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Jomon Pottery Production at Honmura-cho and Isarago Sites: Insights from Geochemistry

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Abstract The purpose of this paper is to examine whether Jomon pottery from two neighboring sites can be chemically distinguished from each other. For this purpose, minor and trace element composition of Jomon potsherds from the Honmura-cho and Isarago sites was determined using energy dispersive x-ray fluorescence (EDXRF). The results supported the hypothesis that the majority of the Early Jomon pottery from each of these two sites was produced locally using different raw materials. The paper also demonstrates the utility of multi-element, multivariate analyses for distinguishing pottery made in different locations.

Keywords: chemical analysis, trace element analysis, energy dispersive x-ray fluorescence (EDXRF), Early Jomon pottery, central Japan

Introduction

Over the past few decades, archaeologists have used chemical analysis as an effective method to examine pottery production and circulation. The underlying principle in most chemical studies of archaeological pottery is quite simple: pottery made in different regions is likely to have different chemical characteristics. This is because the chemical composition of the clay used to manufacture the pottery primarily reflects the local geologic environment in which the clay was formed (Bishop et al., 1982; Bishop and Neff, 1989; Harbottle and Bishop, 1992; Velde and Druc, 1999; Wilson, 1978). Furthermore, ethnographic examples indicate that potters tend to use local clay to manufacture their pottery (Arnold, 1992; Velde and Druc, 1999). Consequently, it becomes possible to distinguish groups of pottery made in different regions. Following this principle, many researchers have conducted major, minor and trace element analyses of pottery (see for example Culbert and Schwalbe, 1987; Mitsuji and Inoue, 1984; Neff, 1992; Ninomiya et al., 1991).

While the basic principle of the chemical analysis of pottery is simple and straightforward, several factors can complicate the situation. First, we do not know the de-

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gree of regional variability in clay deposits: different chemical compositional groups may correspond to different locations that are in close proximity, or they may correspond to regional clay deposits covering much larger areas. Second, the addition of tempers and the purification of clay may alter the chemical signature and preclude sourcing pottery to a specific clay deposit. These problems can be solved if potsherd samples from production sites are available; one can compare the chemical composition of pottery from consumer sites with that of pottery from production sites. However, in the case of the analysis of pottery from the prehistoric Jomon period of Japan (ca. 13,000–2300 b.p.), comparative specimens from production sites are not available. This is because Jomon pottery was open-air fired without any permanent firing facilities. Accordingly, it is extremely difficult to identify the provenience of each pot since there is no way of knowing a priori the number of sources in a given data set.

Despite these problems, we believe that the chemical analysis of Jomon pottery should be extensively conducted. By identifying inter- and intra-site variability in the chemical composition of Jomon pottery, and by examining changes in the chemical composition through time, one can gain useful information regarding Jomon pottery production. This will also lead to discussions on various other aspects of Jomon society, such as the role of ceramics, exchange/trade, and inter- and intra-regional contacts. Unfortunately, however, only a limited number of scholars have conducted systematic research in this field (see for example Ishikawa, 1988; Mitsuji, 1986; Mitsuji and Inoue, 1984; Ninomiya et al., 1991).

In our previous study (Habu and Hall, 1999), we examined whether statistically significant differences exist between Early Jomon Moroiso phase (ca. 5000 b.p.) potsherds excavated from three sites in different geographic regions: the Takada site in Kanagawa Prefecture, the Tenjin site in Yamanashi Prefecture, and the Takenohana site in Saitama Prefecture. The three sites are all located within the Moroiso style zone. The distances between these sites range from approximately 70 to 120 kilometers. Statistical analyses revealed three distinct chemical groups that coincide with the three sites. These results were interpreted as supporting the hypothesis that the majority of the Moroiso style pottery in these regions was locally made.

As the next step to examining chemical variability among Jomon pottery, this paper analyzes the chemical characteristics of pottery from two Jomon sites in close proximity: Honmura-cho and Isarago in Minato Ward, Tokyo. These sites are approximately 1.2 kilometers apart, and are located in the same geological unit. Since large quantities of Early Jomon Moroiso style pottery was recovered from both of these sites, our study primarily focuses on the analysis of Moroiso style pottery. This style of pottery, which is dated to circa 5000 uncalibrated b.p., is distributed throughout the Chubu region and the southern and northwestern Kanto region of Honshu, Japan. While the number of currently available radiocarbon dates from the Moroiso phase is too small to determine the exact duration of the Moroiso phase, scholars believe that the phase lasted for about 200–300 years or longer (see Habu, 1995). The Moroiso phase can be sub-divided into three sub-phases: Moroiso-a, b and c from the oldest to the youngest. Detailed description of the Moroiso phase and pottery is available in Habu (1988, 1995), and Habu and Hall (1999). In addition to Moroiso pottery, a small number of potsherd samples from other phases were also analyzed to examine temporal variability.

Following the analytical methods used in our previous study (Habu and Hall, 1999), the minor and trace element composition was obtained using energy dispersive x-ray fluorescence (EDXRF). The chemical variability of the pottery from these two sites was examined in relation to site location and time period. The results are discussed in the context of the production and circulation of Jomon pottery.

Problem to be Examined

The primary purpose of the paper is to examine whether pottery from the Honmura-cho and Isarago sites can be chemically distinguished from each other. If we find statistically significant differences between the chemical composition of the pottery from the two sites, then we can conclude that the pottery from these two sites was produced at each site using different raw materials. This would not only support our previous conclusion (Habu and Hall, 1999) but also imply that the differences in the chemical composition of pottery are discernable even between sites located on the same geological unit. On the other hand, if there are no statistically distinct chemical differences between the pottery from these two sites, then we suggest that either a) pottery from these two sites was produced by the same group of people and was part of a local trade, exchange or redistribution network, or b) potters who produced the pottery at these two sites utilized raw materials that were geochemically similar.

Archaeological Materials

Honmura-cho and Isarago are sites located in downtown Tokyo in central Japan (Fig. 1). Both sites are located in an area of Early and Late Pleistocene sedimentary deposits of marine origin (Geological Survey of Japan, 1982).

The Honmura-cho site is located in Azabu, Minato Ward, Tokyo. In the 1930s, Esaka (1938) conducted a small-scale excavation of the site, and reported it as an Early Jomon site associated with a shell midden. Because the site is located in the central part of Tokyo, the preservation condition of the site was poor even at the time of Esaka's excavation. Results of his excavation revealed that the site is associated with Early Jomon Kurohama and Moroiso phase pottery. Recent excavation of the site by the Board of Education of Minato Ward (Takayama and Toshida, 1990) re-

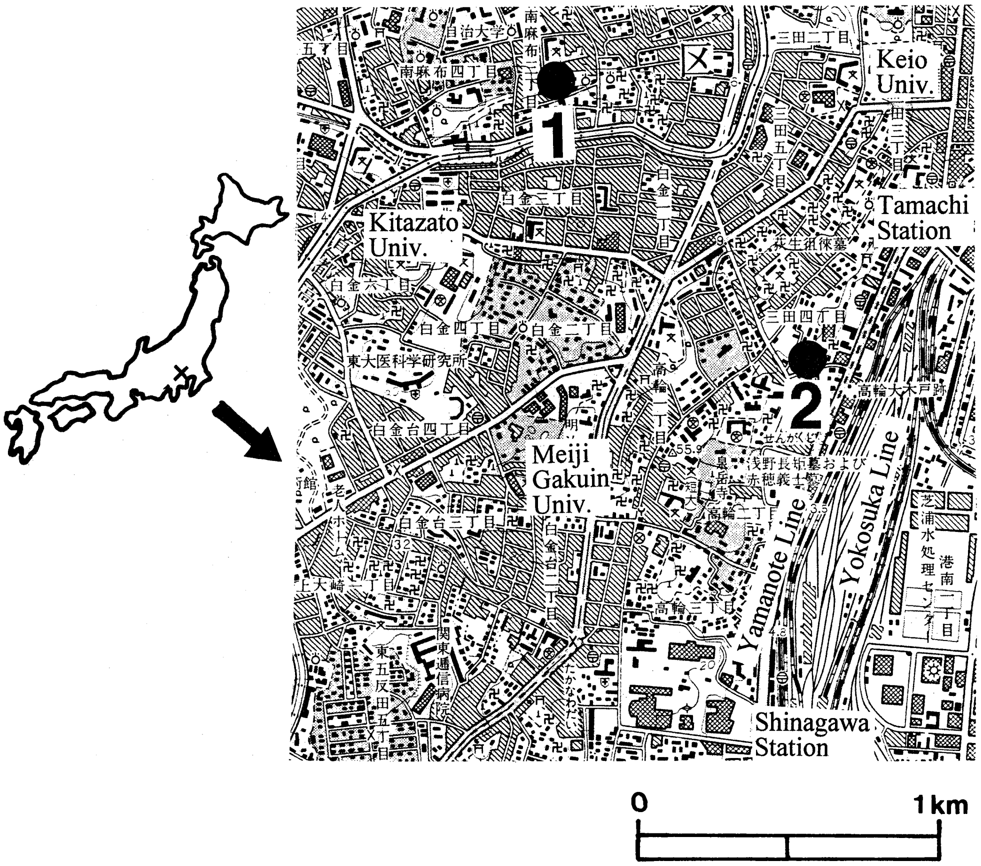

Figure 1. Location of the Honmura-cho (1) and Isarago (2) sites. Scale is 1: 25000. Modified from Kokudo Chiri-in (1999).

vealed the presence of a pit-dwelling from the second sub-phase of the Moroiso phase (Moroiso-b sub-phase).

Fourteen Moroiso-b style potsherds excavated by the Board of Education were provided as samples for chemical analyses. The ink-rubbings of these sherds are shown in Fig. 2. The number in the figure corresponds to the sample numbers from the site (e.g., 1 = H: 001). No information is available in the site report on the soil chemistry, but the sherds came from a part of the site not associated with shellfish remains.

The Isarago site is located in Shiba, Minato Ward, Tokyo. Although the site is primarily known as a Late Jomon shell midden site, results of a salvage excavation conducted by the excavation team of the Board of Education of Minato Ward (Excavation Team of the Isarago Site, 1981) revealed that underneath the Late Jomon shell midden was another cultural layer associated with a large number of Early Jomon

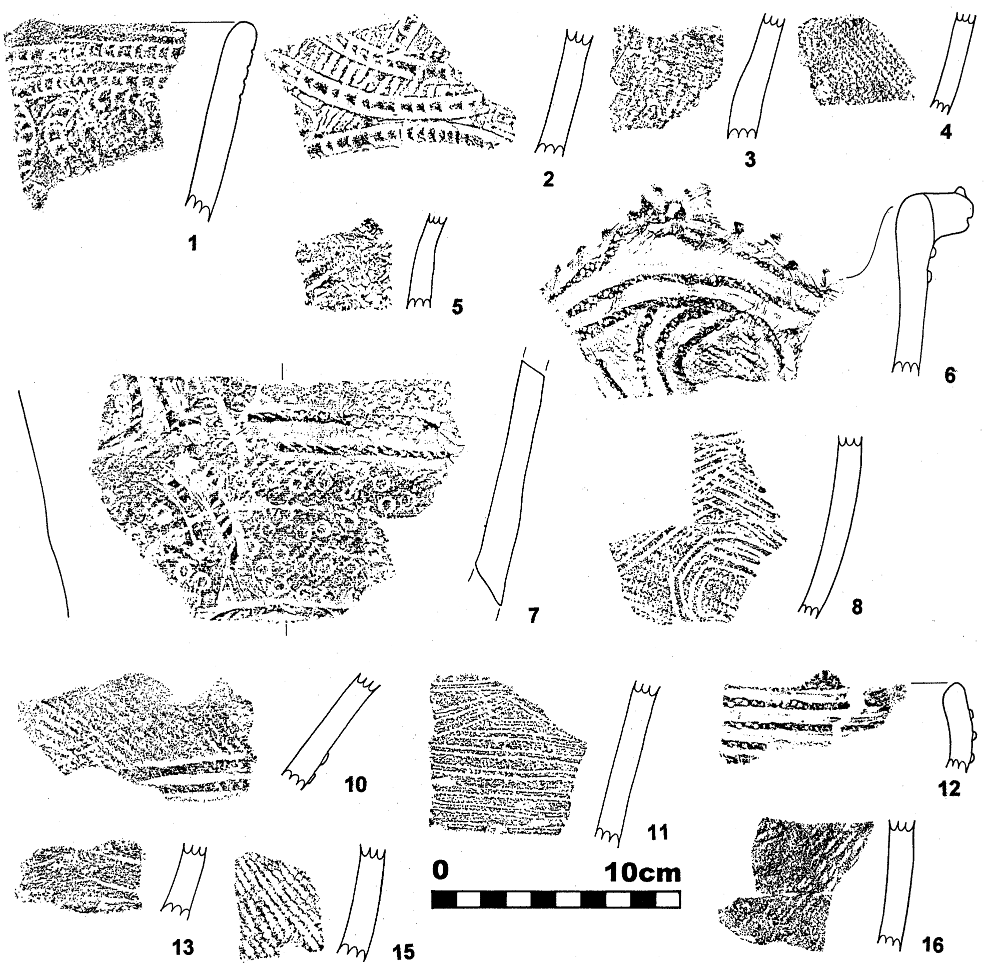

Figure 2. Pottery samples from the Honmura-cho site.

potsherds. No information is contained in the site report on the chemistry of the surrounding soil matrix. The majority of these potsherds are from the Moroiso-b sub-phase (Habu, 1981). Since no pit-dwellings or other types of features from the Early Jomon period were found, it is possible that, during the Early Jomon period, the site functioned as a special purpose site rather than as a residential base.

A total of 56 potsherd samples from the Isarago site were selected for EDXRF analysis. The ink rubbings and vessel profiles are shown in Fig. 3 through 5. Again, the numbers correspond to the sample numbers from the site (e.g., 191 = I: 191); these numbers also correspond to the artifact numbers in the site report. Of the sherds examined, 50 samples are identified as Moroiso style pottery (49 samples from the Moroiso-b sub-phase and 1 sample from the Moroiso-a sub-phase). Also included is

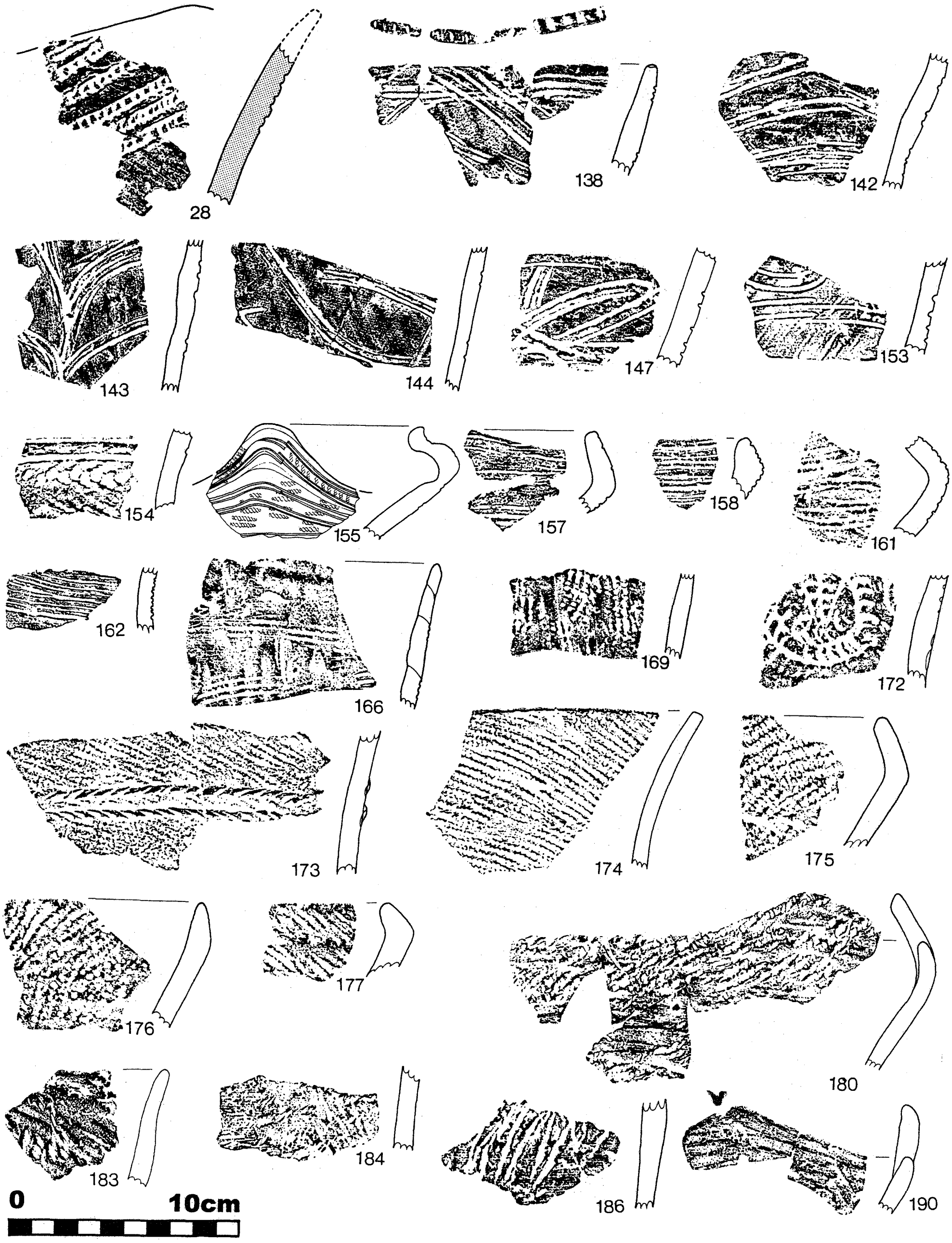

Figure 3. Pottery samples from the Isarago site (1). The shaded profile indicates fiber-tempered pottery.

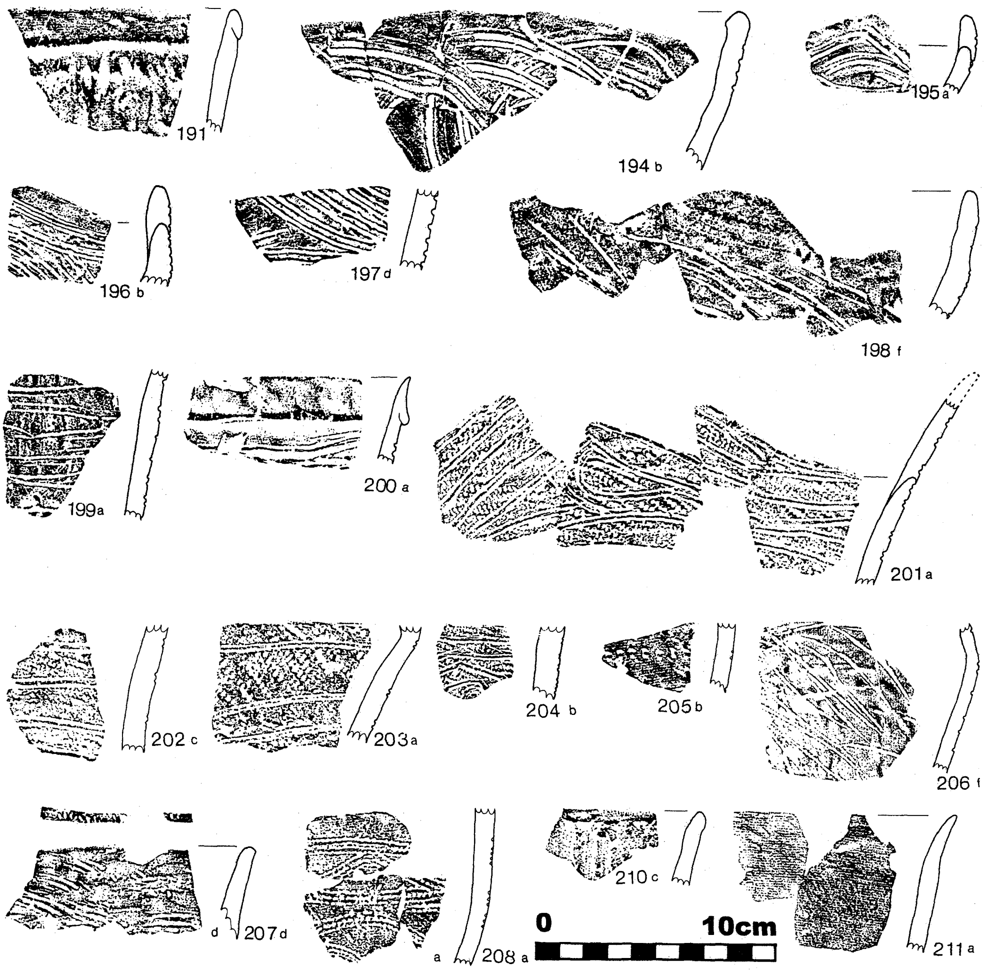

Figure 4. Pottery samples from the Isarago site (2).

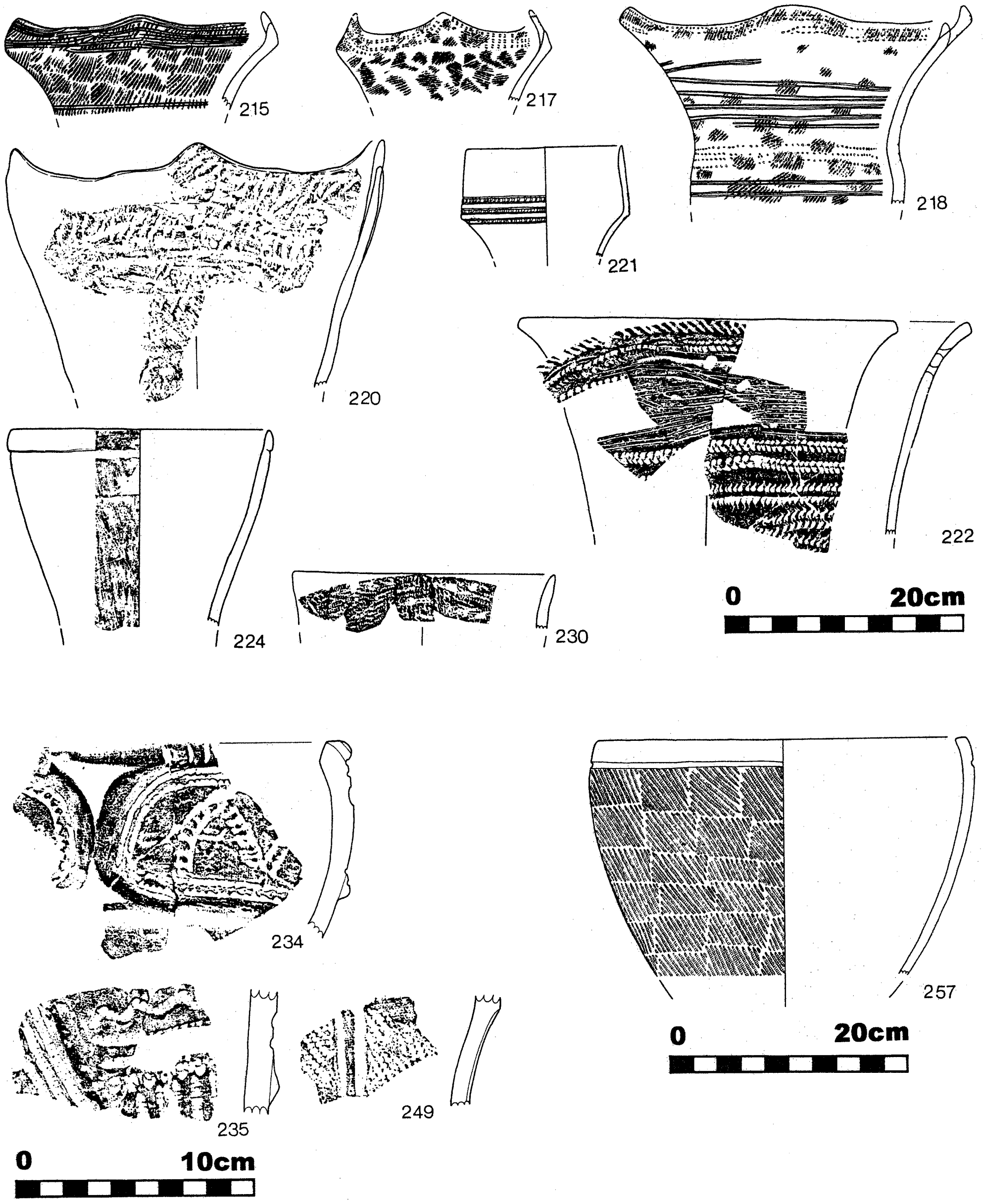

Figure 5. Pottery samples from the Isarago site (3).

one sample of Ukishima style pottery (I: 222, see Fig. 5). This style of pottery is primarily distributed in the eastern part of the Kanto region (i.e., Chiba, Ibaraki, and part of Tochigi and Saitama Prefectures). Stratigraphic excavations of Early Jomon sites which contain both styles of pottery indicate that these two styles of pottery are roughly contemporaneous (Nishimura, 1986). Five sherds from phases other than the Moroiso/Ukishima phase were also analyzed to examine whether the chemical composition of pottery changed through time. Of these, one sherd (I: 028) is from the Kurohama phase, which preceded the Moroiso phase. In addition, four samples (Otamadai and Kasori-E styles) from the Middle Jomon Period were analyzed (see Table 1).

Methodology

Analytical

While not as popular as instrumental neutron activation analysis (INAA) for ceramic analysis, energy dispersive x-ray fluorescence (EDXRF) is a low-cost and rapid technique for determining the major, minor and trace element composition of pottery (see for example Culbert and Schwalbe, 1987; Habu and Hall, 1999; Hall et al., 1999; Mitsuji, 1986; Yap and Tang, 1984). EDXRF can accurately measure elements with atomic numbers 11 through 41 and some of the rare earth elements (Potts, 1987). A comparative study between the EDXRF facility at the University of California at Berkeley and the Research Reactor Facility at the University of Missouri indicates 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).

The elemental analyses were performed using a Spectrace 440 EDXRF machine equipped with a rhodium x-ray tube, a rhodium filter and a Tracor TX 6100 X-ray analyzer located at the University of California at Berkeley. The x-ray tube was operated at 30 kV, 20 mA at 250 seconds livetime with an elliptical beam (0.5 cm by 0.75 cm) to generate x-ray intensity K_α and L_α line data for the following 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). As has been demonstrated by Shackley (1998), the majority of these elements can be measured non-destructive EDXRF with high precision and accuracy. Barium (Ba), cerium (Ce), lanthanum (La), and neodymium (Nd) x-ray intensity K_α line data were generated by using an americium (^{241}Am) gamma-ray source for 500 seconds livetime. The rare earth elements (Ce, La, Nd) are relatively insoluble in water and are seen as reflecting the origin of the sedimentary material (McLennan et al., 1980).

While the calcium (Ca), potassium (K), sodium (Na) and silicon (Si) concentrations can be determined by EDXRF, they were not measured for this study. Accurate measurement of these elements requires a fused sample to be made; permission was not obtained from the Board of Education of Minato Ward to cut the specimens for the making of a fused sample or petrographic study.

Concentration values were obtained by using a Compton scatter matrix correction, a Lucas-Tooth and Price inter-element effect correction, and the linear regression of a set of Japan Geological Survey (JGS), National Bureau of Standards (NBS), National Institute of Standards and Testing (NIST), and United States Geological Survey (USGS) mineral standards. The detection limits, as determined on 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 at 6 sigma. The x-ray counting and least squares linear regression errors are listed in Appendix 1. To monitor precision and accuracy, standards of known composition were always run with the unknowns. Appendix 2 lists the analytical results for the standards.

The cleaned cross-section or surface of the sherd was irradiated. Before irradiation, each sherd was rinsed with distilled, de-ionized water, scrubbed with a nylon brush, and then rinsed with distilled, de-ionized water again. The sherds were air-dried and then irradiated.

Post-depositional, chemical alteration of the sherds is not seen as being a major concern. Raw clay has a cation exchange capacity of 1 to 5 percent, while fired clay has a lower cation exchange capacity (Hedges and McLellan, 1976). The rare earth elements (Ce, La, Nd) and Ga, Nb, Th, Ti, Y and Zr, all of which are elements measured in this study, are only mobile in extreme metamorphic conditions (McLennan et al., 1980; Winchester and Floyd, 1977). Experimental work has demonstrated that in fired clay, post-depositional processes can alter the Ba, Fe, and Mn contents (Freeth, 1967; Hedges and McLellan, 1976; Tubb et al., 1980). For the remaining elements measured in this study (Cu, Ni, Pb, Rb, Sr, and Zn), their mobility would depend on the acidity of the surrounding soil, the permeability of the surrounding soil, the acidity and annual amount of rainfall, and the other mineral species present in both the soil and sherd (Teutsch et al., 1999). Experimental work on sediments and soils under a variety of conditions indicates that the alteration for Cu, Ni, Pb, Rb, Sr, and Zn can be as high as a few parts per million (ppm) (Teutsch et al., 1999; You et al., 1996). Due to its lower cation exchange capability, the alteration would be less in fired clay. Accordingly, we assume that weathering will not significantly affect the results of our analyses.

Statistical Techniques

The statistical methodology of Vitali and co-workers (Vitali and Franklin, 1986;

Vitali et al., 1987) is used in this study. Their approach utilizes the multivariate analysis of variance (MANOVA) test and discriminant analysis.

The MANOVA test is used to examine the relationship between the chemical variation, pottery type, site location, and time period. The goal of this test is to see which factor, or combination of factors, accounts for the variability in the data (see Barker and Barker, 1981; Sharma, 1996). The variance is evaluated using *F* values; the larger the *F* value the more significant a factor or combination of factors is in accounting for the variance.

Linear discriminant analysis (LDA) and step-wise discriminant analysis (SDA) are performed to verify groups in the data set (see Baxter 1994). In LDA, it is assumed that unique groups exist in the data, and linear combinations of variables that maximize the differences between groups are sought. SDA adds or deletes variables to a set of criteria so that group separation is maximized.

MANOVA and discriminant analysis require that the number of groups be assumed a priori. From this perspective, these two statistical techniques can be used to test hypotheses. Unlike principal components analysis (PCA) or cluster analysis, the methodology of Vitali and co-workers cannot be used to determine the number of groups in the data set (Bishop and Neff, 1989). For comparative purposes, the results of a PCA are also presented.

All mathematical and statistical results were obtained using SPSS Release 8.0. The power tests (see Cowgill, 1977) were performed with the program STPLAN.

Results and Data Analysis

The results of the EDXRF analyses are presented in Table 1. While La and Nd were sought, they were not found in quantities above the detection limit. All values, except iron and titanium, are listed in parts per million (ppm). The iron and titanium values are listed in weight percent.

To assess the chemical variability within a single pot, duplicate readings were taken on two samples (HMK: 008 and HMK: 016) from two different locations (a and b) within each pot. The results are in Appendix 3. For most elements, the coefficient of variation (CV) is 10% or less. For group validity, the CV within a pot should be lower than the CV for the group to which it is assigned. This issue will be further discussed below.

The ratio of MnO/TiO_2 for all the sherds is below 0.30. This indicates that the clays used in these sherds are of a marine origin; as noted by Togashi et al. (2000), sedimentary materials in Japan with an MnO/TiO_2 ratio less than 0.50 originated in a marine environment.

The chemical concentrations were transformed to log base 10 values. The iron and titanium values were converted to ppm values, and then transformed. This transfor-

Table 1. Results of the EDXRF analyses

SAMPLE	SITE	PHASE	PERIOD	Ti(%)	Mn	Fe(%)	Ni	Cu	Zn	Ga	Pb	Th	Rb	Sr	Y	Zr	Nb	Ba	Ce
HMK: 001	Honmuracho	Moroiso b	Early Jomon	0.749	550	4.288	29	165	100	20	17	11	46	93	16	135	10	242	31
HMK: 002	Honmuracho	Moroiso b	Early Jomon	1.369	426	3.941	18	190	89	22	17	nd	27	77	18	154	nd	145	24
HMK: 003	Honmuracho	Moroiso b	Early Jomon	1.104	2218	8.023	33	75	212	29	13	21	74	83	13	178	nd	269	32
HMK: 004	Honmuracho	Moroiso b	Early Jomon	1.075	1358	8.157	56	123	174	26	21	14	76	128	15	152	nd	267	34
HMK: 005	Honmuracho	Moroiso b	Early Jomon	1.061	312	4.286	31	98	175	21	15	12	58	57	13	193	11	173	28
HMK: 006	Honmuracho	Moroiso b	Early Jomon	0.974	1049	3.478	35	265	136	21	24	21	53	118	19	193	16	217	31
HMK: 007	Honmuracho	Moroiso b	Early Jomon	0.636	2339	8.181	432	122	165	36	28	18	22	80	nd	77	nd	58	nd
HMK: 008	Honmuracho	Moroiso b	Early Jomon	1.168	1415	5.123	80	106	156	26	17	13	41	122	21	201	17	226	35
HMK: 010	Honmuracho	Moroiso b	Early Jomon	1.219	362	4.491	60	97	89	14	16	nd	30	96	17	193	12	128	25
HMK: 011	Honmuracho	Moroiso b	Early Jomon	1.118	1454	4.541	20	88	95	23	17	16	56	60	11	165	11	199	28
HMK: 012	Honmuracho	Moroiso b	Early Jomon	1.336	375	4.613	64	90	198	21	15	10	43	79	15	146	nd	183	23
HMK: 013	Honmuracho	Moroiso b	Early Jomon	0.833	1202	5.560	44	64	134	22	15	11	41	112	14	126	nd	184	27
HMK: 015	Honmuracho	Moroiso b	Early Jomon	0.981	524	5.002	23	60	93	17	20	13	38	83	12	126	nd	206	55
HMK: 016	Honmuracho	Moroiso b	Early Jomon	0.868	2079	3.987	34	83	210	23	19	14	48	73	17	169	nd	226	35
I: 028	Isarago	Kurohama	Early Jomon	0.771	695	4.213	17	38	81	15	18	18	43	167	14	118	8	239	30
I: 138	Isarago	Moroiso b	Early Jomon	0.761	831	3.877	26	55	87	15	16	18	78	157	17	137	8	385	33
I: 142	Isarago	Moroiso b	Early Jomon	0.694	452	3.826	38	63	86	17	9	12	59	229	15	108	nd	292	23
I: 143	Isarago	Moroiso b	Early Jomon	0.718	689	3.679	28	54	58	16	17	19	106	172	17	143	11	320	38
I: 144	Isarago	Moroiso b	Early Jomon	0.697	664	4.082	25	47	66	16	21	16	116	158	16	152	7	310	33
I: 147	Isarago	Moroiso b	Early Jomon	0.626	420	2.429	47	33	81	18	18	14	127	104	18	186	14	306	46
I: 153	Isarago	Moroiso b	Early Jomon	1.206	429	2.759	24	66	66	17	14	14	69	176	18	169	10	293	28
I: 154	Isarago	Moroiso b	Early Jomon	0.830	613	3.881	39	20	120	17	25	10	83	153	14	151	10	242	26
I: 155	Isarago	Moroiso b	Early Jomon	0.929	870	2.234	25	59	57	24	19	nd	83	113	14	152	9	201	30
I: 157	Isarago	Moroiso b	Early Jomon	0.637	1475	4.659	42	64	129	23	15	14	114	148	15	132	9	262	36
I: 158	Isarago	Moroiso b	Early Jomon	0.364	329	1.956	79	1222	546	93	54	22	26	94	14	102	9	144	20
I: 161	Isarago	Moroiso b	Early Jomon	1.407	1371	6.434	51	48	118	20	17	12	91	139	17	139	14	245	32
I: 162	Isarago	Moroiso b	Early Jomon	1.163	1085	5.955	43	85	91	17	15	17	54	136	18	148	nd	221	26
I: 166	Isarago	Moroiso b	Early Jomon	0.883	494	4.013	41	53	65	17	16	nd	79	122	16	156	nd	263	26

I: 169	Isarago	Moroiso b	Early Jomon	0.864	483	3.189	37	39	108	18	19	14	79	144	12	147	nd	320	29
I: 172	Isarago	Moroiso b	Early Jomon	0.914	926	8.518	17	42	119	17	20	15	50	172	15	139	nd	184	23
I: 173	Isarago	Moroiso b	Early Jomon	0.915	465	2.790	29	32	62	16	20	12	54	211	15	158	15	288	25
I: 174	Isarago	Moroiso a	Early Jomon	0.756	609	4.879	34	34	115	18	16	12	75	176	13	158	nd	346	37
I: 175	Isarago	Moroiso b	Early Jomon	0.639	870	4.093	26	36	80	18	13	14	70	148	13	135	nd	333	30
I: 176	Isarago	Moroiso b	Early Jomon	0.718	1181	4.082	23	70	104	22	13	15	36	139	12	140	9	361	25
I: 177	Isarago	Moroiso b	Early Jomon	0.761	1271	3.324	26	57	106	29	19	15	39	101	15	185	11	247	26
I: 180	Isarago	Moroiso b	Early Jomon	1.025	629	4.735	31	172	59	18	13	nd	61	168	13	123	nd	246	25
I: 183	Isarago	Moroiso b	Early Jomon	0.742	864	3.959	20	35	95	18	17	11	91	140	20	151	10	360	32
I: 184	Isarago	Moroiso b	Early Jomon	0.784	311	2.018	52	29	148	19	17	19	50	158	24	157	nd	287	31
I: 186	Isarago	Moroiso b	Early Jomon	0.757	757	4.299	60	23	176	21	19	14	80	143	20	151	9	493	32
I: 190	Isarago	Moroiso b	Early Jomon	0.563	503	2.741	23	100	61	13	17	14	133	49	18	134	nd	310	35
I: 191	Isarago	Moroiso b	Early Jomon	0.855	754	6.236	33	127	120	23	22	13	122	149	19	141	nd	296	24
I: 194b	Isarago	Moroiso b	Early Jomon	0.727	729	3.758	23	32	92	17	16	13	86	161	22	138	nd	336	34
I: 195a	Isarago	Moroiso b	Early Jomon	0.772	518	4.578	27	142	80	17	14	nd	97	131	19	137	nd	274	33
I: 196b	Isarago	Moroiso b	Early Jomon	1.010	229	3.032	26	106	52	17	13	nd	51	159	13	143	nd	257	20
I: 197d	Isarago	Moroiso b	Early Jomon	0.731	240	2.127	28	39	47	15	16	13	43	154	15	111	9	293	24
I: 198f	Isarago	Moroiso b	Early Jomon	0.925	620	4.896	38	116	63	17	15	12	52	156	17	111	nd	271	25
I: 199a	Isarago	Moroiso b	Early Jomon	0.812	917	4.670	19	48	95	19	18	12	109	150	17	153	nd	351	29
I: 200a	Isarago	Moroiso b	Early Jomon	0.708	808	3.852	24	33	89	16	18	14	151	143	14	146	nd	361	36
I: 201a	Isarago	Moroiso b	Early Jomon	0.764	505	5.313	25	56	127	24	16	11	84	138	13	152	10	316	26
I: 202c	Isarago	Moroiso b	Early Jomon	1.266	450	5.232	62	65	84	26	16	15	71	112	14	164	14	188	26
I: 203a	Isarago	Moroiso b	Early Jomon	0.606	602	2.950	22	62	44	18	14	15	66	152	14	153	8	313	36
I: 204	Isarago	Moroiso b	Early Jomon	1.344	757	5.988	82	32	99	21	14	11	44	116	16	158	12	209	28
I: 205b	Isarago	Moroiso b	Early Jomon	0.784	790	5.878	18	80	73	19	17	10	89	99	14	148	nd	331	27
I: 206	Isarago	Moroiso b	Early Jomon	0.656	485	3.319	40	80	66	18	16	nd	77	138	15	146	nd	336	34
I: 207d	Isarago	Moroiso b	Early Jomon	0.701	221	2.290	27	141	59	11	15	14	59	173	17	129	nd	319	26
I: 208a	Isarago	Moroiso b	Early Jomon	1.215	2276	9.633	165	33	132	18	13	14	82	151	17	156	10	195	26
I: 210c	Isarago	Moroiso b	Early Jomon	0.748	837	4.974	14	67	71	16	16	nd	141	124	17	149	nd	301	33
I: 211a	Isarago	Moroiso b	Early Jomon	1.015	893	7.300	15	106	95	23	18	14	80	139	15	136	8	135	28
I: 215	Isarago	Moroiso b	Early Jomon	0.773	459	3.372	27	168	50	20	19	14	85	153	17	135	8	332	24

Table 1 (continued)

SAMPLE	SITE	PHASE	PERIOD	Ti(%)	Mn	Fe(%)	Ni	Cu	Zn	Ga	Pb	Th	Rb	Sr	Y	Zr	Nb	Ba	Ce
I: 217	Isarago	Moroiso b	Early Jomon	0.797	556	3.506	24	92	56	20	19	15	73	147	16	149	10	320	39
I: 218	Isarago	Moroiso b	Early Jomon	0.944	562	3.773	25	38	76	16	15	13	57	136	12	139	nd	384	22
I: 220	Isarago	Moroiso b	Early Jomon	0.884	187	1.928	24	45	64	19	17	10	61	157	22	150	9	301	46
I: 221a	Isarago	Moroiso b	Early Jomon	0.644	240	2.529	22	33	37	17	16	nd	52	131	13	161	6	259	20
I: 222	Isarago	Ukishima	Early Jomon	0.616	372	2.658	17	63	52	18	15	12	50	115	16	153	nd	277	22
I: 224	Isarago	Moroiso b	Early Jomon	0.629	1194	3.699	33	39	66	17	19	18	98	131	17	150	9	357	31
I: 230	Isarago	Moroiso b	Early Jomon	0.860	349	2.329	28	66	71	15	17	10	93	130	15	151	nd	318	33
I: 234	Isarago	Otamadai	Middle Jomon	0.871	868	4.997	16	24	93	19	24	13	82	244	13	176	11	439	54
I: 235	Isarago	Otamadai	Middle Jomon	0.724	767	3.316	25	37	59	20	16	15	64	188	17	116	nd	338	23
I: 249	Isarago	Kasori E	Middle Jomon	0.704	1301	6.143	23	95	113	22	20	14	104	187	14	121	nd	267	24
I: 257	Isarago	Kasori E	Middle Jomon	0.855	435	3.929	33	80	126	20	23	13	130	179	22	143	nd	373	46

All values except Ti and Fe are listed in parts per million (ppm). Ti and Fe in weight percent. nd = not detected.

mation compensates for the differences in magnitude between the minor and trace elements. For cases below the detection limit, one half the detection limit was used in the transformation and subsequent data analysis.

The MANOVA test was conducted to examine whether site location, pottery type and/or time period accounts for the variation in the data set. The homogeneity of variance is equal for all log base 10 elements except Mn, Y and Zr. These three elements are left out of the MANOVA test since the MANOVA test requires that the homogeneity of variance be equal for all the dependent variables. The *F* values, as determined by Pillai's trace statistic, are presented in Table 2. Site location is the dominant factor in accounting for variability in the data set. Over 70% of the vari-

Table 2. Results from the MANOVA test. The site location accounts for the majority of the variation in the data and is significant at the 95% significance level.

Factor	Pillai's Trace Test Statistic	*F*-value	Significance	Eta
Site	0.714	11.02	0.00	0.714
Phase	0.415	0.735	0.86	0.138
Time Period	0.000	undefined	undefined	undefined
Site*Phase	0.000	undefined	undefined	undefined
Phase*Time Period	0.000	undefined	undefined	undefined
Site*Phase*Time Period	0.000	undefined	undefined	undefined

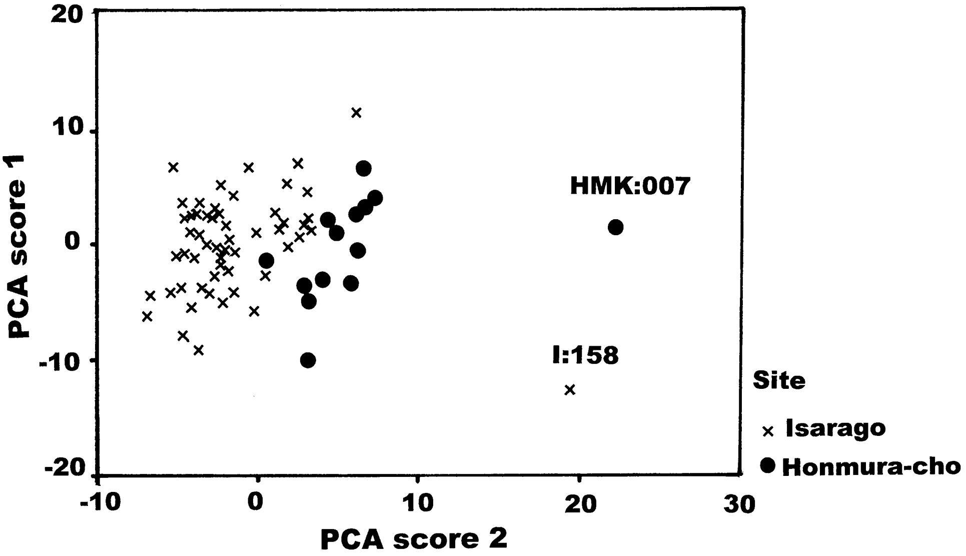

Figure 6. Plot of the first two principal component analysis (PCA) scores.

Table 3. Mis-classified cases from the discriminant analyses

Sample Number	LDA mis-classification	SDA mis-classification
HMK: 006		X
HMK: 007	X	
I: 158	X	X
I: 162	X	
I: 176	X	
I: 177	X	X
I: 190	X	X
I: 204	X	X
I: 208	X	

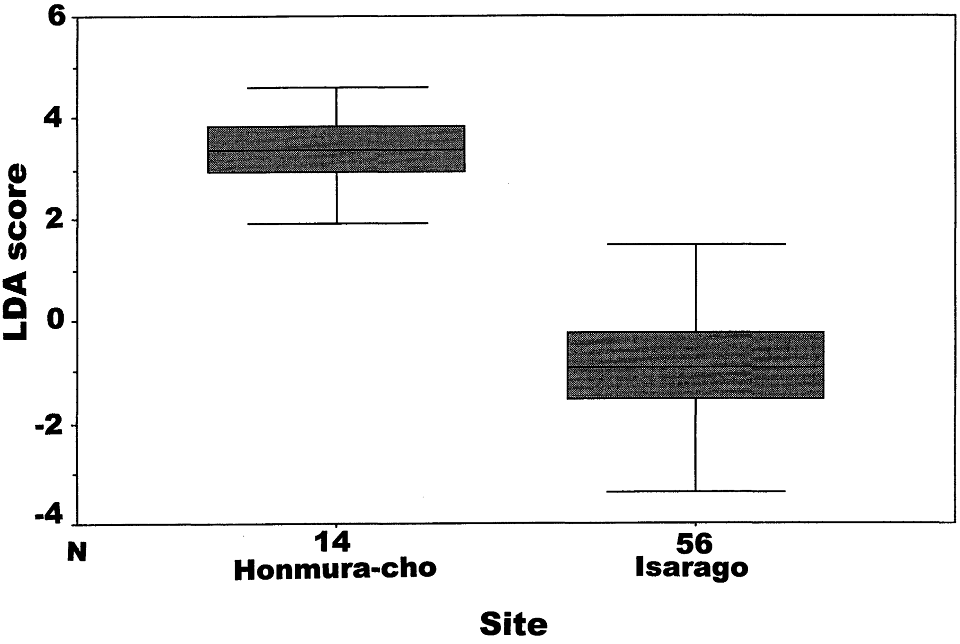

Figure 7. Box and whisker plot of the linear discriminant analysis (LDA) scores for Honmura-cho and Isarago. The bar in each box marks the median value.

ability in the data is accounted for by site location alone. While pottery type accounts for almost 15% of the variability in the data, its significance is extremely low and could be due to chance. The time period, or other combinations of factors, do not account for any of the variation in the data set. At the 95% significance level, the MANOVA test indicates that there are significant differences in the concentration of Ba, Cu, Rb, Sr, Ti, and Zn between the two sites.

A principal components analysis (PCA) was performed on the covariance matrix

Table 4. Average elemental concentrations for the two chemical groups. The number of samples in each group is shown; the first standard deviation is shown for group.

Element	Honmura-cho (n = 13)	Isarago (n = 49)
Ti (%)	1.066 ± 0.185	0.815 ± 0.165
Mn	1024 ± 659	649 ± 243
Fe (%)	5.037 ± 1.458	4.023 ± 1.397
Ni	40 ± 19	29 ± 11
Cu	116 ± 58	64 ± 37
Zn	143 ± 48	83 ± 30
Ga	22 ± 4	18 ± 3
Pb	17 ± 3	17 ± 3
Th	13 ± 5	12 ± 4
Rb	48 ± 15	81 ± 25
Sr	91 ± 23	153 ± 28
Y	15 ± 3	16 ± 3
Zr	164 ± 27	144 ± 16
Nb	8 ± 5	7 ± 4
Ba	205 ± 43	303 ± 62
Ce	31 ± 8	30 ± 7

of the log transformed variables. The plot of the first two PCA scores is in Fig. 6. As can be seen from the plot, the PCA scores for the two groups exhibit good separation. The PCA plot also suggests that specimens HMK: 007 and I: 158 are outliers in the data set.

Discriminant analysis was conducted to assess the validity of the chemical groups based on site location. LDA with cross-validation using all the log-transformed variables correctly classified 88.6% of the cases. The eight mis-classified cases are listed in the column marked "LDA mis-classification" in Table 3. A box and whisker plot of the discriminant function scores is in Fig. 7.

SDA with cross-validation using the log-transformed variables was performed to see which elements were the most discriminating. This analysis was conducted in order to determine which elements contribute to group separation; simulation studies have demonstrated that variables that carry no discriminating information can actually cause mis-classifications between groups (Baxter 1994; Baxter et al., 2000). For a probability of F-to-enter of 0.05, a probability of F-to-remove equal to 0.10, and maximizing the Mahalanobis distance between groups, SDA identified the elements Ce, Fe, Rb, and Sr as the most important discriminators. Over 90% of the cases were correctly classified in SDA. The mis-classified cases in SDA are listed in the right-hand column of Table 3.

The average composition for each group based on site location is listed in Table 4.

The group means and standard deviations were calculated with the mis-classified cases from the LDA removed. At the 95% significance level and a power of 0.80, a difference of means test indicates that there are significant differences between the means of Ba, Cu, Ga, Rb, Sr, Ti, and Zn. For Cu, Rb, and Sr, the difference in means exceeds a few parts per million, and is not viewed as being due to chemical alteration of the sherd.

Discussion

The statistical tests presented in the previous section all indicate that there are two chemical groups in the data that correspond to site location. Following the hypothesis presented above, we suggest that the pottery from the Honmura-cho and Isarago sites was produced at each site from geochemically distinct raw materials. Whether these elemental differences are due to the use of different clays or tempers cannot be determined at this time. Petrographic analysis is required to answer this issue. For example, Ba, Rb and Sr are common trace elements in felsic rocks. The difference in concentration of these three elements, as indicated by the above statistical tests, could be reflecting differing uses of tempering materials.

Depending on the element, the CV in each group ranges from 11% to 64%. For all elements, the CV in each group is larger than the CV as calculated in Appendix 3. This would indicate that the variation within a pot is not affecting the group results.

While chemical zonation in the clay deposit may explain the variability seen in the samples, we do not think this is the case. Many archaeologists believe that the Jomon inhabitants in the Kanto region dug below the Kanto loam (2–4 m in depth) to reach suitable clay deposits. Alteration due to weathering is generally considered to be minimal at those depths (see Tuetsch et al., 1999).

The samples from Isarago date from the Early Jomon period through the Middle Jomon period. The MANOVA test indicates that some of the variability in the chemical data is due to the pottery type, but the low significance and power indicates that this could be due to chance. Future research, with a larger sample size, needs to address the issue of chemical variability within different pottery styles through time.

A plot of the first two PCA scores also reinforces that there are two groups corresponding to site location. Since PCA is a method that reduces multivariate data to a simpler representation, this also confirms that there are differences in the chemistry of the pottery from the two sites. It also points to sherds HMK: 007 and I: 158, two of the sherds mis-classified in LDA, as outliers.

The mis-classification in the discriminant analyses could be due to some form of contact between the two Early Jomon groups. Given the proximity of the two sites, pottery made at one site may have been transported to the other site through exchange (see Habu and Hall, 1999; Kojo, 1981). Another possibility is that the overlap between groups could arise from geochemical similarity in the marine-derived clays that were used to manufacture the two groups of pottery. Alternatively, it must also be kept in mind that the accuracy and precision of the EDXRF analyses could be causing the overlap and mis-classification. As noted by both Bishop et al. (1990) and Wilson (1978), when the precision and accuracy of an analytical method are greater than 5%, the method can often fail to distinguish chemically similar, but statistically different groups.

However, one of the outliers from the PCA, HMK: 007, has an elevated concentration of Cu, Fe, Ga, Ni and Zn. All of these elements are associated with mafic materials and sulphide minerals (Mallory-Greenough et al., 1998). Also, Cu, Ni, and Zn, can substitute into chlorite minerals and replace Fe and Mg (Velde 1995). This sherd also has a low concentration of Ba, Ce, Y, and Zr. These elements are all associated with felsic minerals (Mallory-Greenough et al., 1998). The chemical evidence points to this sherd having been tempered with very different materials than the rest of the Honmura-cho sherds, and/or being made from a different clay source. From a stylistic viewpoint, HMK: 007 also has unique stylistic characteristics. Although all the design techniques used to decorate the pot, such as cord-mark, clay-string applique, parallel-incised lines, and circular thrusts, are common among Moroiso-b style pottery, it is very unusual that all four elements were on one pot. Furthermore, the design motif that is represented with the clay-string applique is unknown among the Moroiso-b style. Takayama and Toshida (1990) suggest that the design motif has some resemblance to Kita-Shirakawa style, which was contemporaneous with Moroiso style but was primarily distributed on the southwestern side of the Moroiso style zone.

The other outlier from the PCA, I: 158, has a low Fe and Zr content, and a high Cu, Ga, and Zn content. Compared to most of the other samples, the color of which is usually dark and/or reddish-brown, this sherd is light yellowish brown in color, and seems to contain less inclusions. The sherd is too fragmentary to determine whether the design configuration is significantly different from the others.

The single Ukishima sample, which is from a nearly complete pot recovered at Isarago, also has a similar chemical composition as the majority of the other Isarago sherds. This result contradicts the conventional view that pots that are dated to the same period but with different stylistic characteristics were made in different regions. As mentioned above, Ukishima pottery is contemporaneous with Moroiso pottery, but is found predominately in eastern Kanto. Many Japanese archaeologists have assumed that Ukishima style pottery recovered in western Kanto, including the west Tokyo Bay area where the Isarago site is located, was "imported" from eastern Kanto. Our results do not support this assumption.

As described in our previous paper (Habu and Hall, 1999), in Japanese archaeology, the various contemporary pottery styles have been interpreted as reflecting group or ethnic identity. For example, Yamanouchi (1969) assumed that each style zone represents the territory of a single tribe:

> During the Jomon period, a large number of tribes were present throughout the Japanese archipelago. These tribes exchanged small amounts of both raw materials and finished products (i.e., artifacts) with each other. No one tribe was completely isolated from the other: archaeological evidence indicates that the culture of each tribe was influenced by cultural waves from other tribes. The distribution area of each tribe (i.e., cultural area, or the distribution area of each pottery style) changed through time (Yamanouchi, 1969).

Similarly, Kobayashi (1992) suggests that the differences in the style of pottery reflect Jomon regional organization. He identified a number of regional units called "nuclear zones", which roughly correspond to style zones, and suggested the presence of common group identity among the members of each "nuclear zone":

> These zones covered the Jomon archipelago like a mosaic and the groups belonging to each zone probably shared behavioral norms stretching from daily activities to beliefs, folk songs and tales, and world view (Kobayashi, 1992).

If, in fact, different pottery styles reflect differences in group or ethnic identity, then the result of our chemical analysis would imply that an "Ukishima" person had taken residence among a group of "Moroiso" people. One possible reason for this kind of movement of people would be inter-community marriage (Kobayashi, 1979; Sasaki, 1981, 1982; Sato, 1974). It is also interesting to note that Harunari's (1986) study of Jomon tooth extraction patterns suggests that there was uxorilocal residence in eastern Japan. Alternatively, the pottery styles could be reflecting something other than ethnic or group identity. As indicated by Hodder (1985, 1991), the relationship between style and social identity can be quite complex. Although the sample size of our present analysis is extremely small (only one Ukishima pot), similar analyses at other Jomon sites (Hall, 2001) also suggest that the presence of stylistically different pots does not necessarily imply that they were made in other regions. Further research on this issue is required to clarify the meaning of stylistic differences between Moroiso and Ukishima.

Conclusions

In summary, the results of this study indicate that the pottery from the Honmura-cho and the Isarago sites can be chemically distinguished from each other. Following the hypothesis presented above, we suggest that the majority of the pots from these two sites were produced at each site. This implies that, while the sites are within 2 kilometers of each other, the potters used different clay(s) and/or tempers, and the difference is discernable using EDXRF. This work also demonstrates that the chemical analysis of pottery can be used to approach various issues, including the meaning of pottery styles and inter-community movement of people.

Furthermore, from a methodological viewpoint, this paper illustrates the importance of analyzing for multiple trace elements in pottery research. Previous x-ray fluorescence studies of Jomon pottery by Japanese scholars have focused primarily on a limited number of elements. Our study demonstrates the utility of multi-element, multivariate analyses for distinguishing pottery made in different locations.

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Appendix 1. X-ray counting and least squares linear regression errors for the the analyzed elements

ELEMENT	Error
Ti (%)	0.025
Mn	54
Fe (%)	0.100
Ni	11
Cu	6
Zn	8
Ga	3
Pb	5
Th	5
Rb	3
Sr	6
Y	3
Zr	8
Nb	5
Ba	12
Ce	4

All values except Ti and Fe are in parts per million (ppm).

Appendix 2. Results from four analyses on the standard RGM-1

ELEMENT	RGM-1 (this study) n = 4	RGM-1 (Govindaraju 1994)	Accuracy (%)
Ti (%)	0.168	0.160	5
Mn	268	279	3.9
Fe (%)	1.333	1.301	2.5
Ni	bdl	4.4	—
Cu	16	11.6	38
Zn	40	32	25
Ga	15	15	0
Pb	22	24	8.3
Th	16	15.1	6
Rb	147	149	1.3
Sr	102	108	5.6
Y	32	25	22
Zr	219	219	0
Nb	12	8.9	35
Ba	795	807	1.5
Ce	44	47	6.4

All values except Ti and Fe are in parts per million (ppm). bdl = below detection limit.

Appendix 3. Multiple analyses on sherds from Honmura-cho. The coefficient of variation is calculated as the standard deviation divided by the mean, and then multiplied by 100%.

ELEMENT	HMK: 008 (a)	HMK: 008 (b)	Average	CV (%)
Ti (%)	1.168	1.108	1.138	4
Mn	1415	1069	1242	20
Fe (%)	5.123	5.039	5.081	1
Ni	80	60	70	21
Cu	106	96	101	7
Zn	156	170	163	6
Ga	26	20	23	19
Pb	17	19	18	9
Th	13	15	14	11
Rb	41	46	44	7
Sr	122	116	119	4
Y	21	18	19	11
Zr	201	191	196	4
Nb	17	14	15	13
Ba	226	240	233	4
Ce	35	38	36	6

ELEMENT	HMK: 016 (a)	HMK: 016 (b)	Average	CV (%)
Ti (%)	8680	8964	8822	2
Mn	2079	2513	2296	13
Fe (%)	3.987	3.933	3.960	1
Ni	34	34	34	0
Cu	83	100	91	13
Zn	210	246	228	11
Ga	23	22	23	5
Pb	19	18	18	0
Th	14	16	15	12
Rb	48	49	48	2
Sr	73	78	76	5
Y	17	14	16	12
Zr	169	162	166	3
Nb	bdl	8	—	—
Ba	226	229	228	1
Ce	35	38	37	5

All values except Ti and Fe are in parts per million (ppm). bdl = below detection limit.