ware (Group 1)
JSW123	0.01	70.25	0.00	Green-glazed/*Qingbai*-style (Group 2)
JSW154	0.00	20.56	0.00	Green-glazed/*Qingbai*-style (Group 2)
JSW188	0.01	50.22	0.00	Green-glazed/*Qingbai*-style (Group 2)
JSW196	0.01	86.78	0.00	Green-glazed/*Qingbai*-style (Group 2)
JSW198	0.01	48.07	0.00	Green-glazed/*Qingbai*-style (Group 2)
JSW199	0.01	92.41	0.00	Green-glazed/*Qingbai*-style (Group 2)
JSW200	0.01	27.21	0.00	Green-glazed/*Qingbai*-style (Group 2)
JSW202	0.00	4.14	0.00	Green-glazed/*Qingbai*-style (Group 2)
JSW203	0.01	79.22	0.00	Green-glazed/*Qingbai*-style (Group 2)
JSW204	0.01	97.07	0.00	Green-glazed/*Qingbai*-style (Group 2)
JSW205	0.00	3.11	0.00	Green-glazed/*Qingbai*-style (Group 2)
JSW206	0.02	52.32	0.00	Green-glazed/*Qingbai*-style (Group 2)
JSW207	0.01	11.44	0.00	Green-glazed/*Qingbai*-style (Group 2)
JSW208	0.02	71.48	0.00	Green-glazed/*Qingbai*-style (Group 2)
JSW126	0.00	0.00	82.05	*Qingbai* (Group 3)
JSW127	0.00	0.00	8.04	*Qingbai* (Group 3)
JSW131	0.01	0.00	63.90	*Qingbai* (Group 3)
JSW133	0.01	0.00	44.30	*Qingbai* (Group 3)
JSW136	0.01	0.00	77.94	*Qingbai* (Group 3)
JSW137	0.01	0.00	45.77	*Qingbai* (Group 3)
JSW138	0.01	0.00	26.24	*Qingbai* (Group 3)
JSW139	0.01	0.00	22.90	*Qingbai* (Group 3)
JSW151	0.00	0.00	53.34	*Qingbai* (Group 3)
JSW152	0.00	0.00	42.27	*Qingbai* (Group 3)
JSW153	0.00	0.00	68.59	*Qingbai* (Group 3)
JSW156	0.00	0.00	42.85	*Qingbai* (Group 3)
JSW157	0.00	0.00	71.71	*Qingbai* (Group 3)
JSW161	0.00	0.00	95.63	*Qingbai* (Group 3)
JSW163	0.00	0.00	16.16	*Qingbai* (Group 3)
JSW168	0.00	0.00	7.25	*Qingbai* (Group 3)
JSW189	0.00	0.00	90.69	*Qingbai* (Group 3)
JSW190	0.00	0.00	26.79	*Qingbai* (Group 3)
JSW191	0.00	0.00	83.97	*Qingbai* (Group 3)
JSW192	0.00	0.00	39.91	*Qingbai* (Group 3)
JSW194	0.00	0.00	74.09	*Qingbai* (Group 3)
JSW195	0.00	0.00	45.84	*Qingbai* (Group 3)
JSW201	0.01	0.00	20.32	*Qingbai* (Group 3)
JSW900	0.00	0.00	8.37	*Qingbai* (Group 3)
JSW902	0.01	0.00	57.21	*Qingbai* (Group 3)

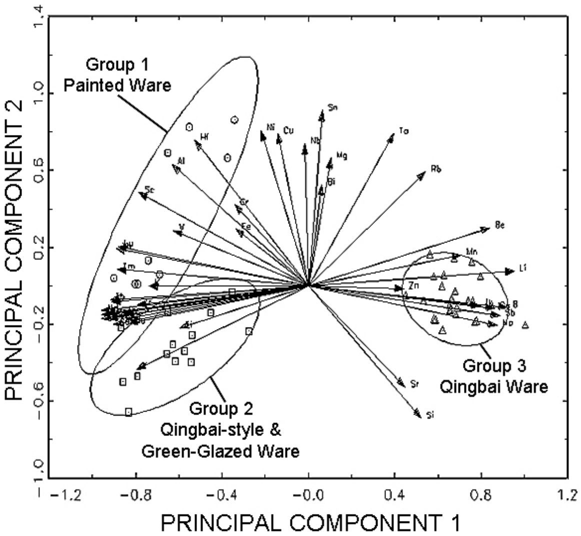

Figure 7: R-Q mode biplot of principal components 1 and 2 based on paste compositions. Ellipses represent 90 percent confidence intervals. Circles represent painted samples (Group 1), squares qingbai-style and green-glazed samples (Group 2), and triangles qingbai samples (Group 3).

Figure 8: Painted ware bowl from the Java Sea Shipwreck (Photo © The Field Museum, Catalog #350229)

Figure 9: Painted ware ewer from the Java Sea Shipwreck (Pho to © The Field Museum, Catalog #350418)

Although it is tempting to hypothesize that the Subgroup 1B samples came from the north because of their similarity to pieces produced at Cizhou kilns, recent kiln excavations at Wuyishan in Fujian have yielded ceramics that are very similar visually to the painted wares from the *JSW* (Underwater Research Center of the National Museum of China, et al. 2015). Amounts of Al_2O_3 and K_2O measured in the shipwreck pieces can be used to support a southern origin since another major determining factor of production region is the amount of Al_2O_3 and K_2O (Pollard and Hatcher 1994). Pieces from the north are higher in Al_2O_3 (greater than 25 percent) and lower amounts of K_2O (less than 2.5 percent). Southern ceramics have Al_2O_3 ranging from 10.3–24.5 percent and K_2O close to 2.0–6.6 percent. This pattern also is observed by Wood (2011:28) and the *JSW* ceramics fit the southern profile.

Findings presented by Zhu, et al. (2012) partially support these kiln assignments. They report that *qingbai* ceramics from Fujian province have amounts of Al_2O_3 and Fe_2O_3 ranging from 16.2–21.4 percent and 0.83–1.44 percent, respectively. The *JSW* samples in Group 2 assigned to Dehua (in Fujian) have concentrations within these ranges. The average Al_2O_3 concentration for Group 2 is 17.30 percent and Fe_2O_3 is 0.99 percent. Zhu et al.'s work also may provide a clue as to from where the pieces in Subgroup 1B are—Fujian, since the average Al_2O_3 concentration for this group is 19.92 percent and the average Fe_2O_3 concentration is 0.91 percent.

Results and Discussion of the Glaze Analysis

The materials used to make the bodies of the ceramics from the period and regions under discussion served as the main ingredients for the glazes (Pierson, et al. 2002; Wood 2011:29). Although there is mention in historical documents of a division of labor in ceramic production (So 1994:12), this has not yet been supported by archaeological evidence. Pieces appear to have been produced at multiple household workshops that engaged in all steps of the preparing, forming, and finishing process and then fed into a single kiln that accommodated the wares from multiple production units (So 1994:12). Most producers at the time tended to use local materials in manufacturing their goods (Zhu 2010:482), and both pastes and glazes have been used in sourcing studies (e.g., Leung, et al. 2000).

The geochemical data from LA-ICP-MS analysis of the glazes underwent similar statistical analysis, however, it was decided to keep the one painted ware sample out since it was clearly very different visually (bright green to oily black) and chemically (extremely high in Pb) from the other glazes sampled. Because there were many fewer glaze samples than elements, the number of variables (elements) had to be reduced to facilitate statistical analysis. Biplots of the logged elemental values were examined to identify elements that would be potentially helpful for differentiating chemical groups. These include 19 elements: Li, U, Bi, Th, Ta, Yb, Gd, Na, La, Sb, Cs, Zr, Y, Rb, Sc, K, Ca, B, and Be. PCA was performed on the logged dataset.

Table 5: Average elemental concentrations of chemical groups based on paste composition

	Paste Group 1A (n = 4)		Paste Group 1B (n = 5)		Paste Group 2 (n = 16)		Paste Group 3 (n = 25)	
Oxide %	**AVG**	**SD**	**AVG**	**SD**	**AVG**	**SD**	**AVG**	**SD**
SiO_2	73.86	1.50	74.28	0.36	77.12	2.16	79.13	1.24
Al_2O_3	20.61	0.95	19.92	0.28	17.17	1.92	14.94	1.01
TiO_2	0.03	0.02	0.74	0.06	0.09	0.04	0.03	0.01
Fe_2O_3	0.70	0.11	0.91	0.17	0.99	0.42	0.68	0.20
CaO	0.03	0.01	0.02	0.02	0.03	0.03	0.56	0.28
MgO	0.53	0.06	0.55	0.11	0.14	0.10	0.28	0.16
K_2O	3.78	0.37	3.14	0.33	4.10	0.36	2.88	0.17
Na_2O	0.10	0.02	0.11	0.04	0.13	0.07	0.95	0.26
MnO	0.05	0.03	0.01	0.01	0.04	0.02	0.06	0.03
P_2O_5	0.00	0.00	0.01	0.02	0.03	0.06	0.02	0.02
Ppm								
Li	39.94	5.20	15.68	1.43	9.03	2.21	373.85	78.16
Be	8.61	2.15	2.92	0.20	1.92	0.59	10.71	1.56
B	11.32	3.32	43.32	15.11	10.29	2.82	463.51	118.25
Na	769.40	155.15	823.30	268.63	983.23	496.96	7026.28	1916.38
Mg	3219.86	356.95	3341.87	682.27	820.42	589.24	1687.73	943.38
Al	109099.49	5020.42	105428.21	1486.30	90864.52	10168.27	79089.02	5319.73
Si	345247.94	7009.38	347224.81	1686.32	360467.56	10113.51	369900.87	5779.12
K	31369.00	3034.25	26088.39	2746.74	34052.62	3028.99	23915.18	1430.72
Sc	11.90	1.18	15.26	0.59	5.57	1.50	2.37	0.96
Ti	173.99	97.47	4454.93	357.72	537.81	211.59	187.45	32.59
V	12.26	4.88	101.82	7.76	8.83	5.63	3.92	1.84
Cr	14.54	5.13	88.39	6.34	5.72	3.49	6.79	4.91
Mn	447.57	36.68	43.58	3.34	231.51	99.39	564.72	189.82
Fe	4914.37	737.65	6357.15	1219.14	6912.07	2912.95	4754.85	1395.46
Ni	29.69	3.82	18.22	6.78	3.16	1.54	4.86	2.60
Cu	41.81	19.82	19.80	17.62	6.47	3.06	13.01	19.99
Zn	45.53	7.47	23.33	2.35	54.09	26.27	71.16	35.92
Rb	624.16	143.66	152.68	22.60	231.61	27.13	397.63	48.43
Sr	11.25	2.60	44.60	16.27	35.27	9.39	52.58	11.45
Y	23.53	9.32	31.54	3.80	46.96	19.68	16.25	4.46
Zr	39.72	5.18	200.77	41.14	62.42	12.40	28.94	5.19
Nb	39.32	9.67	19.12	2.14	19.93	2.69	22.84	4.76
Sn	86.46	15.73	3.62	0.88	3.22	1.45	6.12	1.56
Sb	0.47	0.37	0.88	0.34	0.33	0.18	18.16	12.68
Cs	8.24	1.40	19.12	3.42	5.54	1.28	100.20	35.28
Ba	174.41	43.73	559.90	107.67	295.50	69.96	125.97	27.76
La	32.40	7.32	49.66	9.80	52.91	20.78	5.57	1.53
Ce	36.55	5.38	107.45	13.75	62.79	10.49	12.16	3.43
Pr	9.21	1.48	11.62	1.68	11.80	5.02	1.58	0.43
Nd	33.66	5.88	44.27	5.87	39.22	16.85	5.83	1.73
Sm	8.23	1.51	8.30	1.05	8.72	3.99	2.33	0.68
Eu	1.25	0.31	1.73	0.22	1.44	0.71	0.28	0.07
Gd	6.40	1.91	6.67	1.19	7.40	3.22	2.50	0.70
Tb	1.25	0.50	1.05	0.17	1.34	0.58	0.56	0.16
Dy	7.32	3.43	6.14	1.12	7.90	3.27	3.18	0.88
Ho	1.43	0.72	1.27	0.24	1.67	0.68	0.60	0.17
Er	4.02	1.97	3.45	0.71	4.58	1.89	1.45	0.37
Tm	0.91	0.48	0.51	0.02	0.72	0.32	0.21	0.06
Yb	7.96	3.90	3.99	0.65	5.16	2.14	1.53	0.36
Lu	1.20	0.63	0.59	0.11	0.75	0.33	0.23	0.06
Hf	12.04	3.33	6.32	1.54	3.02	0.65	2.54	0.49
Ta	25.21	11.27	1.47	0.25	1.55	0.42	5.48	1.61
Bi	4.64	3.54	1.04	1.31	0.31	0.42	0.73	0.99
Th	21.37	5.93	18.29	3.77	33.47	9.64	6.59	1.56
U	6.10	1.99	5.65	1.30	5.47	1.88	15.51	4.76

Table 6: Possible kiln assignments of *Java Sea Shipwreck* ceramics (pastes) analyzed using LA-ICP-MS based on Leung and Luo's (2000) classification

		Parts-per-million							
Sample	**Chem. Grp.**	**Rb**	**Y**	**Zr**	**Zr/Rb**	**<1.29?**	**0.79(Rb/Y + Zr/Y)**	**>6?**	**Jingdezhen or Dehua?**
JSW159	1A	814.98	21.73	40.21	0.05	Y	31.09	Y	Jingdezhen
JSW165	1A	608.55	36.46	39.86	0.07	Y	14.05	Y	Jingdezhen
JSW171	1A	606.94	14.21	45.73	0.08	Y	36.28	Y	Jingdezhen
JSW173	1A	466.16	21.72	33.08	0.07	Y	18.16	Y	Jingdezhen
	AVG	**624.16**	**23.53**	**39.72**	**0.06**	**Y**	**22.29**	**Y**	**Jingdezhen**
JSW129	1B	183.53	37.67	264.18	1.44	N	9.39	Y	
JSW169	1B	147.19	30.97	191.38	1.30	N	8.64	Y	
JSW174	1B	155.23	28.68	163.25	1.05	Y	8.77	Y	Jingdezhen
JSW901	1B	156.96	32.18	216.16	1.38	N	9.16	Y	
JSW904	1B	120.49	28.20	168.87	1.40	N	8.11	Y	
	AVG	**152.68**	**31.54**	**200.77**	**1.31**	**N**	**8.85**	**Y**	**?**
JSW123	2	193.78	32.82	48.49	0.25	Y	5.83	N	Dehua
JSW154	2	252.21	70.54	49.65	0.20	Y	3.38	N	Dehua
JSW188	2	245.35	42.60	76.42	0.31	Y	5.97	N	Dehua
JSW196	2	251.25	42.17	67.12	0.27	Y	5.96	N	Dehua
JSW198	2	209.31	72.93	59.15	0.28	Y	2.91	N	Dehua
JSW199	2	271.77	23.07	69.81	0.26	Y	11.70	Y	Jingdezhen
JSW200	2	234.93	62.97	77.73	0.33	Y	3.92	N	Dehua
JSW202	2	250.78	80.64	55.26	0.22	Y	3.00	N	Dehua
JSW203	2	192.70	52.04	43.42	0.23	Y	3.58	N	Dehua
JSW204	2	189.20	57.81	47.51	0.25	Y	3.23	N	Dehua
JSW205	2	237.35	31.08	74.59	0.31	Y	7.93	Y	Jingdezhen
JSW206	2	262.74	15.45	79.16	0.30	Y	17.48	Y	Jingdezhen
JSW207	2	214.06	35.49	57.27	0.27	Y	6.04	Y	Dehua
JSW208	2	237.18	37.89	68.25	0.29	Y	6.37	Y	Dehua
	AVG	**231.61**	**46.96**	**62.42**	**0.27**	**Y**	**4.95**	**N**	**Dehua**
JSW126	3	434.60	20.14	34.72	0.08	Y	18.41	Y	Jingdezhen
JSW127	3	525.66	28.76	41.26	0.08	Y	15.57	Y	Jingdezhen
JSW131	3	376.81	19.98	27.41	0.07	Y	15.98	Y	Jingdezhen
JSW133	3	363.07	11.63	22.90	0.06	Y	26.23	Y	Jingdezhen
JSW136	3	383.14	21.12	39.83	0.10	Y	15.82	Y	Jingdezhen
JSW137	3	371.83	19.88	32.42	0.09	Y	16.06	Y	Jingdezhen
JSW138	3	334.95	12.53	24.93	0.07	Y	22.69	Y	Jingdezhen
JSW139	3	336.42	12.30	29.39	0.09	Y	23.49	Y	Jingdezhen
JSW151	3	394.48	18.99	26.57	0.07	Y	17.52	Y	Jingdezhen
JSW152	3	513.08	15.60	30.59	0.06	Y	27.54	Y	Jingdezhen
JSW153	3	410.22	11.58	28.51	0.07	Y	29.93	Y	Jingdezhen
JSW156	3	381.51	16.52	28.20	0.07	Y	19.60	Y	Jingdezhen
JSW157	3	425.35	11.19	25.38	0.06	Y	31.83	Y	Jingdezhen
JSW161	3	378.88	14.28	35.43	0.09	Y	22.91	Y	Jingdezhen
JSW163	3	431.25	11.72	22.90	0.05	Y	30.60	Y	Jingdezhen
JSW168	3	332.69	8.15	18.74	0.06	Y	34.08	Y	Jingdezhen
JSW189	3	358.62	16.88	29.96	0.08	Y	18.19	Y	Jingdezhen
JSW190	3	436.17	18.03	31.51	0.07	Y	20.49	Y	Jingdezhen
JSW191	3	358.88	18.03	25.93	0.07	Y	16.86	Y	Jingdezhen
JSW192	3	394.16	11.49	26.63	0.07	Y	28.92	Y	Jingdezhen
JSW194	3	435.50	18.37	23.23	0.05	Y	19.73	Y	Jingdezhen
JSW195	3	419.83	18.89	26.91	0.06	Y	18.68	Y	Jingdezhen
JSW201	3	382.24	17.54	29.34	0.08	Y	18.54	Y	Jingdezhen
JSW900	3	401.57	19.23	32.25	0.08	Y	17.82	Y	Jingdezhen
JSW902	3	359.92	13.44	28.66	0.08	Y	22.85	Y	Jingdezhen
	AVG	**397.63**	**16.25**	**28.94**	**0.07**	**Y**	**20.74**	**Y**	**Jingdezhen**

The first four PCs have eigenvalues greater than one, accounting for more than 89 percent of the elemental variance in the dataset. Over the course of the statistical analysis, it became apparent that JSW186 *(qingbai)* along with JSW212 and JSW209 (*qingbai*-style) were outliers to their respective style groups. Because each of these samples has a group membership probability based on Mahalanobis distance calculations of less than one percent in the group containing samples of similar style, they were removed from further analysis. Through the analysis, it also became clear that the *qingbai*-style glazes fell into two chemical subgroups.

Overall, the glaze chemical groups correspond very well with ceramic style (*qingbai, qingbai*-style, and green-glazed). Table 7 provides the average elemental concentrations for the different glaze groups. Whereas it is difficult to distinguish between green-glazed and *qingbai*-style pieces using paste composition, these two styles clearly separate based on their glaze compositions (Figure 10). Group 1, comprised of *qingbai* pieces, is distinguished by higher concentrations of Li, Be, B, Sb, and Cs and lower concentrations of Sc, Y, Zr, and the rare earth elements. The members of this group match those in paste Group 3, hypothesized to have come from Jingdezhen. The major element concentrations of this group correspond with those reported by Wood (2011) for Jingdezhen *qingbai* glazes (and pastes). Glaze Group 3, predominantly green-glazed ware, is a small group with higher amounts of Mg, Mn, P, Ti, V, Mn, Ba, and Pb and is lower in Ca and Ni. The majority of members of this group are from samples assigned to Dehua based on paste composition. Glaze Group 2 is higher in Al, Nb, and Sn and lower in Sb. It can be divided into two subgroups of *qingbai*-style pieces. Subgroup 2A has higher amounts of Ni, Cu, Rb, Nb, Sn, Yb, Lu, Hf, and Ta and lower amounts of Ti. Two samples in this group of four are covered boxes that are slightly different than other boxes in terms of style—instead of having ribbing or being octagonal in shape with decorated lids, these pieces are smooth, round, and undecorated (Figure 11). Subgroup 2B has higher concentrations of La, Nd, Sm, Eu, and Gd and lower concentrations of Zn and Rb. Because there is not a lot of overlap between the glaze Group 2 samples and paste samples that were run, it is difficult to make a production assignment at this time; however, Wood (2011) notes that some Dehua *qingbai*-type ceramics had CaO content ranging from 10–12.5 percent. Both glaze Subgroups 2A and 2B have CaO concentrations closest to this range. At the same time, some Dehua glazes, including pale green ones like those found on the *JSW's* green-glazed bowls, could have very low CaO amounts (only about 5–7 percent) (Wood 2011). The samples in glaze Group 3 have very low CaO concentrations (averaging 3.66 percent) and, based on their paste composition, are possibly from Dehua.

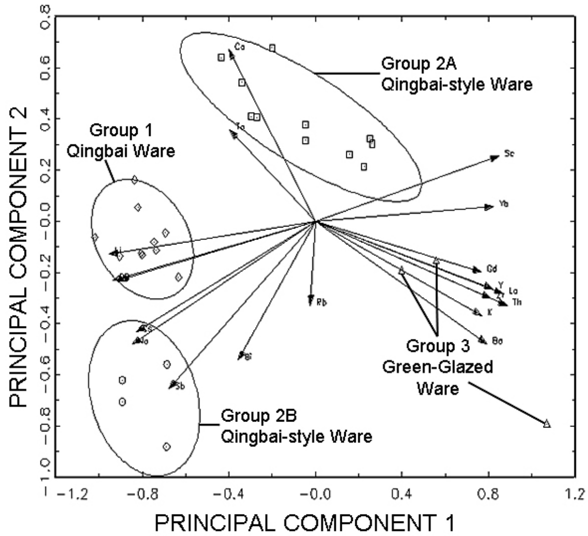

Figure 10: R-Q mode biplot of principal components 1 and 2 based on glaze compositions. Ellipses represent 90 percent confidence intervals. Diamonds represent qingbai samples (Group 1), squares (Group 2A) and circles (Group 2B) are qingbai-style pieces, and triangles are green-glazed samples (Group 3).

Figure 11: Qingbai-style undecorated covered box from the Java Sea Shipwreck (Photo © The Field Museum, Catalog #344282)

CONCLUSION

This paper has examined the results of LA-ICP-MS analysis of a sample of high-fired ceramics from the twelfth-thirteenth-century *Java Sea Shipwreck*. Using major, minor, and trace elemental concentrations, three (possibly four) groups were identified using the paste data and four groups emerged using the glaze data. Through the analysis, ceramic group memberships based on visual assessments of style were able to be tested and refined. For example, one vase neck or rim (JSW214) which was originally thought to be *qingbai* is more compositionally similar to the *qingbai*-style pieces. In addition, painted wares that initially appear to be from the same production area are more likely from two, based on the chemical compositions of their pastes. Furthermore, the possibility of one of these subgroups being from the north cannot be entirely ruled out and presents an intriguing idea requiring additional research.

Table 7: Average elemental concentrations of chemical groups based on glaze composition

	Glaze Group 1 (n = 10)		Glaze Group 2A (n = 4)		Glaze Group 2B (n = 11)		Glaze Group 3 (n = 3)	
Oxide %	**AVG**	**SD**	**AVG**	**SD**	**AVG**	**SD**	**AVG**	**SD**
SiO_2	66.85	1.91	66.54	2.34	67.78	1.94	73.47	2.68
Al_2O_3	14.18	0.80	15.55	1.26	15.55	1.82	14.22	2.88
TiO_2	0.03	0.01	0.01	0.01	0.04	0.02	0.09	0.02
Fe_2O_3	0.89	0.15	0.44	0.15	0.42	0.20	0.69	0.21
CaO	13.62	2.09	12.69	1.71	12.12	1.89	3.66	0.48
MgO	0.31	0.11	0.36	0.17	0.33	0.20	0.61	0.04
K_2O	2.19	0.27	3.77	0.21	3.32	0.48	5.79	0.09
Na_2O	1.18	0.35	0.10	0.03	0.08	0.02	0.42	0.11
MnO	0.11	0.03	0.10	0.03	0.12	0.07	0.23	0.02
P_2O_5	0.10	0.05	0.14	0.08	0.11	0.14	0.35	0.11
Ppm								
Li	953.34	309.26	87.20	10.69	31.52	10.80	32.94	25.61
Be	19.14	6.17	3.49	0.43	1.89	0.80	3.55	0.87
B	271.72	53.70	22.60	10.14	18.61	7.32	22.78	10.78
Na	8733.07	2574.77	734.82	214.87	613.04	121.70	3148.16	805.78
Mg	1877.60	674.50	2165.18	997.47	1981.45	1176.14	3672.19	228.10
Al	75025.71	4210.86	82315.72	6665.98	82311.37	9619.43	75235.55	15218.33
Si	312468.35	8942.62	311029.82	10951.46	316852.43	9086.46	343441.85	12514.02
P	427.71	239.31	626.49	365.61	459.85	600.71	1547.90	495.37
K	18181.64	2236.78	31333.42	1730.14	27573.86	3949.09	48092.03	752.84
Ca	97318.51	14907.12	90656.80	12196.61	86571.74	13472.48	26127.84	3422.85
Sc	1.44	0.52	6.92	0.48	5.69	0.55	4.46	0.63
Ti	156.76	66.38	41.41	36.04	239.45	99.25	543.23	113.86
V	11.47	3.96	9.27	2.22	9.02	2.94	22.65	18.67
Cr	11.84	7.94	8.93	0.78	7.87	3.48	4.33	4.31
Mn	826.06	230.50	789.64	240.08	957.78	534.18	1802.07	148.71
Fe	6245.70	1070.23	3093.37	1041.15	2971.77	1396.89	4840.21	1471.31
Ni	18.24	9.75	42.89	20.73	12.97	5.15	6.80	2.11
Cu	33.75	13.92	85.98	33.36	18.60	8.17	21.18	6.56
Zn	98.61	35.77	112.66	119.66	43.08	30.03	91.42	14.23
Rb	225.74	28.61	409.30	71.57	177.11	33.23	297.09	106.74
Sr	179.57	46.13	317.27	135.07	260.78	55.40	311.06	174.12
Y	17.92	4.97	16.73	2.83	50.61	18.78	40.92	11.18
Zr	28.06	6.42	26.57	4.50	75.57	12.25	85.00	66.21
Nb	23.93	5.44	89.60	10.72	43.07	19.98	23.98	7.89
Sn	5.30	1.96	19.66	12.07	2.26	1.50	6.17	2.64
Sb	9.69	3.82	0.16	0.14	0.21	0.17	2.55	2.82
Cs	31.85	10.83	2.90	0.60	3.14	0.97	5.06	2.22
Ba	133.33	40.82	294.98	189.19	384.86	152.34	1266.31	889.60
La	11.23	8.54	12.98	8.17	82.91	54.29	59.09	10.77
Ce	23.72	21.58	18.73	5.05	60.29	19.14	59.36	14.50
Pr	2.68	1.77	3.54	2.33	16.27	9.31	10.82	1.70
Nd	10.13	7.06	12.22	7.66	57.74	32.70	37.07	5.30
Sm	2.95	1.38	4.06	1.85	11.95	6.46	6.75	1.45
Eu	0.34	0.26	0.29	0.21	2.35	1.55	1.42	0.34
Gd	2.84	1.26	2.96	0.85	9.22	4.81	4.97	2.22
Tb	0.67	0.24	0.83	0.19	1.51	0.69	1.79	1.29
Dy	3.56	1.21	5.84	1.33	8.60	3.50	6.43	1.97
Ho	0.56	0.21	1.16	0.24	1.74	0.63	1.24	0.29
Er	1.50	0.50	3.79	0.91	4.49	1.55	3.67	1.04
Tm	0.21	0.09	0.79	0.13	0.66	0.19	0.46	0.19
Yb	1.56	0.59	8.37	1.85	4.74	1.24	4.97	1.68
Lu	0.16	0.10	1.10	0.28	0.63	0.16	0.52	0.10
Hf	2.03	0.84	5.08	1.43	3.44	0.49	2.91	1.74
Ta	4.08	1.24	20.79	3.82	1.50	0.40	0.97	0.37
Pb	63.12	54.89	39.75	36.91	50.27	45.41	266.04	208.67
Bi	2.60	4.89	1.58	2.58	0.23	0.49	3.40	3.65
Th	6.09	3.18	8.75	0.91	23.91	6.54	29.96	15.50
U	16.50	6.93	7.13	0.72	4.11	0.89	10.12	9.43

Comparing the data generated by this project to data from other compositional studies on Chinese ceramics, two southern production areas for the *JSW* high-fired ceramics made in the *qingbai* tradition were able to be preliminarily identified: Jingdezhen in Jiangxi province and Dehua in Fujian province. Ho (1994a:xi) suggests that by looking at smaller kiln sites—as well as larger ones—we can investigate their role in the export market, competition, distribution patterns and mechanisms, and the organization of the Chinese economy at the time. Information such as that generated by this project will be useful not only for learning more about the products of each of these areas but also for reconstructing distribution networks in China and investigating how these were linked to larger interregional trade systems using comparative archaeological data terrestrial and other maritime sites.

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REFERENCES

Bao, Y., B. Liao, and L. Lane. 2006. *Renaissance in China: The Culture and Art of the Song Dynasty 907-1279*. Lewiston, NY: The Edwin Mellen Press.

Baxter, M.J. 2001. Multivariate analysis in archaeology. In D.R. Brothwell and A.M. Pollard (eds.), *Handbook of Archaeological Sciences*, pp. 685-694. Chichester: John Wiley & Sons, Ltd.

Bronson, B. 1997. The iron industry and trade. In W.M. Mathers and M. Flecker (eds.), *Archaeological Recovery of the Java Sea Wreck*, pp. 95-102. Annapolis, MD: Pacific Sea Resources.

Brown, R. 1997a. High-fired ceramics of Song Dynasty China: the Java Sea cargo in context. In W.M. Mathers and M. Flecker (eds.), *Archaeological Recovery of the Java Sea Wreck*, pp. 103-109. Annapolis, MD: Pacific Sea Resources.

Brown, R. 1997b. Thirteenth century potting techniques: as evidenced by the Java Sea cargo. In W.M. Mathers and M. Flecker (eds.), *Archaeological Recovery of the Java Sea Wreck*, pp. 110-115. Annapolis, MD: Pacific Sea Resources.

Chaudhuri, K.N. 1985. *Trade and Civilisation in the Indian Ocean: An Economic History from the Rise of Islam to 1750*. Cambridge: Cambridge University Press.

Deng, G. 1997. *Chinese Maritime Activities and Socioeconomic Development, c. 2100 B.C.-1900 A.D.* Westport, CT: Greenwood Press. Volume 188.

Descantes, C., H. Neff, and M.D. Glascock. 2002. Yapese prestige goods: the INAA evidence for an Asian dragon jar. In M.D. Glascock (ed.), *Geochemical Evidence for Long-distance Exchange*, pp. 229-256. Scientific Archaeology for the Third Millennium Series. Westport, CT: Bergin and Garvey.

Diem, A.I. 2004. Ceramic evidence of ancient maritime relationships between central Viet Nam and the Philippine archipelago. In V. Paz (ed.), *Southeast Asian Archaeology: Wilhelm G. Solheim II Festschrift*, pp. 463-490. Diliman, Quezon City, Philippines: The University of the Philippines Press.

Dizon, E.Z. 2011.Shipwreck site and earthenware vessels in the Philippines: earthenware vessels of the *Pandanan Shipwreck* site, *Asia-Pacific Regional Conference on Underwater Cultural Heritage*. Manila, Philippines: Museum of Underwater Archaeology.

Dreyer, E.L. 2007. *Zheng He: China and the Oceans in the Early Ming Dynasty, 1405-1433*. New York: Pearson Longman.

Dunn, R.E. 1989. *The Adventures of Ibn Battuta: A Muslim Traveler of the 14th Century*. Berkeley: University of California Press.

Dupoizat, M.-F. 1995. The ceramic cargo of a Song Dynasty junk found in the Philippines and its significance in the China-South East Asia trade. In R. Scott and J. Guy (eds.), *South East Asia and China: Art, Interaction and Commerce*, pp. 205-224. London, England: Percival David Foundation of Chinese Art.

Dussubieux, L. , M. Golitko, P.R. Williams, and R.J. Speakman. 2007. LA-ICP-MS analysis applied to the characterization of Peruvian Wari ceramics. In M.D. Glascock, R.J. Speakman, and R.W. Popelka-Filcoff (eds.), *Archaeological Chemistry: Analytical Techniques and Archaeological Interpretation*, pp. 349-363. Oxford: Oxford University Press.

Eerkens, J.W., H. Neff, and M.D. Glascock. 2002. Ceramic production among small-scale and mobile hunters and gatherers: a case study from the Western Great Basin. *Journal of Anthropological Archaeology* 21(2):200-229.

Flecker, M. 2001. A ninth-century AD Arab or Indian shipwreck in Indonesia: first evidence for direct trade with China. *World Archaeology* 32(3):335-354.

Flecker, M. 2003. The thirteenth-century *Java Sea Wreck*: a Chinese cargo in an Indonesian ship. *The Mariner's Mirror* 89(4):388-404.

Flecker, M. 2005.The advent of Chinese sea-going shipping: a look at the shipwreck evidence, *International Conference: Chinese Export Ceramics and Maritime Trade, 12th - 15th Centuries, Hong Kong, June 24-25, 2004*, pp. 143-162. Hong Kong: City University of Hong Kong.

Flecker, M. 2005-2006. Rescue excavation: the Java Sea Wreck. *Heritage Asia* 3(2):25-29.

Fox, R.B., and A. Legaspi. 1977. *Excavations at Santa Ana*. Manila: National Museum Publications.

Glascock, M.D., H. Neff, and K.J. Vaughn. 2004. Instrumental neutron activation analysis and multivariate statistics for pottery provenance. *Hyperfine Interactions* 154:95-105.

Grave, P., L. Lisle, and M. Maccheroni. 2005. Multivariate comparison of ICP-OES and PIXE/PIGE analysis of East Asian storage jars. *Journal of Archaeological Science* 32:885-896.

Guy, J.S. 1986. *Oriental Trade Ceramics in South-East Asia Ninth to Sixteenth Centuries*. Singapore: Oxford University Press.

Hall, K.R. 1985. *Maritime Trade and State Development in Early Southeast Asia*. Honolulu: University of Hawaii Press.

Hall, K.R. 1999. Economic history of early Southeast Asia. In N. Tarling (ed.), *Cambridge History of Southeast Asia, Volume 1, from Early Times to c. 1500*, pp. 183-275. Cambridge: Cambridge University Press.

Hall, K.R. 2011. *A History of Early Southeast Asia: Maritime Trade and Societal Development, 100-1500*. Lanham, MD: Rowman & Littlefield Publishers, Inc.

Hall, K.R., and J.K. Whitmore. 1976. Southeast Asian trade and the isthmian struggle, 1000-1200 A.D. In K.R. Hall and J.K. Whitmore (eds.), *Explorations in Early Southeast Asian History: The Origins of Southeast Asian Statecraft*, pp. 303-340. Michigan Papers on South and Southeast Asia. Vol. 11. Ann Arbor: Center for South and Southeast Asian Studies, The University of Michigan.

Ho, C. 1994a. The production and distribution of Zhejiang green glazed wares: preface to the conference proceedings. In C. Ho (ed.), *New Light on Chinese Yue and Longquan Wares: Archaeological Ceramics Found in Eastern and Southern Asia, A.D. 800-1400*, pp. ix-xxvi. Hong Kong: Center of Asian Studies, The University of Hong Kong.

Ho, C. 1994b. Yue-type and Longquan-type green glazed wares made outside Zhejiang Province. In C. Ho (ed.), *New Light on Chinese Yue and Longquan Wares: Archaeological Ceramics Found in Eastern and Southern Asia, A.D. 800-1400*, pp. 103-119. Hong Kong: Center of Asian Studies, The University of Hong Kong.

Hughes-Stanton, P., and R. Kerr. 2000. *Kiln Sites of Ancient China: Recent Finds of Pottery and Porcelain*. London: Oriental Ceramic Society.

Junker, L.L. 1999. *Raiding, Trading, and Feasting: The Political Economy of Philippine Chiefdoms*. Honolulu, HI: University of Hawaii Press.

Junker, L.L. 2004. Political economy in the historic period chiefdoms and states of Southeast Asia. In G.M. Feinman and L.M. Nicholas (eds.), *Archaeological Perspectives on Political Economies*, pp. 223-251. Foundations of Archaeological Inquiry. Salt Lake City: The University of Utah Press.

Kauz, R. (ed.). 2010. *Aspects of the Maritime Silk Road: From the Persian Gulf to the East China Sea*. Wiesbaden: Harrassowitz Verlag.

Kennett, D.J., J. Anderson, M.J. Cruz, G.R. Clark, and G.R. Summerhayes. 2004. Geochemical characterization of Lapita pottery via inductively coupled plasma-mass spectrometry (ICP-MS). *Archaeometry* 46(1):35-46.

Krahl, R. 2010. Chinese ceramics in the late Tang Dynasty. In R. Krahl, J. Guy, K.J. Wilson, and J. Raby (eds.), *Shipwrecked: Tang Treasures and Monsoon Winds*, pp. 56-73. Washington, DC: Arthur M. Sackler Gallery, Smithsonian Institution, National Heritage Board, and Singapore Tourism Board.

Krahl, R., J. Guy, K.J. Wilson, and J. Raby (eds.). 2010. *Shipwrecked: Tang Treasures and Monsoon Winds*. Washington, DC: Arthur M. Sackler Gallery, Smithsonian Institution, National Heritage Board, and Singapore Tourism Board.

Kusimba, C.M. 1999. *The Rise and Fall of Swahili States*. Walnut Creek, CA: Altamira Press.

Leung, P.L., and H. Luo. 2000. A study of provenance and dating of ancient Chinese porcelain by X-ray fluorescence spectrometry. *X-Ray Spectrometry* 29:34-38.

Leung, P.L., M.J. Stokes, T. Chen, and D. Qin. A sudy of ancient Chinese porcelain wares of the Song-Yuan dynasties from Cizhou and Ding kilns with energy dispersive x-ray fluorescence. *Archaeometry* 42(1):129–140.

Li, B., A. Greig, J.-X. Zhao, K.D. Collerson, K.-S. Quan, Y.-H. Meng, and Z.-L. Ma. 2005. ICP-MS trace element analysis of Song Dynasty porcelains from Ding, Jiexiu and Guantai kilns, north China. *Journal of Archaeological Science* 32:251-259.

Li, B., J.-X. Zhao, K.D. Collerson, and A. Greig. 2003. Application of ICP-MS trace element analysis in study of ancient Chinese ceramics. *Chinese Science Bulletin* 48(12):1219-1224.

Li, B., J.-X. Zhao, A. Greig, K.D. Collerson, Y.-X. Feng, X.-M. Sun, M.-S. Guo, and Z.-X. Zhuo. 2006. Characterisation of Chinese Tang sancai from Gongxian and Yaozhou kilns using ICP-MS trace element and TIMS Sr-Nd isotopic analysis. *Journal of Archaeological Science* 33:56-62.

Li, Q. 2009. *Nanhai I and the Maritime Silk Road*. Beijing: China Intercontinental Press.

Manguin, P.-Y. 1993. Trading ships of the South China Sea: shipbuilding techniques and their role in the development of Asian trade networks. *Journal of the Economic and Social History of the Orient* 36:253-280.

Manguin, P.-Y. 2004. The archaeology of early maritime polities of Southeast Asia. In I. Glover and P. Bellwood (eds.), *Southeast Asia: From Prehistory to History*, pp. 282-313. London: RoutledgeCurzon.

Mathers, W.M., and M. Flecker (eds.). 1997. *Archaeological Recovery of the Java Sea Wreck*. Annapolis, MD: Pacific Sea Resources.

Miksic, J. 1997. Historical background. In W.M. Mathers and M. Flecker (eds.), *Archaeological Recovery of the Java Sea Wreck*, pp. 5-33. Annapolis, MD: Pacific Sea Resources.

Miksic, J. Recent research in the southeast Sumatran region, *Asia-Pacific Regional Conference on Underwater Cultural Heritage Proceedings*. Manila, Philippines.

Miksic, J.N., and C.T. Yap. 1992. Compositional analysis of pottery from Kota Cina, north Sumatra: implications for regional trade during the twelth to fourteenth centuries A.D. *Asian Perspectives* 31(1):57-76.

Miksic, J.N., C.T. Yap, and H. Younan. 1994. Archaeology and early Chinese glass trade in Southeast Asia. *Journal of Southeast Asian Studies* 25(1):31-46.

Mino, Y. 1992. Recent finds of Chinese Song and Yuan ceramics. In G. Kuwayama (ed.), *New Perpsectives on the*

Art of Ceramics in China, pp. 14-53. Los Angeles: Far Eastern Council, Los Angeles County Museum of Art.

Mino, Y., and P. Wilson. 1973. *An Index to Chinese Ceramic Kiln Sites from the Six Dynasties to the Present*. Toronto: Royal Ontario Museum.

Neff, H. 1994. RQ-mode principal components analysis of ceramic compositional data. *Archaeometry* 36:115-130.

Nishimura, M. 1992. *Long Distance Trade and the Development of Complex Societies in the Prehistory of the Central Philippines: The Cebu Central Settlement Case*. Doctoral dissertation, Anthropology, University of Michigan, Ann Arbor.

Niziolek, L.C. 2013a. Earthenware production and distribution in the prehispanic Philippine polity of Tanjay: results from laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS). *Journal of Archaeological Science* 40:2824-2839.

Niziolek, L.C. 2013b. Examining changes in the organization of earthenware production in a prehispanic Philippine polity using LA-ICP-MS. *Open Journal of Archaeometry* 1(1):1-15.

Oka, R., L. Dussubieux, C.M. Kusimba, and V.D. Gogte. 2009. The impact of imitation ceramic industries and internal political restrictions on Chinese commercial ceramic exports in the Indian Ocean maritime exchange, ca. 1200-1700, *Scientific Research on Historic Asian Ceramics: Proceedings of the Fourth Forbes Symposium at the Freer Gallery of Art*, pp. 175-185. London: Archetype Publications.

Phillips, J.G. 1956. *China-Trade Porcelain*. Cambridge, MA: Harvard University Press.

Pollard, A.M., and H. Hatcher. 1994. The chemical analysis of Oriental ceramic body compositions: part 1: wares from north China. *Archaeometry* 36(1):41-62.

Reid, A. 1988a. *Southeast Asia in the Age of Commerce 1450-1680, Volume 1: The Lands below the Winds*. New Haven: Yale University Press.

Reid, A. 1988b. *Southeast Asia in the Age of Commerce 1450-1680, Volume 2: Expansion and Crisis*. New Haven: Yale University Press.

Rockhill, W.W. 1913. Notes on the relations and trade of China with the eastern archipelago and the coasts of the Indian Ocean during the fourteenth century. *T'oung Pao* 14(4):473-476.

Rockhill, W.W. 1914. Notes on the relations and trade of China with the eastern archipelago and the coasts of the Indian Ocean during the fourteenth century: part I. *T'oung Pao* 15(3):419-447.

Rockhill, W.W. 1915a. Notes on the relations and trade of China with the eastern archipelago and the coasts of the Indian Ocean during the fourteenth century: part II. *T'oung Pao* 16(2):236-271.

Rockhill, W.W. 1915b. Notes on the relations and trade of China with the eastern archipelago and the coasts of the Indian Ocean during the fourteenth century: part II. *T'oung Pao* 16(4):435-467.

Scott, R.E. 1993. *The Porcelains of Jingdezhen*. London: School or Oriental and Africa Studies, University of London.

Scott, W.H. 1989. *Filipinos in China before 1500*. Manila: China Studies Program, De La Salle University.

Singapore National Heritage Board and National Museum (Singapore). 1995. *The Legacy of Majapahit*. Singapore: National Heritage Board.

So, B.K.L. 1994. The trade ceramics industry of southern Fukien during the Sung Dynasty. *Journal of Sung Yuan Studies* 24:1-19.

So, B.K.L. 2000. *Prosperity, Region, and Institutions in Maritime China: The South Fukien Pattern, 946-1368*. Cambridge, MA: Harvard University Asia Center.

Speakman, R.J., M.D. Glascock, R.H. Tykot, C. Descantes, J.J. Thatcher, C.E. Skinner, and K.M. Lienhop. 2007. Selected applications of laser ablation inductively coupled plasma-mass spectrometry to archaeological research. In M.D. Glascock, R.J. Speakman, and R.W. Popelka-Filcoff (eds.), *Archaeological Chemistry: Analytical Techniques and Archaeological Interpretation*, pp. 275-296. Washington, DC: American Chemical Society.

Tenazas, R.C.P., and K.L. Hutterer. 1968. Preliminary report on the salvage excavation project in Cebu City. In R. Rahmann and G.R. Ang (eds.), *Dr. H. Otley Beyer, Dean of Philippine Anthropology (A Commemorative Issue)*. Cebu City, Philippines: The University of San Carlos Divine Word Press.

The Underwater Research Center of the National Museum of China, The Institute of Cultural Relics and Archaeology of Fujian Museum, and Wuyishan Museum (中国国家博物馆水下考古研究中心， 福建博物院文物考古研究所, and 武夷山市博物馆). 2015. *Wuyishan Old Kiln Sites (武夷山古窑址)*. Beijing (北京): Science Press (科学出版社). [In Chinese.]

Wade, G. 2003. *The Pre-modern East Asian Maritime Realm: An Overview of European-language Studies*. www.ari.nus.edu.sg/docs/wps/wps03_016.pdf.

Wade, G. 2009. An Early Age of Commerce in Southeast Asia, 900-1300 CE. *Journal of Southeast Asian Studies* 40(2):221-265.

Wheatley, P. 1959. Geographical notes on some commodities involved in Sung maritime trade. *Journal of the Malayan Branch of the Royal Asiatic Society* 32(2):1-140.

Wong, W.Y. 2010. *A Preliminary Study of Some Economic Activities of Khmer Empire: Examining the Relationship between the Khmer and Guangdong Ceramic Industries during the 9th to 14th Centuries* Doctoral dissertation, Southeast Asian Studies, National University of Singapore.

Wood, N. 2011. *Chinese Glazes: Their Origins, Chemistry, and Recreation*. London: A & C Black.

Wu, C.H. 1959. A study of references to the Philippines in Chinese sources from earliest times to the Ming Dynasty. *Philippine Social Sciences and Humanities Review* 24:1-181.

Yap, C.T. 1987. X-ray fluorescence studies on low-Z elements of Straits Chinese porcelains using Fe-55 and Cd-109 annular sources. *X-Ray Spectrometry* 16:55-56.

Yap, C.T 1991. EDXRF studies of the Nanking cargo with principal component analysis of trace elements. *Applied Spectroscopy* 45(4):584-587.

Ye, W. 1994. A preliminary discussion of Fujian wares made in imitation of Zhejiang glazed wares. In C. Ho (ed.), *New Light on Chinese Yue and Longquan Wares: Archaeological Ceramics Found in Eastern and Southern*

Asia, A.D. 800-1400, pp. 120-128. Hong Kong: Center of Asian Studies, The University of Hong Kong.

Yu, K.N., and J.M. Miao. 1996. Non-destructive and quantitative investigation of Jingdezhen blue and white porcelains using EDXRF. *Journal of X-ray Science and Technology* 6:167-171.

Yu, K.N., and J.M. Miao. 1997. Locating the origins of blue and white porcelains using EDXRF. *Applied Radiation and Isotopes* 48(7):959-963.

Yu, K.N., and J.M. Miao. 1998. Multivariate analysis of the energy dispersive X-ray fluorescence results from blue and white Chinese porcelains. *Archaeometry* 40(2):331-339.

Zhang, H., Z. Zhao, D. Yang, S. Wang, and W. Guo. 2009. X-ray emission fluorescence (XRF) analysis of origin of raw materials of light dark reddish brown porcelain and porcelain with black flower on a white background of Dangyangyu kiln. *Journal of Radioanalytical and Nuclear Chemistry* 279(1):307-312.

Zhao, R. 2012 [1911].*Chau Jukua his work on the Chinese and Arab trade in the twelfth, and thirteenth centuries, entitled Chu-Fan-Chï.* W.W. Rockhill (ed.). Hong Kong: Forgotten Books.

Zhu, T., H. Huang, H. Wang, L. Hu, and X. Yi. 2011. Comparison of celadon from the Yaozhou and Xicun kilns in the Northern Song Dynasty of China by X-ray fluorescence and microscopy. *Journal of Archaeological Science* 38:3134-3140.

Zhu, T., W. Sun, H. Zhang, G. Kuang, and L. Lu. 2012. Study on the provenance of Xicun qingbai wares from the Northern Song Dynasty of China. *Archaeometry* 54(3):475-488.

Zhu, T., C. Wang, H. Wang, and Z. Mao. 2010. The preliminary study on kiln identification of Chinese ancient qingbai wares by ICP-AES. *Journal of Cultural Heritage* 11:482-486.

APPENDIX 1: Ceramic Sample Information

LA-ICP-MS Sample ID	Material Analyzed	Glaze Color	Paste Texture	Paste Color	Object Description	Form
JSW106	Glaze	Bluish-white	Fine	Sugary white	Qingbai-style box	Box lid
JSW107	Glaze	Bluish-white	Fine	Sugary white	Qingbai-style box	Box lid
JSW108	Glaze	Bluish-white	Fine	Sugary white	Qingbai-style box	Box base
JSW109	Glaze	Bluish-white	Fine	Sugary white	Qingbai-style box	Box lid
JSW110	Glaze	Bluish-white	Fine	Sugary white	Qingbai-style box	Box base
JSW111	Glaze	Bluish-white	Fine	Sugary white	Qingbai-style box	Box base
JSW112	Glaze	Bluish-white	Fine	Sugary white	Qingbai-style box	Box base
JSW113	Glaze	Bluish-white	Fine	Sugary white	Qingbai-style box	Box base
JSW114	Glaze	Bluish-white	Fine	Sugary white	Qingbai-style box	Box base
JSW116	Glaze	Bluish-white	Fine	Sugary white	Qingbai-style box	Box base
JSW117	Glaze	Bluish-white	Fine	Sugary white	Qingbai-style box	Box base
JSW121	Paste	Black slip (some green glaze)	Fine-medium	?	Painted ware box	Box base
JSW122	Paste	Milky white	Fine	Sugary white	Qingbai-style box	Box base
JSW123	Paste	Bluish-white	Fine	Sugary white	Qingbai-style box	Box base
JSW124	Paste	Bluish-white	Fine	Sugary white	Qingbai-style box	Box lid
JSW125	Paste	Light blue	Fine	Sugary white	Qingbai-style (white ware?) vase	Vase
JSW126	Paste	Light blue-aqua	Fine-medium	Cream with dark inclusions	Qingbai ewer	Ewer
JSW127	Paste	Light blue-aqua	Fine-medium	Cream with dark inclusions	Qingbai ewer	Ewer
JSW129	Paste	Black slip with green overglaze	Fine-medium	Purplish-gray	Painted ware ewer	Ewer
JSW131	Paste	Light blue-aqua	Fine-medium	Cream with dark inclusions	Qingbai plate	Saucer
JSW133	Paste	Aqua	Fine	Cream with dark inclusions	Qingbai plate	Shallow dish, saucer, or plate base
JSW134	Paste	Light blue (some greenish tint) to aqua when pooling	Fine-medium	Sugary white	Qingbai-style (white ware) vase	Vase
JSW135	Paste	Light greenish-gray	Fine	Light gray	Green-glazed bowl	Bowl
JSW136	Paste	Aqua	Fine-medium	Cream with dark inclusions	Qingbai plate	Saucer?
JSW137	Paste	Light blue-aqua	Fine-medium	Cream with dark inclusions	Qingbai plate	Saucer
JSW138	Paste	Aqua	Fine	Cream	Qingbai plate	Shallow dish?
JSW139	Paste	Aqua	Fine-medium	Cream with dark inclusions	Qingbai ewer	Ewer
JSW151	Paste	Aqua	Fine	White	Qingbai plate	Shallow dish?
JSW152	Paste	Light blue-aqua	Fine-medium	Cream with dark inclusions	Qingbai plate	Saucer or plate base
JSW153	Paste	Aqua	Fine	White	Qingbai plate	Shallow dish?
JSW154	Paste	Light blue	Fine-medium	Cream with dark inclusions	Green-glazed bowl	Bowl
JSW156	Paste	Light blue-aqua (translucent)	Fine	Sugary white	Qingbai plate	Shallow dish
JSW157	Paste	Light blue-aqua (translucent)	Fine	Sugary white	Qingbai plate	Shallow dish
JSW158	Paste	Weathered green glaze over black slip	Fine-medium	Dirty cream	Painted ware ewer	Ewer
JSW159	Paste	Weathered green glaze over black slip	Fine-medium	Sugary white	Painted ware bowl	Bowl
JSW160	Paste	Weathered green glaze over black slip	Fine-medium	Bright white	Painted ware jar	Jar
JSW161	Paste	Light blue-aqua (translucent)	Fine	Sugary white	Qingbai bowl	Bowl

LA-ICP-MS Sample ID	Material Analyzed	Glaze Color	Paste Texture	Paste Color	Object Description	Form
JSW163	Paste	Light blue-aqua (translucent)	Fine	Sugary grayish-white	Qingbai bowl	Bowl
JSW164	Paste	Weathered green glaze over black slip	Fine-medium	Dirty cream	Painted ware ewer	Ewer
JSW165	Paste	Weathered green glaze over black slip	Fine-medium	White?	Painted ware bowl	Bowl
JSW168	Paste	Light blue-aqua (translucent)	Fine	Sugary white	Qingbai plate	Shallow dish
JSW169	Paste	Weathered green glaze over black slip	Fine-medium	Gray	Painted ware ewer	Ewer
JSW170	Paste	Weathered green glaze	Fine-medium	Purplish-gray	Painted ware ewer	Ewer
JSW171	Paste	Weathered green glaze over black slip	Fine-medium	Sugary white	Painted ware ewer	Ewer
JSW173	Paste	Weathered green glaze over black slip	Fine-medium	Sugary white	Painted ware bowl	Bowl
JSW174	Paste	Weathered green glaze over black and white slip	Fine-medium	Gray	Painted ware ewer	Ewer
JSW176	Glaze	Light blue-aqua	Fine-medium	Cream with dark inclusions	Qingbai ewer	Ewer
JSW178	Glaze	Aqua	Fine	Bright white	Qingbai plate	Shallow dish?
JSW180	Glaze	Aqua	Fine-medium	Cream with dark inclusions	Qingbai plate	Saucer
JSW183	Glaze	Light blue-aqua	Fine-medium	Cream with dark inclusions	Qingbai ewer	Ewer
JSW184	Glaze	Aqua	Fine-medium	Cream with dark inclusions	Qingbai ewer	Ewer
JSW185	Glaze	Light blue-aqua (translucent)	Fine	Sugary white	Qingbai plate	Shallow dish
JSW186	Glaze	Aqua	Fine	White	Qingbai plate	Shallow dish?
JSW188	Paste	Light blue	Fine	Sugary white	Qingbai-style (white ware) vase	Vase
JSW189	Paste	Light blue-aqua	Fine-medium	Cream with dark inclusions	Qingbai plate	Saucer
JSW190	Paste	Light blue-aqua	Fine-medium	Cream with dark inclusions	Qingbai plate	Saucer or plate base
JSW191	Paste	Aqua	Fine	Bright white	Qingbai plate	Shallow dish?
JSW192	Paste	Qingbai	Fine-medium	?	Qingbai plate	Shallow dish
JSW193	Paste	Light blue-aqua	Fine-medium	Cream with dark inclusions	Qingbai vase	Vase
JSW194	Paste	Aqua	Fine-medium	Cream with dark inclusions	Qingbai plate	Saucer
JSW195	Paste	Light blue-aqua	Fine-medium	Cream with dark inclusions	Qingbai ewer	Ewer
JSW196	Paste	Light greenish-gray	Fine-medium	White with dark inclusions	Green-glazed bowl	Bowl
JSW197	Paste	Black slip with green overglaze	Fine-medium	Pale gray	Painted ware ewer or vase	Ewer or vase
JSW198	Paste	Light greenish gray	Fine	Sugary white	Green-glazed bowl	Bowl
JSW199	Paste	Light-medium olive-green	Fine	Lavender gray	Green-glazed bowl	Bowl
JSW200	Paste	Light olive-green	Fine	Lavender gray	Green-glazed bowl	Bowl
JSW201	Paste	Qingbai weathered to tan		Cream with thin gray core	Qingbai bowl	Bowl
JSW202	Paste	Light grayish-green	Fine	Sugary white	Green-glazed bowl	Bowl
JSW203	Paste	Light greenish gray	Fine	Sugary white	Green-glazed bowl	Bowl
JSW204	Paste	Light greenish gray	Fine	Sugary white	Green-glazed bowl	Bowl
JSW205	Paste	Light olive-green	Fine	Lavender gray	Green-glazed bowl	Bowl
JSW206	Paste	Light-medium olive-green	Fine	Lavender gray	Green-glazed bowl	Bowl

LA-ICP-MS Sample ID	Material Analyzed	Glaze Color	Paste Texture	Paste Color	Object Description	Form
JSW207	Paste	Light blue-aqua	Fine	Sugary white	Qingbai-style bowl	Bowl
JSW208	Paste	Light-medium bluish-olive-green	Fine	Lavender gray	Green-glazed bowl	Bowl
JSW209	Glaze	Light blue	Fine	Sugary white	Qingbai-style (white ware) vase	Vase
JSW211	Glaze	Light-medium bluish-olive-green	Fine	Lavender gray	Green-glazed bowl	Bowl
JSW212	Glaze	Light blue-aqua	Fine	Sugary white	Qingbai-style bowl	Bowl
JSW213	Glaze	Light blue-aqua	Fine-medium	Cream with dark inclusions	Qingbai plate	Saucer or plate base
JSW214	Glaze	Light blue-aqua	Fine-medium	Cream with dark inclusions	Qingbai vase	Vase
JSW219	Glaze	Light greenish gray	Fine	Sugary white	Green-glazed bowl	Bowl
JSW220	Glaze	Light greenish gray	Fine	Sugary white	Green-glazed bowl	Bowl
JSW900	Paste	Aqua	Fine-medium	Cream with dark inclusions	Qingbai plate	Saucer
JSW901	Paste	Black slip with green overglaze	Fine-medium	Grayish lavender	Painted ware vase	Vase
JSW902	Paste	Aqua	Fine-medium	Cream	Qingbai ewer	Ewer
JSW904	Paste	Weathered green glaze over black slip	Fine-medium	Gray	Painted ware ewer	Ewer
JSW905	Glaze	Bluish-white	Fine	Sugary white	Qingbai-style box	Box lid
JSW906	Glaze	Bluish-white	Fine	Sugary white	Qingbai-style box	Box lid
JSW907	Glaze	Bluish-white	Fine	Sugary white	Qingbai-style box	Box lid
JSW908	Glaze	Light blue-aqua	Fine-medium	Cream with dark inclusions	Qingbai plate	Saucer
JSW909	Glaze	Light blue-aqua	Fine-medium	Cream with dark inclusions	Qingbai plate	Saucer or plate base
JSW910	Glaze	Light blue-aqua	Fine-medium	Cream with dark inclusions	Qingbai plate	Shallow dish