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Pottery Production and Circulation at the Sannai Maruyama Site, Northern Japan: Chemical Evidence from Early and Middle Jomon Pottery

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This paper examines issues concerning the production and circulation of Early and Middle Jomon pottery in the Tohoku region of northern Japan. An attempt is made to determine whether the copious amounts of pottery found at the Sannai Maruyama site were produced locally (i.e., made either at Sannai Maruyama or in the near vicinity), or were brought in from other areas. Using energy-dispersive x-ray fluorescence (EDXRF), we measure minor and trace element composition of 58 pottery samples from Sannai Maruyama and three other Early and Middle Jomon sites (Futatsumori, Korekawa Ichioji and Hatanai) in the Tohoku region. Clay samples from the Sannai Maruyama site are also analyzed. Multivariate analysis of variance (MANOVA), linear discriminant analysis (LDA) with cross-validation, and step-wise discriminant analysis (SDA) with cross-validation are the statistical techniques used to analyze the chemical data. The results support the hypothesis that the majority of the pots examined in this study, including those excavated from Sannai Maruyama, were produced locally, and not imported from other areas. This study also highlights the importance of minor and trace element analysis for the geochemical differentiation of pottery.

INTRODUCTION

The purpose of this paper is to examine the production and circulation of Early and Middle Jomon pottery in the Tohoku region of northern Japan through chemical analysis of the pottery. The central question that we are asking in this paper is whether pottery excavated from the Sannai Maruyama site, which is located in the northern part of the Tohoku region, was made locally (i.e., either at Sannai Maruyama or in the vicinity), or brought in from elsewhere.

Sannai Maruyama is a large prehistoric site dated primarily to the Early and Middle Jomon periods. Radiocarbon dates indicate that the site was occupied from approximately 5050 to 3900 uncalibrated b.p., or 5900 to 4300 calibrated B.P. [TSUJI 1999]. Salvage excavations of the site from 1992 to 1994, which were to precede the construction of a baseball stadium, revealed that the entire area planned for the stadium was actually underlain by diverse features from the Early and Middle Jomon periods [OKADA 1995]. Because of the importance of this archaeological

discovery, the governor of Aomori Prefecture halted construction of the stadium and declared that the site would be preserved. Subsequent test excavations at the site revealed that the actual site area extends outside the planned stadium area [HABU and FAWCETT 1999]. To date, more than 700 pit-dwellings, and many other features, have been identified at the site. Chronological seriation of pottery from the pit-dwellings indicates that not all the pit-dwellings were occupied simultaneously. Nevertheless, the size of the site seems unusually large compared to other Early and Middle Jomon settlements [for details of the site, see HABU 2002, n.d.; HABU *et al.* 2001; OKADA, this volume.]

Of particular interest to archaeologists is an abundance of artifacts recovered from the Sannai Maruyama site. The 1992 to 1994 excavations yielded more than 40,000 cardboard boxes (approximately 40 x 30 x 25 cm) of excavated materials [OKADA 1995]. The majority of these were potsherds. Traditionally, many Japanese scholars have assumed that Jomon pottery, at least pottery from the Incipient to Middle Jomon periods, was produced separately at each site where it was found. However, because of the abundance of pottery found at the Sannai Maruyama site, some scholars recently began to question this interpretation. They have suggested that Sannai Maruyama was a trade center where large amounts of exotic goods and everyday commodities, including pots, were exchanged. The presence of artifacts made from exotic materials such as jade and obsidian, neither of which is available near Sannai Maruyama, suggests that long-distance trade was undertaken by the Sannai Maruyama residents. However, very few systematic analyses have been conducted regarding the possible exchange of pottery and other commodities.

As a first step to address this issue, we conducted a preliminary study of the minor and trace element variability in Jomon pottery from four sites in the Tohoku Region. The sites selected were Sannai Maruyama, Futatsumori, Korekawa Ichioji and Hatanai, all of which are located within Aomori Prefecture. All pottery samples examined date to the Early and Middle Jomon periods.

THEORETICAL BACKGROUND

As has been demonstrated elsewhere (e.g., POLLARD and HERON 1996), chemical analysis of pottery is an effective way to examine the issues of pottery production and circulation. While there have been some chemical studies of Jomon pottery [e.g., ISHIKAWA 1988, 1989; MITSUJI and INOUE 1984; NINOMIYA *et al.* 1990], only a limited number of these studies have specifically focussed on pottery production and circulation [e.g., HABU and HALL 1999].

Behind much of the research in chemical studies of archaeological ceramics is the assumption that chemical characteristics of the clay used to manufacture the pottery reflect the local geological environment. The principal raw material in the production of pottery is clay, which is usually collected from sub-surface deposits. Since clay chemistry typically reflects the local geological environment, clays collected in different regions tend to exhibit different chemical characteristics [HARBOTTLE and BISHOP 1992: 27; JONES 1986: 5-9; MOMMSEN *et al.* 1988; STEPONAITIS *et al.* 1996: 555-560; WILSON 1978: 220-221]. Therefore, if we assume that prehistoric potters used local clay to manufacture their pottery [ARNOLD 1992:160, see also for example KING *et al.* 1986: 362-363; ZEDEÑO 1994: 14-21, 50-51], we can expect that prehistoric

pots made in different regions have different chemical characteristics.

While this seems straightforward, there are several other factors that need to be taken into consideration. First, variability in clay chemistry is not necessarily a function of the distance between different clay sources. If the geological environment of a particular region is composed of many different rock types, then clays collected within the same region may have large chemical variability. Conversely, if the geological environments of two or more geographic regions are not significantly different, the clay chemistry between the regions may be similar. Second, clay is not necessarily the only raw material used to make pottery. Potters usually add one or more types of temper, such as sand, fiber, and shell fragments, to the clay. Since various types of temper may affect the overall chemical characteristics of pottery, chemical differences between pots may reflect differences in temper, not clay.

With these caveats in mind, demonstrated differences in the chemical composition of separate pieces of pottery could correspond to either (1) specific clay deposits, (2) regional clay deposits, (3) production workshops, or groups of potters who used similar raw materials and prepared the clay in similar fashion, or (4) a combination of two or more of these [Arnold *et al.* 1991: 84-88; Clark *et al.* 1992; Costin 1991]. On the other hand, if there are no clear differences between separate pieces of pottery, it may imply that they were made at the same geographic locality, but there is also a possibility that they were made at different localities associated with geochemically similar raw materials.

Because of these complexities, provenience studies of pottery from historical periods typically use kiln samples (potsherds excavated from production sites) as comparative specimens [e.g., Habu 1989]. At the first stage of the analysis, chemical characteristics of kiln samples are examined. Once these characteristics are known, it is much easier to provenience samples from consumer sites to specific production areas. However, most prehistoric pottery, including Jomon pottery, was open-fired without using kilns. As a result, there are no proven specimens from production sites that can be used as reference materials. While one can still identify chemical similarities and differences between different groups of pottery, there is no method of determining *a priori* the number of sources in the pottery samples examined, nor the dissimilarity between the sources.

Despite these problems, we suggest that the chemical characterization of Jomon pottery can provide insights into pottery production and circulation. The hypothesis that we test in this paper is the following: if Jomon potters in the Tohoku region produced and used much of their own pottery locally, we should expect to find statistically significant differences in the chemical composition between pottery samples from different sites. If this hypothesis is rejected (i.e., if there are no statistically significant differences), it would suggest either (1) the Jomon potters used raw materials that were geochemically similar, or (2) pottery was part of a trade/exchange/redistribution network between settlements.

To test the hypothesis, the methodology advocated by Vitali and co-workers [Vitali and Franklin 1986; Vitali *et al.* 1987] was employed. This methodology uses discriminant analysis and multivariate analysis of variance (MANOVA) to examine the relationships between chemical variation, site location and time. Unlike correspondence analysis (CA) and other ordination methods, these tests cannot be used to determine the number of groups in a given data set. The groups in the data must be assumed *a priori*.

SITES AND ARCHAEOLOGICAL MATERIALS

Figure 11.1 shows the locations of the four sites analyzed in this paper. Sannai Maruyama is located in Aomori City, on the southeast bank of the Okidate River, which runs into Aomori Bay. Details of the site are outlined in Okada's paper (this volume), as well as by Kidder [1998], Habu [2002, n.d.] and Habu *et al.* [2001] . A total of 30 pottery samples excavated at the site by three different institutes were analyzed in this paper. Figure 11.2 shows 12 potsherds excavated by the Board of Education of Aomori Prefecture. Figure 11.2.1 through 7 date to the Early Jomon period, whereas Figure 11.2.8 to 12 are from the Middle Jomon period. Figure 11.3 shows ten sherds excavated by Keio University during the 1960s. These sherds date to the Middle Jomon period. Finally, Figure 11.4 illustrates 18 Early Jomon potsherds recovered from the columnar soil sample collected in the 6th Test Excavation Area by the Berkeley Sannai Maruyama Project. In addition to these potsherd samples, 13 clay samples collected from natural deposits at the site were also analysed as possible source materials for potsherds at the site.

The second site, the Futatsumori shell-midden, is located in Kamikita Town, on the east terrace of the Akagawa River near Lake Ogawara [Aomori Prefectural Museum of Local History 1992]. Although the site spans both the Early and Middle Jomon periods, the four potsherds examined here (Figure 11.5) were all dated to the Early Jomon period. These samples were surface collections.

The third site, Korekawa Ichioji (abbreviated as Ichioji in Tables 11.1 and 11.4), is located in Hachinohe City, on the west bank of the Niida River, about six kilometers away from the present-day coastline. The site is part of the famous Korekawa site complex, including Korekawa Ichioji, Nakai and Hotta. Potsherds examined in this paper (Figure 11.6) are all from the Ichioji area of the site complex, dating to the Middle Jomon period.

Finally, the Hatanai site is located in the upper valley of the Niida River in Nango Village, Sannohe County. Surveys and salvage excavations of the site prior to construction of the Yomasari dam, which is part of the Reclamation and Construction Plans of the Hachinohe Plain, revealed that the area was an Early and Middle Jomon settlement associated with large earthen middens with numerous potsherds [Archaeological Center of Aomori Prefecture 1994, 1995, 1996, 1997, 1999, 2000]. Pottery samples examined from the site (Figure 11.7) are all from the Early Jomon period.

COMPOSITIONAL ANALYSIS

Methodology

The minor and trace element composition of the clay and pottery examined in this study was determined using energy dispersive x-ray fluorescence (EDXRF). EDXRF is a low-cost method that can be used to 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

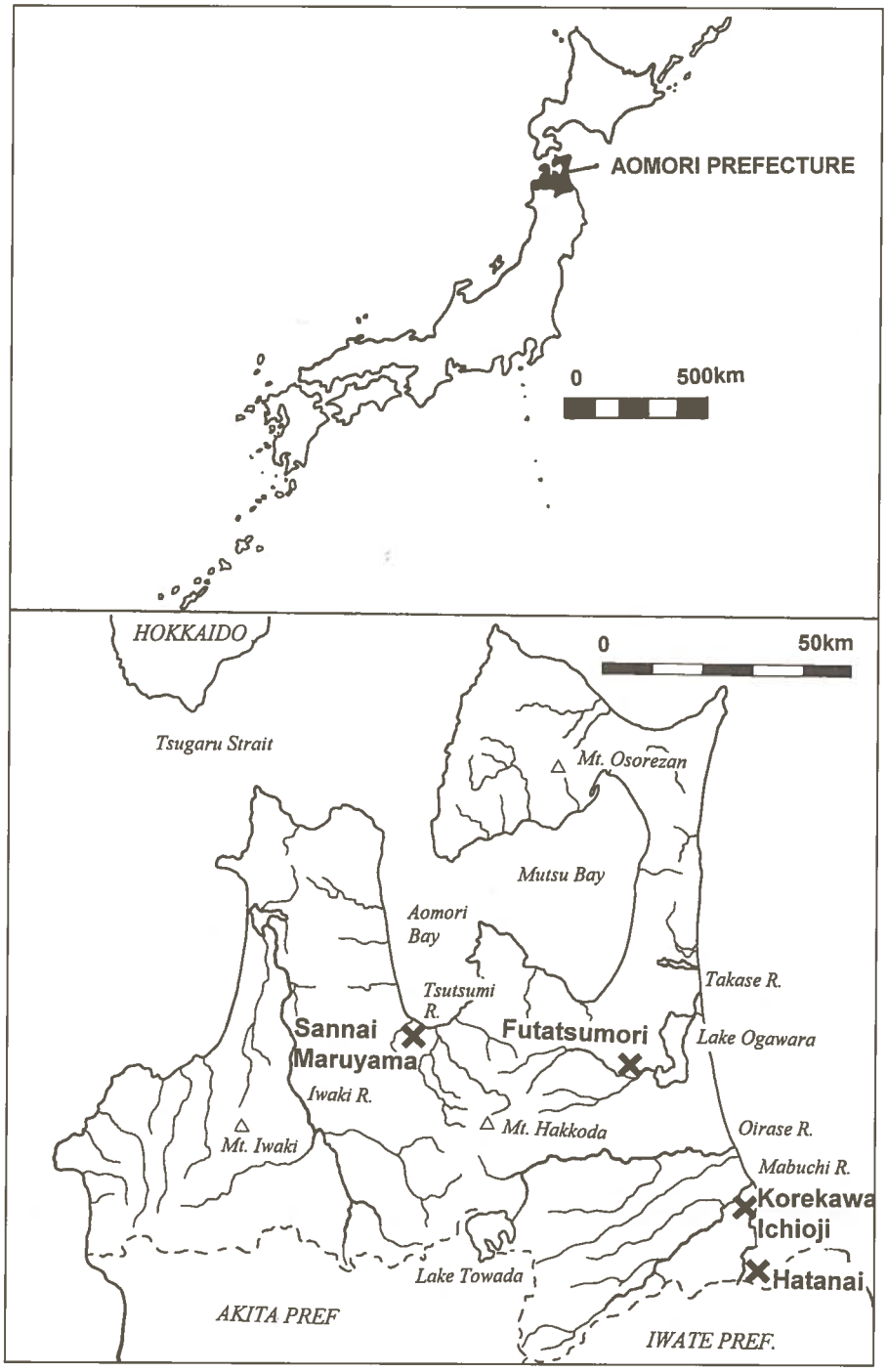

Figure 11.1 Map of Japan showing the location of Aomori Prefecture (upper), and map of Aomori Prefecture with four sites mentioned in the text (lower).

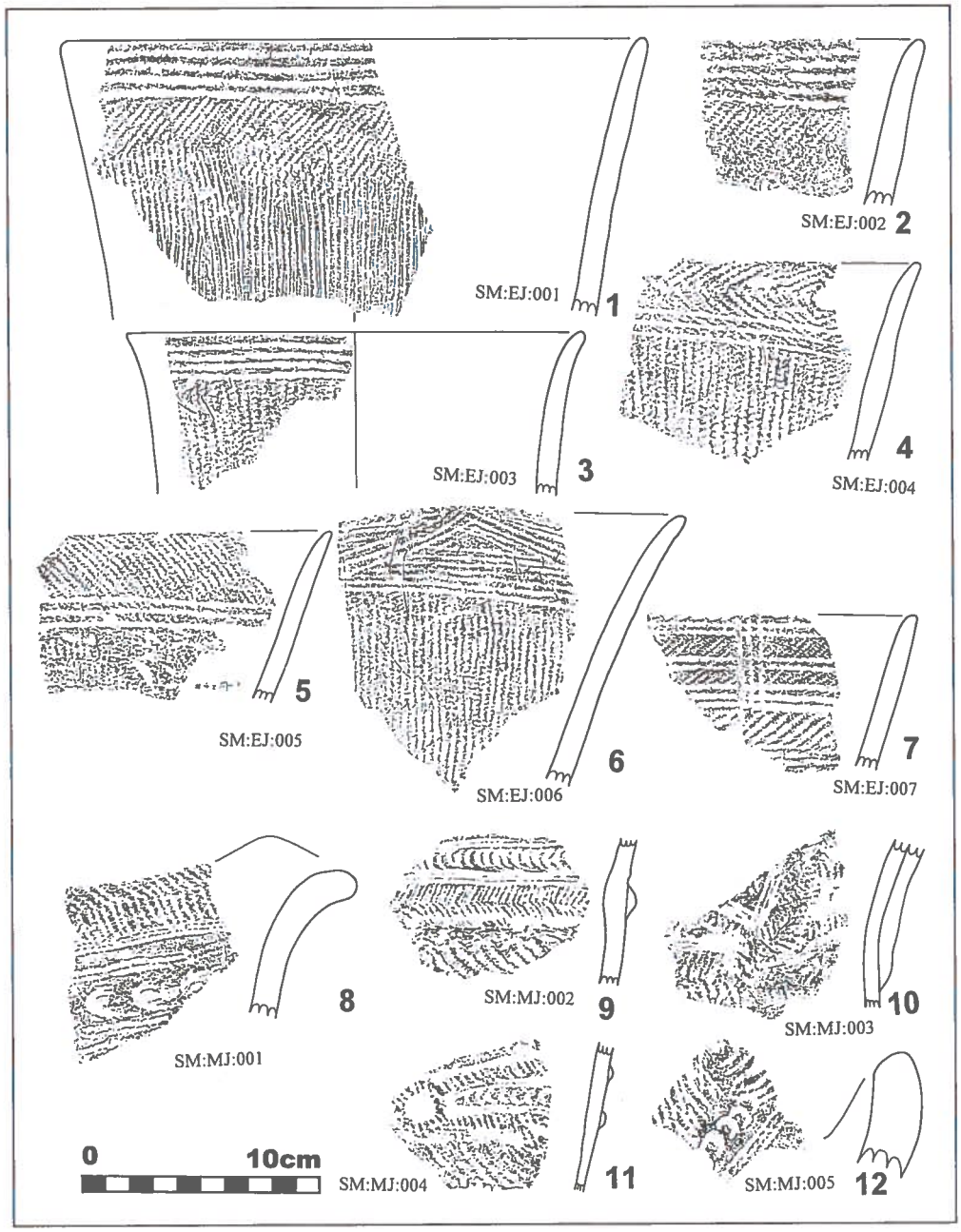

Figure 11.2 Rubbings of surface treatment and vessel profiles of the pottery from the Sannai Maruyama site (excavated by the Board of Education of Aomori Prefecture).

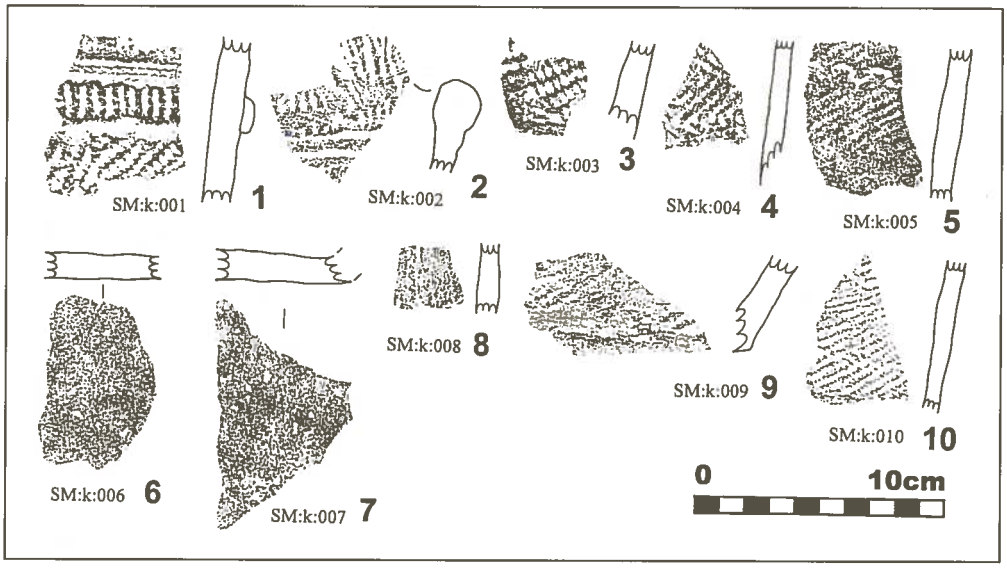

Figure 11.3 Rubbings of surface treatment and vessel profiles of the pottery from the Sannai Maruyama site (excavated by Keio University).

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 air at 250 seconds livetime to generate x-ray intensity 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 0.5 cm to 0.75 cm in diameter. X-ray intensity data for barium (Ba), cerium (Ce), lanthanum (La), and neodymium (Nd) were generated by using an americium (^{241}Am) gamma-ray source for 500 seconds livetime in air. The Kα and Lα x-ray intensity line data were converted to concentration values using a Compton scatter matrix correction and the linear regression of a set of Geological Survey of Japan (GSJ), 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 the Lucas-Tooth and Price (1961) correction.

The detection limits, as determined using geological standards [SHACKLEY 1995], are as follows: Ba 20 ppm, Ce 20 ppm, Cu 10 ppm, Fe 10 ppm, Ga 7.8 ppm, La 20 ppm, Mn 40 ppm, Nb 8 ppm, Nd 20 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 the University of California at Berkeley with the Research Reactor Facility at the University of Missouri shows that EDXRF can obtain the same sensitivity, precision and accuracy as neutron activation for the alkali, alkaline earth and transition metals in a silicic matrix [SHACKLEY 1998: 267].

To monitor the operation of the EDXRF unit, standards of known composition were run with the unknowns (results in Appendix). Using the Bishop *et al.* [1990] definitions for precision and accuracy, our precision was 10% or less for all elements, and the analytical

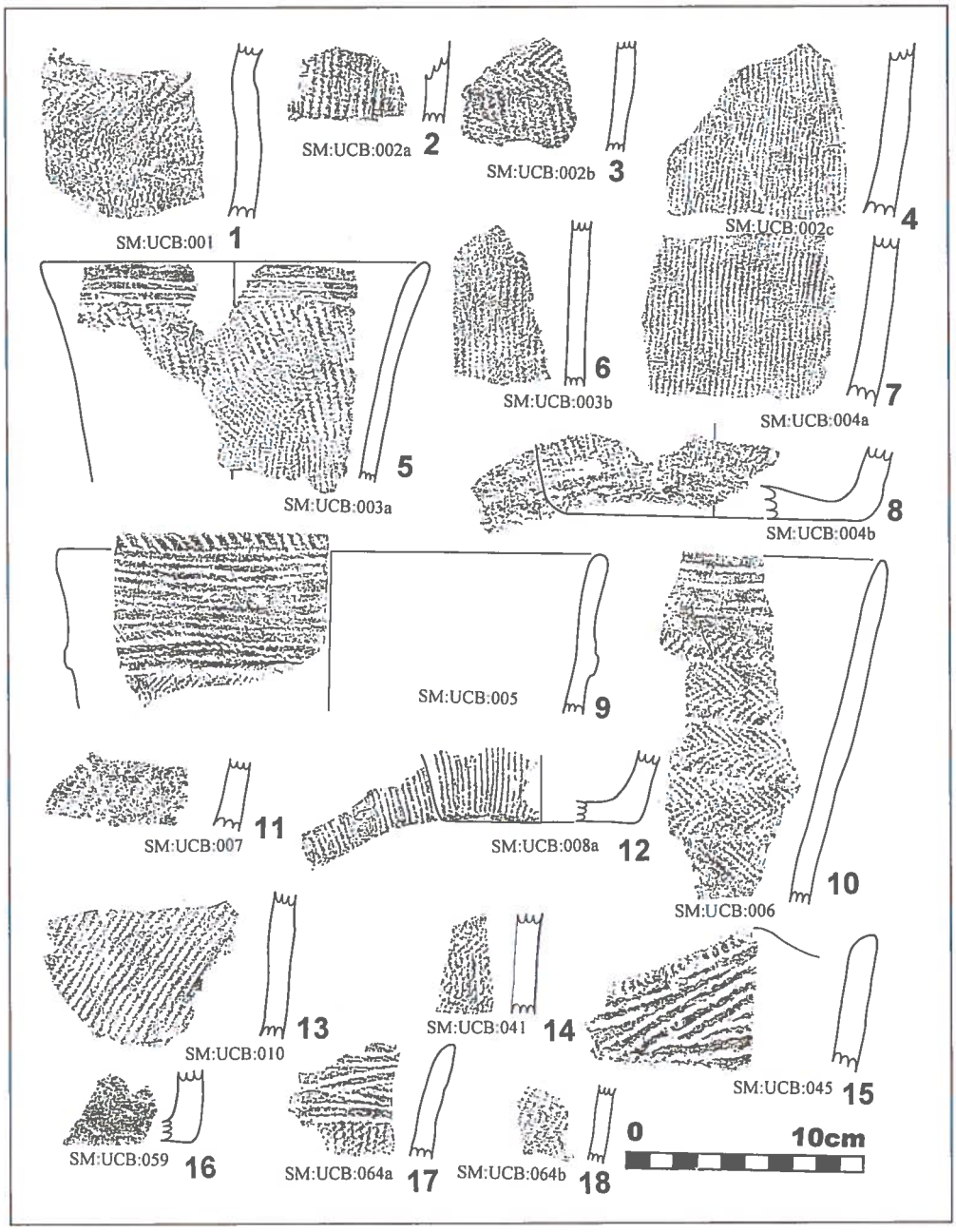

Figure 11.4 Rubbings of surface treatment and vessel profiles of the pottery from the Sannai Maruyama site (excavated by the Berkeley Sannai Maruyama Project).

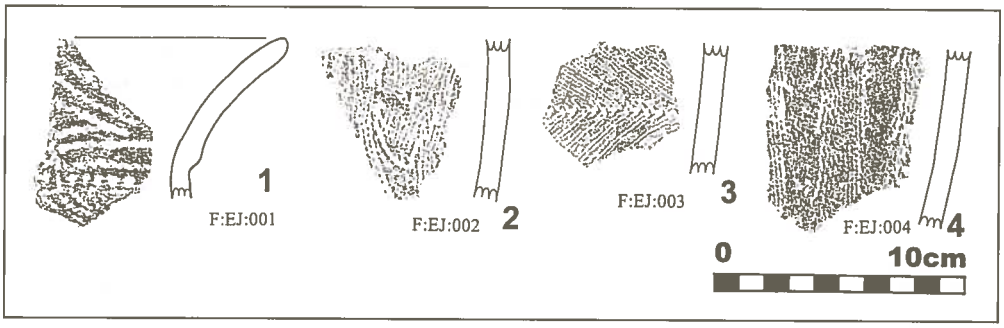

Figure 11.5 Rubbings of surface treatment and vessel profiles of the pottery from the Futatsumori shell-midden.

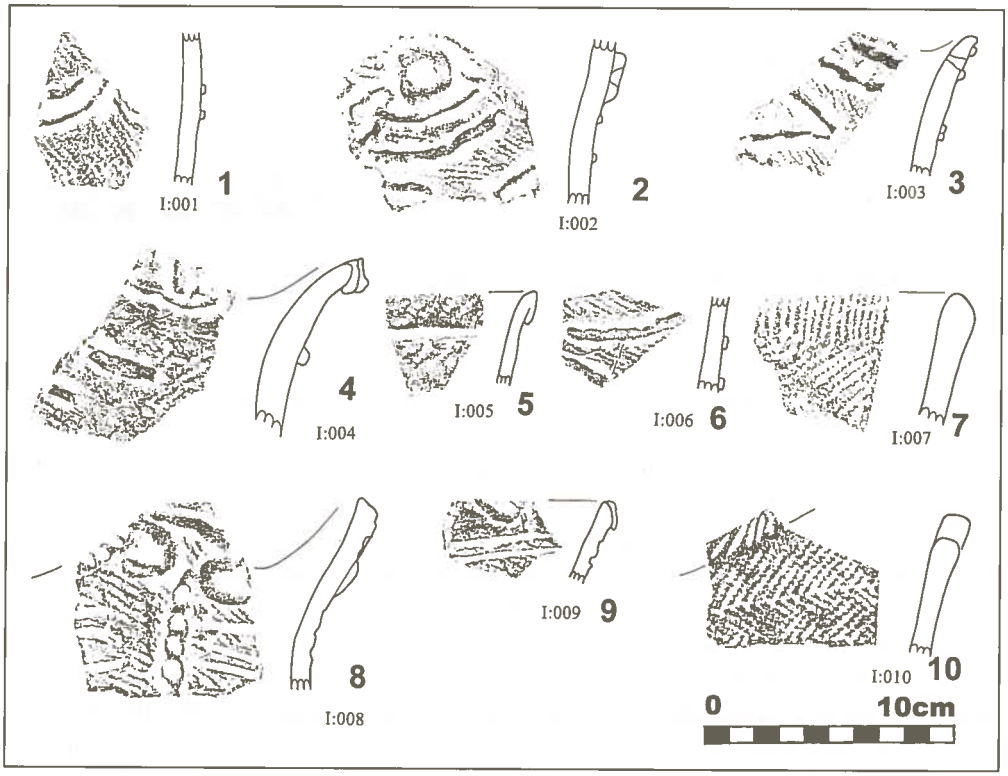

Figure 11.6 Rubbings of surface treatment and vessel profiles of the pottery from the Korekawa Ichioji site.

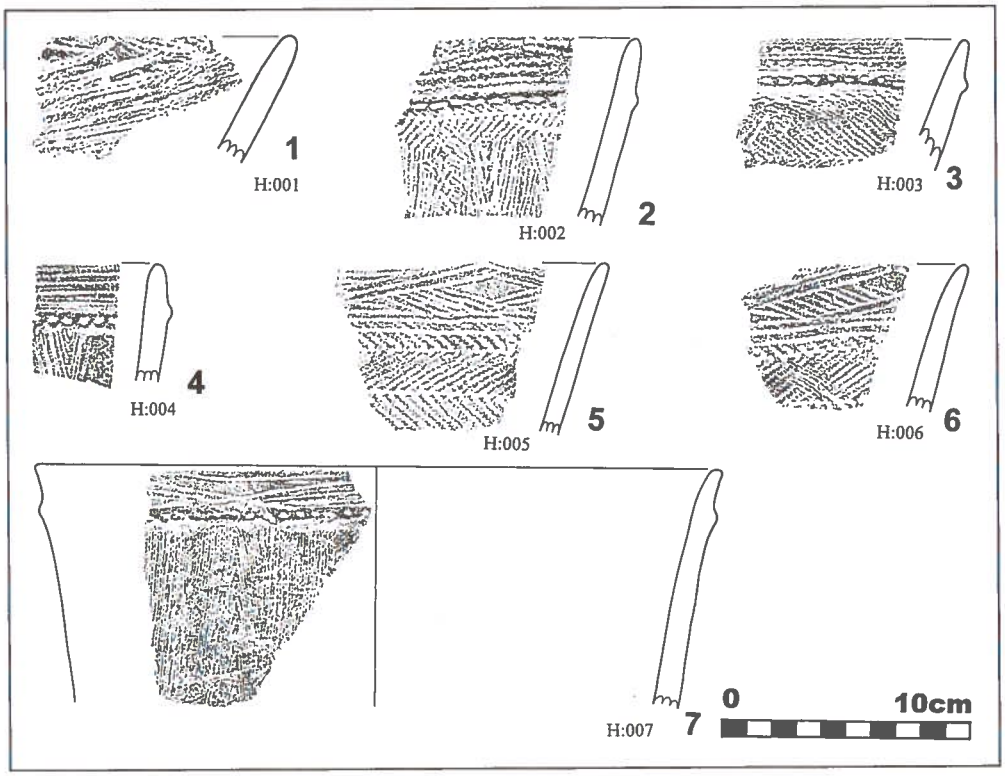

Figure 11.7 Rubbings of surface treatment and vessel profiles of the pottery from the Hatanai site.

accuracy for most elements was 15% or less. The accuracy was calculated as follows:

|(standard value - mean value)| * 100% / standard value

Precision was calculated in an analogous fashion. These numbers are good since they are a measure of the difference between a standard value and an observed value.

Destructive EDXRF analysis was not permitted for the sherds from Hatanai and Korekawa Ichioji. Accordingly, only non-destructive analyses were conducted. Before irradiation, each potsherd was rinsed with distilled, de-ionized water, scrubbed with a nylon brush, and then rinsed with distilled, de-ionized water again. The sherds were allowed to air dry. In most cases, the x-ray analysis was conducted on the cross-section of the sherds. The clay samples were formed into a flat pellet with the aid of a hand press and fired at 850°C for one hour and allowed to cool in the furnace over night.

We do not regard postdepositional chemical alteration as a major concern. Raw clay has a cation-exchange capacity of only 1% to 5% [HEDGES and MCLELLAN 1976], and fired clay has an even much lower cation-exchange capacity. Because of this, scholars such as Bishop *et al.* [1982] and Hedges and McLellan [1976] assert that the trace element concentrations are not

significantly altered by post-depositional processes (for details, see Habu and Hall [2001: 150]).

All statistical operations were performed with SPSS Release 8.0.

Compositional Data and Analysis

Table 11.1 contains the minor and trace element data for each sample. All values are listed in parts per million (ppm). Table 11.2 contains the minor and trace element data for the fired clay samples from Sannai Maruyama.

The elemental values were transformed to log base 10 values. This transformation compensates for the differences in magnitude between minor and trace elements [PEISACH *et al.* 1982: 355-356; POLLARD 1986: 69-71; WILSON 1978: 226,227]. For cases below the detection limit, one half the detection limit was used in the transformation and subsequent data analysis.

A multivariate analysis of variance (MANOVA) was performed to assess the overall variance in the data set [see NOURŠIS 1993: 57-95; SHARMA 1996: 342-371]. The goals of this analysis were to see (1) if the log-transformed population means of the chemical variables are the same for the four sites, and (2) whether location or time period, or the combination of both factors, accounts for the variability in the data. The variance is evaluated by means of *F*-values, which are defined as the ratio of between-group to within-group variance for the elements under consideration. An *F*-value can range from 0 to infinity. The larger the *F*-value, the more significant a factor or combination of factors is in accounting for the variance [VITALI *et al.* 1987: 428-429]. Akin to the Student's t-test or the chi-square test, the significance of the *F*-values is evaluated against the *F*-distribution. In this study, the *F*-values were determined using Pillai's trace statistic. Statistical studies have demonstrated that *F*-values based on Pillai's trace are exceedingly robust and detect true differences in the data [SHARMA 1996: 348]. The eta-squared test statistic, which indicates the proportion of the variability each factor or combination of factors represents, is also calculated [NOURŠIS 1993:41]. A value near 0 indicates the factor represents little of the variance in the data. A value near 1 indicates that nearly 100% of the variability is accounted for by the factor.

Table 11.3 contains the results of the MANOVA test. The clay samples from Sannai Maruyama were not included in the MANOVA test since the deposit could have been exploited at any time, and not necessarily in the Jomon period. While the *F*-values for both the time period and site location are statistically significant at the 95% confidence level, most variance in the data is due to site location: the eta-squared test statistic indicates that site location accounts for nearly 70% of the variability in the data.

Discriminant analysis [see BAXTER 1994a: 185-218, 1994b] was performed to assess separation between the four sites and see which subset of variables separates the four groups best. In linear discriminant analysis (LDA), it is assumed that unique groups exist in the data and linear combinations of variables that maximize the differences between groups are sought. Stepwise discriminant analysis (SDA) adds or deletes variables in a set of criteria so that group separation is maximized. This method results in the removal of variables that can blur the distinctions between groups. More realistic classification rules were then obtained using a cross-validation algorithm [BAXTER 1994b]. In this "leave one out" process, each sample was allocated to a group on the basis of discriminant functions that were calculated without the sample.

Table 11.1 Minor and trace element composition of the pottery sherds (ppm).

SAMPLE#	SITE	PHASE	Ti	Mn	Fe	Ni	Cu	Zn	Ga	Pb	Th	Rb	Sr	Y	Zr	Nb	Ba	La	Ce	Nd
F:EJ:001	Futatsumori	Early Jomon	8012	511	23603	24	42	209	21	20	13	115	250	22	152	16	641	22	nd	nd
F:EJ:002	Futatsumori	Early Jomon	8062	349	27002	21	32	123	17	25	10	55	358	33	180	8	1387	29	nd	nd
F:EJ:003	Futatsumori	Early Jomon	8513	649	21995	26	37	92	27	34	16	74	81	24	211	11	375	nd	nd	nd
F:EJ:004	Futatsumori	Early Jomon	11250	602	34206	19	377	80	27	28	nd	58	169	22	216	15	305	nd	nd	nd
H:001	Hatanai	Early Jomon	13560	537	51067	33	28	125	26	29	nd	40	82	19	215	14	391	nd	49	nd
H:002	Hatanai	Early Jomon	10290	398	41101	25	25	109	24	22	13	33	116	19	195	11	276	nd	34	nd
H:003	Hatanai	Early Jomon	10970	311	46409	40	23	144	30	20	13	51	139	24	263	8	382	26	nd	22
H:004	Hatanai	Early Jomon	7991	285	30379	17	21	95	24	17	nd	22	104	20	133	nd	293	nd	29	nd
H:005	Hatanai	Early Jomon	8747	323	26621	19	39	121	22	25	nd	55	150	22	186	12	384	nd	nd	nd
H:006	Hatanai	Early Jomon	7635	293	25334	25	24	186	24	20	nd	77	124	20	172	nd	389	nd	nd	nd
H:007	Hatanai	Early Jomon	9805	366	35332	29	21	97	32	27	19	56	114	18	181	15	354	nd	37	nd
I:001	Ichioji	Middle Jomon	6942	340	37586	40	37	267	20	30	14	92	317	30	167	9	939	20	56	24
I:002	Ichioji	Middle Jomon	11420	623	53161	16	73	182	23	25	nd	75	277	25	149	nd	671	nd	nd	20
I:003	Ichioji	Middle Jomon	8922	486	43798	20	167	191	18	20	nd	63	279	32	125	nd	712	nd	43	21
I:004	Ichioji	Middle Jomon	9034	211	37849	17	60	210	19	27	nd	53	263	52	158	11	996	39	63	46
I:005	Ichioji	Middle Jomon	6336	313	31074	19	141	288	16	25	19	84	202	21	178	11	591	20	41	nd
I:006	Ichioji	Middle Jomon	9299	940	51855	22	40	261	22	42	nd	83	274	28	177	14	916	nd	39	28
I:007	Ichioji	Middle Jomon	9419	1359	54866	12	151	356	18	33	nd	73	315	32	158	11	875	20	nd	21
I:008	Ichioji	Middle Jomon	12194	229	31520	36	51	180	39	55	16	72	469	47	190	nd	900	28	73	34
I:009	Ichioji	Middle Jomon	8284	289	43950	15	50	216	19	23	nd	66	263	23	156	14	839	nd	33	22
I:010	Ichioji	Middle Jomon	11277	544	49564	26	142	326	21	45	nd	62	417	47	171	nd	868	23	51	25
SM:EJ:001	Sannai Maruyama	Early Jomon	11026	752	36279	nd	38	114	23	38	16	132	275	26	212	nd	2142	nd	61	40
SM:EJ:002	Sannai Maruyama	Early Jomon	6691	438	31183	32	46	137	24	37	19	71	159	40	216	12	1560	20	55	36
SM:EJ:003	Sannai Maruyama	Early Jomon	8990	360	22412	27	25	114	17	28	14	51	518	38	178	9	3090	23	47	49
SM:EJ:004	Sannai Maruyama	Early Jomon	7603	617	39083	31	38	140	23	37	11	93	211	39	239	12	2318	nd	48	42
SM:EJ:005	Sannai Maruyama	Early Jomon	5148	226	17161	25	37	108	19	29	10	72	503	32	197	12	4369	24	56	73
SM:EJ:006	Sannai Maruyama	Early Jomon	7473	216	25837	30	73	92	19	35	13	107	217	33	216	10	2225	29	60	43
SM:EJ:007	Sannai Maruyama	Early Jomon	6824	233	15822	23	62	57	21	23	nd	71	191	24	166	12	1471	nd	31	22
SM:k:001	Sannai Maruyama	Middle Jomon	10348	419	48585	26	41	161	29	48	19	91	139	34	254	20	763	nd	49	26
SM:k:002	Sannai Maruyama	Middle Jomon	6950	467	33022	16	65	167	25	35	15	88	203	26	163	10	1033	nd	38	26
SM:k:003	Sannai Maruyama	Middle Jomon	7750	659	39686	24	30	78	27	37	15	81	164	39	212	12	682	nd	49	26
SM:k:004	Sannai Maruyama	Middle Jomon	6101	288	28852	21	58	92	21	32	12	99	153	22	156	12	543	23	40	22
SM:k:005	Sannai Maruyama	Middle Jomon	6902	235	37069	15	32	69	16	36	13	41	180	25	158	9	831	nd	28	24
SM:k:006	Sannai Maruyama	Middle Jomon	8649	265	36257	30	39	150	26	34	15	67	169	44	225	16	979	21	47	29
SM:k:007	Sannai Maruyama	Middle Jomon	8378	296	37559	26	52	195	28	40	10	85	153	34	213	9	1224	22	54	34
SM:k:008	Sannai Maruyama	Middle Jomon	7269	238	39334	19	31	150	26	23	12	52	167	34	183	9	849	23	41	27
SM:k:009	Sannai Maruyama	Middle Jomon	8866	488	34854	14	24	149	24	30	nd	58	242	27	174	11	904	20	30	24
SM:k:010	Sannai Maruyama	Middle Jomon	8562	652	55762	21	71	114	26	39	17	124	105	24	203	16	670	nd	40	nd

SM:MJ:001	Sannai Maruyama	Middle Jomon	7210	273	28063	21	24	65	28	38	nd	74	145	27	200	11	346	22	nd	25
SM:MJ:002	Sannai Maruyama	Middle Jomon	7123	297	30900	29	75	64	23	42	14	91	126	28	193	12	362	21	32	nd
SM:MJ:003	Sannai Maruyama	Middle Jomon	6685	180	35759	37	13	93	26	30	10	65	131	27	190	16	369	22	nd	nd
SM:MJ:004	Sannai Maruyama	Middle Jomon	9611	497	40705	53	26	132	36	30	11	67	141	37	201	12	384	27	nd	27
SM:MJ:005	Sannai Maruyama	Middle Jomon	6769	309	37126	26	37	77	25	39	12	108	126	25	185	15	347	nd	nd	30
SM:UCB:001	Sannai Maruyama	Early Jomon	6919	676	40927	48	44	87	21	43	17	86	236	37	155	12	981	20	49	33
SM:UCB:002	Sannai Maruyama	Early Jomon	7923	593	29163	33	34	76	22	39	16	48	201	27	183	14	771	nd	36	nd
SM:UCB:002	Sannai Maruyama	Early Jomon	6222	446	25209	17	34	75	19	30	17	46	208	34	175	12	606	nd	41	25
SM:UCB:002	Sannai Maruyama	Early Jomon	6719	549	35450	39	30	227	31	40	17	17	191	38	165	nd	605	24	41	22
SM:UCB:003	Sannai Maruyama	Early Jomon	6507	560	38361	18	24	172	29	38	16	97	219	36	175	13	821	27	52	25
SM:UCB:003	Sannai Maruyama	Early Jomon	6853	653	37400	37	26	161	28	39	21	93	231	39	184	11	821	20	49	26
SM:UCB:004	Sannai Maruyama	Early Jomon	7372	579	40545	27	42	118	22	39	16	69	208	37	183	nd	784	21	35	27
SM:UCB:004	Sannai Maruyama	Early Jomon	6025	622	34810	29	32	212	27	47	22	107	215	33	166	16	665	27	48	23
SM:UCB:005	Sannai Maruyama	Early Jomon	6550	954	39158	33	48	196	24	43	20	71	280	42	167	15	1285	26	47	30
SM:UCB:006	Sannai Maruyama	Early Jomon	6106	1128	41575	33	54	132	23	49	14	54	261	36	206	8	1394	25	52	28
SM:UCB:007	Sannai Maruyama	Early Jomon	9772	808	71413	nd	20	59	23	37	16	38	161	19	183	9	1078	nd	32	24
SM:UCB:008	Sannai Maruyama	Early Jomon	6119	790	27709	39	22	94	20	39	11	60	151	31	159	9	662	21	32	23
SM:UCB:010	Sannai Maruyama	Early Jomon	6130	483	33363	14	25	154	25	31	15	57	159	26	182	10	646	nd	30	20
SM:UCB:041	Sannai Maruyama	Early Jomon	7346	1084	42736	11	25	90	23	51	10	37	286	28	195	nd	1661	nd	42	32
SM:UCB:045	Sannai Maruyama	Early Jomon	6735	623	40042	22	33	62	25	43	14	92	213	36	161	14	868	23	49	29
SM:UCB:059	Sannai Maruyama	Early Jomon	6207	770	35511	21	33	128	21	41	13	69	156	42	169	11	361	nd	40	nd
SM:UCB:064	Sannai Maruyama	Early Jomon	6227	584	34930	15	61	120	24	49	12	44	190	31	215	10	795	nd	30	nd
SM:UCB:064	Sannai Maruyama	Early Jomon	5475	318	19811	17	16	50	16	60	17	47	218	28	157	10	677	nd	32	nd

Note: "nd"stands for not detected.

Table 11.2 Minor and trace element composition of the Sannai Maruyama clay (ppm).

SAMPLE#	SITE	Ti	Mn	Fe	Ni	Cu	Zn	Ga	Pb	Th	Rb	Sr	Y	Zr	Nb	Ba	La	Ce	Nd
clay01	Sannai Maruyama-clay	8512	1252	50126	26	20	111	26	52	14	139	156	34	223	13	647	25	51	23
clay02	Sannai Maruyama-clay	8673	1383	53018	18	23	108	23	44	12	137	170	36	227	11	676	24	53	26
clay03	Sannai Maruyama-clay	7570	1365	47853	18	17	86	25	47	16	124	165	33	206	10	637	28	46	30
clay04	Sannai Maruyama-clay	8740	1382	53208	16	29	106	29	48	19	130	175	35	221	19	573	20	47	20
clay05	Sannai Maruyama-clay	7375	1294	46293	25	18	88	26	42	12	116	151	36	209	13	537	nd	44	nd
clay06	Sannai Maruyama-clay	9443	1489	54942	17	18	94	21	51	20	137	168	34	231	17	625	25	55	31
clay07	Sannai Maruyama-clay	8512	1252	51898	26	20	111	26	52	15	139	157	34	223	13	573	22	48	24
clay08	Sannai Maruyama-clay	7801	1049	47915	24	17	90	27	52	18	139	148	29	223	15	572	nd	53	21
clay09	Sannai Maruyama-clay	8809	1279	54066	16	9	104	29	57	16	133	165	36	222	12	569	nd	45	24
clay10	Sannai Maruyama-clay	7671	1178	50766	30	19	95	24	48	21	143	146	33	219	12	565	26	53	28
clay11	Sannai Maruyama-clay	8051	1277	52556	29	21	95	22	50	13	132	153	30	219	15	508	24	53	26
clay12	Sannai Maruyama-clay	7419	978	48863	19	17	98	29	40	16	141	134	30	215	18	502	21	44	24
clay13	Sannai Maruyama-clay	8814	1875	57689	22	40	101	30	47	17	111	174	36	218	18	670	29	56	22

Table 11.3 Multivariate analysis of variance results.

	Pillai's Trace	*F*-value	Eta^2
Site	2.09	5.21	0.697
Phase	0.63	3.70	0.630
Site*Phase	undefined	0.000	0.000

Looking at site location, LDA with cross-validation resulted in 77% of the cases being correctly classified. The misclassified cases are listed in Table 11.4. A plot of the cross-validated discriminant functions is in Figure 11.8. For a probability of *F*-to-enter of 0.05, a probability of *F*-to-remove equal to 0.10, and maximizing the Wilks' lambda score between groups, SDA with cross-validation correctly classified 85% of the cases. The following log-transformed elements were identified as the most important discriminators: Cu, Nd, Pb, Sr, Ti, Zn, and Zr. The misclassified cases for the SDA with cross-validation are also listed in Table 11.4.

Finally, Figure 11.8 also plots the discriminant scores for the 13 clay samples from the Sannai Maruyama site. While the discriminant functions do associate the Sannai Maruyama clay samples with the Sannai Maruyama pottery samples, the discriminant scores for pottery samples have more spread. In other words, the minor and trace element characteristics of the clay samples are more homogenous than those of the pottery samples.

DISCUSSION

The *F*-statistic from the MANOVA test and the results from the discriminant analysis tests indicate that the log-transformed population means of the chemical variables for the four sites differ, and that most variance in the data is due to site location. LDA and SDA with cross-validation resulted in 77% and 85% of the cases being correctly classified respectively. These results support the hypothesis that the majority of the pottery samples examined here are likely to have been produced locally.

Among the four sites, the Futatsumori shell-midden had the highest percentage of misclassified samples (75% in both LDA and SDA). The large variability among Futatsumori sherds is illustrated in Figure 11.4. Unfortunately, because the sample size from this site is extremely small (only four samples), no definite conclusions can be drawn from these particular results. The percentage of misclassified samples from the Korekawa Ichioji site using LDA with cross-validation (40%) was also high, but in SDA with cross-validation, the percentage misclassified was only 10%. This difference (40% vs. 10%) is likely due to the fact that SDA only uses the variables that can discriminate between groups [see BAXTER 1994a: 212-213]. The percentages for misclassified samples from the Sannai Maruyama and Hatanai sites were relatively low: 15% (LDA with cross-validation) and 10% (SDA with cross validation) for Sannai Maruyama, and 14% in both methods for Hatanai.

The discriminant functions indicate association of natural clay samples from Sannai Maruyama with pottery samples from the same site. This supports our interpretation that Jomon potters at Sannai Maruyama used local clay resources. It must be emphasized, however, that matching a clay source to a ceramic group on geochemical grounds is not always straightforward

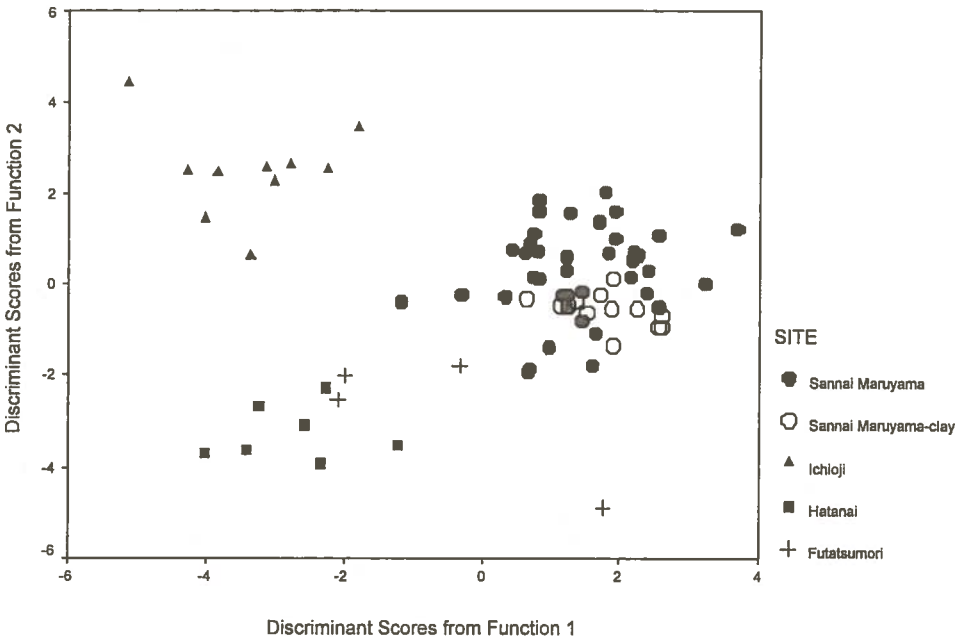

Figure 11.8 Plot of the first two discriminant functions obtained from linear discriminant analysis with cross validation.

Table 11.4 Misclassified cases from the discriminant analysis for groups based on site location.

Sample No.	Actual Group	Predicted Group, LDA with cross validation	Predicted Group, SDA with cross validation
F:EJ:001	Futatsumori		Ichioji
F:EJ:002	Futatsumori	Sannai Maruyama	
F:EJ:003	Futatsumori	Sannai Maruyama	Hatanai
F:EJ:004	Futatsumori	Ichioji	Ichioji
H:005	Hatanai	Futatsumori	Futatsumori
I:004	Ichioji	Sannai Maruyama	
I:005	Ichioji	Futatsumori	Futatsumori
I:007	Ichioji	Futatsumori	
I:008	Ichioji	Sannai Maruyama	
SM:EJ:003	Sannai Maruyama	Futatsumori	Hatanai
SM:EJ:007	Sannai Maruyama	Futatsumori	
SM:K:009	Sannai Maruyama	Hatanai	
SM:K:010	Sannai Maruyama		Futatsumori
SM:MJ:003	Sannai Maruyama		Hatanai
SM:MJ:004	Sannai Maruyama	Futatsumori	
SM:UCB:002a	Sannai Maruyama	Futatsumori	Futatsumori
SM:UCB:002c	Sannai Maruyama	Hatanai	

Note: A blank entry indicates that the specimen was not misclassified.

[ADAN-BAVYEWITZ and PERLMAN 1985; ARNOLD *et al.* 2000; SUMMERHAYES 1997]. In the present study, natural clay samples were obtained from only one location near the site, and little attention was paid to the depth from which the samples were taken. Ideally, clay samples should be taken from several locations throughout a clay deposit to fully document geochemical variation within the deposit. Thus, the spread of discriminant scores for the Sannai Maruyama pottery observed so far could be due to either geochemical variation in a single clay deposit, or the mixing of clays and tempers from elsewhere with the clay from the site. Further research is needed to assess these posibilities.

The misclassified cases in discriminant analysis could have a variety of causes. One possibility is that the misclassified samples indeed belong to their predicted geochemical groups. This could mean that some pots were moved between sites. Kojo's [1981] petrographic study indicates that an average of 20 to 30 % of the pottery at Moroiso-b phase sites in central Japan was imported. The overall percentage misclassified in the present study is in this range, and could reflect cases of pottery movements between sites. Therefore, it is possible that the misclassified samples actually belong to the cross-validated groups predicted by LDA and SDA.

Alternatively, the misclassified samples may not belong to the predicted groups. Although both MANOVA and LDA/SDA assume that actual chemical groups have been recognized in the data set, this assumption may be inappropriate: some samples may have been from chemical groups that are not represented by any of the four groups.

The misclassified cases may be due to the use of different tempers, or of more than one clay source, at a given site. Petrographic analysis can provide further insights as to the clay "recipes" used, while beryllium and lead isotopes can be used to provenance the specific clays used in pottery [IMAMURA *et al.* 1998].

Misclassification could also be due to similarity in the chemistry of regional clay sources. For example, since the Futatsumori and Sannai Maruyama sites are both located in areas of Holocene and Quaternary muds, sands and gravels that were formed primarily by the erosion of the Ou mountains [JAPANESE GEOLOGICAL SURVEY 1982: 9], it is possible that the chemical characteristics of clays in or near the two sites are geochemically similar. Quantitative petrography could possibly address whether this is an issue or not.

Finally, another possibility is that misclassification and overlap between groups was due to the accuracy and precision of the EDXRF analyses. Bishop *et al.* [1990: 540] and Wilson [1978: 222] note that when the accuracy and/or precision of an analytical method are greater than 5%, the analytical method sometimes masks the statistical differences between groups. Further analyses, using a technique such as neutron activation analysis, will be necessary in order to clarify these issues.

Our results using SDA with cross-validation indicated that Cu, Fe, Ga, Mn, Nd, Pb, Ti, Zn and Zr are the most important discriminating elements. Other than iron and titanium, all these elements occur at trace levels. Past x-ray fluorescence (XRF) studies of Jomon pottery by Japanese scholars have focussed on measuring major and minor elements. This study, as well as our previous studies [HABU and HALL 1999, 2001], emphasizes the importance of minor and trace element analysis for sourcing Jomon pottery.

CONCLUSION

In conclusion, although the analysis presented here is still preliminary, the results do support the hypothesis that most pots excavated from Sannai Maruyama were made locally, with little if any introduction of pottery from other areas. The results of our study also demonstrate the importance of minor and trace element analysis, as opposed to only the study of major elements, for distinguishing pottery made in different areas.

In order to investigate why large amounts of pottery were produced at the Sannai Maruyama site, we need to consider site functions in relation to subsistence, settlement, religion and social networks [HABU 2002, n.d.; HABU *et al.* 2001). Future chemical analyses should include (1) more systematic testing for changes through time in the chemical composition of pottery, (2) further comparison with other Jomon sites in the vicinity of Sannai Maruyama, (3) investigation of possible correlations between stylistic variation and the chemical composition of pottery, and (4) analyses of clay artifacts other than pots, such as clay figurines.

Because of its extraordinarily large size and the abundance of associated artifacts, the archaeological study of the Sannai Maruyama site has attracted the attention of many scholars [e.g., KIDDER 1998; UMEHARA and YASUDA 1995]. As recent studies [e.g., HABU 2002, n.d.; HABU *et al.* 2001; OKADA, this volume] indicate, however, the intra-site spatial patterns, as well as their changes through time, are extremely complex, and we are just beginning to understand the structural complexity. Although the results presented here deal with only one specific research question regarding pottery production and circulation, we hope that our research will help to clarify the nature and function of this extremely interesting Jomon site.

APPENDIX Values obtained for RGM-1 Standard (ppm).

Element	RGM-1 (Govindaraju 1994)	RGM-1, this study (n=7)
Ba	807	798
Ce	47	45
Cu	11.6	17
Fe_2O_3	18600	19000
Ga	15	15
La	24	26
MnO	360	349
Nb	8.9	12
Nd	19	26
Ni	4.4	6
Pb	24	23
Rb	149	148
Sr	108	102
Th	15.1	16
TiO_2	2670	2810
Y	25	31
Zn	32	39
Zr	219	218

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