Jomon Pottery Production in Central Japan

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UNLIKE MANY OTHER PREHISTORIC HUNTER-GATHERER CULTURES, the Jomon culture (c. 12,500–2300 B.P.) in Japan is characterized by the production and use of pottery (Pearson 1990, 1992). The great antiquity of Jomon pottery, the oldest of which is dated to 12,700 B.P., has attracted the attention not only of archaeologists working on East Asia but also researchers who investigate the origins of pottery in world prehistory. Nevertheless, for many Japanese archaeologists, the primary goal of studying Jomon pottery has been to establish a detailed chronology of the Jomon period. From the pioneering studies of Yamanouchi (1937, 1939, 1964) to the present, typological study of pottery has figured predominantly in the investigation of the Jomon culture. Since Yamanouchi's initial classification, pottery types have been further subdivided, and these units have subsequently been further refined. Today, most Jomon researchers agree on a basic typological ordering of Jomon pottery (see the chronological table in Kobayashi 1992:88, but see Hudson and Yamagata 1992 for various approaches to typological and/or stylistic analyses of Jomon pottery adopted by Japanese archaeologists).

While many Jomon archaeologists have been working on chronological studies of pottery, relatively few attempts have been made to analyze pottery in connection with the study of Jomon subsistence, settlement, and society. Through the course of the development of chronological studies, researchers have noticed that stylistic characteristics of pottery not only change through time but also differ between regions, thus forming distinct regional stylistic zones (e.g., Kamaki 1965). Each stylistic zone covers a substantially large area, some of which measure hundreds of square kilometers large and include thousands of sites from a specific time period within the Jomon. Because some of these sites are several hundred kilometers apart, it is very unlikely that all these sites were left by the same people. Many Jomon archaeologists therefore assume that each style zone represents a confederation of groups of people, or "tribes," who shared a common cultural and/or social identity (Kobayashi 1992; Yamanouchi 1969). Unfortunately, however, most of the discussions on the interpretations of style zones do not go beyond these general statements. Consequently, many questions regarding the production and circulation of Jomon pottery remain unanswered.

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Asian Perspectives, Vol. 38, No. 1, © 1999 by University of Hawai'i Press.

One way to approach the issues of pottery production and circulation is through the chemical analysis of pottery (Orton et al. 1993; Pollard and Heron 1996). The principal raw material for manufacturing pottery is clay. The chemical composition of raw clay is a function of the parent materials from which the clay was derived; thus, clays from different regions tend to show different chemical characteristics. Furthermore, the chemical characteristics of raw clay do not change significantly after it is fired (Cogswell et al. 1996). Therefore, if no temper is present, we can assume that variation in the chemical composition of pottery is due to the regional variation in clay source material. Although the addition of tempers and the removal of impurities from the clays may alter the chemical signature and preclude sourcing it to a specific clay source, it does not prevent the analyst from identifying unique compositional groups (Kilikoglou et al. 1988; Neff et al. 1988; Neff et al. 1989). Thus, demonstrated differences in the chemical composition between separate pieces of pottery can be used to discern regional clay sources and/or different "production workshops" (Costin 1991; Steponaitis et al. 1996; Wilson 1978).

In Japanese archaeology, chemical analyses of pottery have made significant progress over the past decade in the field of protohistoric and historic archaeology. Both energy dispersive X-ray fluorescence (EDXRF) and instrumental neutron activation analyses (INAA) have proved useful for identifying the provenience of ceramics excavated from protohistoric and historic sites (Habu 1989; Mitsuji 1986, 1995, Ninomiya et al. 1991). In these successful case studies, however, the ceramic samples examined were all kiln-made and mass-produced, and both production sites (i.e., kiln sites) and consumer sites have been identified and excavated by archaeologists. Thus, researchers were able to identify the provenience of ceramic samples from consumer sites by comparing their chemical composition with that of samples from kiln sites.

Contrary to the steady progress in chemical analyses of protohistoric and historic ceramics in Japan, application of EDXRF and INAA to prehistoric (i.e., Jomon and Yayoi) pottery has been relatively limited. Initial work has been done by Ishikawa (1988, 1989), Mitsuji and Inoue (1984), and Ninomiya et al. (1990). Unlike ceramics from the later periods, Jomon and Yayoi pottery is believed to have been open-air fired without any permanent firing facilities (Arai 1973; Goto 1983). As a result, no comparative samples from production sites are available. This drawback has made the interpretation of the results of chemical analyses of Jomon and Yayoi pottery significantly more difficult. In the case of Jomon pottery, the pottery may have been circulated through exchange and/or may have been transported as a result of residential or logistical moves (for discussions on Jomon residential mobility, see Habu 1995, 1996).

Despite this limitation, we suggest that the potential of chemical analyses of Jomon pottery should be further pursued. In particular, we believe that variability in the chemical composition of Jomon pottery within a single style zone, as well as between style zones, should be examined more systematically. Stylistic analyses will not tell us whether potsherds from each site were locally made or introduced from other regions within the same style zone, since potsherds recovered from a single style zone share similar stylistic attributes. On the other hand, chemical analyses of pottery might provide us with different kinds of information, some of which might be critical to distinguish "imported" pots from locally made ones.

Because of the lack of comparative data, we decided that our first task should be to examine whether statistically significant differences exist between potsherds excavated from sites in different regions within a single style zone. Potsherd samples were taken from three Jomon sites dating primarily to the Moroiso phase (early Jomon; c. 5000 B.P.) in central Japan. If the Jomon settlements considered here produced and utilized much of their own pottery, we should expect to find statistically significant differences in the chemical composition between potsherds from different sites. If there are no statistically significant differences, then we can assume that (1) the Jomon potters utilized raw materials that were geochemically similar, or (2) pottery was part of a trade/exchange/redistribution network between Jomon settlements. To explore these hypotheses, the methodology advocated by Vitali and co-workers (Vitali and Franklin 1986; Vitali et al. 1987), utilizing discriminant functions and multivariate analysis of variance (MANOVA), is employed. This methodology is well suited for looking at the chemical variation between sites, ware types, and time periods, and determining the most discriminating elements. As long as the data are normal, this technique is quite robust (Vitali and Franklin 1986). However, MANOVA and discriminant analysis, like any other statistical techniques, do have their limitations. Unlike ordination methods, such as principal component analysis (PCA), correspondence analysis (CA), and cluster analysis, this methodology cannot determine the number of groups in a given data set. The number of groups must be assumed a priori.

GEOGRAPHICAL AND CULTURAL SETTINGS

The archaeological data examined here are primarily from the Moroiso phase of the early Jomon period. "Moroiso" refers to a style of early Jomon pottery distributed throughout the Chubu region and the southern and northwestern parts of the Kanto region in Japan. Radiocarbon dating indicates that Moroiso-style pottery was used around 5000 B.P. (Keally and Muto 1982). The area enclosed by the dotted line in Figure 1 shows the approximate distribution range of sites with which Moroiso-style pottery is dominantly associated. Although distribution of Moroiso-style potsherds extends to the outside of the enclosed area, other styles of pottery contemporaneous to Moroiso-style pottery tend to dominate pottery assemblage in the other areas. On the northeastern side of the Moroiso-style zone, Ukishima and Okitsu styles of pottery tend to dominate the assemblages (Nishimura 1986). Across the southwestern border, Kita-Shirakawa–style pottery is commonly found.

The Moroiso-style zone roughly corresponds to six present-day prefectures: Gumma, Saitama, Tokyo, Kanagawa, Yamanashi, and Nagano. Although the exact number of Moroiso phase sites within the stylistic zone is unknown, more than 1000 Moroiso phase sites have been reported from the six prefectures (Habu 1995). These sites include large settlements associated with several dwellings, small settlements with only a few dwellings, open sites with no significant features, shell middens, cemeteries, and rock shelters.

The Moroiso phase has traditionally been divided into three subphases based on typological chronology of pottery (Yamanouchi 1937, 1939). These subphases are Moroiso-A -B, and -C, from the oldest to the youngest. While recent studies indicate that more detailed subdivisions are possible, the conventional three divi-

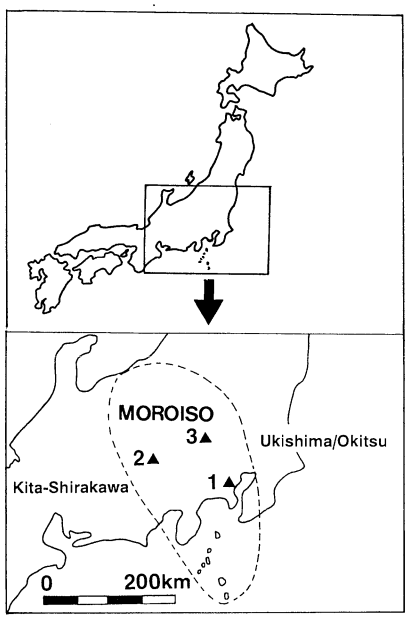

Fig. 1. Map of central Japan and sites mentioned in the text: 1, Takada; 2, Tenjin; 3, Takenohana.

sions will be used in this study (for examples of Moroiso-style pottery, see Fig. 10 in Habu 1995). The exact duration of the Moroiso phase is yet to be determined. For the moment, it can be estimated that the Moroiso phase probably lasted for about 200 to 300 years (Habu 1995 : 204).

The areal distribution of Moroiso pottery does not correspond to a particular environmental zone. It includes both coastal and inland areas, which indicates possible variability in adaptive strategies among the Moroiso-phase people. Furthermore, analyses of settlement pattern data from this phase indicate that, generally speaking, the people of the Moroiso phase were relatively sedentary, although they did not necessarily remain in the same settlement throughout the year (Habu 1995, 1996). The only possible exception is the settlement system of the Moroiso-C subphase in the Kanto region: during this subphase, all the large settlements disappeared from the Kanto region (Habu 1996), and the settlement patterns became very similar to that of mobile "foragers" (Binford 1980).

Very few studies have been conducted on the production and circulation of Moroiso pottery. One of the few exceptions is the petrographic study of Moroiso and Ukishima styles of pottery by Kojo (1981). The results of his study indicate that, in many cases, at least 20–30 percent of the Moroiso style pottery in each site was nonlocally made. Based on this result, Kojo suggests that, although independent pottery production was carried out by each "social unit," long-distance pottery movement has also taken place. Kojo points out that the cause of the pottery movement could be either the intersite migration of the possessor of the pottery or the mere movement of pottery alone, and suggests that further study will be necessary.

The fact that Kojo (1981) was able to distinguish "imported" pottery from locally made pottery on the basis of petrological analysis is encouraging for those

who try to use fabric analysis to study Jomon pottery. His results are particularly interesting in that they revealed the common presence of "imported" pottery at each Moroiso phase site. However, since Kojo's study does not include samples from the Chubu region, his study does not tell us whether the movement of pottery between the Kanto and Chubu regions took place. Furthermore, since his paper does not give us the description of detailed stylistic characteristics of each potsherd sample, it is difficult to interpret his results in relation to the stylistic characteristics of each potsherd.

ARCHAEOLOGICAL MATERIALS

In this study, 61 Jomon potsherd samples were selected for EDXRF analysis (Fig. 2, nos. 1–43 and Fig. 3, nos. 1–18). These potsherds were recovered from three sites, all located within the Moroiso-style zone: the Takada shell midden, the Tenjin site, and the Takenohana site (the location of each site is indicated in Fig. 1). The largest number of samples for the EDXRF analysis were taken from the Takada shell midden. The site is located in Yokohama City, Kanagawa Prefecture. Although the site has been known since the late nineteenth century (Inoue and Torii 1893), no large-scale excavation of the site has taken place to date. Results of previous surveys and small excavations (Chikamori 1955; Esaka 1972*a*, 1972*b*) indicate that the site area includes several small shell middens, most of which are dated to the Moroiso phase. A rescue excavation by Keio University (Esaka 1972*a*, 1972*b*) revealed the presence of a pit dwelling from the Moroiso phase. Because of the large amount of artifacts found through surface surveys, it is expected that numerous unrecovered pit dwellings are associated with the site. A small amount of middle and late Jomon potsherds has also been reported from the site.

The ink rubbings and profiles of potsherd samples from the Takada shell midden are illustrated in Figure 2. These potsherds were excavated by an excavation team of Keio University in 1971 (Esaka 1972*a*, 1972*b*) and are currently being studied at the Asian Archaeology Laboratory at the University of California, Berkeley. These samples include 13 Moroiso-A sherds (Fig. 2, nos. 1–13), 13 Moroiso-B sherds (Fig. 2, nos. 14–26), and two Moroiso-C sherds (Fig. 2, nos. 37 and 38). Samples illustrated in Figure 2, nos. 27–36 are decorated only with cord marks or have no decorations: these can be identified as either from the Moroiso-A or -B subphases, but the specification of subphases was not possible. Besides these 38 samples dated to the Moroiso phase, five samples from the middle and late Jomon periods were also analyzed (Fig. 2, nos. 39–43). All of these potsherds, with the exception of Figure 2, no. 23 and 24, are derived from jars, which were probably used either for cooking or for storage. Figure 2, no. 23 is a part of a small bowl, whereas Figure 2, no. 24 is a rim sherd of a shallow bowl. Several researchers suggest that these forms of pots are used primarily for ceremonial purposes (e.g., Kobayashi 1979).

Potsherd samples from the Tenjin site are shown in Figure 3, nos. 1–12. The site is located at Oizumi Village, Kita-Koma County, Yamanashi Prefecture. A rescue excavation by the Board of Education of Yamanashi Prefecture revealed the presence of a large Jomon settlement associated with 58 pit dwellings and 488 grave pits. Of the 58 Jomon dwellings, 49 are attributed to the Moroiso-B and -C

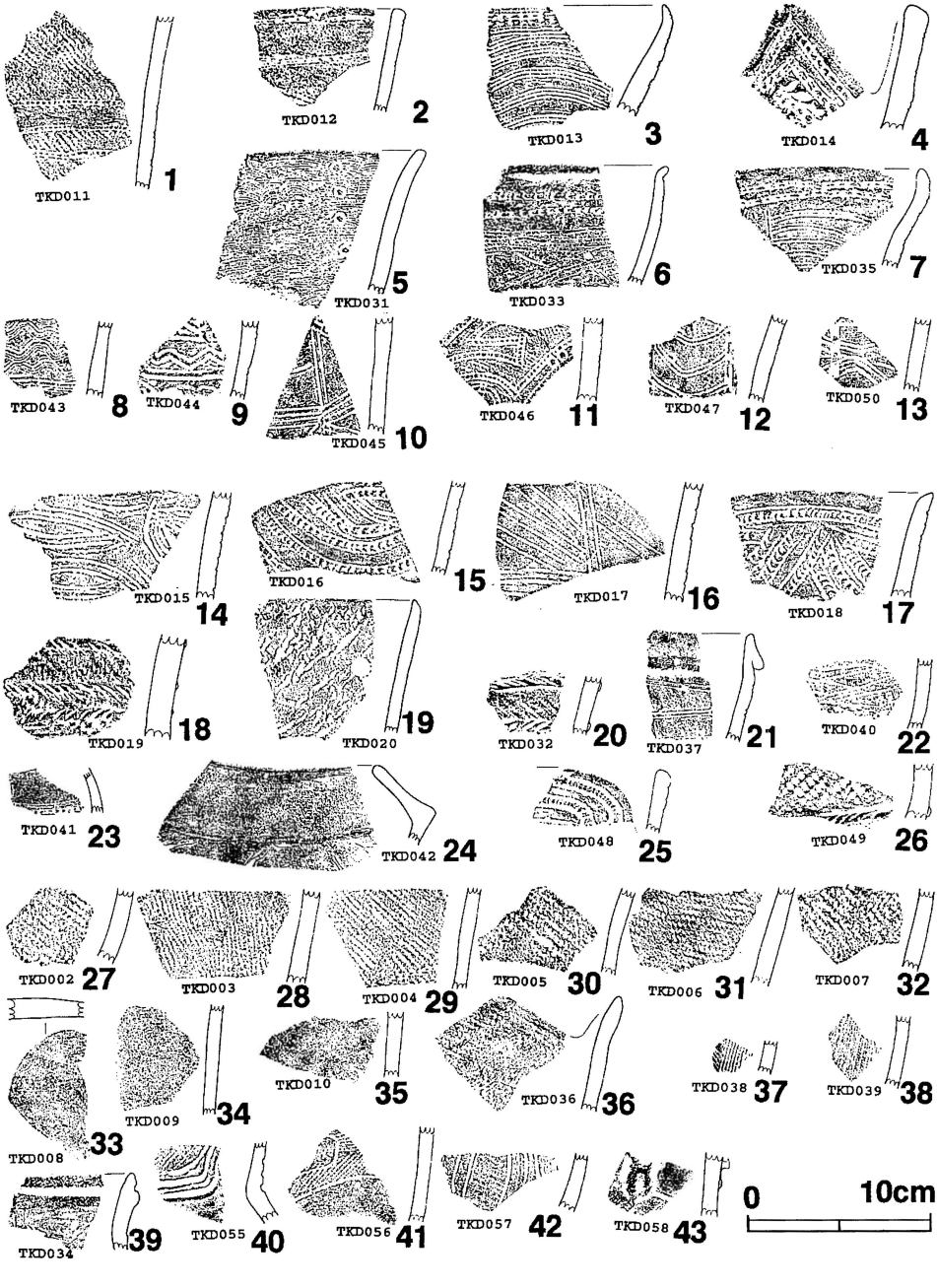

Fig. 2. Rubbings of surface treatment and vessel profiles of the pottery from the Takada site.

subphases. Potsherds from the end of the early Jomon to the beginning of the middle Jomon periods have also been recovered (Archaeological Center of Yamanashi Prefecture 1994).

Samples from the Tenjin site include seven Moroiso-B sherds (Fig. 3, nos. 1–

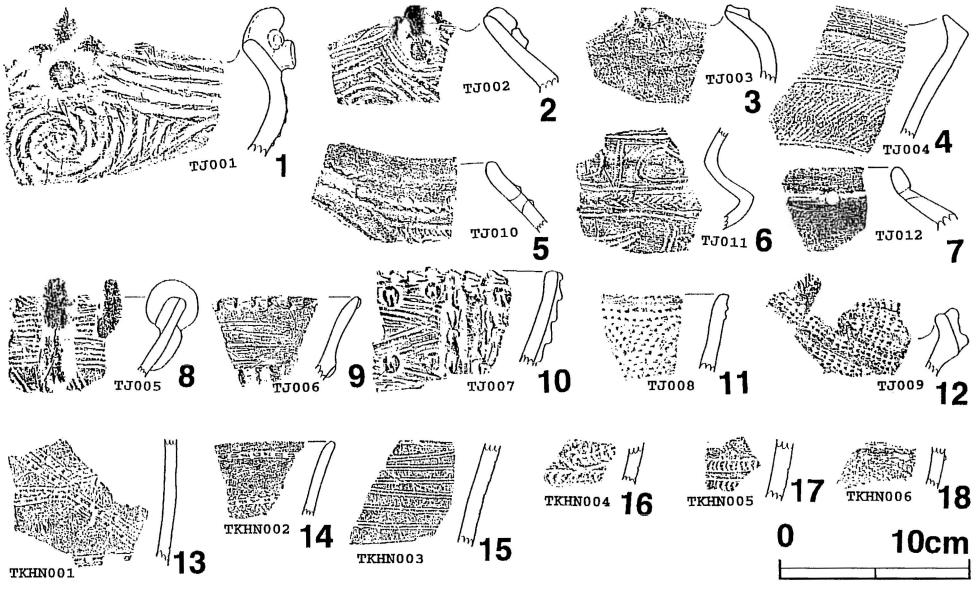

Fig. 3. Rubbings of surface treatment and vessel profiles of the pottery from the Takenohana (TKHN) and Tenjin (TJ) sites.

7), and four Moroiso-C sherds (Fig. 3, nos. 8–11). In addition, a potsherd dating to the early Jomon Jusanbodai phase, which follows immediately after the Moroiso phase, was also analyzed (Fig. 3, no. 12). Figure 3, nos. 5, 6, and 7 are sherds of shallow bowls. The rest of the samples are probably derived from jars. These samples were provided by the courtesy of the Archaeological Center of Yamanashi Prefecture.

Figure 3, nos. 13–18 are potsherd samples from the Takenohana site. The site is located at Kawamoto Town, Osato County, Saitama Prefecture (Archaeological Research Foundation of Saitama Prefecture 1991). Samples from the Takenohana site are all from the Moroiso phase. Figure 3, nos. 13–15 are from the Moroiso-A subphase, whereas Figure 3, nos. 16–18 are from the Moroiso-B subphase. The six sherds from the Takenohana site are all derived from jars. These potsherds were provided by the courtesy of the Archaeological Research Foundation of Saitama Prefecture.

COMPOSITIONAL ANALYSIS

Methodology

While not as popular as INAA for ceramic analysis, EDXRF is a low-cost, nondestructive, rapid technique for determining the minor and trace element composition of prehistoric pottery (Culbert and Schwalbe 1987; Pollard and Højlund 1983; Yap and Tang 1984). EDXRF can accurately measure elements with atomic numbers 11 through 41 and some of the rare earth elements (Hampel 1984:21, 22; Potts 1987:312, 313).

The elemental analyses were performed using a Spectrace 440 EDXRF machine equipped with a rhodium X-ray tube and a Tracor TX 6100 X-ray analyzer. The X-ray tube was operated at 30 kV, 20 mA in vacuum at 250 seconds livetime to generate X-ray intensity Kα line data for the elements copper (Cu), gallium (Ga), iron (Fe), lead (Pb), manganese (Mn), nickel (Ni), niobium (Nb), rubidium (Rb), strontium (Sr), thorium (Th), titanium (Ti), yttrium (Y), zinc (Zn), and zirconium (Zr). The X-ray beam size was 0.50–0.75 cm in diameter. X-ray intensity Kα line data for barium (Ba) and cerium (Ce) were generated by using a ^{241}Am gamma-ray source for 500 seconds livetime in an air path. The X-ray intensities are converted to concentration values using a Compton scatter matrix correction and the linear regression of a set of Japan Geological Survey (JGS), National Bureau of Standards (NBS), National Institute of Standards and Technology (NIST), and United States Geological Survey (USGS) mineral standards. Inter-element effects are accounted for by using a Lucas-Tooth and Price (1961) correction.

The detection limits, as determined on geological standards (Shackley 1995), are as follows (all values are listed in parts per million [ppm]): Ba 20 ppm; Ce 20 ppm; Cu 10 ppm; Fe 10 ppm; Ga 7.8 ppm; Mn 40 ppm; Nb 8 ppm; Ni 10 ppm; Pb 8 ppm; Rb 5 ppm; Sr 3.5 ppm; Th 9 ppm; Ti 23 ppm; Y 7 ppm; Zn 4 ppm; and Zr 7 ppm. A comparative study between the EDXRF facility at Berkeley with the Research Reactor Facility at the University of Missouri shows that EDXRF can obtain the same sensitivity, precision, and accuracy as INAA for the alkali, akaline earth, and transition metals in silicic materials (Shackley 1998).

Standards of known composition were run with the unknowns. The results are presented in Appendix I. The analytical accuracy, following the definition of Bishop et al. (1990), for most elements is 15 percent or less. The precision, also following Bishop et al. (1990), is 10 percent or less.

Permission was not obtained for destructive EDXRF analysis to be done on all the potsherds. Before irradiation, each potsherd was rinsed with distilled, deionized water, then scrubbed with a nylon brush, and then rinsed with distilled, deionized water again. The sherds were allowed to air dry. All analyses were done on a clean, ceramic surface. Other than sample number TJ005, none of the sherds appeared to be slipped or painted.

Because EDXRF is in essence a method of surface analysis, postdepositional chemical alteration could be a problem. However, the authors here do not see this as a major concern. Raw clay has a cation exchange capacity of only 1 to 5 percent (Hedges and McLellan 1976). Fired clay has a much lower cation exchange capacity. Because of this, some authors assert that the trace element concentrations are not significantly altered by postdepositional processes (Bishop et. al. 1982; Hedges and McLellan 1976). The few studies done on this matter indicate that the barium (Ba), calcium (Ca), iron (Fe), magnesium (Mg), manganese (Mn), phosphorus (P), potassium (K), and sodium (Na) contents can be altered by postdepositional processes (Freeth 1967; Hedges and McLellan 1976; Pollard and Heron 1996; Tubb et al. 1980).

The MANOVA and discriminant analysis results were obtained using SPSS Release 6.0.1 for Windows 3.1. All cross-validation was done in MINITAB Release 8 for DOS.

TABLE 1. MULTIVARIATE ANALYSIS OF VARIANCE RESULTS

TEST NAME	VALUE	APPROXIMATE F VALUE	DEGREES OF FREEDOM	SIGNIFICANCE OF F	ETA SQUARED VALUE
Pillias	1.29	6.03	28	.000	0.65
Hotelling's	4.82	7.58	28	.000	0.71
Wilk's	0.10	6.78	28	.000	0.68

Note. The F-statistics of the MANOVA test indicate that the results are significant at the 99 percent confidence level. The eta statistics indicate that nearly two-thirds of the variability in the chemical data is accounted for by site location.

Compositional Data and Analysis

Appendix II contains the chemical compositions for each sherd. All values are listed in parts per million (ppm). The chemical concentrations were transformed to log base 10 values. For cases below the detection limit, one-half the detection limit was used in the transformation and subsequent data analysis. Not only does the log transformation compensate for the differences in magnitude between the minor and trace elements, it also "normalizes" the data. Except for Y, the kurtosis ranges from 0.01 to 4.00 and the skewness is between −1.5 and 2.0.

A multivariate analysis of variance (MANOVA) is performed to see if the population means of 14 chemical variables (Ba, Ce, Fe, Ga, Mn, Nb, Ni, Pb, Rb, Sr, Th, Ti, Zn, and Zr) are the same for the three sites. The Y content was not used in MANOVA because it deviates from normality; the MANOVA test assumes all dependent variables are normally distributed. Table 1 contains the results for three different measures of multivariate difference. The resultant F values, defined as the ratio of between-group variance to within-group variance, are significant and indicate that the population means for the 14 chemical variables are different for the three sites. The η-squared statistic indicates that the site location accounts for nearly two-thirds of the variability in the data.

The multivariate variances due to the temporal characteristics are not statistically significant for this data set. This may be because of the paucity of samples from time periods later than the Moroiso-A and -B subphases.

Discriminant analysis (see Baxter 1994*a*: 185–218; 1994*b*) was done to assess the separation between the three sites and to see which subset of variables separates the three groups best. In linear discriminant analysis, it is assumed that unique groups exist in the data, and linear combinations of variables are sought that maximize the differences between groups. Stepwise discriminant analysis adds or deletes variables to a set of criteria so that group separation is maximized. This method results in the removal of variables that can blur distinctions between the groups. As noted by Baxter (1994*a*: 201–204, 1994*b*), both of these methods can provide an "overoptimistic" success rate. A more realistic classification rule is obtained by using a cross-validation or "jack-knifing" algorithm. In this process, a case is allocated to a group on the basis of the discriminant functions that are calculated omitting it.

Linear discriminant analysis with all the variables entered at once results in 98.4 percent of the cases being correctly classified. Linear discriminant analysis with

TABLE 2. MISCLASSIFIED CASES FROM LINEAR DISCRIMINANT ANALYSIS WITH CROSS-VALIDATION, SHOWING GROUPS TO WHICH THEY WERE ASSIGNED

SPECIMEN NUMBER	PREDICTED GROUP
TJ001	Takada
TJ005	Takenohana
TKD011	Tenjin
TKD038	Takenohana
TKD040	Tenjin
TKD048	Takenohana
TKHN002	Tenjin
TKHN005	Takada

cross-validation using all 15 variables resulted in only 86.9 percent of the cases being correctly classified. The results of the cross-validation test are in Table 2. Stepwise discriminant analysis was done to see which subset of variables were the most important discriminators. For a probability of F-to-enter of 0.05, a probability of F-to-remove equal to 0.1 and maximizing the Mahalanobis distance between groups, the stepwise discriminant analysis identified Fe, Ni, Pb, Sr, Y, and Zn as the most important discriminators. Depending on whether the prior probabilities or equal probabilities for group membership and the within-group or separate-group covariance matrices were used, the stepwise discriminant analysis correctly classified 95.8–98.4 percent of the cases. The results for the stepwise discriminant analysis calculated using equal probabilities for group membership and the within-group covariance matrices, which only correctly classify 95.8 percent of the cases, are presented in Figure 4 and Table 3.

Figure 4 is a plot of the discriminant scores for each case. The group centroids are clearly separated, but there is overlap between the three chemical groups at the 95 percent confidence interval.

Linear discriminant analysis with cross-validation using only the log base-10 values of the Fe, Ni, Pb, Sr, Y, and Zn contents correctly classified 91.8 percent of the cases. The misclassified cases are also presented in Table 3. It must be stressed that discriminant analysis assumes that all possible a priori groups are denoted in the data set. Thus, while the misclassified cases in Tables 2 and 3 may actually belong to their predicted groups, they may also belong to a "production workshop" not denoted in the data. This may be the case for sherds TJ005 (Fig. 3, no. 8) and TKD040 (Fig. 2, no. 22). TJ005 appears to have a white slip on its exterior, and the fracture surface is flaky. In contrast to the rest of the pottery from the Takada site, TKD040 is a bright orangish red and has no visible temper in it. Furthermore, the spread in the discriminant functions for the Takenohana site may indicate that two raw material sources were utilized by the potters (see Fig. 4). Although the sample size from the Takenohana site is small (six specimens), the discriminant scores for the specimens potentially indicate the presence of two separate groups.

Finally, the results of our analysis indicate no clear difference between different phases. In particular, it is important to note that the five middle and late Jomon potsherds from the Takada site (TKD 034, 055 to 058; Fig. 2-39 to 43) were all

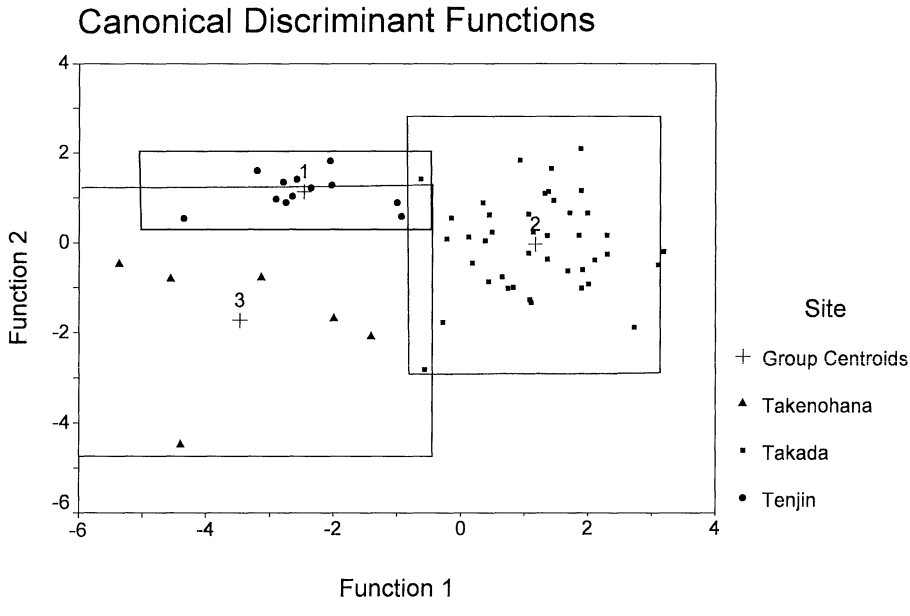

Fig. 4. Plot of the first two discriminant functions obtained from the stepwise discriminant analysis of Jomon pottery. The boxes around each group represent the 95 percent confidence interval.

TABLE 3. MISCLASSIFIED CASES FROM STEPWISE DISCRIMINANT ANALYSIS

SPECIMEN NUMBER	PREDICTED GROUP	PREDICTED GROUP (CROSS-VALIDATION)
TKD038		Tenjin
TKD040	Tenjin	Tenjin
TKD048	Takenohana	Takenohana
TKHN001		Tenjin
TKHN002		Tenjin

correctly classified together with early Jomon Moroiso-phase potsherds from the site. Although the sample size of non-Moroiso–phase pottery is too small to draw a final conclusion, it is very likely that the site residents of both the early Jomon and the middle and late Jomon periods produced their own pottery by utilizing local clays.

DISCUSSION

From the above, it is clear that EDXRF analysis can contribute significantly to the investigation of pottery production during the Jomon period. The results of the MANOVA and discriminant analysis tests suggest that there are three distinct groups of ceramics that coincide with the three sites. These findings support the hypothesis that each settlement produced its own pottery, probably utilizing local

clays. This result is not unexpected, since the geologic environment around each site is considerably different. Takada is located in the Tama Hills complex of Upper Neogene and Pleistocene clays, mudstones, and sandstones (Geological Survey of Japan 1976, 1987), while the Takenohana site is situated in the Sambagawa metamorphic belt (Geological Survey of Japan 1991). The Tenjin site is located in an area of volcanic rocks composed mainly of andesite (Geological Survey of Japan 1956). Further analytical studies of pottery from other nearby sites is required to determine whether the geochemical groups found here are reflecting site-specific clay deposits or regional clay deposits.

Results of linear discriminant analysis with cross-validation (Table 2), stepwise discriminant analysis, and stepwise discriminant analysis with cross-validation (Table 3) indicate that two to eight samples (3–13 percent) out of the 61 samples examined were incorrectly classified. One possible reason for this is that there could be overlap among the three groups resulting from the tempers added to the clays or other geochemical similarity between the raw materials. All three sites are in a region of Japan where there were numerous Quaternary volcanic ashfalls. If this volcanic ash was incorporated in the pottery, it could be "diluting" or "enriching" the geochemical signature of the clay (Neff et al. 1989). We hope petrographic analysis can resolve this issue in the future.

Another possibility is that the misclassified cases and overlap between groups could be due to the accuracy and precision limits of the EDXRF analyses. Both Bishop et al. (1990 : 540) and Wilson (1978 : 222) note that when the accuracy and precision of an analytical method are greater than 5 percent, the method can sometimes fail to distinguish geochemically similar but chemically different groups. Alternatively, the incorrectly classified cases could be the result of trade or exchange of pottery between sites. Kojo's (1981) petrographic study indicated that an average of 20–30 percent of the pottery at Moroiso-B sites was imported. While the percentages are slightly higher than the percentages of the misclassified cases in the present study, both cases may represent similar kinds of pottery movement between sites.

The driving force behind the movement of the pottery is uncertain. Kojo (1981) does not believe that the pottery itself had any significant exchange value, since stylistic characteristics of "imported" pots are no different from those of "domestic" ones. Similarly, there is nothing unusual about the decoration and vessel forms of misclassified cases in our study: stylistically, they are all within the range of typical Moroiso-A, -B, or -C pottery. Therefore, it is clear that, even if these misclassified pots were "imported," it was not because of the special quality of the pots themselves.

It may be that pottery was used as containers for exchange goods. Previous studies indicate that the people of the Jomon period had an extensive trade network between regions. Long-distance trade of obsidian, jade, and amber was commonly practiced throughout the Jomon period (Okada 1995; Osawa et al. 1977; Suzuki 1973, 1974). The fact that the distribution range of Moroiso-style pottery extends over 200 km also indicates active interaction between communities within the style zone (Fig. 1). Given such evidence, it is quite likely that food, as well as various kinds of utilitarian and nonutilitarian goods, were commonly exchanged.

Finally, the presence of nonlocally produced pottery may reflect the move-

ment of community members between sites, including intercommunity marriage. In the past, several Japanese archaeologists have suggested the possibility of inferring postmarital residential patterns by examining the presence of stylistically different pottery (Kobayashi 1979; Sato 1974; Sasaki 1981, 1982). Alternatively, the presence of nonlocally produced pottery may be related to residential and/or logistical moves of Jomon hunter-gatherers. As outlined previously, Habu (1995, 1996) has argued that, based on the analysis of settlement patterns and associated lithic assemblages, the people of the Moroiso phase were probably relatively sedentary, moving their residential bases several times a year. While the ceramic data presented here are too limited to determine the relationships between pottery movement, settlement patterns, and subsistence strategies, this area of research should be further pursued (for discussions on pottery movement and hunter-gatherer subsistence-settlement systems, see also Zedaño's [1994] work on ceramic assemblages in the American Southwest).

As a final note, the analytical method could be having a minor effect on the results. As noted above, the overlap between groups could be because of the accuracy and precision limits. Furthermore, calcite, lime, certain types of sand, and quartz, all materials that could have been added as temper, are not detected by EDXRF and NAA (Mommsen et al. 1988 : 47; Steponaitis et al. 1996 : 557–560). These tempers would be detected by petrographic analysis; this could be one possible reason why we are seeing a lower level of pottery movement than Kojo (1981).

CONCLUSION

The results of our analysis indicate that the majority of Jomon pottery from three Moroiso-phase sites were locally made. The MANOVA and discriminant analysis tests indicate that the chemical composition of the pottery found at the three sites are significantly different. Stepwise discriminant analysis identifies Fe, Ni, Pb, Sr, Y, and Zn as the most significant chemical discriminators between the three sites; other than Fe, all these elements are found in trace amounts. In other words, for the provenience study of Jomon pottery, analysis of trace elements is more effective than that of major elements. In the past, XRF analyses of Jomon pottery conducted by Japanese scholars have primarily focused on measuring major elements. The results of our analysis indicate the importance of trace element analysis for sourcing Jomon pottery.

Archaeology of the Jomon period is a growing field. As an example of a "complex hunter-gatherer" culture (Price and Brown 1985), Jomon has attracted the attention of many researchers in the field of hunter-gatherer archaeology (Aikens and Dumond 1986; Aikens et al. 1986; Cohen 1981; Hayden 1990; Pearson 1977; Price 1981; Soffer 1989). Recent discovery of extraordinarily large settlements in northern Japan, such as the Sannai Maruyama site (Okada and Habu in press) and the Nakano B site (Izumida 1996), further demonstrates the complexity of Jomon settlement systems. In addition, recent excavations in Kagoshima, southern Kyushu, indicate that a semisedentary lifestyle had developed earlier in this region than in the rest of the Japanese Archipelago (Shinto 1995). These findings suggest that regional and temporal variability of the Jomon culture was far more diverse than archaeologists have previously assumed. Also, recent discoveries

of early pottery from continental East Asia, including Siberia (e.g., Kuzmin et al. 1998; Kuzmin and Orlova 1998), indicate that the Jomon pottery can be discussed in the context of late Pleistocene and early Holocene pottery-making traditions in East Asia.

Despite the richness of archaeological data from the Jomon period, we know very little about the production and distribution of Jomon pottery. While the total number of samples examined here is small, our study indicates that chemical analysis can provide us with extremely useful information for the study of Jomon sites. We hope future chemical and petrographic analysis of Jomon potsherds will help answer various questions regarding pottery production and distribution, as well as economic and social behavior of the Jomon people.

ACKNOWLEDGMENTS

We would like to thank the Archaeology and Ethnology Department of Keio University, the Archaeological Center of Yamanashi Prefecture, and the Archaeological Research Foundation of Saitama Prefecture for providing us with the potsherd samples. We would also like to thank the anonymous reviewers, whose comments have helped improve the quality of this paper.

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ABSTRACT

Energy dispersive X-ray fluorescence (EDXRF) analysis was used to examine the chemical composition of Jomon potsherds. Jomon is the name of a prehistoric hunter-gatherer culture in Japan that lasted from about 12,500 to 2,300 B.P. It is characterized by the production and use of pottery, large settlements, and long-distance trade. Potsherd samples were taken from three Jomon sites in the Kanto and Chubu regions in central Japan. The majority of the samples are dated to the Moroiso phase (c. 5000 B.P.) of the early Jomon period. Linear discriminant analysis, with and without cross-validation, and multivariate analysis of variance (MANOVA) indicate that there are three distinct chemical groups that coincide with the three sites. Stepwise discriminant analysis indicates that the iron (Fe), nickel (Ni), lead (Pb), strontium (Sr), yttrium (Y), and zinc (Zn) are the most significant chemical discriminators between the three sites. These findings are interpreted as indicating that each settlement produced its own pottery, utilizing local materials. The misclassified sherds could be the result of some form of trade or exchange, or of movement of people between communities. KEYWORDS: Jomon hunter-gatherers, Japan, energy dispersive X-ray fluorescence (EDXRF), multivariate analysis of variance (MANOVA), discriminant analysis.

APPENDIX I. VALUES OBTAINED FOR RGM-I STANDARD

STANDARD	Ba	Ce	Cu	Fe_2O_3	Ga	La	MnO	Nb	Nd	Ni	Pb	Rb
RGM-1												
Govindaraju (1994)	807	47.0	11.6	18600	15	24	360	8.9	19	4.4	24	149
This study ($n = 4$)	796	43.6	16.3	19060	15	25	347	11.7	26	4.7	22	147

STANDARD	Sr	Th	TiO_2	Y	Zn	Zr
RGM-1						
Govindaraju (1994)	108	15.1	2670	25	32	219
This study ($n = 4$)	102	16.4	2809	24	40	218

Appendix II. Chemical Composition of the Jomon Potsherds

sample* (Time Period)**	Ba	Ce	Cu	Fe	Ga	Mn	Nb	Ni	Pb	Th	Ti	Rb	Sr	Y	Zn	Zr
TJ001 (Mor-B)	170	27	49	65410	19	1028	n.d.	18	18	n.d.	11574	39	114	27	94	145
TJ002 (Mor-B)	301	30	37	66595	26	926	n.d.	12	23	14	13667	79	90	25	71	156
TJ003 (Mor-B)	285	37	98	65654	24	881	n.d.	18	25	11	11471	71	115	20	84	129
TJ004 (Mor-B)	267	25	119	61063	27	468	10	n.d.	26	19	13319	82	95	15	67	254
TJ005 (Mor-C)	288	39	47	20763	15	1106	12	18	25	12	5736	55	122	21	47	160
TJ006 (Mor-B)	249	35	97	55707	26	738	n.d.	19	23	12	12126	65	132	20	59	172
TJ007 (Mor-C)	235	37	172	54144	23	526	14	17	23	13	14951	64	114	20	128	200
TJ008 (Mor-C)	162	31	106	62546	24	665	12	13	22	n.d.	12315	38	329	10	49	167
TJ009 (Jus)	272	22	43	59994	25	1105	n.d.	22	24	12	12142	83	97	18	53	134
TJ010 (Mor-B)	233	n.d.	123	66436	25	2188	n.d.	n.d.	20	15	12127	56	130	18	60	124
TJ011 (Mor-B)	160	n.d.	72	34586	34	1135	1 0	25	38	14	11410	80	169	18	107	252
TJ012 (Mor-B)	160	n.d.	41	86168	28	944	n.d.	n.d.	19	16	12132	35	98	17	66	133
TKD002 (Mor-A, B)	322	58	153	48476	27	612	27	95	15	13	12591	96	101	24	420	218
TKD003 (Mor-A, B)	242	27	96	32115	22	426	n.d.	16	17	n.d.	8324	26	344	18	92	120
TKD004 (Mor-A, B)	262	n.d.	201	43292	16	431	9	25	10	10	7782	44	114	16	116	138
TKD005 (Mor-A, B)	284	20	165	32693	31	561	12	41	18	12	11125	43	122	16	177	203
TKD006 (Mor-A, B)	340	37	145	65460	25	2052	17	76	20	12	12894	74	122	20	353	176
TKD007 (Mor-A, B)	295	24	158	65448	17	813	8	10	19	n.d.	5617	64	133	12	150	125
TKD008 (Mor-A, B)	285	23	70	23547	14	372	12	18	13	n.d.	8058	45	148	20	157	144
TKD009 (Mor-A, B)	264	27	60	38301	16	342	12	28	13	n.d.	7899	36	147	20	145	125
TKD010 (Mor-A, B)	251	31	55	32765	20	583	11	32	16	16	11176	36	162	24	88	182
TKD011 (Mor-A)	217	29	129	71822	20	1091	10	20	16	n.d.	4189	153	181	27	183	161
TKD012 (Mor-A)	249	n.d.	115	48440	16	959	n.d.	n.d.	14	n.d.	5770	43	145	16	115	95
TKD013 (Mor-A)	335	26	70	26838	18	431	10	23	15	n.d.	7636	78	139	13	186	152
TKD014 (Mor-A, B)	211	n.d.	91	81101	16	1015	n.d.	n.d.	11	n.d.	6112	43	121	14	140	120
TKD015 (Mor-B)	279	22	94	44703	22	535	n.d.	27	17	12	6617	55	225	16	208	130
TKD016 (Mor-B)	280	27	90	39538	17	549	9	n.d.	19	n.d.	7351	36	233	19	112	134
TKD017 (Mor-B)	333	29	213	39665	21	588	n.d.	15	21	11	9496	60	139	21	130	143
TKD018 (Mor-B)	262	20	68	32983	23	386	12	31	14	n.d.	7774	44	230	12	96	138
TKD019 (Mor-B)	262	27	114	35078	18	314	12	15	14	n.d.	7955	63	103	13	209	187
TKD020 (Mor-B)	298	30	157	35299	22	382	10	26	21	14	9131	60	154	23	125	151
TKD031 (Mor-A)	281	29	54	36623	16	527	n.d.	54	17	n.d.	10840	59	287	25	152	167
TKD032 (Mor-B)	443	48	121	65513	30	3941	23	43	30	23	9009	128	107	18	403	212

(Continues)

APPENDIX II *Continued.*

SAMPLE* (Time Period)**	Ba	Ce	Cu	Fe	Ga	Mn	Nb	Ni	Pb	Th	Ti	Rb	Sr	Y	Zn	Zr
TKD033 (Mor-A)	359	24	69	29466	17	428	9	27	20	14	9966	82	186	19	180	185
TKD034 (Mor-A, B)	228	23	56	33921	24	845	n.d.	11	19	n.d.	10949	17	232	24	83	163
TKD035 (Mor-A)	258	26	138	64932	22	1471	n.d.	14	17	10	6770	51	179	26	141	73
TKD036 (Mor-A, B)	278	26	78	50681	24	1729	n.d.	40	21	n.d.	9160	33	327	19	118	155
TKD037 (Mor-C)	308	n.d.	40	33156	16	315	n.d.	25	17	12	7792	60	146	20	97	126
TKD038 (Mor-C)	187	23	1101	19718	94	488	9	73	51	23	3246	26	96	8	593	118
TKD039 (Mor-C)	281	32	71	56865	22	679	n.d.	25	21	n.d.	10836	59	107	19	320	145
TKD040 (Mor-B)	149	22	70	55672	30	3962	11	n.d.	21	n.d.	17968	34	109	17	111	139
TKD041 (Mor-B)	411	38	50	41213	14	333	n.d.	34	21	13	8828	80	233	22	147	152
TKD042 (Mor-B)	630	36	63	63563	24	3475	n.d.	16	26	11	10468	88	193	27	229	148
TKD043 (Mor-A)	281	25	59	49139	18	352	n.d.	19	15	n.d.	7826	88	102	13	193	137
TKD044 (Mor-A)	259	22	113	44778	19	580	n.d.	13	16	9	8066	48	126	14	167	122
TKD045 (Mor-A)	276	26	136	31421	14	291	n.d.	35	15	n.d.	8541	50	249	28	94	126
TKD046 (Mor-A)	253	21	82	53108	15	725	n.d.	15	20	9	10103	48	107	22	141	138
TKD047 (Mor-A)	229	29	203	52006	16	631	10	34	19	10	11099	42	121	16	211	134
TKD048 (Mor-B)	186	20	196	66981	20	4447	n.d.	212	16	n.d.	12704	53	129	15	212	141
TKD049 (Mor-B)	375	40	109	24263	16	408	15	28	18	15	7301	62	136	23	125	182
TKD050 (Mor-A)	360	35	56	58510	20	1065	n.d.	n.d.	15	n.d.	8482	71	155	17	126	154
TKD055 (Hor)	295	35	84	39418	16	364	n.d.	29	16	12	9775	53	138	18	191	153
TKD056 (Hor)	294	24	227	20990	12	213	n.d.	20	16	10	8273	41	119	19	85	139
TKD057 (Hor)	291	31	80	48626	19	686	11	21	12	10	8331	60	135	21	165	146
TKD058 (Kas)	331	29	76	33086	21	565	10	21	16	14	7515	89	148	16	280	143
TKHN001 (Mor-A)	170	30	38	58816	24	527	8	22	19	n.d.	11224	41	49	17	43	184
TKHN002 (Mor-A)	248	20	53	62941	26	1457	8	93	23	14	11275	58	157	17	88	181
TKHN003 (Mor-A)	198	26	63	66026	26	1548	16	46	27	14	16650	58	59	17	104	203
TKHN004 (Mor-B)	117	n.d.	1274	47834	95	961	n.d.	226	53	18	5469	23	58	4	628	77
TKHN005 (Mor-B)	190	n.d.	635	36172	60	648	n.d.	60	31	10	6627	46	72	9	331	125
TKHN006 (Mor-B)	304	37	62	54639	22	1653	9	44	21	n.d.	8138	83	91	10	164	169

All values are in parts per million (ppm). The barium and cerium concentrations were determined using an americium gamma-ray source for 500 seconds in an air path. The remaining elemental concentrations were determined using an X-ray tube operated in vacuum at 30 kV, 20 mA, for 250 seconds. Lanthanum and neodymium were searched for but were below the detection limit of the EDXRF unit.

nd = not detectable.

* TJ = Tenjin; TKD = Takada; TKHN = Takenohana.

** Mor-A, -B, and -C = Moroiso-A, -B, and -C; Jus = Jusanbodi; Hor = Horinouchi; Kas = Kasori B.