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Title	Study on the production region of iron goods and the roots of forging technology of the Okhotsk Culture
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Citation	北海道大学総合博物館研究報告, 6, 1-17
Issue Date	2013-03
Doc URL	https://hdl.handle.net/2115/52575
Type	departmental bulletin paper
File Information	v. 6_1.pdf

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北海道大学総合博物館研究報告 **6**: 1–17. 2013 年 3 月
Bulletin of the Hokkaido University Museum. **6**: 1–17. March, 2013.

Study on the production region of iron goods and the roots of forging technology of the Okhotsk Culture

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Abstract: The forging technology of the Okhotsk culture, using pottery shards in substitution for tuyere and for furnace walls, was quite unique. The author had an assumption that based on this technology there were two kinds of metallurgical processes of techniques, facilities, raw materials, and products in the Okhotsk culture. One is the relatively popular forging, operating by twin blowing through two shards constructing the furnace. The raw material used is steel. The other is the refining of high carbon material or cast iron into steel using single blowing associated with heavy slag as a byproduct.

While for a long time “the northern continent” was generally assumed to be the place of origin of the forging technology and some iron goods of the Okhotsk culture, it has now become possible to narrow such places down from Middle Amur region to Baikal region as one of the actual areas of origin of the unique forging technology and iron goods. Beside, combining archaeological evidence with metallurgical analysis, it become possible to point out that the production areas of iron goods changed from continent to Honshu the main island of Japan at the late stage of the culture, and the unique forging technology fell into a decline.

Keywords: chemical components of iron goods, forging technology, metallurgy, Okhotsk culture, production areas of iron goods

Introduction

The ancient Okhotsk culture was characterized by high maritime adaptation of imported metal goods such as knives, axes, swords and so on from the northern continent and Japan. The Okhotsk people not only used metal tools but also mended and reformed them by their own forging technology.

The forging technology of the Okhotsk culture, using pottery shards not only in substitution for tuyere but also for furnace walls, was quite different from neighboring ancient Japan and Satsumon cultures (Utagawa 1975, Amano 1985). Such pottery shards have a hole about two centimeters in diameter perforated from both sides. Around the hole on the outside is partially melted and foamed due to high temperature. The inside of the shards around the hole have a reddish color zone from high temperature but have not been melted and foamed. These shards have been reported all over Hokkaido from Rebun Island in the north and Nemuro in the east of Hokkaido along the Okhotsk seacoast, but not from Sakhalin till now (Fig. 1).

This paper investigates the origin and roots of this forging technology and its raw materials from the perspective of ancient North East Asia.

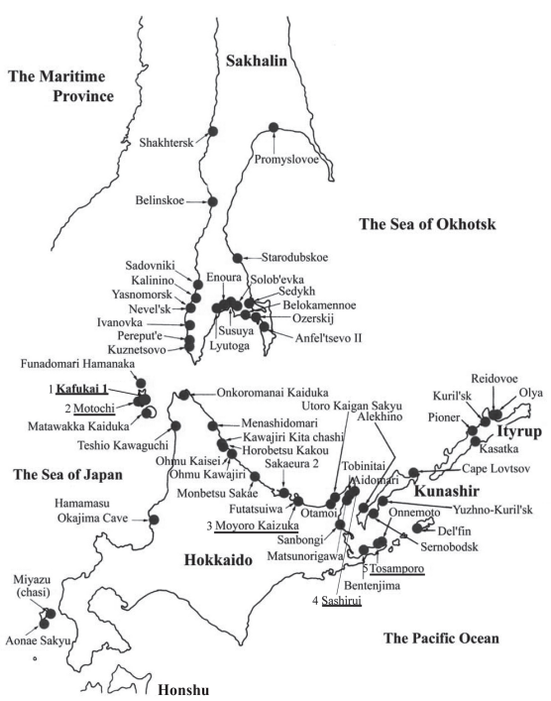


Fig.1 Main sites of the Okhotsk Culture

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I Archaeological research

1. Hokkaido

1–1 Kafukai 1on the estern coast of Rebun Island

About 6 shards used for a forging furnace were found from cultural layers (rich in fish bones) in this settlement (Oba & Ohyi 1976, 1981; Amano 1985). Most of them were partially melted and had turned red under high temperatures. Some of them had remaining holes and were covered with slag on the outside (Fig. 2).

The oldest one was found in cultural layer IV (intermediate early and middle stage) and the most recent one was found in cultural layer I (late stage).

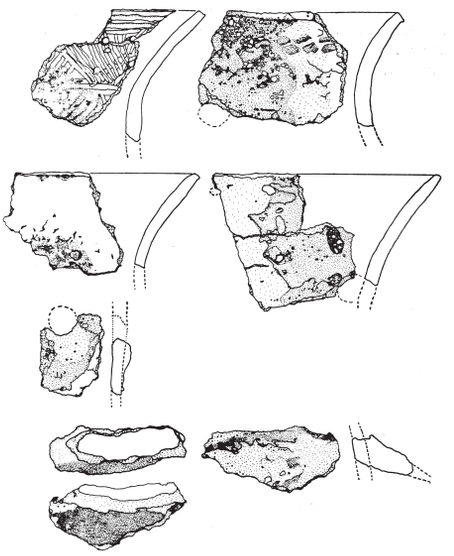


Fig. 2 Pottery shards used for forging furnace. Kafukai-1 settlement. (Oba & Ohyi 1976, 1981)

1–2 Motochi on the western coast of Rebun Island

The materials excavated at this site are important for showing us two kinds of forging technologies (Amano 1991). The material No.1 was found broken into three pieces: two shards and a clay plate covered with slag (Figs. 3, 4). Each shard, that came from a single pottery, has one hole about two centimeters in diameter. Around the hole on the outside was partially melted and foamed due to high temperature. The inside of the shards around the hole had turned into a reddish color under high temperatures but had not melted and foamed. The clay plate has a triangular shape and two sides with smooth concave facets with a negative print of potteries (Fig. 4).



Fig. 3 Reconstructed forging furnace. Motochi settlement. (Amano 1991)

After reconstruction work of the material it was revealed that the clay plate was a part of furnace bottom surrounded by two shards standing vertically. These two shards formed the furnace walls at an angle of 60 degrees. Part of the shards, especially beneath the hole, were melted down to the clay bottom and mixed with slag. The slag is glassy and expected to be a lower specific gravity than material No.2 (2.8). Air was blown into the furnace through the holes in these shards alternately to provide a continuous flow. The continuous blowing necessary to forging was realized by a twin blower by most indigenous people and by a valve device in historic Japanese forging.



Fig. 4 Bottom of forging furnace. Motochi settleent. (Amano 1991)

Specimen No.2 is also a furnace shard with slag stuck to it (Fig. 5). The slag was tapped beneath the hole of the shard. It has a round shape in plan and a convex lens shape in cross section. The specific gravity of this slag is over 2.8 with small shard. From the shape of the slag we can expect that this furnace had only one wall of shard. Such heavy slag with a convex lens shape in cross section is a byproduct associated with refining (reducing carbon) high carbon iron material or cast iron into steel.

The ornamentation on the pottery No.1 with horizontal wide lines smooth in cross section was in the ascendancy at the late stage of this culture.

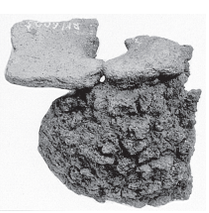


Fig. 5 Pottery shard used for forging furnace and slag stuck on it. Motochi settlement. (Amano 1991)

1–3 Moyoro shell mound site in Abashiri

Six shards used for forging were found in the sacred zone of pit house No.9 surrounded by brown bear skulls (Kumaki *et al.* 2009; Amano 2009). Two of

them from one pottery overlapped. These two shards about 16cm in square have one hole about two centimeters in diameter perforated from both sides (Fig. 6). Around the hole on the outside is partially melted and foamed at high temperature. The inside of the shards around the hole has turned reddish under high temperature but has not melted and foamed.

While we have no information till now on the forging workshop or place where forging was conducted using these pottery shards as a forging furnace, it is interesting that this type of shard was found at the sacred zone in a pit house at Moyoro and also in Tosamporo L Nemuro. There is no data for the distribution of forging scale and slag in this house but it is difficult to assume that forging was carried out at this sacred zone itself. So forging might be carried out near the hearth or out of the house. Anyway these materials imply that forging was looked upon as a sacred productive action.

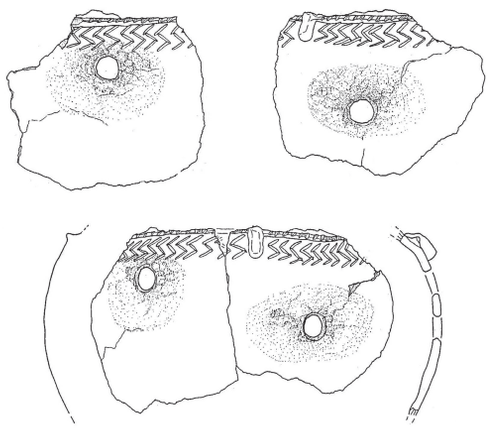


Fig. 6 Pottery shards used for forging furnace. Pit house No.9 in Moyoro settlement. (Kumaki & Fukuda 2009)

The pottery has a typical pod style with a narrow neck. The band ornamentation (widened "n" shape like iron clamp) with oblique cutting on the shoulder and cut ornamentation with a zigzag motif under the band ornamentation were popular at the middle stage of the culture.

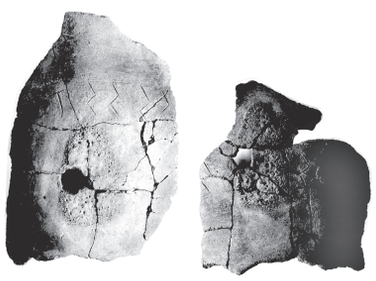


Fig. 7 Pottery shards used for forging furnace. Sashirui settlement. (Utagawa 1975)

1–4 Sashirui in Shiretoko peninsula in Rausu

Two relatively large shards from one pottery were found in the deposit layer of a pit house (Utagawa 1975). These two shards about 20cm in length have one hole about two centimeters in diameter perforated from both sides (Fig. 7). Around the hole on the outside is partially melted and foamed at high temperature. The inside of the shards around the hole has turned reddish under high temperature but has not melted and foamed.

Such cut ornamentation with a zigzag motif on the shoulder of this pottery (and the shards at Moyoro too) implies that this pottery has cut ornamentation on the mouth like the pottery from Tosamporo L. If so it can be estimated that these pottery shards were from the middle stage of the culture.

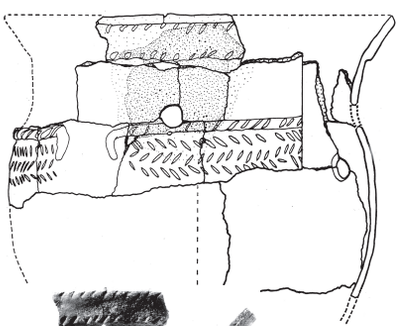


Fig. 8

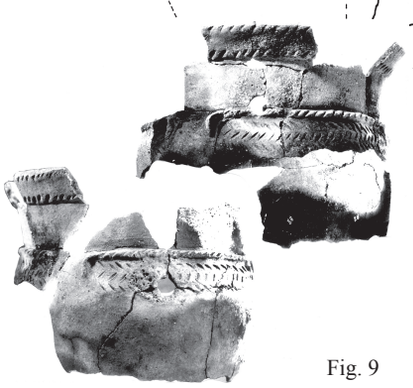


Fig. 9

Fig.8, 9 Reconstructed pottery of which shards were used for forging furnace. Pit house in Tosamporo L settlement. (Kitakamae *et al.*, 1984)

1–5 Tosamporo L in Nemuro

One pottery with two holes on the body found at the sacred place of a pit house was reconstructed (Kitakamae *et al.* 1984; Amano 1985). These holes are about 1.4cm in diameter perforated from both sides (Fig. 8, 9). Around the hole on the outside is partially melted and foamed at high temperature. The inside of the shards around the hole has turned reddish under high temperature but has not melted and foamed. The shards with holes must have been used for a furnace the same as in Moyoro and other cases mentioned above.

This pottery has cut ornamentation on the mouth and from

the shoulder to body it has a band (widened “n” shape) with oblique cutting and cut ornamentation with a zigzag motif. These ornaments were very popular in the middle stage of this culture.

1–6 Temporal and spatial range of this technology in the Okhotsk culture

The oldest example of a pottery shard reused for forging was found in Kafukai 1 cultural layer IV. So there is a high possibility that this unique forging technology was introduced into the Okhotsk culture at the end of its early stage or the beginning of the middle stage (around 6th century).

It is clear that it became most popular during the middle stage (approximately 7–8th century) of the Okhotsk culture in Hokkaido. As for this stage we should not overlook the remarkably wide range distribution (from the Amur region to the Baikal region) of band ornamentation with a special motif (widened “n” shape) preferably decorating the pottery reused for the forging furnace.

The latest example was found only in northern Hokkaido (Kafukai 1 cultural layer I and Motochi site: after 10th century) but not in eastern Hokkaido. At the late stage of this culture the eastern group was able to get more iron goods than the northern group from the Satsumon (pre-Ainu) people and even possibly had them repaired by Satsumon people.

Finally it is worth to note that different from Amur region, crucible is quite absent in this culture. The Okhotsk culture did not accept metal casting technology even it prevailed into neighboring peoples.

2. Amur oblast

Reused potteries with a perforated hole for metallurgy were found in pit house No.2 at Osinovoe Ozero Konstantinovka, Amur oblast Russia (Derevyanko *et al.* 2010). One of them is a fragment with a hole. Around the hole on the outside is partially melted due to high temperatures (Fig. 10), the same as the shards from the Okhotsk culture.

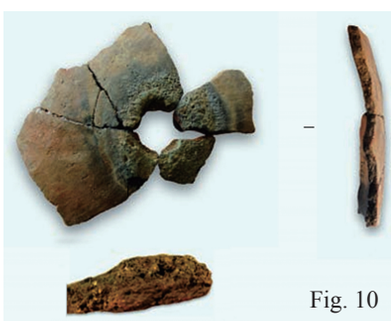


Fig. 10



Fig. 11

Fig. 10, 11 Pottery used for metallurgical furnace. Pit house No.2 in Osinovoe Ozero settlement. (Derevyanko *et al.* 2010)

The other one is a pottery with a hole perforated from the outside (Fig. 11). It is interesting that on the outside the upper part of the hole has turned a red color under high temperature, but not melted. On the contrary, the inside of the pottery around the hole is melted and partially covered with slag. In this case the pottery, not shard, worked as a furnace blown from the outside through a single hole.

Researchers of the site realized that the fragment with a hole was set in the pottery furnace to suspend crucible on it. As the whole surface of the crucible is covered with slag, the outside of the shard, at least the part around the hole, might have slag tapped from the crucible. In fact there is no trace of slag on the shard contrary to the expectation.

So the shard has possibly been used solely or with one more shard for forging work as the same way as in the Okhotsk culture. If so, the function of the pottery furnace was not forging by twin blowing. The author wishes to argue that this single blowing furnace was used for the refining of high carbon iron material or cast iron into steel the same as material No.2 from Motochi, or even for the smelting of iron ore.

It is worth noting that ornamentation with the special motif (widened “n” shape) was used too on some potteries including the one reused for a metallurgical furnace in Osinovoe Ozero dated 8–9th century A.D.

3. Predbaikal, and Angara river region

Many ancient (Elgin culture) metullargical sites have been researched along the south western coast of Baikal by Kharinsky (Kharinskiy, Snopkov 2004, Kozhevnikov, Kharinskiy 2005). Underground type of iron smelting/refining furnace is dominant in these sites. It is noteworthy that cast iron was identified in the slag from one of these sites Kruma 28 site (Fig. 12). Charcoals associated with these slags are dated to the 5th century A.D.

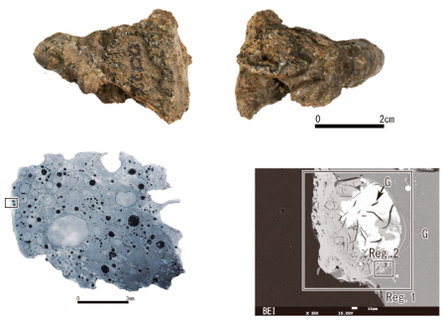


Fig. 12 Cast iron in the slag. Kruma 28 site.

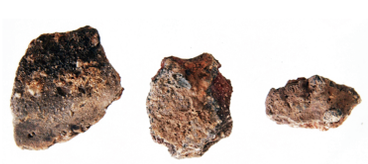
Petri excavated pottery used for iron smelting at the Obogn site, Murin river, upper stream of Angara (Petri 1923). The pottery was 55cm in height, 35cm in diameter at the mouth and perforated by two holes on both sides on the body. This type of pottery was found by Gladilin at the Chadobets site in the northern part of the Angara river basin too. These were dated around 3-4 century B.C. (Gladilin 1985). They belong to the Krumutinsk culture characterized by pottery ornamentation with a “sheep horn” motif which has characteristics in common with the special motif (widened “n” shape) of the Okhotsk culture.

The materials excavated by Petri have been separately preserved in Kust Camer in St.Petresburg and in Irkutsk Regional Museum but neither have been reported. In Petri’s collection in Irkutsk Regional Museum, the author could not find pottery used for iron smelting itself, only the fragment with ornamentation of a “sheep horn” motif on the neck (Fig. 13). So there is still a possibility that the pottery used for iron smelting in the Obogn site on the Murin river belongs to the Krumutinsk culture. Anway it is more important that technological tradition of mettullargy using pottery as furnace was founded as early as 3–4 century B.C. in this region. This unique technology, replaced by underground type of smelting furnace by 1 century B.C. then selfstanding shaft type furnace by 8 century in Angara river region, might diffused into neighboring area (including East of Baikal) with its unique ornamentation of a “sheep horn” and its variant widened “n” shape motif for the pottery.


Fig.13 Pottery fragment with ornament “sheep horn.” Krumutinsk culture. Obogn site. (Irkutsk Regional Museum)

4. Primorie region

Two fragments of pottery with perforation presumed to be used for the production of bronze tools/objects were found in pit house No.1 and No.3 in Elizavetovka 1 Primorie krai (region) (Nikitin 2012; Kiyama *et al.* 2013). These are melted and foamed under high temperature (Fig. 14).


Fig.14 Pottery shards used for forging furnace. Elizavetovka 1 settlement. (Nikitin 2012)

A crucible covered with slag and foamed material was found at this site. There is a possibility that the crucible was used in a furnace constructed from pottery shards such as in the Okhotsk culture.

Charcoals associated with these melted potteries and slag are dated 210–385 A.D. (Politse culture).

II Chemical-metallurgical research

1. Objects analyzed

Five archaeological objects made of iron were found in from the cultural layer 3 of the excavated trench in 1968, and the cultural layers from II to III at the site of Kafukai-1 (the 5th to 9th century A.D.) of the Okhotsk cultural area on Re-

No.	Object	Description of Excavation		
		Name of site	Detection of stractural remains	Estimated stage
1	Knife-like artifact	Kafukai-1	Cultural layer II	Late
2	Undefined iron artifact		Cultural layer IIIo	Middle
3	Knife-like artifact		Cultural layer IIIo/III	Middle
4	Undefined iron artifact		Cultural layer III	Middle
5	Undefined iron artifact		Cultural layer 3 of excavated trench in 1968	Early
Rf1	Short Sword	Rishirifuji town hall site	Burial pit No.1	Early
Rf2	Knife		Pit dwelling No.3	Early
Rf3	Bent haft knife		Cultural layer of trench GH5	Okhotsk Cultural Period
Rf4	Estimated to be needle		Deposit of trench H4	Okhotsk Cultural Period
Rf5	Undefined iron artifact		Deposit of trench H4	Okhotsk Cultural Period
Rf6	Fragment		Cultural layer of trench CD2	Middle
Rf7	Bent haft knife	Sakaeura 2 site in Tokoro	Pit 28	Middle
Rf8	Bent haft knife		Pit 72	Late
Rf9	Bent haft knife		Pit 2	Late
Rf10	Bent haft knife		In grid P-40 (Cultural layer Ⅱ)	Uncertain
Rf11	Bent haft knife		Pit 48	Uncertain
Rf12	Short Sword		Deposition of pit 78	Middle
Rf13	Axe		Deposition of pit 79	Middle
Rf14	Bent haft knife	Menashidomari site	Burial pit No.40	Middle
Rf15	Knife		Burial pit No.3	Middle
Rf16	Short Sword		Burial pit No.32	Late
Rf17	Bent haft knife	Omusaro C site	Burial pit No.3	Middle-Late
Rf18	Short Sword	Utoro site	Layer containing archeological objects	Okhotsk Cultural Period
Rf19	Pike		Layer estimated to be containing archeological objects	Okhotsk Cultural Period
Rf20	Axe		Burial pit No.3	Okhotsk Cultural Period

Table 1 Examined objects

bun Island near the coast, north-northwest of Hokkaido, Japan. Samples No.1 and No.3 (Figs. 15 and 17) are the knife-like objects. Samples No.2, No.4, and No.5 (Figs. 16, 17, and 19) are iron artifacts whose shape categories are undefinable. Table 1 lists the archaeological provenience data for each object.

2. Sample preparation

Samples of approximately 30–50 mg were taken from the five iron artifacts during their conservation treatment. This was performed using a portable drill equipped with a diamond cutting wheel. The portions where the samples were extracted were repaired with epoxy resin. Each extracted sample was divided into two parts: the larger part was used for metallographic observation, and the smaller part was used for chemical analysis.

3. Analytical method used

The samples to be used for metallographic observation were sectioned, mounted with epoxy resin, ground with emery paper, and then polished using diamond paste. The prepared samples were then examined under an optical microscope. Since five extracted samples had large areas of metallic iron, they were etched with nital (2.5ml HNO_3 and 97.5ml EtOH) before optical examination. The samples after optical examination were re-polished using diamond paste. Electron microprobe analyses (EPMA) were then performed with a JEOL JXA-8232, equipped with four wavelength-dispersing X-ray spectrometers, in order to examine the microstructure and to identify the mineral phase compositions of the non-metallic inclusion found in each sample.

The samples used for chemical analysis had their external corrosion layers removed with a diamond-coated wheel to avoid contamination from burial deposits. Inductively coupled plasma optical emission spectroscopy (ICP-OES), using a PERKIN ELMER Optima 4300DV, was employed for the chemical analysis of eighteen elements (indicating in Table 2)

No.	Chemical component(mass%)																		Elemental ratios:Ni,Co,Cu			
	T.Fe	Cu	Ni	Co	Mn	P	Ti	Sn	Sb	Mo	S	Si	Ca	Al	Mg	V	As	W	Co* (Co/Ni)	Cu* (Cu/Ni)	Ni** (Ni/Co)	Cu** (Cu/Co)
1	99.19	<0.001	<0.001	0.008	<0.001	0.01	<0.001	<0.01	0.01	0.001	0.01	<0.01	0.02	0.001	0.002	0.001	0.02	0.003	-	-	0.06	0.06
2	94.72	0.111	0.037	0.031	<0.001	<0.01	<0.001	0.01	<0.01	0.001	<0.01	<0.01	0.03	0.007	0.002	0.001	0.02	0.002	0.84	3.00	1.19	3.58
3	95.41	0.005	<0.001	0.005	<0.001	0.02	<0.001	<0.01	<0.01	0.002	0.01	<0.01	0.00	0.004	<0.001	<0.001	0.03	0.001	-	-	0.10	0.10
4	55.29	<0.001	<0.001	0.001	0.002	1.59	0.002	<0.01	<0.01	0.001	0.09	0.50	0.23	0.057	0.018	<0.001	0.01	0.001	-	-	-	-
5	75.55	0.310	0.013	0.017	-	<0.01	<0.001	0.20	<0.01	0.005	0.02	<0.01	0.01	<0.001	<0.001	<0.001	0.06	0.004	1.31	23.85	0.76	18.24

Table 2 Chemical composition of iron artifacts by ICP-OES

contained in the samples. The elements determined, and the analytical lines selected (nm), were as follows: Fe(239.562), Cu (324.752), Ni (231.604), Co (228.616), Mn (257,610), P(231,617), Ti (334.940), Sn (189.927), Sb (206.836), Mo (202.031), S (181.975), Si (251.611), Ca (317.933), Al (396.153), Mg (285.213),V (290.880), As (193.696) and W (207. 912).

4. Analytical results

4-1 Chemical Composition of iron goods

Table 2 shows the analytical data obtained by ICP-OES. The total iron content (T.Fe) of the three samples (Samples No.1, No.2, and No.3) was above 94 mass%. This indicates that there was little influence of the contamination of the trace element from the soil surrounding these three samples. This was because most of them were made of metal. The Co content of Sample No.1, the Cu, Ni, and Co contents of Sample No.2,and the Cu and Co content of Sample No.3 were greater than or equal to 0.005 mass%. The concentration of these three elements in the three samples is believed to be from the objects themselves.

On the other hand, T.Fe of Samples No.4 and No.5 was less than 76 mass%. The extracted samples from these two iron artifacts can be considered to be composed mainly of iron corrosion. In the case of such corroded samples, the contamination of trace elements from the surrounding soil must have occurred. Therefore, we should consider the possibility of contamination of trace elements from the surrounding soil before discussing each analytical result first. Sample No.5 had 75.55 mass% of T.Fe, 0.310 mass% of Cu, 0.013mass% of Ni, 0.017mass% of Co, 0.20 mass% of Sn, and 0.06 mass% of As, respectively. The sample extracted from No.4 had 55.29mass% of T.Fe, and Cu, Ni, Co, Sn, and As contents were less than or equal to 0.01mass%. Considering the progress of corrosion of Sample No.4 compared to Samples No.5, the concentration of Cu, Ni, Co, Sn and As contained in Samples No.4 and No.5 is believed to originate from the objects themselves, specifically from the raw iron materials used to produce them.

P is an important element for appraising the quality of iron ore. However, there is a possibility of contamination of P from the surrounding soil (Akanuma 2003). Though it is necessary to consider the possibility of contamination in this case through examining the composition of the soil surrounding the object, it was impossible to examine that, because a soil sample was not obtained. Therefore, it is difficult to use this element to classify the analyzed iron artifacts.

4-2 Metallographic examination of iron goods

Samples No.1 and No.3 were composed almost completely of metallic iron, so they were etched with nital. The macrostructures are etched almost uniformly (Fig.15$b_1$and Fig.17b_1). The microstructure of the area (Reg.1) in the macrostructure of Sample No.1 consisted mainly of coarse-grained ferrite (Fig.15c_1), and that of Sample No.3 was composed mainly of coarse-grained ferrite and a small amount of pearlite {lamellar structure composed of alternating layers of alpha-ferrite (αFe) and cementite(Fe_3C)}(Figs.17$c_{1\,.\,2}$ and Figs.17$d_{1\,.\,2}$). These four structures appear to have been air-cooled from a temperature above 723C°to room temperature. The carbon contents of Samples No.1 and No.3 are estimated to be less than 0.1mass%, and 0.1mass% to 0.3mass%, respectively, based on a comparison to the structure of standard carbon steel.

The non-metallic inclusions consisting of a light-gray and granular phase (Wus),a gray phase (Ol), and a dark gray area (Ma) were found in the macrostructure of Sample No.1(Fig.15d_1).The phase (Ol) is believed to be (Fe,Ca)-olivine according to the result of the quantitative analysis by EPMA in Table 4. Fig.15d_2 shows the Fe-Lα and Fe-Lβ spectra of

No.	Spot (Mineral Phase)	Fig.	chemical components (mass %)													Total
			Na	P	Si	O	Ca	Ti	V	Mg	Al	K	Fe	Mn	Cr	
1	Wus(1)	Fig.1d_1	<0.01	<0.01	0.12	20.6	<0.01	0.01	0.02	0.12	0.14	<0.01	72.8	<0.01	0.02	93.83
4	Wus(1)	Fig.4d_1	<0.01	<0.01	0.05	20.3	<0.01	0.01	0.06	0.21	0.15	0.01	73.4	0.08	0.01	94.28

Wus=Wüstite

Table 3 Results of quantitative analyses of the mineral phases found in the non-metallic inclusion by EPMA

No.	Spot (Mineral Phase)	Fig.	chemical components (mass %)												Total
			Na_2O	P_2O_5	SiO_2	CaO	TiO_2	V_2O_5	MgO	Al_2O_3	K_2O	FeO	MnO	Cr_2O_3	
1	Ol(1)	$1d_1$	<0.01	0.91	30.4	12.4	<0.01	0.06	2.21	0.30	0.37	51.1	0.39	0.01	98.15
2	Gl(1)	$2d_1$	0.01	1.55	34.0	19.7	1.36	<0.01	0.41	9.44	0.48	27.8	0.31	<0.01	95.06
	Gl(2)		0.21	0.05	36.9	34.3	<0.01	<0.01	1.56	5.82	0.42	15.6	0.07	0.01	94.94
	Gl(1)	$2e_1$	0.14	3.46	32.8	23.6	0.69	<0.01	0.97	6.92	0.86	25.0	0.39	<0.01	94.83
3	Fa(1)	$3f_1$	0.33	0.58	30.7	3.8	0.04	<0.01	0.93	3.75	1.34	55.7	0.56	<0.01	97.74
4	Fa(1)	$4e_1$	<0.01	0.32	32.0	1.40	0.06	0.09	4.37	0.83	0.44	60.4	0.20	0.02	100.13
	Fa(2)		0.08	0.27	31.1	1.04	0.02	0.02	5.12	0.36	0.17	60.9	0.20	<0.01	99.28
	Gl(1)	$4e_2$	1.02	0.26	54.4	8.15	0.76	0.12	1.94	11.7	5.46	13.4	0.31	<0.01	97.52
5	Gl(1)	$5d_1$	0.25	1.88	33.2	10.3	0.35	<0.01	0.92	7.30	1.16	41.2	0.39	<0.01	96.95
	Gl(1)	$5e_2$	0.20	1.33	33.0	18.0	0.33	<0.01	1.09	5.09	1.30	35.6	0.43	0.03	96.40

Table 4 Results of quantitative analyses of the mineral phases found in the non-metallic inclusion by EPMA

three Fe standard samples (FeO, Fe_3O_4, and Fe_2O_3), and a phase (Wus) in Fig. $15d_1$. The peakshape of the phase (Wus) is almost the same as that of wüstite (FeO). This result is quite consistent with the results in Table 3. The dark gray area (Ma) was composed of a glassy silicate with minute compounds in it. Sample No.1 also had a non-metallic inclusion whose mineral compositions was a Fe-Mg-Ca-O system compound (XF) and a glassy silicate with minute compounds (Figs.$15e_{1\cdot2}$).

Non-metallic inclusions with the almost the same mineral composition as those of Sample No.1 were found in Sample No.3 (Fig.$15e_1$ and f_1, Table 4).

Sample No.2 was an undefined iron artifact. The macrostructure of the extracted sample was etched with nital almost uniformly. Acicular ferrite was observed in the microstructures of the areas (Reg.1) and (Reg.2) (Figs.$16b_1$, $16c_1$, and $16c_2$). They appear to have been air cooled rapidly from a temperature above 723 C° to room temperature. The estimated carbon content from this structure is between 0.3 and 0.5 mass%, based on a comparison with the structure of standard carbon steel. A similar structure was found in the areas (Reg.1) and (Reg.2) in Sample No.5 (Figs.$19b_1$, $19c_1$, and $19c_2$). Non-metallic inclusions with a dark gray phase {Gl(1)}, a dark phase {Gl(2)}, and minute grains of metallic iron (Me) were presented in Sample No.2(Fig.$16d_1$). The phase {Gl(1)} and phase {Gl(2)} consisted of a FeO-CaO-Al_2O_3-P_2O_5-SiO_2 system and a FeO-CaO-Al_2O_3-MgO-SiO_2 system, respectively (Table 4). The non-metallic inclusions composed of a glassy silicate were also found in Samples No.2 and No.5 (Figs. $16e_1$, $19d_1$, $19e_1$, and $19e_2$, Table 4).

Metallic iron remained in the inner portion of Sample No.4. The macrostructure was etched almost uniformly (Fig.$18a_1$). In the microstructure of the areas (Reg.1) and (Reg.2) in the macrostructure pearlite/ferrite bands were observed (Figs.$18b_1$, $18c_1$, and $18c_2$). It is estimated that these bands were formed during the process when the steel was heated and forged in order to produce Sample No.4. It is probable that this formation arose from an influence of the segregation of some elements, for example, P, Mn, Sn, Ni, and Cr (Osawa 1961). This matter should be clarified by further research. The estimated carbon content of Sample No.4 from this structure is between 0.2mass% and 0.4mass%.The non-metallic inclusions found in Sample No.4 were composed of wüstite (Wus) and glassy area which contains minute particles of undetermined composition (Ma), and fayalite(Fa) and glassy silicate(Gl) according to the chemical state analysis and quantitative analysis by EPMA (Figs. $18d_1$, $18e_1$,and $18e_2$, and Tables 3 and 4).

5. Discussion

According to the archaeometallurgical analysis of ironware from the site of Kafukai-1, the carbon content of steel used to manufacture the analyzed five iron artifacts is equal to or less than 0.5mass%. The structures indicating that any kind of heat-treatments (such as quenching and tempering) had been carried out were not found in the five samples extracted from the ironware. It is certain that the steel to be used for manufacturing ironware was produced in a multi-stage process. Even if the same raw iron materials were used to make iron as a starting material, different manufacturing methods and production conditions could have been produced a difference in the composition of the final steel product, because chemical segregation and volatilization of the chemical ingredients occur. In addition, we have to consider the contamination of trace elements from the surrounding soil in the corroded samples such as Samples No.4 and No.5 in Table 2.

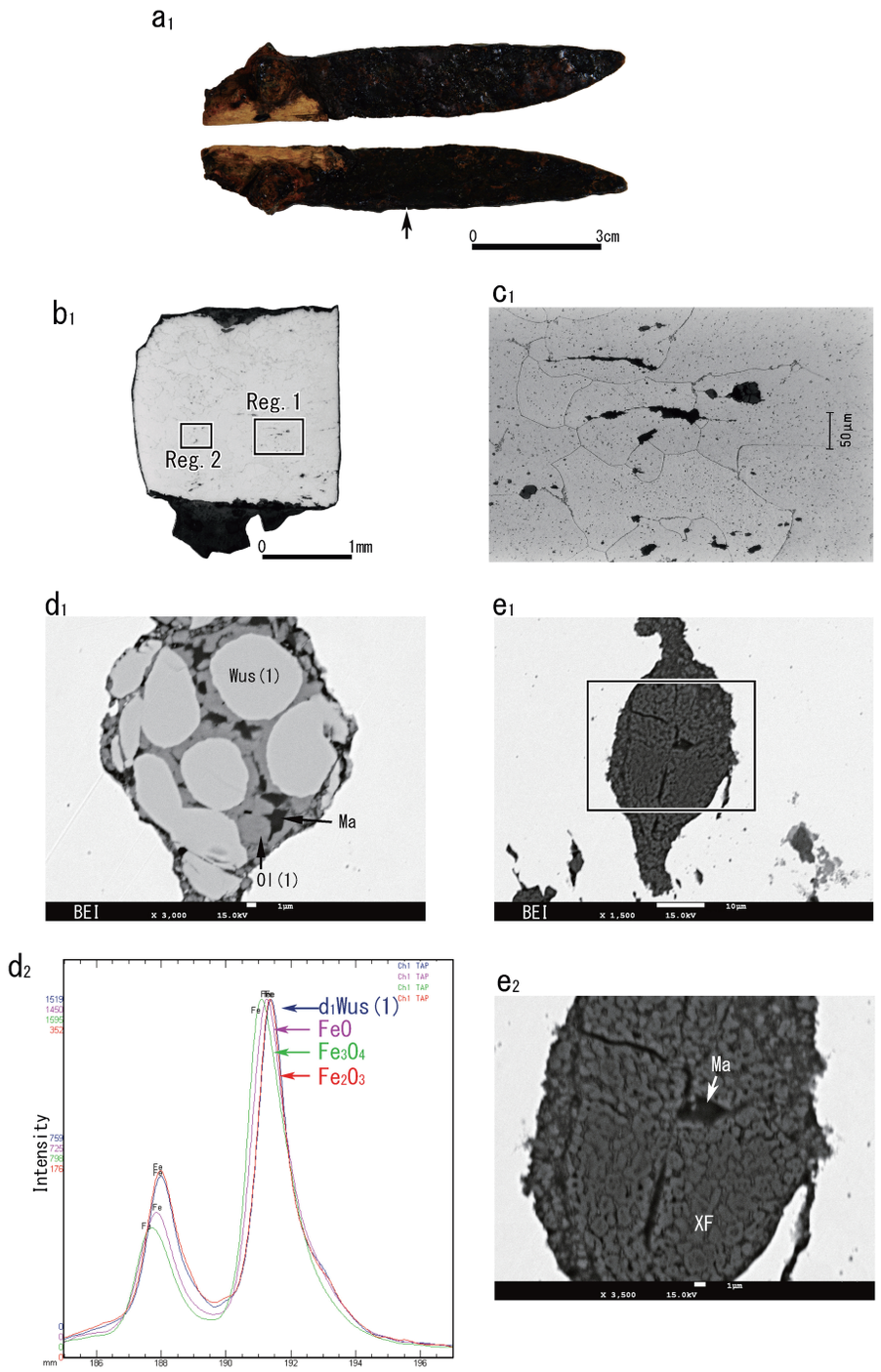


Fig.15 Metallographic analysis of Sample No.1.a_1:External appearance. The metallographic sample was extracted from the marked location.b_1 and c_1: Macrostructure of the extracted sample and microstructure in the area (Reg.1) in b_1 etched with nital, respectively.d_1:EPMA backscattered electron image (BEI) of the non-metallic inclusion found in the area (Reg.1) in b_1. Wus=wüstite, Ol=(Fe,Ca)-olivine, Ma=glassy area containing minute compounds.d_2: Fe-Lα and Fe-Lβ spectra of three Fe standard samples (FeO, Fe_3O_4, and Fe_2O_3), and the phase {Wus(1)} in d_1 by EPMA.$e_{1\cdot2}$: EPMA backscattered electron images of the non-metallic inclusion found in the area (Reg.2) in b_1. e_2: Marked area in e_1. XF=a Fe-Mg-Ca-O system compound, Ma=glassy area containing minute compounds.

As mentioned in the section 4-1, it was hypothesized that the contamination from the burial deposit was very poor about three elements (Ni, Co, and Cu). These elements are believed to remain in the iron metal throughout the processes

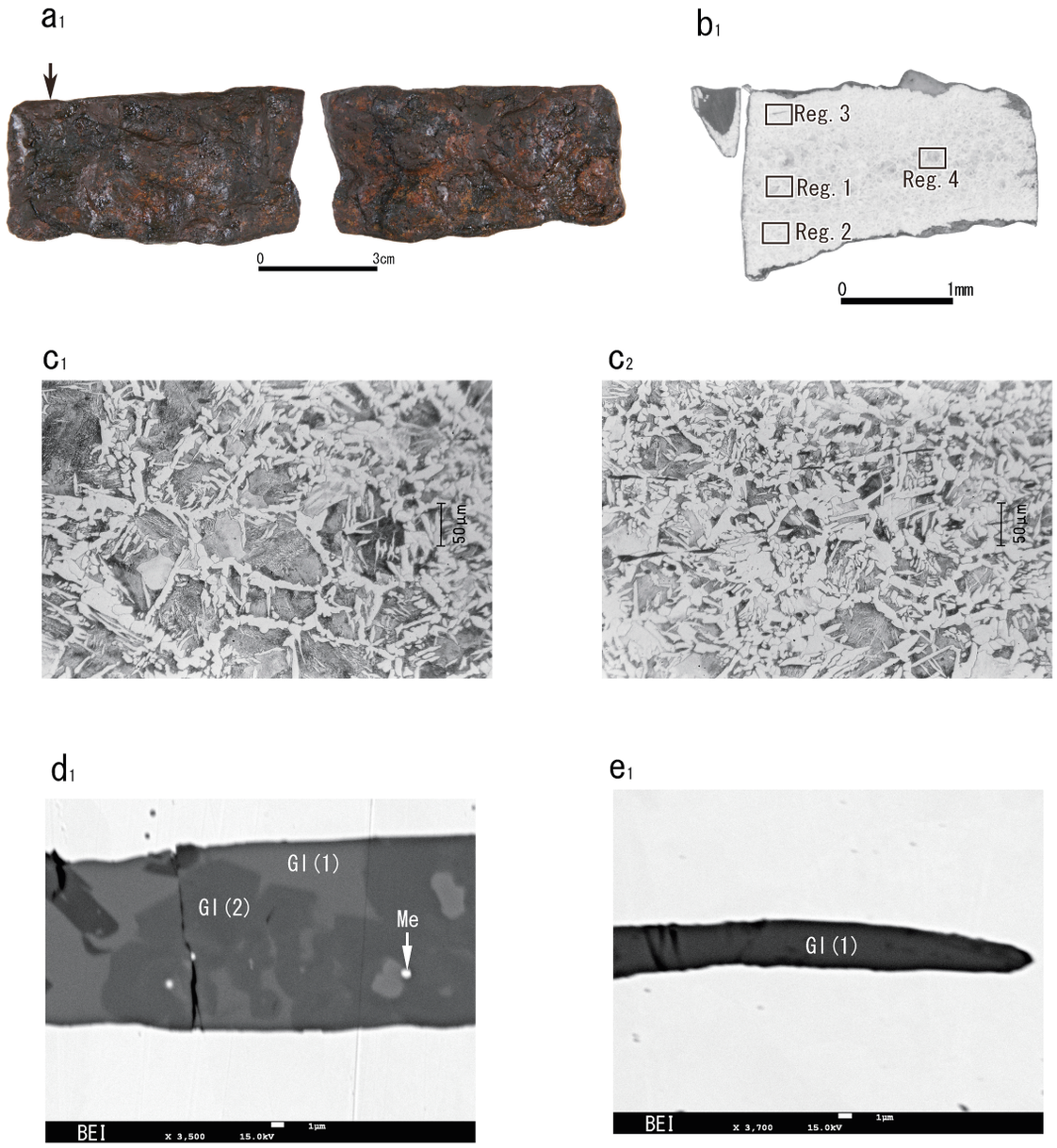


Fig.16 Metallographic analysis of Sample No.2.a_1:External appearance. The metallographic sample was extracted from the marked location.b_1 and $c_{1\cdot2}$: Macrostructure of the extracted sample and microstructures in the areas (Reg.1) and (Reg.2) in b_1 etched with nital, respectively.d_1 and e_1:EPMA backscattered electron images (BEI) of the non-metallic inclusions found in the areas (Reg.3) and (Reg.4) in b_1. Gl=a glassy silicate, Me=metallic iron.

of smelting, refining, and forging. Therefore, the concentration ratios in the archaeological objects should be similar to those in the raw materials used to produce the objects, provided that no additional alloying was carried out. The values of (mass%Co)/(mass%Ni) and (mass%Cu)/(mass%Ni) were calculated for the iron artifacts which contained more than 0.005mass% Ni. Also the values of (mass%Ni)/(mass%Co) and (mass%Cu)/(mass%Co) were calculated for the samples containing more than 0.005mass% Co. The calculated results are listed in Table 2. The relationship between the values of (mass%Co)/(mass%Ni) and (mass%Cu)/(mass%Ni), and the values of (mass%Ni)/(mass%Co) and (mass%Cu)/(mass%-Co) are indicated on Figs. $20a_1$ and $20b_{1\cdot2}$. In these figures, twenty-five iron artifacts, of which twenty iron artifacts archaeometallurgical analysis was documented previously by the author (Akanuma 2005; 2009; 2011), excavated from the archaeological sites belonging to the Okhotsk cultural period (the 6th to 11th century A.D.) are also plotted. Samples Rf1

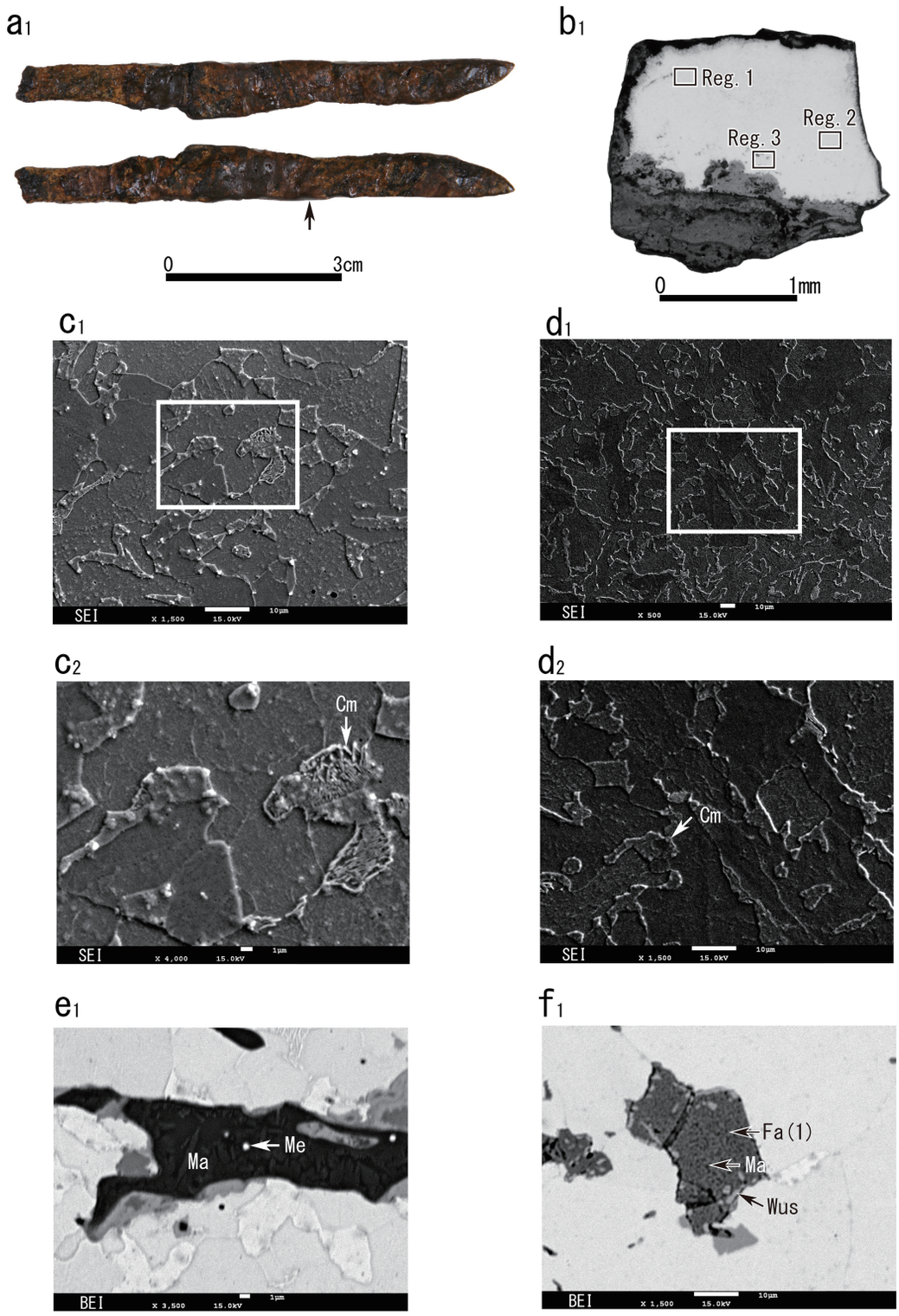


Fig.17 Metallographic analysis of Sample No.3.a_1:External appearance. The metallographic sample was extracted from the marked location.b_1:Macrostructure of the extracted sample etched with natal. $c_{1\cdot2}$ and $d_{1\cdot2}$:EPMA secondary electron images (SEI) in the areas (Reg.1) and (Reg.2)in b_1, respectively. c_2 and d_2: Marked areas in c_1 and d_1,respectively.Cm=cementite (Fe_3C). e_1 and f_1: EPMA backscattered electron images (BEI) of the non-metallic inclusions found in the areas (Reg.1) and (Reg.3) in b_1. Wus=wüstite, Fa=fayalite, Me=metallic iron, Ma= glassy area containing minute compounds.

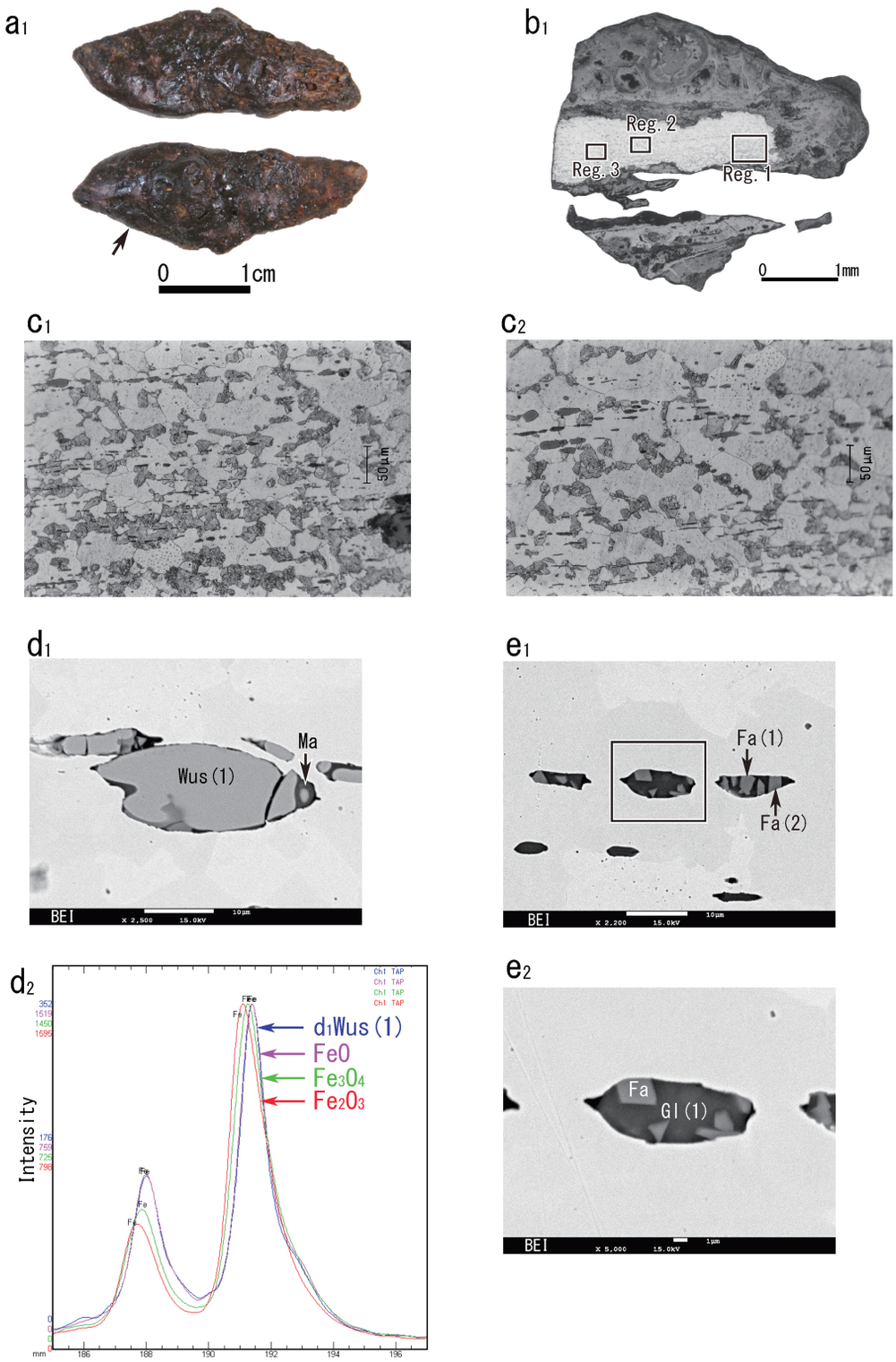


Fig.18 Metallographic analysis of Sample No.4.a_1:External appearance. The metallographic sample was extracted from the marked location.b_1 and $c_{1\cdot2}$: Macrostructure of the extracted sample and microstructures in the areas (Reg.1) and (Reg.2) in b_1 etched with nital, respectively.d_1:EPMA backscattered electron image (BEI) of the non-metallic inclusions found in the area (Reg.3) in b_1. Wus=wüstite, Ma=glassy area containing minute compounds.d_2: Fe-Lα and Fe-Lβ spectra of three Fe standard samples (FeO, Fe_3O_4, and Fe_2O_3), and the phase {Wus(1)} in d_1 by EPMA.$e_{1\cdot2}$: EPMA backscattered electron images of the non-metallic inclusions found in the area (Reg.1) in b_1. e_2: Marked area in e_1. Fa=fayalite, Gl=a glassy silicate.

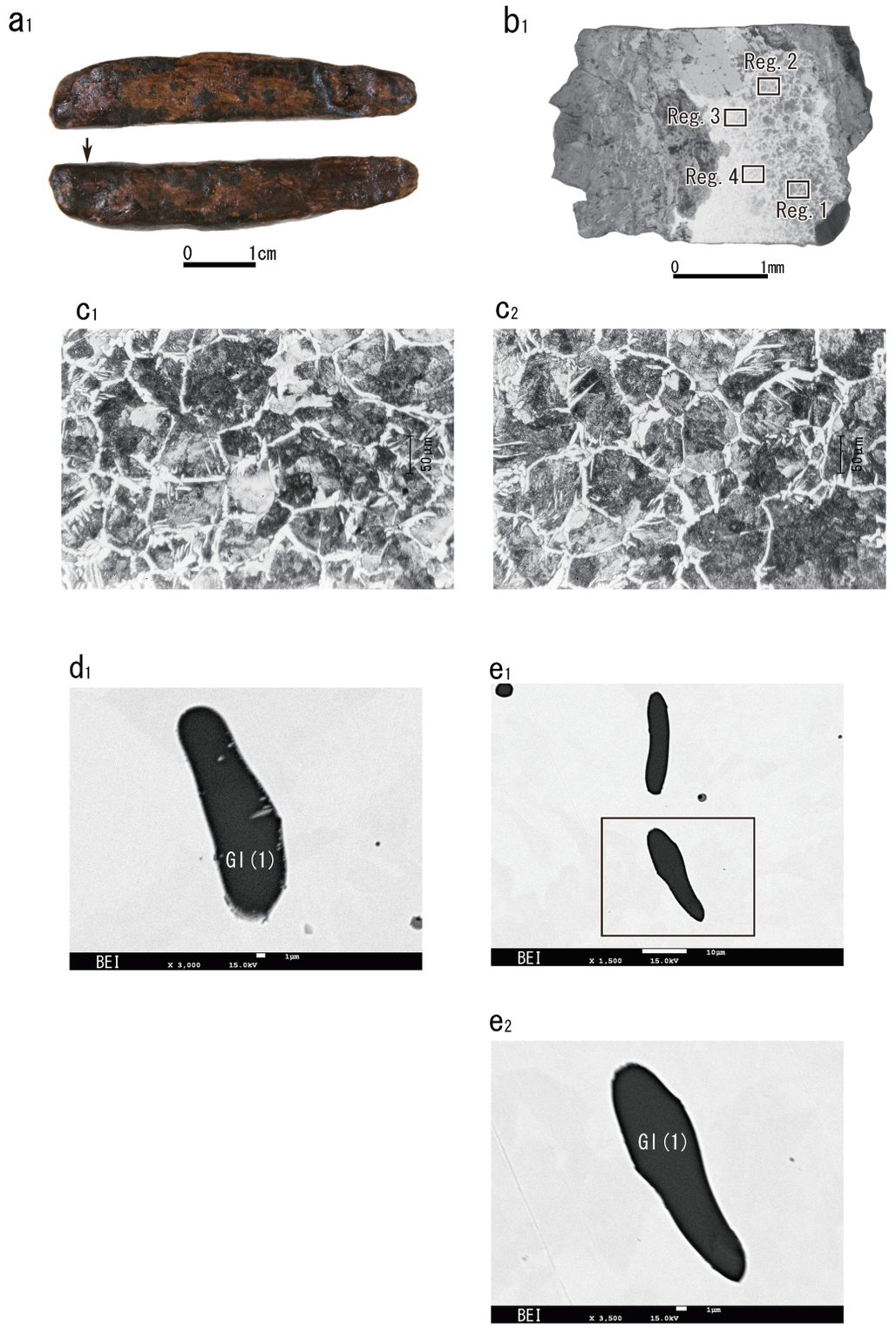


Fig.19 Metallographic analysis of Sample No.5.a_1:External appearance. The metallographic sample was extracted from the marked location.b_1 and $c_{1\cdot2}$: Macrostructure of the extracted sample and microstructures in the areas (Reg.1) and (Reg.2) in b_1 etched with nital, respectively.d_1 and $e_{1\cdot2}$:EPMA backscattered electron images (BEI) of the non-metallic inclusions found in the areas (Reg.3) and (Reg.4) in b_1. e_2: Marked area in e_1.Gl=a glassy silicate.

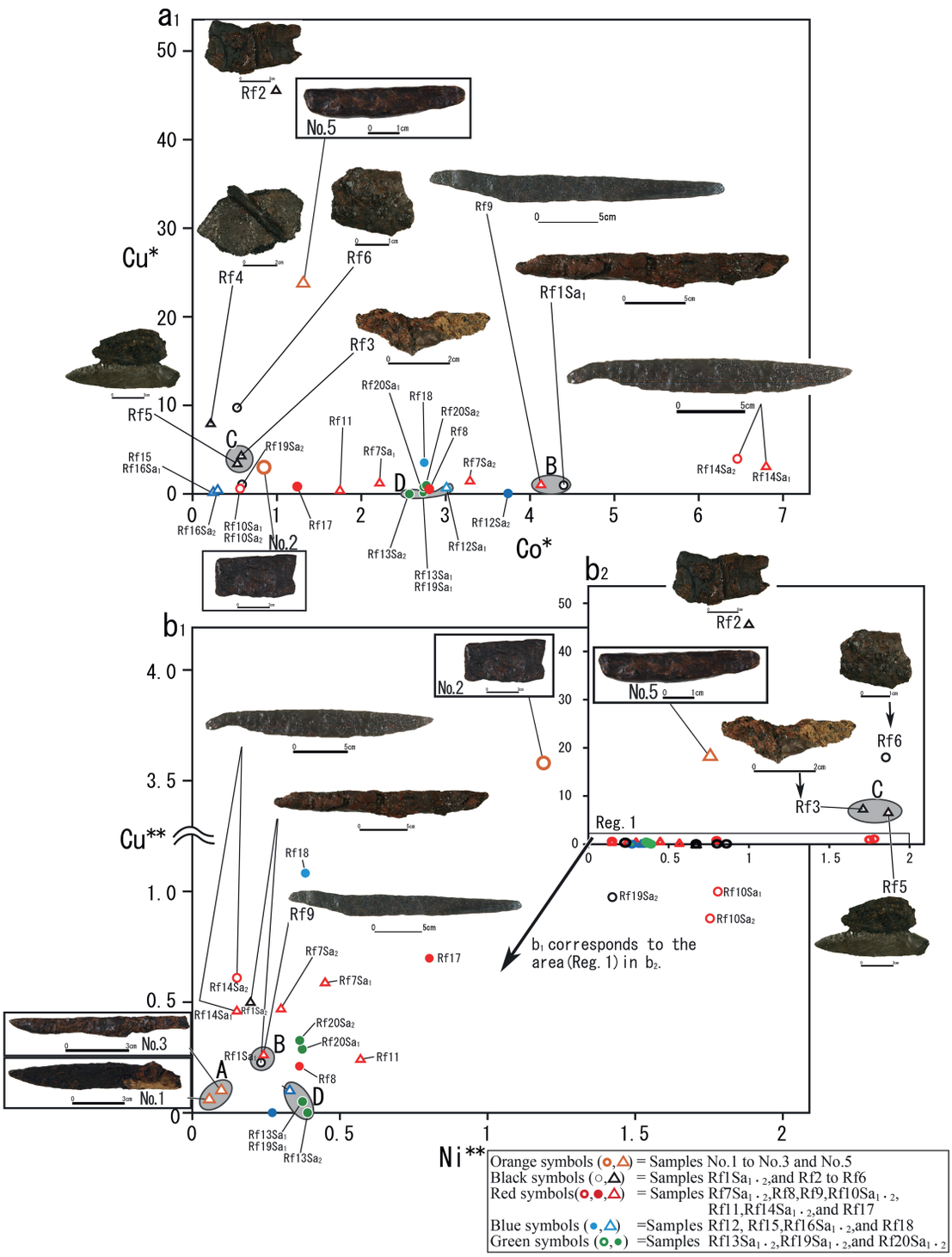


Fig.20 Relationship between Co* {the values of (mass% Co)/(mass% Ni)} and Cu* {the values of (mass% Cu)/(mass% Ni)} and between Ni** {the values of (mass% Ni)/(mass% Co)} and Cu** {the values of (mass% Cu)/(mass% Co)} in the iron artifacts excavated from the Kafukai site. The plots with numbers are analytical results in this paper. Samples Rf1 to Rf6 are the samples excavated from the Rishirifuji town office site in Rishirifuji town, Hokkaido, Samples Rf7 to Rf13 are the samples from the Sakaeura 2 site in Tokoro, in Kitami, Hokkaido, Samples Rf14 to Rf16 are the samples from the Menashidomari site in Esashi-cho, Hokkaido, Sample Rf17 is the sample from the Omusaro C site, in Monbetsu, Hokkaido, and Samples Rf18 to Rf20 are the samples excavated from the Utoro site in Shari-cho, Hokkaido. The samples having the non-metallic inclusions where titanium compounds were found are expressed with a solid circle (●), the samples having the non-metallic inclusions where titanium compounds were not found are represented by an open circle (○), and the samples where non-metallic inclusions were not found are represented by open triangle (△).

to Rf6 were excavated from the Rishirifuji town hall site in Rishirifuji, Hokkaido, samples Rf7 to Rf3 from the Sakaeura 2 site in Tokoro-cho, Kitami, Hokkaido, Rf14 to Rf16 from the Menashidomari site in Eshashi, Hokkaido, Rf17 from the Omusaro C site, in Monbetsu, Hokkaido, and R518 to R20 from the Utoro site in Shari, Hokkaido. Their archaeolog-

ical provenience date is indicated in Table 1.

In Figs.20a_1・$b_{1.2}$ the samples having the non-metallic inclusions where titanium compounds were found are represented with a solid circle (●). The samples having the non-metallic inclusions where titanium compounds were not found are represented by an open circle (○). Finally, the samples where non-metallic inclusions were not found are represented by an open triangle (△).

Samples No.2 and No.5 are plotted in the upper left side of Fig.20a_1 and in the upper center area of Figs.20b_1 and b_2, respectively. Samples Rf2, Rf3, Rf5, and Rf6 are also distributed in the upper area of Figs.20a_1・$b_{1.2}$, and Sample Rf4 is plotted in the upper left side of Fig.20a_1.These results were derived from the high values of element ratios of Ni to Cu (above 3) or Co to Cu (above 3.58), especially from the high content of copper (over 0.052mass%). It is probable that these seven samples (Samples No.2, No.5, Rf2 to Rf6) were produced using raw iron materials containing a copper mineral. As examples of deposits of iron ore accompanied with copper minerals in Japan, the Kamaishi mine in Iwate Prefecture and the Akatani mine in Niigata Prefecture are well known. However, objective facts indicating that these two mines had been in operation time during the period listed in Table 1 has not been clarified. Considering that the archaeological sites discussed in this paper had a close relationship with the northern continent in terms of the effect of material culture, Samples No.2 and No.5 are likely to have come from the northern continent. Samples Rf2 to Rf6 also can be estimated to have been brought from the northern continent because of their high copper content. Samples Rf14$Sa_{1.2}$ and Rf18 are plotted in the right side of Fig.20a_1 and in the center area of Fig.20a_1, and in the left side of Fig.20b_1.The values of (mass% Cu)/(mass% Ni) of Samples Rf14$Sa_{1.2}$ and Rf5 are 3.20, 3.91, and 3.45, respectively. The copper contents of these three samples (0.016, 0.043,and 0.038) are lower in comparison with the above-mentioned seven samples. Therefore, this result may be due to the fact that the raw iron material used to produce Samples Rf14 and Rf18 had a copper content that was three or four times higher than that of nickel.

Samples No.2 and No.5 have differing chemical compositions, because high levels of Sn and As (above 0.06mass%) were detected in Sample No.5. This result indicates that it is likely that these two samples were manufactured using different raw materials. On one hand, Samples No.1 and No.3 are plotted in the same area (Area A) of Fig.20b_1. Conversely, in Fig.20a_1, these two samples could not be plotted because of their low Ni content (below 0.001 mass%). Considering both samples have almost the same chemical composition as seen in Table 2, it is possible that Samples No.1 and No.3 were manufactured using the same raw materials. Samples Rf1Sa1 and Rf9,samples Rf3 and Rf5, and Samples Rf12Sa_1, Rf13$Sa_{1.2}$, and Rf19Sa_1 are distributed in nearly the same areas (Areas B, C, and D). It is possible that the samples classified into these two areas were manufactured using the same raw materials.

Ironware which has ratios of Ni, Co, and Cu similar to the ironware distributed in the area D, was found from the Tangotai burial mounds in Hachinohe, Aomori prefecture, Japan, and the Fujisawaezomori burial mounds in Yahaba, Iwate Prefecture, Japan. Furthermore, most of the above-mentioned ironware had non-metallic inclusions where titanium compounds were found.

On the basis of the analytical results of this study, the following three points are surmised. First, it is certain that there were multiple supply regions for iron artifacts during the Okhotsk cultural period. Second, we can hypothesize that the suppliers changed with the passage of time. Finally, from the 8th century to the 9th century, through contact with the Satsumon culture in the central region (Ishikari lowland) of Hokkaido, ironware supplied to the areas belonging to the Okhotsk culture, increased.

Conclusion

As mentioned above, using pottery shards in substitution for tuyere and for furnace walls, there were two kinds of metallurgical processes of techniques, facilities, raw materials, and products in the Okhotsk culture. One is the relatively popular forging using twin blowing through two shards constructing the furnace. The raw material used is steel (broken tools etc.). The other is the refining of high carbon material or cast iron into steel in the furnace of one shard wall using single blowing associated with heavy slag as a byproduct (No.2, Motochi).

While for a long time “northern continent” was generally assumed to be the place of origin of the forging technology and some iron goods of the Okhotsk culture, now it has become possible to nominate a more specific region, namely from the middle Amur region to the Predbaikal (west of Baikal) region, as one of the actual areas of origin of this unique forging technology and iron goods (Fig. 21). It is true that there is still a vast blank between the Predbaikal and Amur-Okhotsk regions, as no information exists on metallurgy for the Burkhotoi culture (2–8 A.D.) in the Zabaikal (East of Baikal) region, but it should not be overlooked that pottery ornamentation with the “sheep horn” and “wedend “n” motif on the shoulder was also popular in this culture.

At this moment we do not have enough data and information on iron material with a high composition ratio of Cu and Ni, so it is interesting that an iron arrowhead excavated in Nitappunai, Atsuma town Hokkaido, has the characteristic style of Pokrovka the medieval culture in middle region of Amur and contains Cu and Ni at a high ratio (Akanuma 2009). This arrowhead might have been made in the middle region of the Amur River and carried into Hokkaido (Kikuchi 2010). Similar to this arrowhead, most of iron goods at the early stage and middle stage of the Okhotsk culture have a high possibility of being made in the Northeastern continent, including from the Amur region the main territory of the Mokhe culture which kept a strong relationship with the Okhotsk culture to the Baikal region.

The drastic change in the chemical character of iron goods that occurred between the middle stage and the late stage is interesting. This change is understood as the result of new social contact grew between the Okhotsk people and the Satsumon people. This is because the Satsumon people lived in the central part (The Ishikari lowland) of Hokkaido imported iron goods directly from Honshu Isl. where iron material with a low composition ratio of Cu and Ni was popular. The forging technology of the Okhotsk culture started to decline already at the beginning of its late stage in the eastern part of Hokkaido then in the northern part of Hokkaido, for under the new condition of the social contact, importing of iron goods became easer for them.

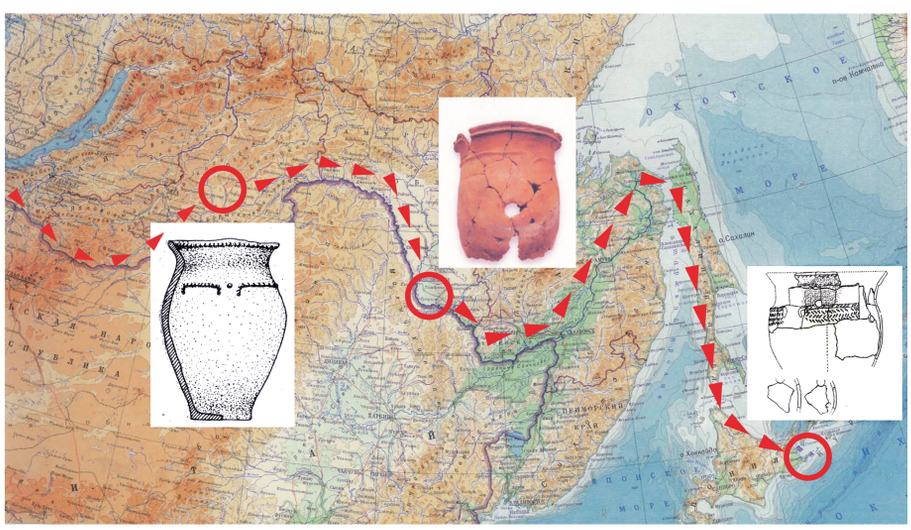


Fig. 21 Presumed route of forging technology diffusing from Baikal region to the Okhotsk culture.

Acknowledgment

We are grateful to Dr. H. Matsueda and Dr. J. Yamamoto (Hokkaido University Museum), Dr. I. Usuki (Sapporo Gakuin University), Dr. T. Sasada (Ehime University), Prof. Y. Kojima (Kanazawa Gakuin University), Dr. G. Ivanov (Irkutsk Regional Museum), Dr. P. Nesterov (Institute of Archaeology and Ethnology of the Siberian Branch of the Russian Academy of Sciences), Dr. Yu. Nikitin (Institute of History, Archaeology and Ethnology of Peoples of the Far Eastern Division of the Russian Academy of Sciences).

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