Estimating the Sources of Stone Tools Made of Tuffites during the Yayoi Period and Their Archaeological Significance

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ABSTRACT
In the northern Kyushu region, various woodworking adzes and polished stone daggers from the first half of the Yayoi period were made of a characteristic sedimentary rock type, known commonly as tuffite. However, the source of this stone material remains unclear. Thus, this study compares the whole-rock chemical composition of tuffites from the Lower Cretaceous Wakino Subgroup and Mt. Uibong-san, Korea, to estimate the source of materials for stone tools. The results demonstrated that four ternary diagrams using trace element and total rare earth element contents can distinguish effectively between the two stone sources. A geochemical analysis of the stone adzes excavated from the Shimohieda site and an investigation of the sources of the stone materials using these figures revealed that the chemical composition of the stone tools was within the range of tuffites from Mt. Uibong-san, Korea. Therefore, this study presumed that the stone tools excavated from the Shimohieda site are composed of tuffites from Korea. In the first half of the Yayoi period, when tuffite stone tools were widely used, metal tools, such as cast iron reworked tools were used in the Japanese archipelago. The results suggest cultural contact between groups across the straits during this period.

KEYWORDS: Yayoi period of protohistoric Japan, northern Kyushu island, Japan-Korea interactions, stone sources, whole-rock chemical compositions, Shimohieda site

1. Introduction

In the northern Kyushu region, sedimentary rocks commonly known as *tuffite* (層灰岩 sōkaigan) were used for various woodworking adzes (especially flat-shaped stone adzes) and polished stone daggers in the first half of the Yayoi period. Previous scholars

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pointed out, mainly through visual observations, that these tuffite stone tools were similar to those from the south-eastern part of the Korean Peninsula in terms of form and stone characteristics. This notion suggests that these stone tools may have been brought to northern Kyushu, in the Japanese archipelago, during the first half of the Yayoi period. Tuffite is an extremely important stone tool material and is indispensable for understanding the exchange between Japan and Korea during the Yayoi period, the production and distribution of tools and the acceptance of early ironware culture.

However, the stone source of the tuffite used for tools remains unclear because of the presentation of various views. The reason underlying this notion is that this stone tool material is geologically widespread, ranging from the Mesozoic Cretaceous Wakino Subgroup in north-eastern Kyushu (Kitakyushu City area) to the Nakdong group in the south-eastern part of the Korean Peninsula across the Tsushima Strait, which makes narrowing down its source extremely difficult.

Thus, this study compares the whole-rock chemical compositions of tuffites of the Wakino Subgroup in Kitakyushu City and those of Mt. Uibong-san in Korea. The chemical composition of the tuffite stone tools excavated from the Shimohieda site in Yukuhashi City, Fukuoka Prefecture, is similar to those of the two regions. The study estimates the source of the stone materials using the content ratios of the constituent elements.

2. Previous studies and issues

2-1. Previous studies

In this study, tuffite is “a rock in which volcaniclastic and sedimentary clastic materials are mixed and solidified, especially volcanic ash and fine-grained clastic materials” (Suzuki 2005, p.419), with characteristics intermediate between shale and tuff. This rock was widely used as a material for stone adzes and polished stone daggers in northern Kyushu during the Yayoi period. Tuffite stone adzes are widely distributed mainly in the Fukuoka plain, Futsukaichi area, and Saga plain (Mori 2013) of northern Kyushu and are scattered along the coast of the Sea of Japan and elsewhere as far east as the Yōkaichi Jikata site in Komatsu City, Ishikawa Prefecture (Sato & Miyada 2018). Conversely, polished stone daggers composed of tuffite are distributed mainly in northern Kyushu, such as a polished stone dagger with a handle excavated from wooden coffin tomb no. 15 at the Zasshonokuma site in Fukuoka City, and the fragment of a polished stone dagger excavated from the Ishigo site in Matsumoto City, Nagano Prefecture, which is presumed to be made of the same stone material (Shitara 1995) (Figure 1, 2).

Geologically, tuffite is a weakly thermally metamorphosed hornfels of tuffaceous mudstone and shale, which occur in the lower part of the Wakino Subgroup of the Kanmon Group during the Mesozoic Cretaceous. The Wakino Subgroup is a freshwater stratum

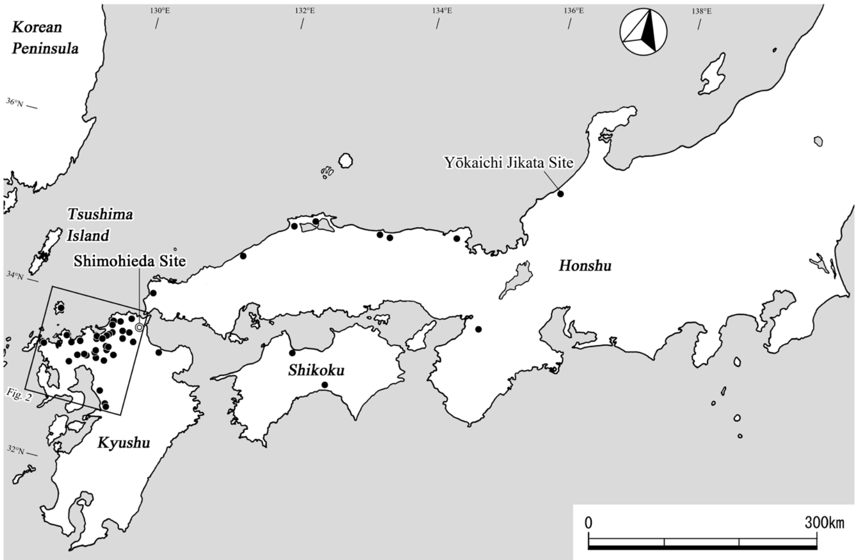

Figure 1. Distribution of tuffite stone tools

widely distributed from the upper reaches of the Yakiyama River in Miyawaka City, Fukuoka Prefecture (which is considered a stone extraction site of Tateiwa stone harvesting knives) to the western part of Yamaguchi Prefecture (where the Ayaragi-go site is located) (Figure 3). The Wakino Subgroup is contrasted with the Nakdong Group of the lower part of the Gyeongsang Supergroup in Korea across the Tsushima Strait (Inoue 1981; Geology of Japan "Kyushu Region" Editorial Committee 1992). Figure 3 shows the location of the Japanese Islands and the Korean Peninsula during the Cretaceous and the locations where rock samples were collected. The Kanmon Group and the Gyeongsang Supergroup are considered to be non-marine strata deposited in lakes and marshes formed on the margins of Eurasia at that time. The vertical variation of the lithology is similar, such that a layer-by-layer comparison can be performed. Moreover, many species are common between the fossil assemblages of the two groups (Ota 1960).

The outer surface of the tuffite stone tools display the following characteristics: (1) the colour tone is greyish-yellowish-brown and blackish-grey, and the fresh surface is jet black; (2) the lamina is well developed, and the stripes (grain-like patterns) are relatively clear; (3) the grain size of the stone is dense and has a sense of weight. The polished surface is smooth and oftentimes shiny (Mori 2013).

In northern Kyushu during the Yayoi period, geological conditions suggest that tuffites from the Wakino Subgroup in the Kitakyushu area were used for polished stone tools (Umezaki 1999, 2005). Conversely, Mori (2013) examined the sizes and production

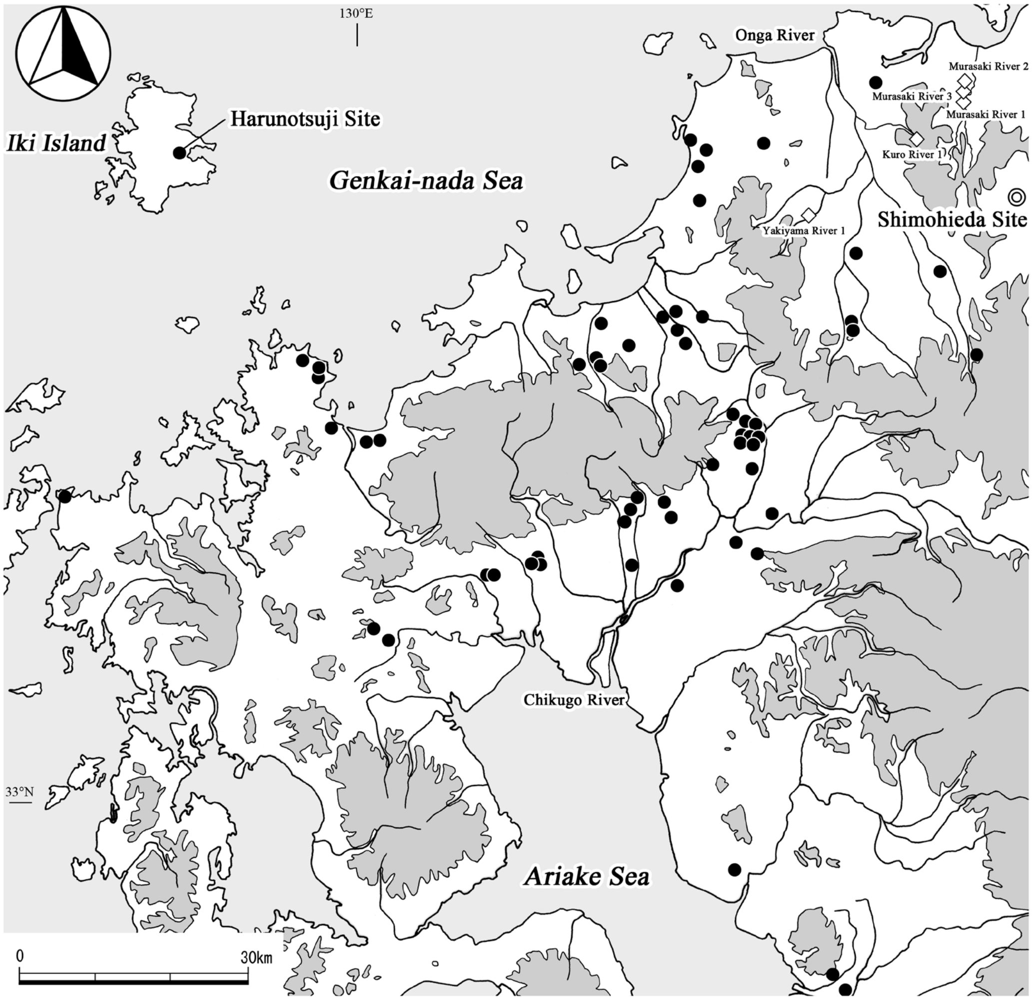

Figure 2. Site locations excavated tuffite stone tools in northern Kyushu region and sampling points

techniques of stone adzes made of tuffites and rejected the abovementioned theory, that is, tuffites from the Wakino Subgroup in the Kitakyushu area were used. Mori also pointed out the possibility that the source of the stone material could be found in the Taishu Group in the southern part of Tsushima Island or the Nakdong Group in the southeastern part of the Korean Peninsula. Furthermore, Mori proposed that the stone materials were brought to the Harunotsuji site and that the stone tools produced were distributed to northern Kyushu. The author based these proposals on the fact that the Harunotsuji site in Iki City, Nagasaki Prefecture, is the only site from which a large number of uncompleted stone adzes made of

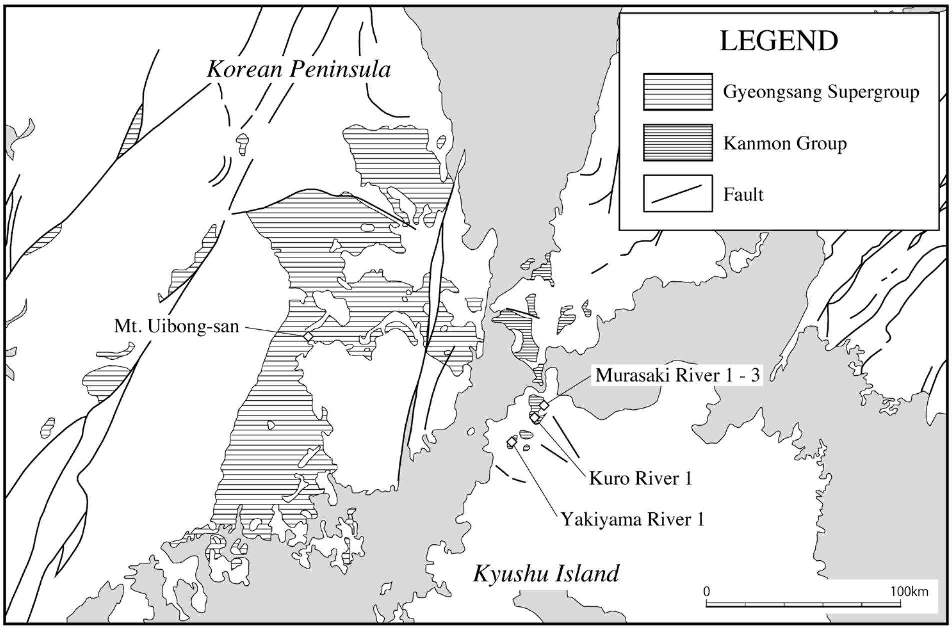

Figure 3. Position of the Korean peninsula and Kyusyu island during the Cretacous and distribution of Cretaceous non-marine deposits, Gyeongsang Supergroup and Kanmon Group, and sampling points (modified from Chough & Sohn 2010)

tuffites and materials related to their production process have been excavated. Conversely, Sato (2017) analysed the specific gravity of stone adzes made of tuffites and distinguished its sources. The most frequent difference in specific gravity between tuffite stone adzes excavated in northern Kyushu, tuffite stone tools (spherical stone hammers used for stone tool making) from the Kitakyushu area and tuffite stone adzes from the Harunotsuji site pointed out the possibility of the existence of an unknown source in northern Kyushu.

Alternatively, Whang (2011) conducted a study on the Korean side and examined the geology of hornfels, which was used as the stone material for the polished stone daggers of the Bronze Age in Korea. Furthermore, the author conducted a field survey of stone sources and the distribution of the production sites of stone tools. The only place where hornfels, that match the shape of polished stone daggers, can be collected is the Mt. Uibong-san area in Goryeong-gun, Gyeongsangbuk-do (Figure 3). In Goryeong-gun, previous scholars (Whang 2020) confirmed large-scale stone tool production sites using hornfels at the Bongpyeong-ri site, located approximately 4 km southwest of Mt. Uibong-san. Other production sites were identified at the Daeheung-ri and Kwaebin-ri sites. This finding suggests that Mt. Uibong-san was the source of the stone tools.

The present study conducted a petrological examination of the Wakino Subgroup in the

Kitakyushu City area to perform a basic analysis to estimate the source of stone tools made of tuffites. Umezaki and Yuhara (2016) found that the tuffites are composed of tuffaceous mudstone and sandstone intercalations and are andesitic in SiO_2 content but rich in CaO.

Moreover, Yuhara *et al.* (2020) conducted major and trace element measurements and rare earth element (REE) analyses of tuffites in the Wakino Subgroup of the Kanmon Group (Figure 3). Their results suggested that the total rock chemical compositions of the tuffites in the Murasaki River and the Kurokawa River basins were similar. However, tuffites in the Yakiyama River basin exhibited lower TiO_2 and Al_2O_3 contents and slightly lower Cr, Ga, Nb, Th, and Zr contents. These differences in content are considered to reflect differences in the stratigraphic level of production. This study predicted that these elements can be used to verify differences in the sources of tuffites. However, the question of whether tuffites are tuffaceous or not remains unanswered based on their lithology and chemical composition. This is one of the biggest problems in understanding the origin of tuffites.

2-2. Issues

The source of the tuffite stone tools excavated in northern Kyushu during the Yayoi period remains unclear, with three theories, namely, Kitakyushu City area, an unknown stone source in the northern Kyushu region, and outside Kyushu Island (the Taishu or Nakdong Group in Korea). Furthermore, studies discussed the source of stone materials based on visual observations and specific gravity analyses. However, studies that conducted petrological and geochemical analyses of the stone materials or the stone tools themselves or verified each region of Japan and Korea, are lacking.

Thus, this study compares the whole-rock chemical composition of the tuffites of the Wakino Subgroup (i.e., the Murasaki River, Kurokawa River and Yakiyama River basins) in the Kitakyushu area, which is a candidate site for the source of stone materials, and the tuffites of Mt. Uibong-san in Korea, to obtain a marker to distinguish the stone source. The chemical composition of the tuffite tools excavated from the Shimohieda site is similar to that of the other region, and the source of the stone materials is estimated by comparing the content ratios of the constituent elements.

3. Samples and methods of analyses

Tuffite boulders (Figure 4) collected from Mt. Uibong-san (Figure 3), Goryeong-gun, Gyeongsangbuk-do, Korea, were used as samples for analyses. The area of Mt. Uibong-san is considered to be about 120 km away from the Kitakyushu city area when the tuffite was deposited (Figure 3). Similar to the stone tools excavated from the archaeological sites, the weathered surface of the tuffite boulders are brownish to bluish-grey (Figure 4c).

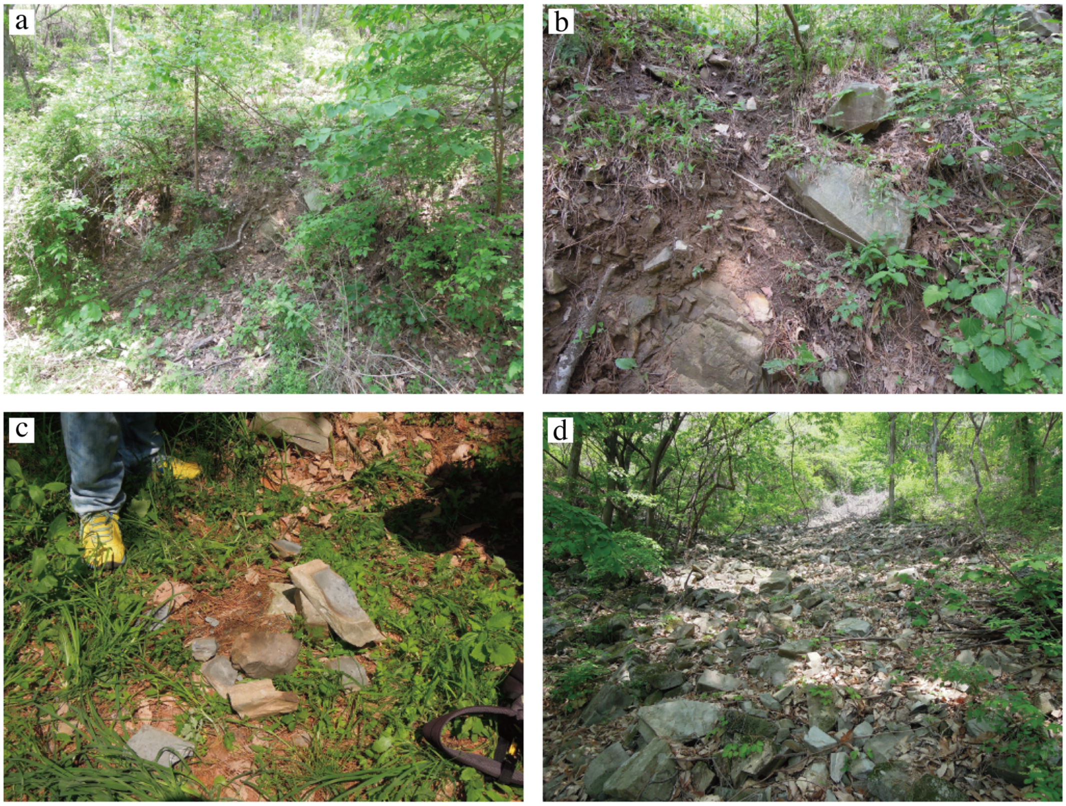

Figure 4. Photographs showing field occurrence of rolling stones of tuffite at Mt. Uibong-san. a: Slope condition of Mt. Uibong-san, b: Enlarged photo of the slope, c: Tuffite boulders are composed of angular gravels and reach a maximum length of 40 cm, d: Tuffite boulders deposited in a rain fissure on the slope

The tuffite boulders are composed of alternating dark and light layers, and the thickness of a single layer ranges from 0.5 to 50 mm (Figure 5). The dark layer consists of black to dark grey mudstone to fine-grained sandstone and dark green to greenish-grey mudstone to fine-grained sandstone. The light layer consists of light greenish-grey to white mudstone to fine-grained sandstone. In many cases, calcite veins are visible. These characteristics are similar to those of the tuffite of the Kanmon Group (Yuhara *et al.* 2020).

The stone artefacts are a pillar-shaped stone adze (Shimohieda 1, sample no. 2422) and a flat-shaped stone adze (Shimohieda 2, sample no. 2253) excavated from the Shimohieda site in Yukuhashi City, Fukuoka Prefecture (Figure 6). The two stone artefacts were cut at the red line in Figure 7a, c, and the smaller one was used as the analysis samples. It was polished with a grinder to remove weathered areas up to 1 mm thick and to eliminate iron

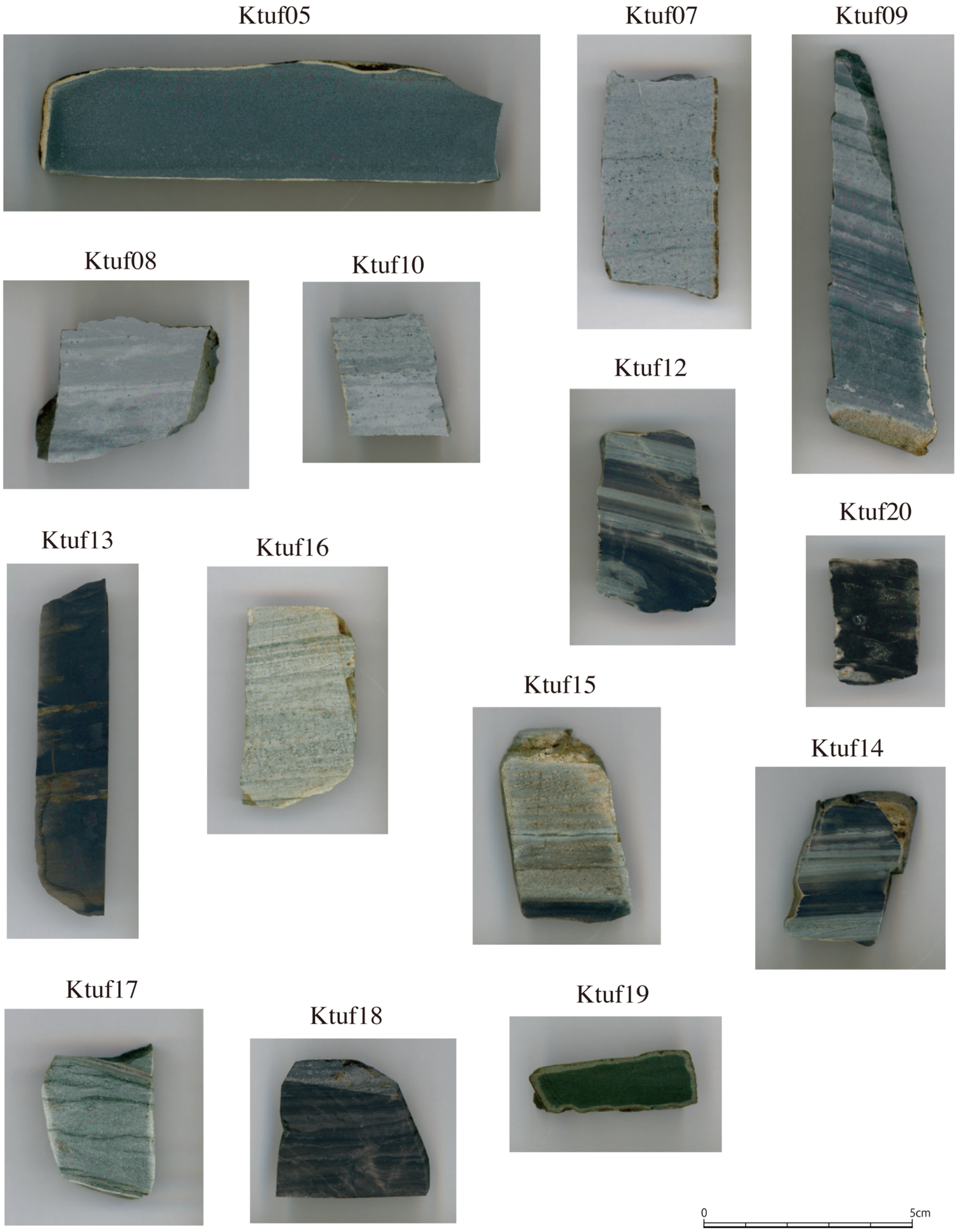

Figure 5. Photographs of polished slabs of representative tuffite at Mt. Uibong-san

contamination on the cut surface. The samples were then cleaned with ion-exchange water using an ultrasonic cleaner in the same way as the rock samples. The samples were dried at 110°C and powdered by vibration sample mill (CMT TI-100). For details of sample preparation, please refer to Yuhara and Taguchi (2003a). The masses of Shimohieda 1 (2422) and Shimohieda 2 (2253) before powdering were 19.65 g and 4.33 g, respectively.

The major and trace element concentrations of the whole-rock samples of tuffites and stone tools were analysed using X-ray fluorescence (RIGAKU ZSX100e) at Fukuoka University, following the methods outlined by Yuhara and Taguchi (2003a, 2003b, 2006), Yuhara *et al.* (2004), and Takamoto *et al.* (2005) using 1 : 5 glass bead and 1 : 1 pressed pellet. The total iron content is denoted as Fe_2O_3*.

In addition, the contents of REEs and trace elements of five rock samples (Ktuf03, Ktuf09, Ktuf10, Ktuf13, Ktuf16) and one stone artefact sample were determined with laser ablation-inductively coupled plasma mass spectrometry (LA-ICP-MS: PerkinElmer NexION2000) with Nd-YAG laser system (New Wave Research UP-213) at the Rissho University using 1 : 2 glass beads. After introducing the sample aerosolized from the beads by laser into ICP-MS, it is decomposed by plasma and the intensity is measured for each element, and it is compared with the standard sample to measure the rare earth element. (Shindo *et al.* 2009; Kawano and Shimizu 2017).

At least 5 g of powder sample is required to perform all the analyses. Therefore, 1 : 1 pressed pellet and 1 : 2 glass bead fabrication were not possible for Shimohieda 2 (2253), and REE and some trace elements could not be measured.

4. Results

4-1. Overview of stone tools made of tuffites excavated from the Shimohieda site

Two stone adzes, one pillar-shaped stone adze and one flat-shaped stone adze, which were excavated from the Shimohieda site, were analysed (Figure 6, 7).

Shimohieda 1 is the base fragment of a pillar-shaped stone adze excavated from storage pit no. 21 in district H. It measures 6.6 cm in length, 2.5 cm in width, 3.3 cm in thickness (Figure 6) and 81.99 g in weight. The transverse cross-sectional shape is an oblique trapezoid, and the direction of the lamina is slightly oblique and longitudinal (Figure 7b). It slopes down from the inner surface to the base, whereas the upper end of the base is rounded. A few traces of what appears to be the upper edge of the gouge used to secure it to the handle were noted. The surface is severely weathered and contains a light yellow coloration (Figure 7a). Indistinct polishing marks are visible on all surfaces.

Shimohieda 2 is a fragment from the base to the centre of the flat-shaped stone adze excavated from storage pit no. 156 in district F. It measures 4.7 cm in length, 2.5 cm in

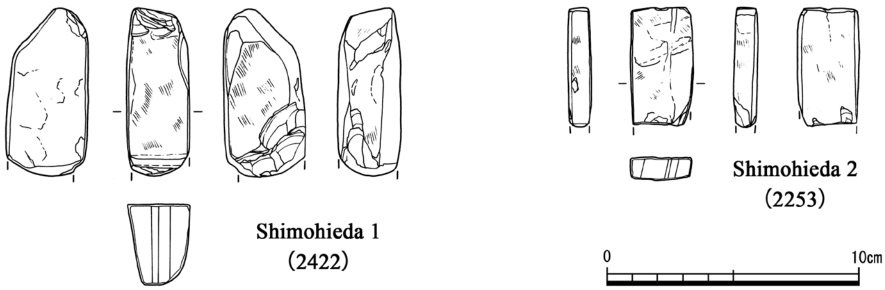

Figure 6. Drawings of stone tools excavated from the Shimohieda site as analysis samples. Data sources: The drawings were made by the author (Mori). The sample numbers are based on the report (Nagamine & Suenaga (ed.) 1985).

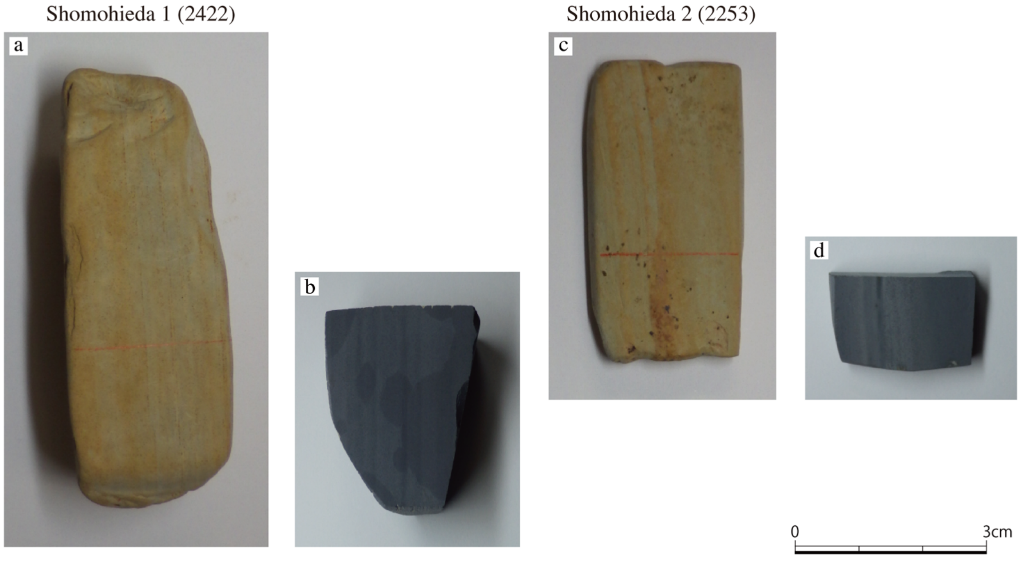

Figure 7. Photographs of stone tools. a: photograph of Shimohieda 1 (2422), b: photograph of polished surface of Shimohieda 1 (2422), c: photograph of Shimohieda 2 (2253), d: photograph of polished surface of Shimohieda 2 (2253). The red lines in these photos are the cut lines.

width, 0.95 cm in thickness (Figure 6) and is 21.03 g in weight. The planar and transverse shapes are rectangular, whereas the direction of the lamina is slightly oblique and longitudinal (Figure 7d). The outer and inner surfaces are flat, and the longitudinal cross-sectional shapes are parallel from the centre to the top of the base. The surface is severely weathered and exhibits a light yellow coloration (Figure 7c). Indistinct polishing marks are visible on all surfaces.

Based on pottery types and chronological studies of stone adzes (Shimojo 1996, 1997), Shimohieda 1 and 2 are inferred to have been produced in the late-early to early-middle Yayoi period.

4-2. Chemical composition of tuffites

Table 1 presents the results of the chemical analyses of the tuffites. The SiO_2 content of tuffites of the Mt. Uibong-san ranges from 50.0 to 65.9 wt%, which nearly overlaps with the compositional ranges of the tuffites in the Murasaki River and Kuro River basins (46.2–64.8 wt%: 43 data from 24 samples; Umezaki and Yuhara 2016; Yuhara *et al.* 2020). In the variation diagram of the major elements (Figure 8), the compositional ranges of tuffites of the Murasaki River and Kuro River basins overlap with those of the tuffites of Mt. Uibong-san. Meanwhile, in the variation diagram of trace elements (Figure 9), many elements overlap with the compositional range of tuffites in the Murasaki River and Kuro River basins. The contents of Cr, Nb, Ni, Th, and Zr tend to be higher than these, although a few overlaps were noted. In contrast, the Sr content tends to be lower, and the V content tends to be slightly lower, although they also overlap. The chemical composition of the stone tools excavated from the Shimohieda site is nearly within the composition range of the tuffites from Mt. Uibong-san, Korea.

Table 2 provides the results of the analyses of REEs. The REE patterns of tuffites normalised by C-1 chondrites (Anders & Grevesse 1989) (Figure 10) all demonstrate a decreasing rightward pattern rich in light REEs and poor in heavy REEs. Although differences were noted in the elemental content, distinguishing the stone sources remains difficult because of the absence of a clear pattern of differences.

5. Discussion

5-1. Estimation of stone sources using the chemical composition of tuffites

The elemental content variation diagrams in Figure 8 and 9 illustrate the whole-rock chemical compositions of the tuffites of the Murasaki River, Kuro River basins and of Mt. Uibong-san, which displayed overlapping compositional ranges. The Cr, Nb, Ni, Th, and Zr contents of the tuffites of Mt. Uibong-san were higher than those of the tuffites of the Murasaki River and Kuro River basins, whereas the Sr and V contents were lower. However, distinguishing the tuffites of the two regions using these variation diagrams alone is difficult. Therefore, this study intended to classify them using a ternary diagram that can be compared using the ratio of the content of the three elements. In this regard, the Cr–V–Rb, Sr–V–10Th, Ga–Th–Pb, and 10Ni–10Th–Sr diagrams were relatively effective (Figure 11). However, using a combination of the four diagrams proved more effective because determining each ternary diagram by itself is difficult.

The tuffite stone tools excavated from the Shimohieda site are plotted within the

Table 1. Whole-rock chemical compositions of tuffites and stone tools

	Tuffite from Mt. Uibong-san							
Sample No.	Ktuf01	Ktuf02	Ktuf03	Ktuf04	Ktuf05	Ktuf06	Ktuf07	Ktuf08
SiO_2 (wt%)	59.89	51.88	57.55	52.12	57.09	56.21	49.96	55.63
TiO_2	0.76	0.65	0.70	0.67	0.81	0.66	0.44	0.67
Al_2O_3	15.63	12.86	13.63	13.43	14.91	13.48	9.78	13.63
Fe_2O_3*	5.32	5.33	4.84	5.19	7.82	5.39	2.81	5.68
MnO	0.08	0.19	0.15	0.18	0.09	0.17	0.33	0.18
MgO	3.65	3.26	3.45	3.20	4.33	3.39	1.79	3.65
CaO	9.12	15.49	11.40	16.30	9.16	12.46	19.12	12.25
Na_2O	1.46	1.36	1.54	1.25	1.14	1.25	1.90	1.24
K_2O	2.81	2.42	4.06	2.22	2.71	3.40	2.31	3.32
P_2O_5	0.18	0.16	0.17	0.17	0.18	0.16	0.10	0.17
L.O.I.	1.14	5.99	2.79	4.91	1.60	3.87	10.85	4.03
Total	100.04	99.59	100.28	99.64	99.84	100.44	99.39	100.45
As (ppm)	29	<4	12	5	5	<4	20	<4
Ba	644	303	625	401	583	487	532	470
Cr	99	86	95	82	111	86	53	81
Cu	<4	23	<4	41	27	<4	<4	<4
Ga	20	17	15	16	19	16	11	17
Nb	19	16	17	16	20	16	11	16
Ni	59	55	55	51	72	44	27	47
Pb	16	13	15	12	17	10	21	9
Rb	113	152	172	98	103	188	72	182
S	n.d.	215	16	85	9	56	42	54
Sr	352	361	396	323	320	343	394	336
Th	18	13	13	14	17	14	7	14
V	106	86	88	87	97	89	54	87
Y	34	35	32	32	33	34	20	34
Zn	71	160	64	109	99	82	43	82
Zr	208	172	208	194	250	177	151	181

*: total iron as Fe_2O_3, L.O.I.: loss on ignition, n.d.: not detected.

Table 1. Continued

	Tuffite from Mt. Uibong-san							
Sample No.	Ktuf09	Ktuf10	Ktuf11	Ktuf12	Ktuf13	Ktuf14	Ktuf15	Ktuf16
SiO_2 (wt%)	57.13	50.84	57.43	62.47	61.85	63.09	63.38	63.11
TiO_2	0.69	0.64	0.67	0.72	0.69	0.69	0.54	0.54
Al_2O_3	13.81	12.51	13.45	15.80	15.41	15.39	15.23	13.69
Fe_2O_3*	4.98	5.23	4.91	5.54	5.20	5.53	4.49	4.44
MnO	0.15	0.20	0.17	0.09	0.05	0.08	0.06	0.13
MgO	3.54	3.19	3.60	3.02	2.95	2.95	3.03	4.01
CaO	10.50	16.44	10.60	4.54	3.73	4.37	3.90	4.22
Na_2O	1.70	1.36	1.64	3.32	3.28	3.35	4.69	5.29
K_2O	4.08	2.18	4.43	2.81	3.94	2.56	2.56	3.22
P_2O_5	0.17	0.16	0.16	0.14	0.20	0.14	0.14	0.15
L.O.I.	2.79	7.03	2.28	1.24	1.86	1.10	1.09	0.70
Total	99.54	99.78	99.34	99.69	99.16	99.25	99.11	99.50
As (ppm)	12	<4	11	12	12	12	7	5
Ba	658	248	675	355	505	324	324	361
Cr	96	88	92	90	65	83	83	67
Cu	n.d.	15	16	20	18	9	9	<4
Ga	15	17	15	19	18	20	15	11
Nb	17	17	18	16	16	15	15	12
Ni	56	52	55	43	29	45	45	27
Pb	16	12	14	23	19	19	7	15
Rb	162	142	183	114	181	116	82	165
S	15	165	14	n.d.	268	n.d.	n.d.	n.d.
Sr	398	361	387	144	226	137	499	132
Th	14	13	14	14	13	13	11	12
V	86	82	89	105	94	102	74	64
Y	31	34	32	28	27	27	22	23
Zn	52	109	57	79	70	81	51	76
Zr	209	178	211	154	206	150	140	204

*: total iron as Fe_2O_3, L.O.I.: loss on ignition, n.d.: not detected.

Table 1. Continued

	Tuffite from Mt. Uibong-san				Shimohieda Site	
Sample No.	Ktuf17	Ktuf18	Ktuf19	Ktuf20	2253	2422
SiO_2 (wt%)	65.86	55.68	60.67	65.84	56.26	52.15
TiO_2	0.54	0.66	0.57	0.72	0.75	0.73
Al_2O_3	14.07	15.62	13.55	15.58	15.50	17.18
Fe_2O_3*	3.74	5.34	4.57	5.27	7.27	7.15
MnO	0.06	0.08	0.08	0.05	0.10	0.11
MgO	3.31	3.75	3.15	1.91	3.86	4.14
CaO	3.45	6.50	4.69	2.42	9.92	10.85
Na_2O	3.61	3.13	4.24	3.11	0.82	0.80
K_2O	3.25	3.80	1.98	3.10	3.79	3.44
P_2O_5	0.13	0.13	0.20	0.13	0.18	0.18
L.O.I.	1.42	4.37	5.69	1.24	0.95	2.71
Total	99.44	99.06	99.39	99.37	99.40	99.44
As (ppm)	<4	9	14	<4	—	7
Ba	460	683	396	355	743	596
Cr	77	72	70	85	84	111
Cu	<4	4	20	20	52	24
Ga	16	19	15	19	—	21
Nb	12	15	11	17	19	18
Ni	34	43	28	41	61	90
Pb	11	18	8	20	—	19
Rb	129	163	59	150	132	132
S	n.d.	35	48	9	366	508
Sr	295	356	201	136	443	447
Th	10	14	9	14	—	19
V	70	98	74	85	106	125
Y	20	27	19	35	35	34
Zn	54	76	63	71	98	56
Zr	190	182	171	219	171	138

*: total iron as Fe_2O_3, L.O.I.: loss on ignition, n.d.: not detected.

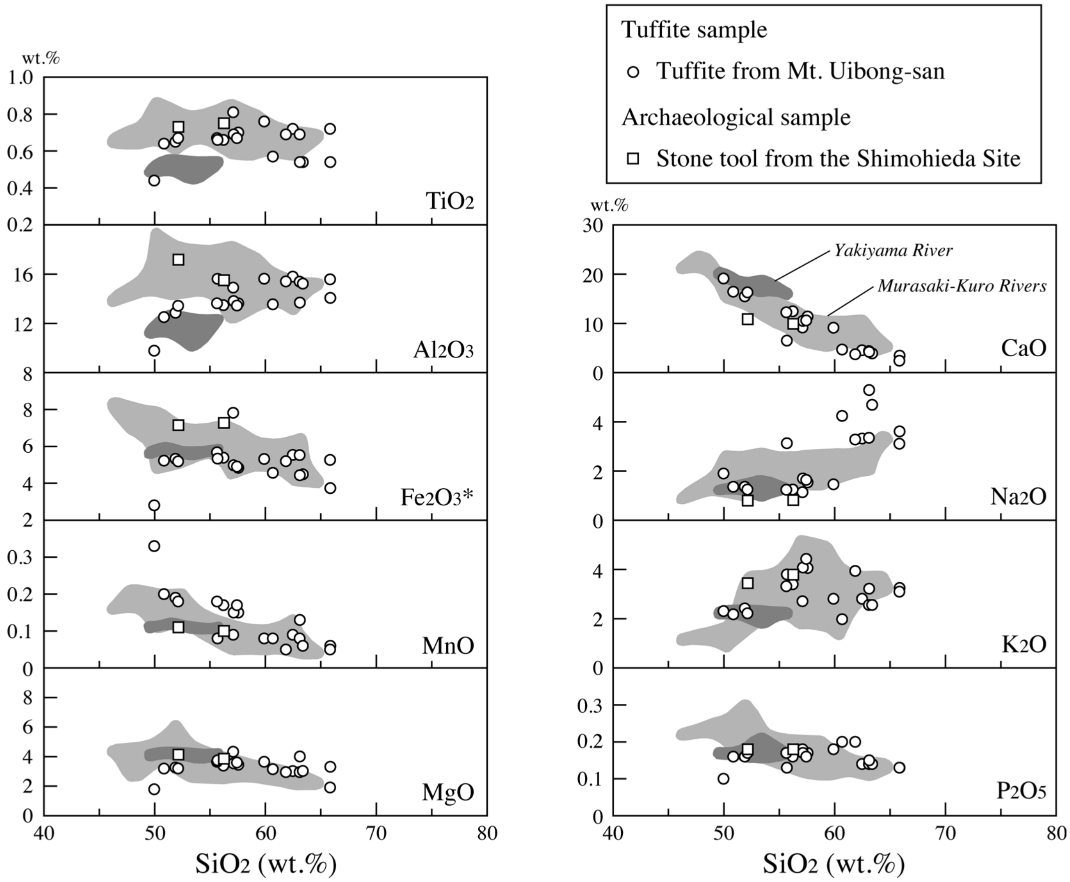

Figure 8. Diagrams showing major element variation in SiO_2 content for samples of tuffite and stone tool. Data sources: Umezaki & Yuhara (2016), Yuhara et al. (2020) and this study. Light grey: range of tuffites from the Murasaki River and Kuro River basins (43 data from 24 samples). Dark grey: range of tuffites from the Yakiyama River (5 data from 2 samples)

compositional ranges of the tuffites of Mt. Uibong-san in the abovementioned ternary diagrams (Figure 11).

Therefore, the stone source of these stone tools is estimated to be Mt. Uibong-san in Korea.

The REE patterns of the tuffites indicate a similar downward pattern, with light REE-rich and heavy REE-poor elements (Figure 10). Therefore, classifying the stone sources using the difference in patterns is impossible. In this regard, the patterns are similar, but the elemental contents are different; therefore, this study compared the total REE content. The REE contents are 133.97–167.01 ppm in the Murasaki River and Kuro River basins,

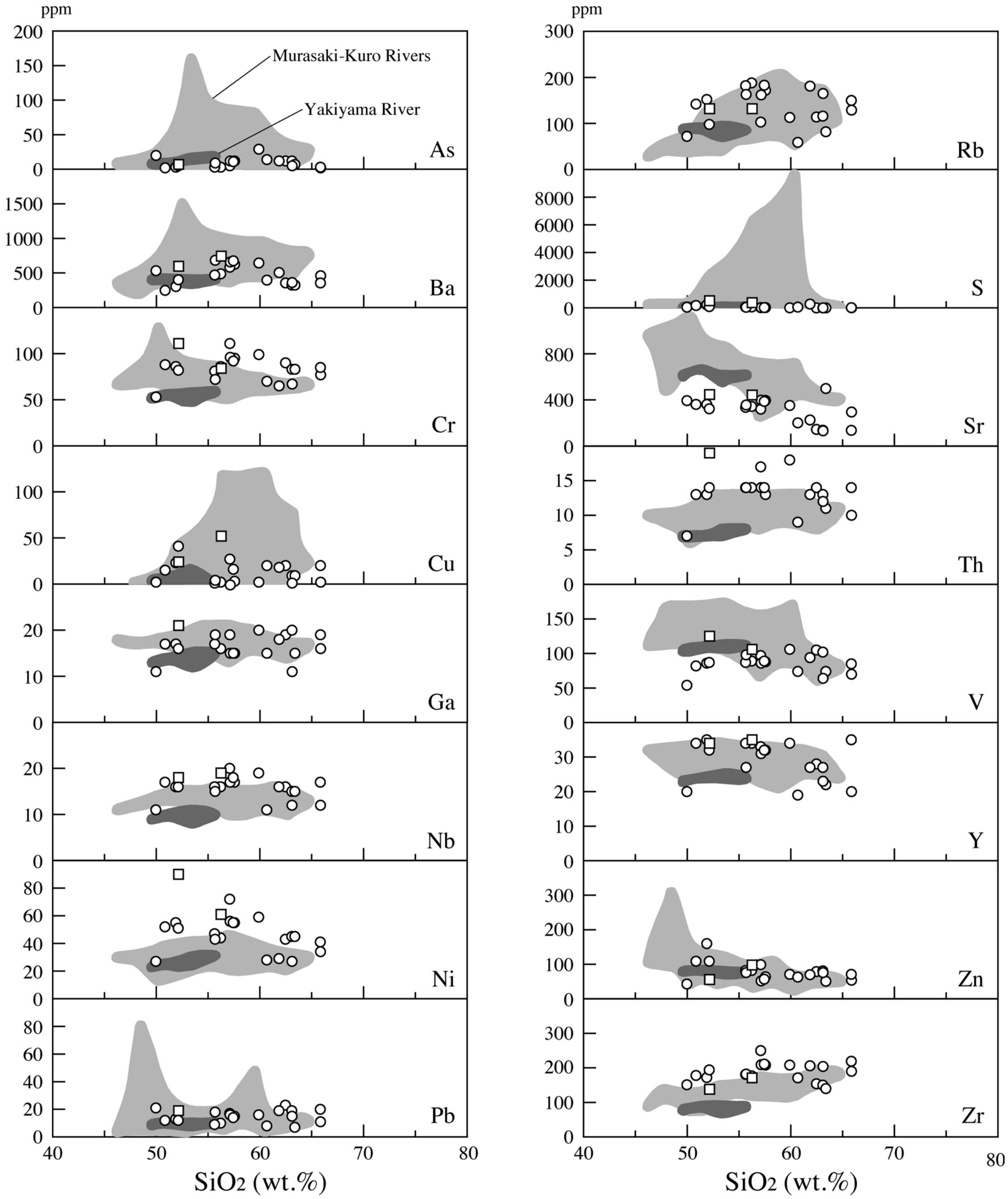

Figure 9. Diagrams showing minor element variation in SiO_2 content for samples of tuffite and stone tool. Symbols are the same as those in Figure 8. Data sources: Umezaki & Yuhara (2016), Yuhara et al. (2020) and this study. Light grey: range of tuffites from the Murasaki River and Kuro River basins (43 data from 24 samples). Dark grey: range of tuffites from the Yakiyama River (5 data from 2 samples)

Table 2. Rare earth element (REE) compositions of tuffites and stone tool

Sample No.	Ktuf03	Ktuf09	Ktuf10	Ktuf13	Ktuf16	2422
La (ppm)	44.57	48.97	49.66	36.22	30.44	50.84
Ce	85.14	89.53	91.76	67.09	59.79	101.88
Pr	11.16	11.69	12.04	9.04	7.57	12.88
Nd	38.27	40.40	42.66	32.51	26.32	44.24
Sm	6.83	7.31	7.91	6.05	4.90	8.01
Eu	1.57	1.54	1.86	1.39	1.02	1.70
Gd	6.36	5.53	6.11	4.82	3.92	6.91
Tb	0.92	0.94	1.07	0.80	0.68	1.00
Dy	4.51	4.82	5.27	4.03	3.49	4.96
Ho	0.82	0.85	0.94	0.71	0.62	0.88
Er	2.48	2.64	2.87	2.15	1.89	2.66
Tm	0.34	0.37	0.39	0.30	0.27	0.37
Yb	2.45	2.63	2.71	2.11	1.86	2.68
Lu	0.38	0.43	0.44	0.35	0.28	0.41
Total REE	205.80	217.65	225.69	167.57	143.05	239.42
Hf	5.10	5.90	4.83	5.01	4.99	3.68
Ta	1.20	1.29	1.17	1.05	1.05	1.21
U	2.42	2.36	2.53	2.28	2.53	3.16

114.39 ppm in the Yakiyama River basin and 143.05–225.69 ppm in Mt. Uibong-san; however, tuffites in Mt. Uibong-san tend to display higher values. The variation of the total REE contents with SiO_2 contents (Figure 12) indicates that the total REE contents of the tuffites of Mt. Uibong-san tend to decrease with the increase in SiO_2 contents. Furthermore, the rate of decrease seems to increase with SiO_2 contents at approximately 60 wt. %. Moreover, reading the trend on the side of high SiO_2 contents is difficult because of the small number of samples from the Murasaki River, Kuro River, and Yakiyama River basins. However, the results clearly indicate total REE contents lower than those of Mt. Uibong-san. Therefore, a possibility exists that this figure can also be used to classify stone sources. The tuffite stone tool (Shimohieda 1) excavated from the Shimohieda site show a high total REE content of 239.42 ppm and are plotted on the Mt. Uibong-san side. Thus, REE analyses of a larger number of rock samples are required to verify the validity of this figure.

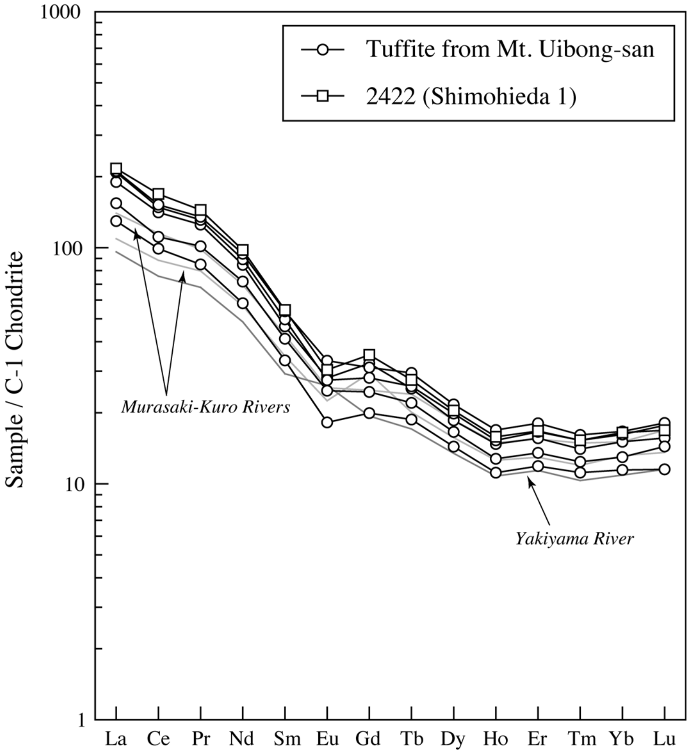

Figure 10. C-1 chondrite-normalized rare earth element (REE) abundances of tuffites and stone tool. Normalization values are quoted after from Anders & Grevesse (1989). Data sources: Yuhara et al. (2020) and this study. Light grey line: Murasaki River and Kuro River basins. Dark grey line: Yakiyama River

5-2. Archaeological significance of estimating the sources of tuffite stone tools

According to previous studies, the production and distribution of stone tools during the Yayoi period were generally considered a result of the development of high-quality stone production sites in Kyushu Island during the first half of the Yayoi period. Furthermore, they pointed to the emergence of stone tools that could be distributed over a wide area as a result of the division of labour among small regions (e.g., Shimojo 1989; Teramae 2011). However, the results of our analyses demonstrated that tuffite stone tools were sought outside Kyushu Island and that the products were distributed over a wide area, which suggested that the production and consumption systems of stone tools were multilayered. This finding is in contrast to those of previous studies. Especially during the late-early to early-middle Yayoi period, the distribution of stone tools may have been established and developed as a result of external influences, such as the arrival of people from the southern part of the Korean Peninsula. At present, the Harunotsuji site in Iki City, Nagasaki

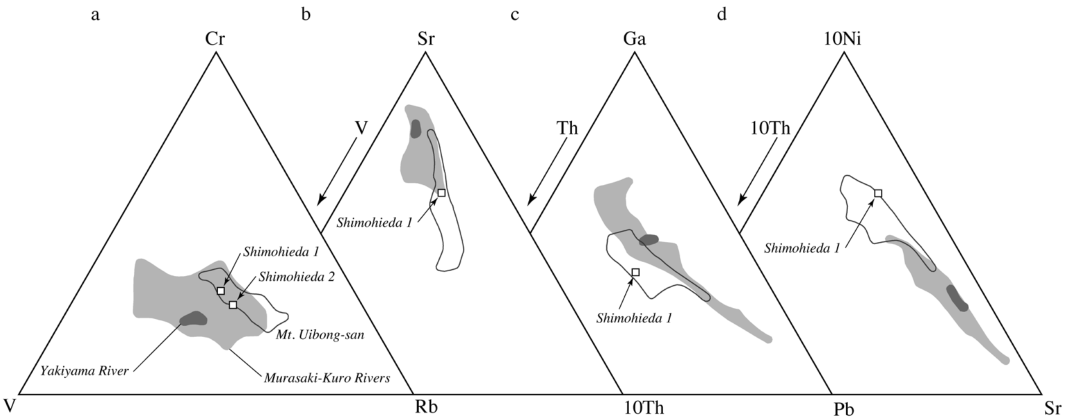

Figure 11. Ternary diagrams for presumption place of production of tuffite stone tool. Data sources: Umezaki & Yuhara (2016), Yuhara et al. (2020) and this study. a: Cr-V-Rb diagram, b: Sr-V-10Th diagram, c: Ga-Th-Pb diagram, d: 10Ni-10Th-Sr diagram. Light grey: range of tuffites from the Murasaki River and Kuro River basins (43 data from 24 samples). Dark grey: range of tuffites from the Yakiyama River (5 data from 2 samples)

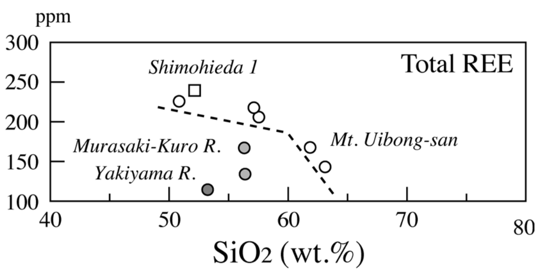

Figure 12. Diagrams showing total rare earth element (REE) variation in SiO_2 content for samples of tuffite and stone tool. Data sources: Yuhara et al. (2020) and this study

Prefecture, is the only site from which a large number of uncompleted stone adzes made of tuffites and materials related to their production process have been excavated. This raises the probability of the hypothesis that tuffite stone adzes were distributed using the Harunotsuji site as a production base and transit point (Mori 2013). However, petrological and geochemical analyses of stone tools excavated from the Harunotsuji site is a future issue.

Moreover, many sites, where tuffite stone adzes were excavated, were well known to have reworked cast iron axes (Mori 2013). This notion suggests that reworked cast iron axes were included in the distribution of stone adzes in the late-early to early-middle Yayoi period. Moreover, reworked cast iron axes may have been included in the category of tools related to woodworking activities. Although the majority of the tuffite stone adzes were excavated from the northern Kyushu region, they were also distributed sporadically throughout western Japan in the late-early to early-middle Yayoi period, including the Nakakuwano site in Kōge Town, Fukuoka Prefecture; the Ōkubo site in Saijō City, Ehime Prefecture; the Nishikawazu site in Matsue City, Shimane Prefecture; and the Yōkaichi Jikata site in Komatsu City, Ishikawa Prefecture. Although whether the tuffite stone adzes and cast iron axe fragments were distributed in a set relationship remains unknown, visualising that they were distributed in entirely different contexts is difficult because of their similar distribution.

Furthermore, a trend was noted in the consumption patterns, with many of the tuffite stone adzes being highly used and shrunken. This tendency indicates that the use value of tuffite stone adzes was higher than those made of other stone materials. The stone adzes for woodworking were a foreign cultural element that originated from the Mumun culture of the southern Korean Peninsula. Moreover, the fact that it was obtained from outside the range of everyday communication adds a new faraway value, which may have resulted in its prolonged use.

The first half of the Yayoi period, when tuffite stone tools were actively used, was the period when metal tools, such as reworked cast iron tools, began to be used in the Japanese archipelago. The results of the estimation of the sources of the tuffite stone tools presented in this study reflect the cultural contact between groups across the straits during the transition from stone to iron tools.

6. Conclusion

This paper compares the whole-rock chemical composition of tuffites from the Lower Cretaceous Wakino Subgroup and Mt. Uibong-san in Korea to estimate the source of materials for tuffite stone tools. The results demonstrated that four ternary diagrams using trace element content and total REE content were effective in distinguishing between the two stone sources. A geochemical analysis of the stone adzes excavated from the Shimohieda site and an investigation of the sources of the stone materials using these figures revealed that the chemical composition of the stone tools was within the chemical composition range of tuffites from Mt. Uibong-san, Korea. Therefore, this study presumes that the stone tools excavated from the Shimohieda site are made of tuffites from Korea. In the first half of the Yayoi period, when tuffite stone tools were widely used, metal tools, such as cast iron reworked tools began to be used in the Japanese archipelago. These results suggest cultural contact between groups across the straits during this period.

The stone tools of the Yayoi period are characterised by the extensive use of sedimentary rocks, such as tuffite, as agricultural tools and weapon-shaped stone tools, such as polished stone daggers. Analyses of the sources of stone tools over a wide area in Japan and Korea are important in examining the historical process of how cultural elements of the Mumun pottery culture, which originated from the southern part of the Korean Peninsula, became accepted and localised in the Japanese archipelago. Moreover, the study highlights the actual conditions of the bearers of this culture.

Nevertheless, only one lithic material could be analysed for Ga, Th, Pb, and REEs because of the low mass of the samples. Moreover, the investigation was limited by the nature of the material as a cultural property because the analysis required destruction. To increase the accuracy of the estimation of the stone sources, future studies should increase the number of materials analysed.

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