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Abstract

To understand the behavioral significance of the emergence and proliferation of blade technology in the northeastern Asian Upper Paleolithic, this paper explores the function of the earliest blade technology in Hokkaido, northern Japan, through an integrated analysis of edge morphology and use-wears on blade tools from the Last Glacial Maximum (LGM) assemblage of Kawanishi C. Although varied edge morphologies (i.e., straight, convex, concave, denticulate) have been distinguished, the results of use-wear analysis suggest that morphological differences of edges are not related to specific functions. Straight and convex edges experienced different use-lives and use-trajectories: both straight and convex edges were principally served for cutting/sawing and whittling, while some edges changed their functions to scraping as edge resharpening blunted the edges. The results of use-wear analysis also suggest that LGM blades were intensively used for performing a narrow range of activities (e.g., skin and meat stripping). Because this blade technology differs from the dominant flake technology in LGM Hokkaido, LGM foragers were able to employ it to perform intensive processing activity to exploit critical faunal resources that may have been sporadically clumped in the landscape.

Keywords blade; edge morphology; use-wear; Last Glacial Maximum; Upper Paleolithic; Hokkaido

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Fig7.pdf [Figure]

Table1.docx [Table]

Table2.docx [Table]

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Table5.docx [Table]

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3 October 2017

Submission of the revised manuscript to Quaternary International "**Honor of Lawrence Guy Straus**" special issue

Dear Prof. Min-Te Chen,

We would like to submit the present manuscript that was revised in response to the reviewers' comments. This is original research article entitled "A functional approach to the use of the earliest blade technology in Upper Paleolithic Hokkaido, northern Japan" by Yuichi Nakazawa, Akira Iwase, Toshiro Yamahara, and Minoru Kitazawa for consideration for publication in Quaternary International, special issue "Honor of Lawrence Straus" edited by Dr. Lisa Fontes. This manuscript has not been published previously and is not under consideration for publication elsewhere. We have no conflicts of interest to disclose.

Many thanks for your consideration of our resubmission. We look forward to hearing from you in due course.

Sincerely yours,

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3 October 2017

Submission of the revised manuscript to Quaternary International "**Honor of Lawrence Guy Straus**" special issue

Dear Prof. Min-Te Chen,

The major parts of revisions are shown in red letters in the text. In response to comments from Reviewer 1, some grammatical corrections were also made particularly in Introduction, Materials and Methods, and Results. We added the percentages besides counts in Tables 3a and 3b. The redundant and obvious phrased in the Conclusions were also deleted. The image of Figure 2 is based on the illustrations from the final monograph, and scar patterns as shown in the ripples and fissures are default in the Japanese and Korean site reports. We know that this kind of drawing may be odd for archaeologists who have got used to European style of drawings of stone tools and other objects. Redrawing the original illustrations in the monograph is particularly sensitive for the Japanese archaeological community because original researchers who organize the report maintain a sort of "privilege" to let archaeological community to use the original drawing. Make a new illustration for a well-known archaeological collection such as the study site may sometimes make a conflict with the original researchers (actually they are third and fourth authors of the present manuscript). Under this circumstance, for us it is difficult to make a completely new illustration to satisfy Reviewer 1 by revising some characteristics such as "crowded" scar patterns by replacing original ones with any other ways. For compromise, we added shadows on the resharpened stone tools illustrations in Figure 2.

In response to the comments from Reviewer 2, we made some clarification in supporting the statement in P4, L.5 "As a result, the proliferation of blade technology in East Asia was not only achieved by modern human population dispersal but also created by technological transmission from modern humans to multiple biologically distinctive populations that survived in diverse and unique ecological niches in the region of East Asia." by adding some recent finding of pre-modern *Homo sapiens* and genetic admixture model in Eurasia particularly from studies in Altai region. In P.4, We changed the dates of initial Upper Paleolithic in the Suidonggou and added the Suyanngae Loc. 6 with the earlier dates of blade assemblage. In response to the last comment regarding the relationships between the questions in Introduction and Discussion and Conclusion, in P.20, we added an argument that LGM blade technology in Hokkaido was likely cultural diffusion or demic diffusion, rather than the independent innovation.

Sincerely yours,

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A functional approach to the use of the earliest blade technology in Upper Paleolithic Hokkaido, northern Japan

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Abstract

To understand the behavioral significance of the emergence and proliferation of blade technology in the northeastern Asian Upper Paleolithic, this paper explores the function of the earliest blade technology in Hokkaido, northern Japan, through an integrated analysis of edge morphology and use-wears on blade tools from the Last Glacial Maximum (LGM) assemblage of Kawanishi C. Although varied edge morphologies (i.e., straight, convex, concave, denticulate) have been distinguished, the results of use-wear analysis suggest that morphological differences of edges are not related to specific functions. Straight and convex edges experienced different use-lives and use-trajectories: both straight and convex edges were principally served for cutting/sawing and whittling, while some edges changed their functions to scraping as edge resharpening blunted the edges. The results of use-wear analysis also suggest that LGM blades were intensively used for performing a narrow range of activities (e.g., skin and meat stripping). Because this blade technology differs from the dominant flake technology in LGM Hokkaido, LGM foragers were able to employ it to perform intensive processing activity to exploit critical faunal resources that may have been sporadically clumped in the landscape.

Keywords: blade; edge morphology; use-wear; Last Glacial Maximum; Upper Paleolithic; Hokkaido

1. Introduction

In the course of human evolution, blade technology was doubtless a critical technological innovation, which had relations to the cultural and socio-economic spheres notably modern human dispersal, technological transmission, the emergence of behavioral modernity, and subsistence strategies among various regions in the Old and New Worlds (e.g., Mellars, 1989; Bar-Yosef and Kuhn, 1999; Goebel, 1999; Bar-Yosef, 2000; McBreaty and Brooks, 2000; Blades, 2001; Groucutt and Petraglia, 2012; Bar-Yosef and Belfer-Cohen, 2013; Kuhn and Zwyns, 2014). Despite the caution against the normative view of the coincidence of blade technology and emergence of modern humans from the presence of the earlier blade industries in Middle Stone Age (MSA), Levant, and Europe (e.g., Conard, 1990; Bar-Yosef and Kuhn, 1999; McBreaty and Brooks, 2000), the use of blade technology dramatically increased as the Aurignacian technocomplex proliferated across and beyond Europe at the onset of the Upper Paleolithic (e.g., Straus, 1992, 2005; Blades, 1999; Kozlowski and Otte, 2000; Mellars, 2006; Teyssandier et al., 2010; Hoffecker, 2011), as did the Clovis technocomplex in North America (e.g., Collins and Lohse, 2004; Waters et al. 2011).

In East Asia, the emergence of blade technology is also significant for the consideration of the paleoanthropological question of how the modern human population expansion relates to the proliferation and innovation of new technologies, such as blade and microblade technologies. This pan-regional question cannot be simply addressed by a single set of regional data from Eurasia, although it can also be broken down to regional-scale questions. Is the blade technology of East Asia indeed technologically and functionally comparable to that of western Eurasia? In other words, does East Asian blade technology have unique and specific characteristics differentiating it from that of western Eurasia, or vice versa? Regardless of the origin of blade technology in East Asia, whether blade technology in East Asia was invented by local occupants (e.g., archaic *Homo sapiens*) independently (cf. Bar-Yosef and Kuhn, 1999), was transmitted by interaction with neighboring populations of modern humans (i.e., cultural diffusion), or appeared as the result of modern human dispersal (i.e., demic expansion) is a critical issue (cf. Mesoudi, 2011). We are still far from choosing among these possible scenarios, given the lack of synthetic data sets from human fossil, genetic, and archaeological records. Archaeology can determine the implications of the relationships between domains of human behavior and technology, not only of manufacturing technology but also use technology. Thus, we are concerned with the behavioral significance of Upper Paleolithic blade technology in the emergence and proliferation of blade technology in northeast Asia. This paper explores the function of the earliest blades in Hokkaido (northern Japan) through an integrated analysis of edge morphology and use-wear on blades and blade-based retouched tools. The materials are from the Last Glacial Maximum (LGM) lithic assemblage of Kawanishi C, consisting of abundant blades characterized by edge resharpening and retooling (Kitazawa et al., 1998; Nakazawa et al., 2010).

2. Upper Paleolithic blade technology in northeast Asia, the Japanese Archipelago, and Hokkaido

Unlike in Europe, where the appearance of blade technology is deeply relevant to modern human origins, the proliferation of blade technology into East Asia shows a complex picture. First, hominin populations prior to 40,000 years ago in East Asia were likely more complex than those of Europe because of the various populations presumably consisting of modern *Homo sapiens*, archaic *Homo sapiens*, *Homo neandertalensis* and *Denisovans* (Reich et al., 2010; Demeter et al., 2012; Bar-Yosef and Belfer-Cohen, 2013; Li et al., 2017). A genetic exchange between populations of *Homo neandertalensis* and *Denisovans* in Altai appears to suggest that genetic admixture of human populations were likely occurred in the vast regions of Eurasia (Prüfer et al., 2014; Smith et al., 2017). Second, since East Asia is geographically so vast and diverse (encompassing desert, high mountains, various forests, steppe, plains, basins), the ecological capacity to sustain regional population varied among regions (Dennell, 2009). As a result, the proliferation of blade technology in East Asia may not only simply achieved by modern human population dispersal but also created by technological transmission from modern humans to biologically distinctive local populations that survived in diverse and unique ecological niches in the region of East Asia, or by independent innovation among local human populations (Boëda et al., 2013; Li et al., 2014).

Despite the historical and ecological complexity of East Asia, northeastern Asia, consisting of modern northern China, Korea, Mongolia, eastern Siberia, and Japan, blade technology consistently appeared in the Upper Paleolithic archaeological record from the late Marine Isotope Stage (MIS) 3 to MIS 2 (ca. 40,000–11,000 BP) (e.g., Brantingham et al., 2001; Vasilevsky, 2006; Bar-Yosef and Wang, 2012; Gladyshev et al., 2012; Morisaki, 2012; Wang and Qu, 2014; Yi et al., 2014; Lee, 2016; Terry et al., 2016). For example, in China, blade technology probably appeared due to human southward migration to northwest China around 38,000–34,000 cal. BP at the Locality 1 and 2 in the Shuidonggou site (Li et al., 2013a, 2013b, but see Keates and Kuzmin, 2015), while the southern Chinese lithic industry is characterized by flake-dominant technology (Bae and Bae, 2012; Gao, 2013). Similar observations have also made in the Suyanggae site, Locality 6 (Cultural Layer 4) in Korea, date to 45,000 – 38,000 cal. BP (Woo et al., 2017). While the geographic differences in the emergence of blade technology have been acknowledged from earlier stages of Japanese Paleolithic studies (e.g., Ohyi, 1968; Yamahara, 2010), the geographic proliferation of blade technology at the beginning of Upper Paleolithic is pronounced on the Paleo-Honshu Island (e.g., Morisaki, 2012). It is still debatable whether blade technology appeared at the very beginning of the Japanese Upper Paleolithic at 38,000 cal. BP or slightly later around 36,000–36,500 cal. BP (e.g., Nakamura, 2012). Regardless of the period of its emergence, blades are at least appeared among most regional lithic complexes in Paleo-Honshu Island by the end of the early Upper Paleolithic, dated to 30,000 cal. BP (e.g., Yoshikawa, 2010; Morisaki, 2012). Only in Hokkaido, the northernmost island of Japan, then the southern margin of a peninsula called the Paleo-Sakhalin/Hokkaido/Kuril Peninsula, does blade technology appear later than southern part of Japan, dated to 25,000 cal. BP, at the LGM (Terasaki and Yamahara, 1999; Terasaki, 2006; Izuho et al., 2012). Thus, the emergence of blade technology in Upper Paleolithic Japan shows a substantial time lag between the earlier southern and later northern parts.

In Hokkaido, even though a number of excavations have been conducted, there have been less than a half dozen assemblages unquestionably attributable to the pre-LGM and early Upper Paleolithic sites (ca. 25,000–30,000 cal.BP) (Izuho et al., 2012; Naoe, 2014; Nakazawa and Yamada, 2015). Pre-LGM lithic industry in Hokkaido such as the Wakabanomori (Kitazawa et al., 2004) is predominated by a generalized flake technology with low variability in formal tools (e.g., minimally retouched flakes).

Similar to the pre-LGM, the majority of LGM lithic industry are characterized by flake tools made from a generalized flake technology. What makes the LGM technology unique is that there is a remarkable interassemblage variability (Nakazawa and Izuho, 2006). Besides the flake assemblages that are dominant (e.g., Shimaki, Marukoyama-L, Kashiwadai 1-FL), the blade assemblage (i.e., Kawanishi C) appeared almost contemporaneously with the earliest microblade technology represented by the Kashiwadai 1 (Nakazawa et al., 2005; Izuho et al., 2012) (Fig. 1).

3. Materials and methods

3.1. Materials

The blade tools are from the study site of Kawanishi C, which is located in the southern terraces on the southeastern Tokachi Plain, eastern Hokkaido (42°52'N, 143°11'E) (Koaze et al., 2003) at the edge of the Kamisatsunai I terrace of the Satsunai River at an altitude of 70 m a.s.l. (Fig. 1). A total of 6,856 m^2 were uncovered in three excavation campaigns conducted by the archaeologists affiliated with the Obihiro Board of Education (Kitazawa et al., 1998, 2000; Kitazawa, 2000). Three archaeological layers identified within the eolian units classified from top to bottom as the Jomon assemblage in the black humus soil above the Tarumae-D tephra (Ta-d, 7,000 cal yr BP), the microblade assemblage in an eolian loam between the Ta-d and En-a (17,000–15,000 cal yr BP) tephras, as well as the blade assemblage in an eolian loam between the En-a and Spfa-1 (45,000–40,000 cal yr BP) tephras 0.7m below the surface (Kitazawa et al., 1998; Izuho et al., 2014).

As summarized in Table 1, a total of four AMS dates of charcoals from the upper level of the Paleolithic occupation between the Ta-d and En-a tephras were reported:

16,920 ± 50 ^{14}C yr BP, 13,020 ± 40^{14}C yr BP, 12,900 ± 50 ^{14}C yr BP, and 12,290 ± 08 ^{14}C yr BP and they have been calibrated to 20,590 – 13,990 cal yr BP by CALIB 7.0 (Stuiver et al., 2016). For the lower level of Paleolithic occupation between En-a and Spfa-1, there are five AMS radiocarbon dates. Among these, four dates have been securely obtained from the hearths, reported as 21,780 ± 09 ^{14}C yr BP, 21,420 ± 190 ^{14}C yr BP 21,710 ± 07 ^{14}C yr BP, 21,480 ± 120 ^{14}C yr BP, and their calibrated dates are fallen in 26,190 – 25,330 cal yr BP. The integration of geoarchaeological and statistical analyses of the artifacts' spatial distribution in the lower occupation of Kawanishi C shows that post-depositional disturbance slightly displaced the artifacts vertically, suggesting that low-energy eolian sediments are enough to preserve potential data on site-scale human behavior (Nakazawa, 2007; Izuho et al., 2014).

The blade assemblage from the lower component has a total of 19,000 lithic specimens consisting of five distinctive but neighboring concentrations with and without hearths (Nakazawa, 2007; Nakazawa et al., 2010). The raw material mainly consists of obsidian followed by a small amount of hard shale, agate, andesite, and coarse-grained igneous cobbles and pebbles. The lithic assemblage consists of tools made from blades including sidescrapers, endscrapers, burins, perforators, and wedge-shaped tools, as well as flakes, a flake core, ocher nuggets and fragments, choppers, and hammerstones. Continuous lateral retouches, endscraper edge resharpening and burin faceting were commonly conducted (Kitazawa et al., 1998, 2000; Kitazawa, 2000; Yamahara, 2004; Nakazawa, 2007; Izuho et al., 2012).

3.2. Methods

Both unmodified and retouched edges are present on the blade tools, leading us to analyze 537 edges on the total of 224 specimens, mainly consisting of blades and blade tools from the lower level of Kawanishi C (hereafter called Kawanishi C-L). Some refitted blade tools consisting of tools and edge-resharpening flakes exhibit a morphological transformation of the entire tool shape. As continuous rejuvenation progressed, some tools exhibited morphological changes that cross over listed tools in the stone tool classificatory system (e.g., Frison, 1968; Cahen et al., 1979). A similar transformation of tools is also notable in Kawanishi C-L, such as from an endscraper or a sidescraper to a burin (Fig. 2). Given the variation in edge morphologies of the blade tools of Kawanishi C-L, we hypothesize that edge morphological variation was largely created either by tool use-lives or functional differences. To evaluate this hypothesis, we incorporate the analysis of edge reduction into edge morphological analysis, followed by lithic use-wear analysis to help clarify how functions and use-lives contributed to create edge morphological variation in blades.

3.2.1 Edges as an analytical unit

To integrate use-wear and edge morphologies, we choose our unit of analysis as the edge, here defined as the sharp or continuously retouched portion on a blank, because edges securely retain both evidence of use-wear and morphological attributes relevant to reductions throughout use. Data regarding use-wears and reductions have been independently created in part because of the difference in the scale of observations. When observations are made to determine the presence or absence and kinds of use-wears (e.g., types of polishes), all are converted into nominal or ordinal scales. By contrast, because reductions with respect to working edges are a continuum (Dibble, 1987) often assessed by a comparison of edge attributes (e.g., edge angles, retouch intensity) and original blank size (Dibble, 1987; Kuhn, 1990, 1995), the scale of measurements is at the ordinal, interval, and ratio scales.

3.2.2 Edge-morphological analysis

Edges of blades are inherently sharp and straight, while their morphology is subject to change by retouching. In the chipped stone typology, the edge morphology represented by the overall shape often associated with edge angles exhibits considerable variation (e.g., Semenov, 1964; Sackett, 1966; Dibble, 1984, 1987; Barton, 1990). While some non-metric variables such as retouch intensity on a single edge given by observation on an angle, have provided implications of the human use of chipped stone tools (e.g., Blades, 2001), the degree of retouch intensity may vary depending on the characteristics of the stone tools, such as blank types and lithic raw material availability (Kuhn, 1992). Here we solely evaluate the edge morphologies using two metric variables: (a) edge shape and (b) edge angle on each retouched and unretouched blade. On the blade tools from study assemblage of the Kawanishi C-L, edge resharpening is often observed by the refitted specimens and abundant use of edge-resharpening flakes (Nakazawa, 2007). This leads one to expect that the observed variation in edge morphology was the result of human decision-making on the use of edges and changes in blade use-lives (Morrow, 1995; Shott, 1995; Blades, 2001). To see whether edge use intensity was related to changes in edge function, we also assess the intensity of edge resharpening through the thickness of retouches relative to the thickness of the stone tool, known as the reduction index (Kuhn, 1990; Hiscock and Clarkson, 2008). While the measurement of reduction intensity has been elaborated both through the archaeological and experimental works (e.g., Hiscock and Clarkson, 2005; Eren et al., 2005; Marwick, 2008), because of its simplicity and convenience in dealing with numerous blades, we employ the reduction index proposed by Kuhn (1990). Edge shape is a nominal scale, simply defined as overall shape (e.g., Bordes, 1961), while edge angle and reduction index, each measured by a goniometer and caliper, are ratio scale.

3.2.3 Use-wear analysis

Microscopic use-related traces can be divided into five categories: microchipping (microflaking), striations (linear trace), rounding (abrasion), micropolishes (use-wear polish), and residues (e.g., Keeley, 1980; Vaughan, 1985; van Gijn, 1989; Sano, 2012). Present-day microscopic use-wear analysts agree that a functional analysis of prehistoric stone tools must be based on the results of a systematic framework of use-wear experiments. A large number of experiments have shown that the distribution, direction, and morphologies of microchipping, striation, rounding, and use-wear polish can indicate particular use motions and worked materials (e.g., Tringham et al., 1974; Keeley, 1980; Kajiwara and Akoshima, 1981; Odell, 1981; Moss, 1983; Vaughan, 1985; Midoshima, 1986, 1988; van Gijn, 1989; Sano, 2012; Iwase, 2015). Of these, the low-power approach employs low magnification up to 100× and is especially focused on the analysis of microchipping to determine the relative hardness of worked materials and their motions of usage (Tringham et al., 1974; Odell & Odell-Vereecken, 1980; Odell, 1981). By contrast, the high-power approach is characterized by the analysis of micropolishes that can be observed at high magnification over 100×, and it can be used to indicate relationships between polish morphologies and specific worked materials. It is now accepted that the association is moderate, with some overlap rather than a one-to-one correlation (e.g., Keeley, 1980; Kajiwara & Akoshima, 1981; Moss, 1983;

Vaughan, 1985; Midoshima, 1986, 1988; van Gijn, 1989; Sano, 2012). Since the integration of two methods assures validity in identification of tool function (Vaughan, 1985), current microwear studies generally employ both approaches to precisely interpret the functions of stone tools.

Thus, we employ both the low-power and high-power approaches. To observe the microscopic traces of utilization on lithic surfaces, a metallurgical microscope (Olympus BX-FMS) was used at magnifications ranging from 50× to 500×, and a digital camera (Olympus DP-21) was used for recording. In addition, the present study follows Kajiwara and Akoshima (1981), Midoshima (1986), and Iwase (2015) as references for the identification and classification of use-wear polishes on obsidian and hard-shale artifacts. Similar to the flint experiments, various contact materials, including grass, wood, antler, bone, ivory, dry hide, flesh hide, flesh, shell, and stone can form distinctive polished appearances, which can also partially overlap with each other, on obsidian and hard shale.

4. Results

The examined assemblage of Kawanishi C-L is characterized by the abundant use of blades. To see the extent to which the blades are included in the examined specimens, width-to-length ratios in the complete blades are designed in the stem-and-leaf diagram (Fig. 3). The length to width ratios of the majority of the complete specimens show greater than two, suggesting that the observed abundance of blades is supported. On the other hand, the mode of ratios falls in the range of 1 – 2. This is partially because blade tools, notably endscrapers were often reduced along the longest axis. Indeed, a large number of processing tools including endscrapers (n = 60), sidescrapers (n = 82), and burins (n = 39) are associated in the Kawanishi C-L assemblage (Table 2).

4.1. An analysis of edge morphology

Since edge resharpening sometimes altered the edge morphologies, which in turn altered tool classes, such as from scrapers to burins (Fig. 2), the functions of edges rather than the functions of tools are primarily scrutinized. A comparison of the distribution of edge angles among the morphological classes shows that the burin facet shows the greatest angle (mean = 88°) and the other edge classes (e.g., straight, convex, concave, denticulate) exhibit acute angles falling in the range of 40 – 60° (Fig. 4). While both retouched and unretouched edges are categorized, excluding the angles of burin facets, there are no significant differences in edge angles among the morphological categories (one-way ANOVA: $F = 0.864$, $df = 7$, $p = 0.535$). Comparing the edge angles between the retouched and unretouched edges in similar edge morphology (i.e., straight, concave, convex), no significant differences in edge angles are also found ($t_{straight} = 0.6986$, $df = 296$, $p = 0.4859$; $t_{concave} = 1.4604$, $df = 27$, $p = 01557$; $t_{convex} = 1.6219$, $df = 168$, $p = 0.1067$). The results of edge morphological analysis suggest that edges on blades and blade tools were not designed for performing specific tasks. In other words, it is likely that the edges were used rather randomly in completing the required tasks, or the edges were basically provided for multiple tasks not predetermined by the edge morphological variation.

4.2. Relationships between patterns of edge morphologies and use-wear

Table 3-a summarizes the frequency of identified motions based on use-wear analysis among the categories of edge morphologies. The patterns of use-wear detected

are displayed in Fig. 5. Use-wear identified in more than five occurrences is only found in straight and convex edges. Straight and convex edges retain various kinds of use-wear with higher frequencies than other edge morphological categories, which may be affected by their large sample sizes. By the same token, higher frequencies in cut or saw motions on straight and convex edges may be because blades and blade tools were mainly used for cutting or sawing. Because of the small number of associations for most edge categories, we lumped counts of concave, denticulate, and burin facets into the single category “others” and eliminated counts of unretouched edges (Table 3-b). The associations of motions of edges among these three classes of retouched edge-morphologies show random distribution at the 5 % level ($\chi^2 = 17.3994$, df = 12, p = 0.1352). This result suggests that cutting/sawing is the major motion for the edges regardless of their morphologies. In other words, edge morphological variability is independent of actual edge functions. This also indicates that functional estimates of the morphological variation in stone tool edges are not necessarily equivalent to typological classifications based on edge morphology, locations of edges, and edge retouches (see Sonneville-Bordes and Perrot, 1954). A comparable situation is found in case studies of Middle Paleolithic scraper morphology, where edge morphologies were subject to being transformed by edge resharpening through uses (Dibble, 1987, 1995).

Given the prospect that edge resharpening could create morphological variation in blade edges, we examine whether and the extent to which edge functions changed as edge resharpening progressed. Reduction indices compared among the four major retouched edges show a significant difference (one-way ANOVA: F = 4.952, df = 3, p = 0.002), and it is likely that mean reduction indices are higher in convex and denticulate edges than straight and concave ones (Table 4). Because the results of the Kolmogorov-

Smirnov test show that the distributions of reduction indices for all four edge categories are normal at the 5 % level (Table 4), we perform Tukey's multiple comparison to see which edge classes are significantly different. We find that a difference in reduction indices between convex and straight edges (Tukey's multiple comparison: $p = 0.0019$) makes the difference among the four edge classes.

The difference in the degree of edge resharpening between convex and straight edges may suggest the functions of the edges changed during their use. In use-wear analysis, there are nine occurrences in scraping motion on the convex edge, while there are only two occurrences of scraping on the straight edge (see Table 3-a). This leads to two alternative interpretations. The first is that convex edges served more for scraping tasks, as the edges were resharpened. The second is that the edges initially used for scraping were changed to serve for cutting or sawing tasks as edges were resharpened. To distinguish between these two processes of functional change, we further scrutinize the relationship between the intensity of edge reduction and estimated edge function.

Table 5 displays the edge reduction indices among the estimated use motions by use-wear analysis. Among the four classes of edge morphology, only straight and convex edges have reduction indices for various motions, including cutting /sawing, whittling, and scraping. Cutting/sawing is the most pronounced motion of use on the Kawanishi C-L blade edges, and their reduction indices are moderate, in the range of 0.5–0.68 on average. By contrast, scraping has high reduction indices, 0.7–0.89. The reduction indices of whittling show a disparate pattern: straight edge has low (0.21) and convex edge is moderate (0.67). Variation in reduction indices among three kinds of edge motions (i.e., cutting/sawing, whittling, and scraping) suggests that straight and convex edges experienced various trajectories of uses. The straight edge initially functioned for whittling, followed by cutting/sawing and scraping. In convex edge, edge functioned as cut/saw with minimum retouches, gradually followed by whittling and scraping. Straight and convex edges have higher reductive values for scraping, while scraping is more associated with convex edges than straight edges (Table 3-a). These observations may suggest differences in tool use-lives and use-trajectories between straight and convex edges. Although the flat flake problem is potentially present in assessing the reduction indices (Hiscock and Clarkson, 2005), it is accepted that unretouched blade edges generally have acute angles that later get thicker toward increasing reduction indices as retouches accumulate during use (Hiscock and Clarkson, 2008). Thus, it is expected that reduction indices reflect general reductive processes during the course of edge resharpening. An earlier stage of use would result in relatively lower to moderate reduction indices, suggesting that cutting/sawing and whittling were likely performed at an earlier stage in tool use-lives. However, a late stage of use would result in higher reductive indices, suggesting that scraping was used in the latter stage of tool use-lives. Because cutting/sawing shows the most frequent occurrence regardless of edge morphological classes (Table 3-b), blade edges principally served for cutting or sawing activities, regardless of the variation in edge morphologies.

4.3. An assessment of functional change by use-wear analysis

The question becomes what makes a functional edge from the earlier to later stages of use. While we cannot specify the behavioral changes associated with functional changes, such as functional shifts in task processes, or sequential changes in multiple tasks, worked materials from use-wear patterns may provide evidence of whether edge functional changes occurred through any directional (organizational) changes in tool functions.

A systematic observation of the second author on the 537 retouched and unretouched edges shows that there are 144 edges with use-wear (27%). Approximately half of the edges with use-wear (73/144 edges, 51%) are considered to have worked materials (Table 6). Among others, dry hide (DH) is the most frequently identified worked material (n = 21), followed by soft material (SM, a generic category that cannot be assigned a specific type of worked material), and flesh hide and flesh (FH, F). A large number of cutting/sawing blades worked DH (n = 15) and some amount of FH, F, and SM. This variation in worked materials shows that edges used for cutting/sawing were more often used for SM (e.g., flesh, hide) than hard materials (e.g., bone, antler, wood). Similar to cutting/sawing edges, edges used for whittling and scraping were used for soft material (i.e., DH, FH, F, and SM) and not for hard materials. However, functional changes in worked materials are not observed. It is only suggested that the edges of blades generally served for processing SM such as dry/flesh hide and flesh meat, regardless of the use motions. To further investigate potential functional changes of edges, the modifications of use-wear on edges are scrutinized. Among a total of 144 edges, the majority of used edges are either partially removed by new retouches or overlapped with other use-wears (Fig. 6). As summarized in Table 7, 42% (61 out of 144) edges have use-wear that is partially removed and 15% (22 out of 144) edges retain multiple overlapping use-wears. Use-wear was removed when the used edges were resharpened after performing certain activities, while intact use-wear was not likely subjected to resharpening. Edges that worked DH and SM are mostly intact, while those that worked flesh hide and flesh (FH, F) have partially wear removal rather than being intact. The difference in proportions between intact and partially wear-removed edges suggests that edges served for dry hiding were mostly discarded after they were used without receiving much resharpening. In other words, tools used on DH may have been used intensively and/or used for longer duration than those used for FH and F. However, RI for both groups have moderate mean values (> 0.5) and no significant difference in reduction indices for edges that worked with FH and F and those used for DH is found ($t = 1.3515$, $df = 25$, $p = 0.1887$). These results may suggest that edge use intensity was *not* different with respect to worked materials. By contrast, the working motions of edges provide clear explanation of the history of edge use. Table 8 summarizes the frequencies of motions identified among the use-wear patterns intact, partially removed, and overlapped. Evidence of wear removal (i.e., partially removed) is more pronounced in cutting/sawing than whittling and scraping. In other words, use-wear that indicates whittling and scraping is more intact than that of cutting/sawing. Cutting/sawing and whittling are a more frequent use-war pattern. As we have seen, a large number of edges served for cutting/sawing, and the wear on a majority of them was partially removed. However, because no overlapping use-wear has been found on edges serving for cutting/sawing, partially removed edges after cutting/sawing would not experience such intense use as to leave use-wears. Some association of cutting/sawing with whittling ($n = 16$, Table 8) suggests that a portion of edges used for cut/saw was likely converted into whittling, or vice versa. No significant difference in reduction indices between cutting/sawing and whittling ($t = 0.9451$, $df = 91$, $p = 0.3471$) supports this observation.

5. Discussion and conclusions

An integrated analysis of edge morphology and use-wear on a large number of blade tools of Kawanishi C-L has shown that the edges of blades were mostly used for cutting or sawing. Straight and convex edges were independently prepared in blade tools and they served for cutting and/or sawing, such as processing DH, flesh hide, and flesh. Straight edges were flexible enough to convert them into convex edges as edges were resharpened (Fig. 7). While some portion of the edges were changed to serve for scraping, both straight and convex edges are continuously used for cutting and/or sawing. Since the present use-wear analysis suggests that cutting and sawing were used on generic materials of skin and meat, blades of the Kawanishi C-L generally served for a narrow range of tasks, probably skin and meat stripping, rather than wide-ranging or complex activities, such as manufacturing osseous projectiles. In performing cutting and sawing, blade edges surely provide ample lengths of working edges. Although SM can be cut by generic flake edges, formalized tools such as blade tools would be appropriate for processing large numbers of medium-to-large bodied prey (e.g., Tomka, 2001). A blade edge can serve both for longitudinal and transverse motion. Moreover, a straight blade edge would be particularly effective for continuous strokes of movement to cut material into sizable pieces. Conversely, when scraping things (e.g., removing fat in skin hiding), sharp blade edges need to be retouched to make certain angles less sharp (e.g., Takase, 2010; Sano, 2012). In the blade technology of Kawanishi C-L, this kind of a functional change from cutting/sawing to scraping was probably achieved by edge resharpening. Blades of the Kawanishi C-L, a wedge-shaped microblade core technology in central Hokkaido (Fukui and Koshida, 1999; Nakazawa et al, 2005) are wider than the blades of the microblade complexes (Nakazawa and Izuho, 2006). A relatively larger initial blade blank could have provided ample mass for the Kawanishi C-L blades to have flexible reduction, not only of longitudinal directions along the longest axis but also lateral directions perpendicular or oblique to the longest axis.

Intensive resharpening indicated by the reduction index also suggests that the LGM blade technology of the Kawanishi C-L was intentionally designed to expect intensive use of edges with increasing frequency in edge reductions, without supplying new blades. This further implies that LGM blade technology in Kawanishi C-L was employed to satisfy two goals for foragers, both to conduct intensive processing activities at the site and to maintain highly mobile lifeways. The latter goal of a highly mobile lifeway became achievable when lithic material availability was high. Although obsidian pebbles are locally available along the lower Tokachi River near the site and larger cobbles that are large enough to make blades are distributed along the upper tributaries of Tokachi River (Tokachi-Mitsumata) (Kitazawa, 1999), only blades and blade tools were transported to the site of Kawanishi C (Kitazawa et al., 1998). In addition, relative to the mountainous landscape (e.g., Cantabria, northern Spain [Straus, 1986, 1991]), the flat topography of the extensive Tokachi Plain (3600 km^3) where Kawanishi C is located would require more searching time (*sensu* Stephens and Krebs, 1986) to procure resources in the cool temperate and boreal forest (dominated by *Picea*) termed a "pan-mixed forest" (e.g., Igarashi, 1994: 336, 1996). Visiting primary obsidian outcrops to manufacture blades was less prioritized than the first goal. That is, foragers could have maximized their foraging time by completing intensive processing activity at the site. Given this, it is inferred that the LGM foragers of Hokkaido using blade technology targeted critical faunal resources that may have been sporadically clumped on the landscape even in a low-productive LGM resource environment.

Unlike was the case with the LGM Solutrean technocomplex in Western Europe (e.g., Straus, 2002, 2016), comparable to Kawanishi C, lithic weapons such as projectile points, bladelets, and microblades are absent from Kawanishi C and other generalized flake assemblages in the LGM Hokkaido (Nakazawa and Izuho, 2006; Izuho et al., 2012). Given the later and abrupt emergence of blade technology in Hokkaido compared with neighboring regions (e.g., Paleo-Honshu), it would not be independently innovated among the LGM foragers in Hokkaido, unlike the situation in the other context such as in MSA in South Africa (e.g., McBrearty and Brooks, 2000). Rather, LGM blade technology in Hokkaido represented by the Kawanishi C-L could be either adopted by cultural diffusion to LGM foragers who had basically employed generalized flake technology, or brought by demic diffusion into the LGM hunter-gatherer society. To disentangle the cultural diffusion and demic diffusion, one has to employ genetic data sets, like the case in adoption of agriculture at the transition of Mesolithic and Neolithic in central Europe (Bramanti et al., 2009). However, given the lack of Paleolithic genetic data sets in the study region of Hokkaido, to distinguish cultural diffusion and demic diffusion in the proliferation of blade technology during the Upper Paleolithic, a clarification of LGM interassemblage variability will be the most viable way. Regardless of the mode of technological transmission, the results of our functional study of blades imply that blade technology was emerged through recognition of its functional and behavioral advantages over flake technology in the given LGM environment. A further comparative analysis of the edges of stone tools in the other LGM assemblages (i.e., LGM flake assemblages in central and eastern Hokkaido and the microblade assemblage from Kashiwadai 1 in central Hokkaido) may help clarify the contextual reason why the blade technology in Hokkaido was emerged during the LGM.

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Captions of figures

Fig. 1. Locations of Kawanishi C site in eastern Hokkaido.

Fig. 2. Refitted chipped stone tools from the Kawanishi C-L, showing morphological changes by edge resharpenings. Gray-shaded stone tools in the refitted specimens were subject to be modified. 1: A distal portion of blade was modified into sidescraper, followed by its medial breakage and the right edge of distal part of the sidescraper was burinated, 2: A sidescraper was broken into several pieces and reused for burins. The medial portion of sidescraper was split into half and both pieces were burinated. Illustrations are adopted from Kitazawa et al. (1998).

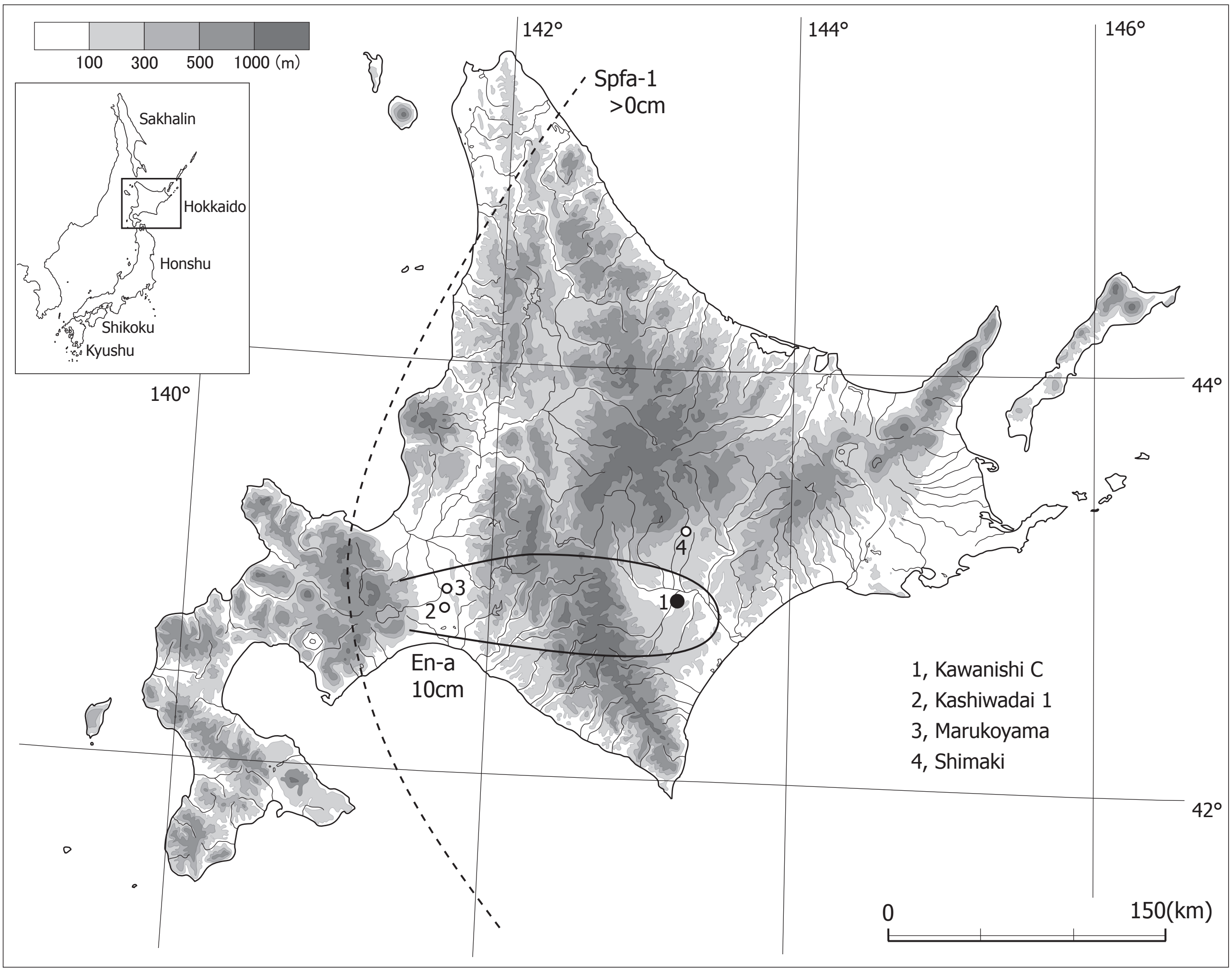
Fig. 3. Stem-and-leaf diagram of width-to-length ratios of complete chipped stone tools from the Kawanishi C- L (N = 186). Those showing ratios greater than 2 are classified into blades.

Fig. 4. Distributions of edge angles by categories of edge morphologies (retouches vs. unretouched).

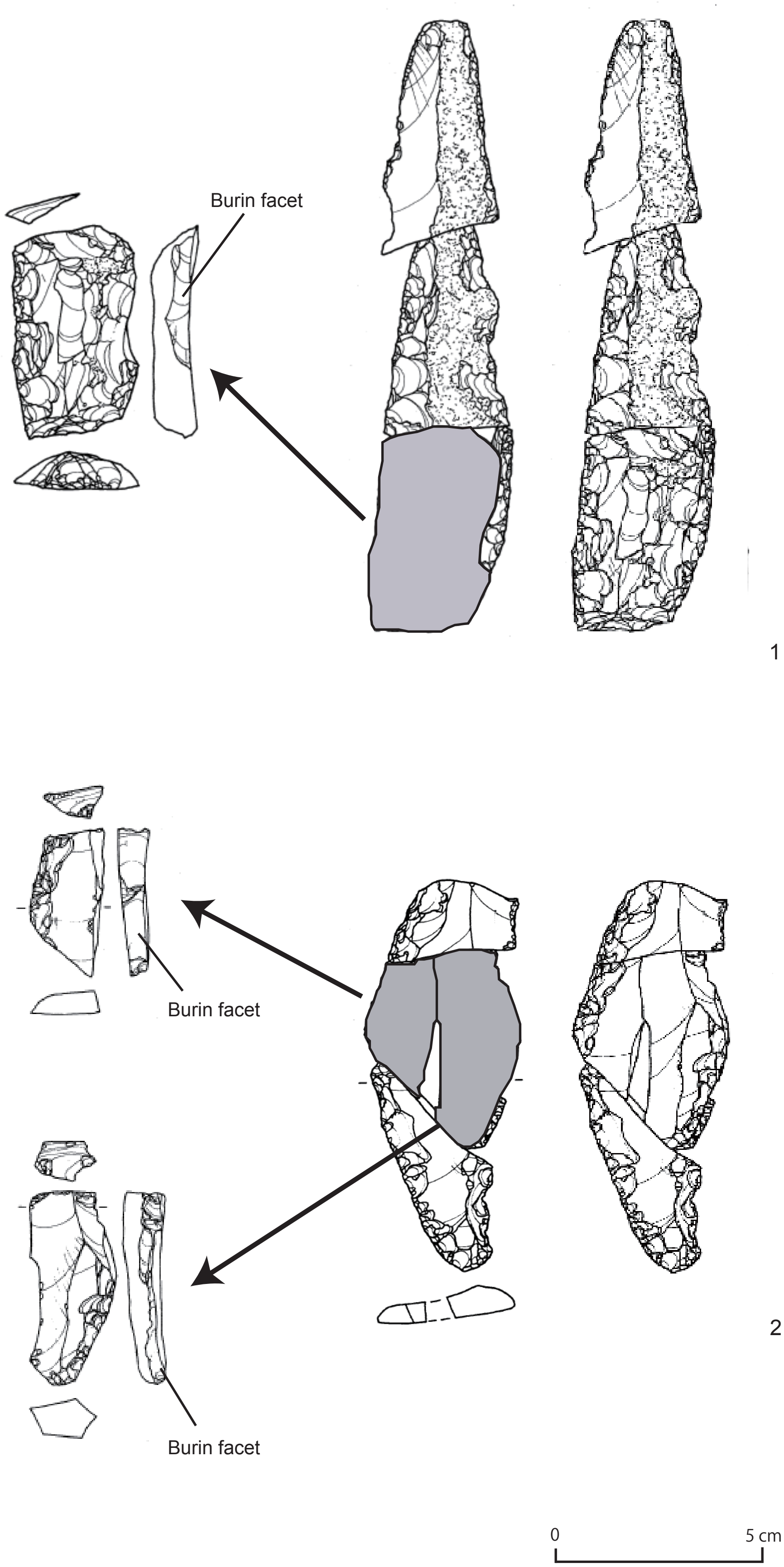
Fig. 5. Use-wear patterns observed on the edges of stone tools of Kawanishi C-L. 1, 2 and 4, sidescrapers; 3 and 5, endscrapers; 6, burin-endscraper. Photo a shows polishes from dry hide cutting or sawing accompanied with numerous parallel striations. Photos b and c show polishes from dry hide scraping and whittling accompanied with perpendicular striations. Photos d and e show edges with distinctive abrasion from dry hide scraping. Photo f shows polishes from processing antler, bone, or ivory accompanied with numerous perpendicular striations. Illustrations are adopted from Kitazawa et al. (1998).

Fig. 6. Evidence of edge modifications in the use-wears on the blade tools of Kawanishi C-L. 1 and 2: sidescrapers. Photo a: parallel striations are partially removed by following lateral retouches, indicating the resharpening of worn edge. Photo b: parallel and perpendicular striations overlap each other, suggesting the edge were utilized for multiple purposes (i.e., sawing and whittling activities). Illustrations are adopted from Kitazawa et al. (1998).

Fig. 7. A schematic illustration showing the processes that created edge morphological variation and functional variability in the use-lives of blade tools from the Kawanishi C-L.



100 300 500 1000 (m)
Sakhalin
Hokkaido
Honshu
Shikoku
Kyushu
142°
144°
146°
140°
44°
42°
Spfa-1
>0cm
En-a
10cm
1
2
3
4
1, Kawanishi C
2, Kashiwadai 1
3, Marukoyama
4, Shimaki
0
150(km)


Burin facet
1
Burin facet
Burin facet
2
0
5 cm

0 | 5558999

1 | 0011112222233344444444444444455555555555555666666677777777888999999999

2 | 0000011111111111112222222222222222222222233333333333333333444669999

3 | 00000111222222333368

4 | 0000145

5 | 79

6 | 4444488

7 | 444

8 |

9 |

10 |

11 |

12 | 2

Blade (length/width > 2.0)

Fig. 3.

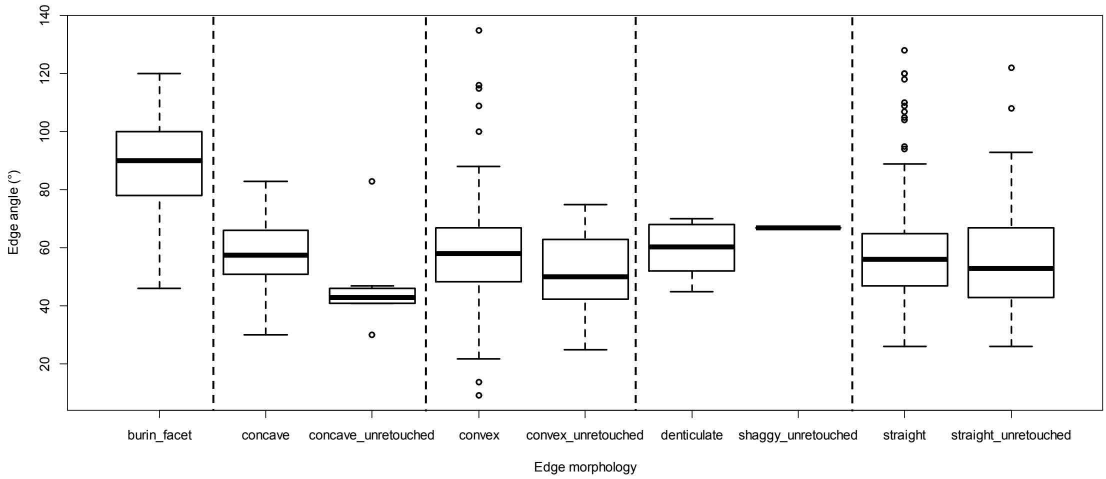
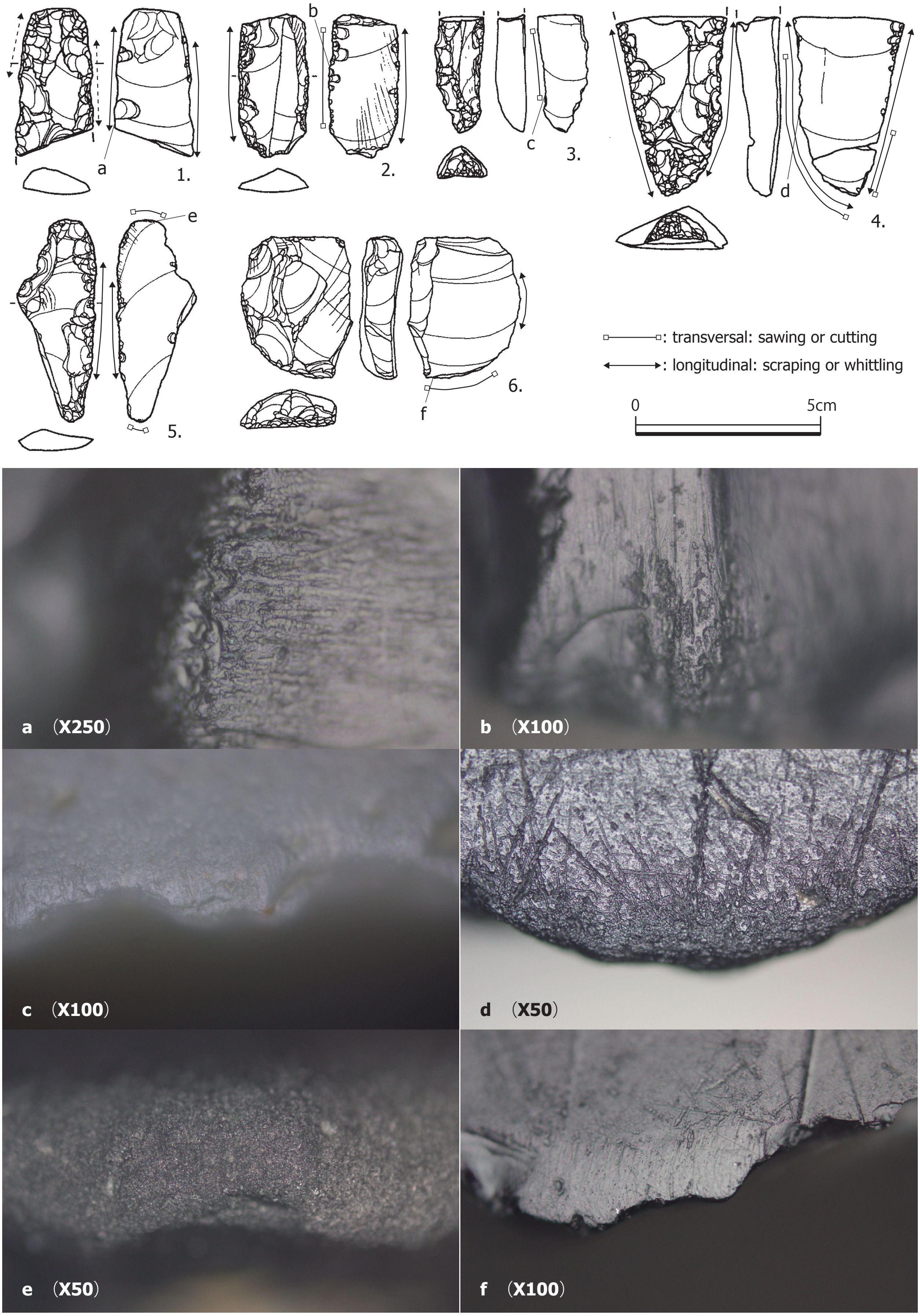
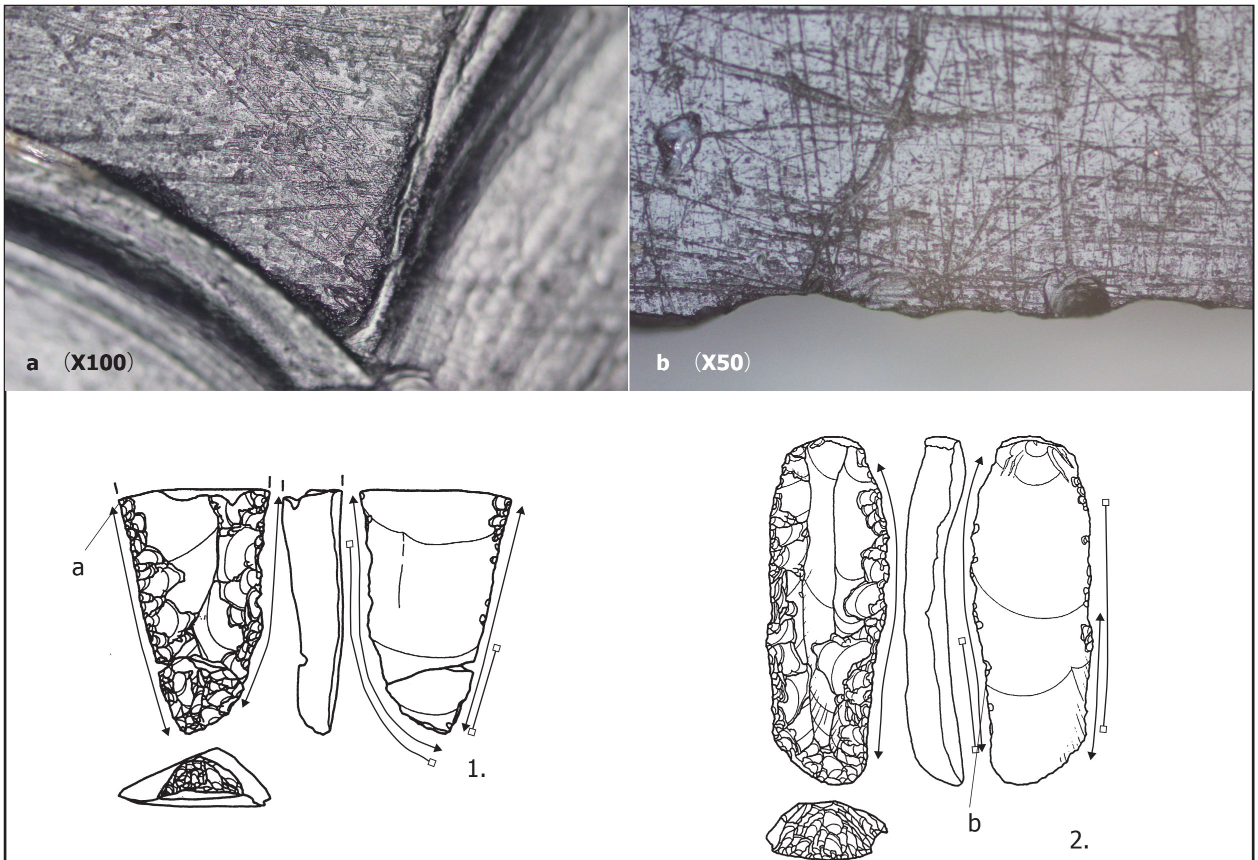

Edge angle (°)
140
120
100
80
60
40
20
burin_facet
concave
concave_unretouched
convex
convex_unretouched
denticulate
shaggy_unretouched
straight
straight_unretouched
Edge morphology

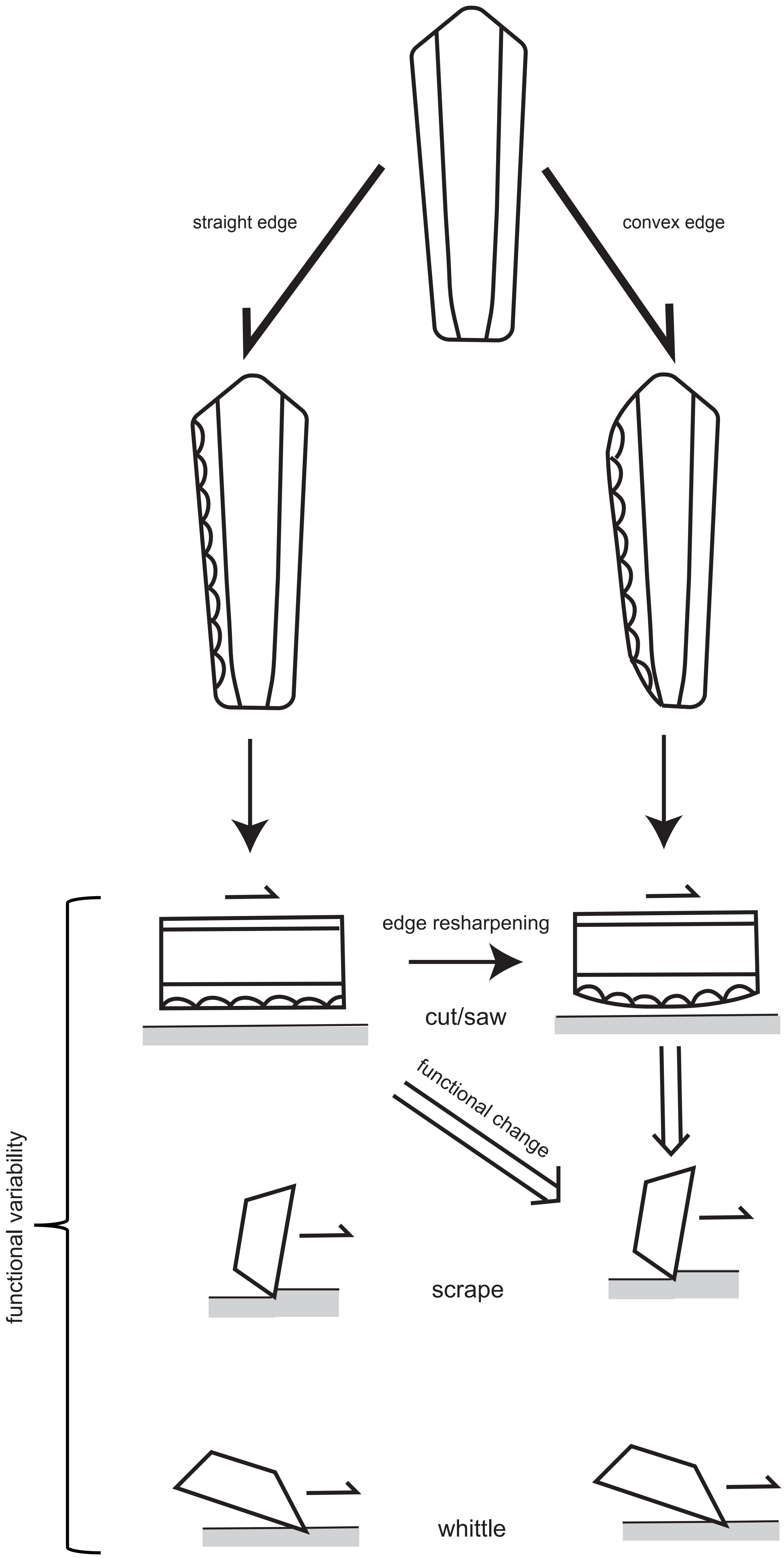
Fig. 4



a
1.
b
2.
c
3.
d
4.
e
5.
f
6.
: transversal: sawing or cutting
: longitudinal: scraping or whittling
0
5cm
a (X250)
b (X100)
c (X100)
d (X50)
e (X50)
f (X100)



a (X100)
b (X50)
a
1.
b
2.



straight edge
convex edge
edge resharpening
cut/saw
functional change
scrape
whittle
functional variability

Lab No.	Cultural Layer	Tephrostratigraphy	Sampling Provenance	Conventional	cal BP (2σ)*	δ13C	Reference
Beta-107731	Layer VI	Between En-a and Spfa-1	Burned sediment in Artifact Cluster 1	21,780±90	26,190-25,830	-26.3	Obihiro Board of Education (1998)
Beta-106506	Layer VI	Between En-a and Spfa-1	Burned sediment in Artifact Cluster 5	21,420±190	26,050-25,330	-26.1	Obihiro Board of Education (1998)
NutA2-7677	Layer VI	Between En-a and Spfa-1	Burned sediment from Artifact Cluster 1	21,710±70	26,100-25,810	-23.8	Obihiro Board of Education (1998)
Beta-126151	Layer IV	Between Ta-d and En-a	From artifact concetration 17	16,920±50	20,590-20,200	-26.7	Nakamura (2005)
Beta-126150	Layer IV	Between Ta-d and En-a	From artifact concetration 17	13,020±40	15,780-15,350	-28.1	Obihiro Board of Education (2000)
Beta-127399	Layer IV	Between Ta-d and En-a	From artifact concetration 16	12,900±50	15,630-15,200	-26.2	Obihiro Board of Education (2000)
TKa-15535	Layer IVb	Between Ta-d and En-a	-	12,290±80	14,710-13,990	-26.0	Izuho et al. (2014)
TKa-15536	Layer VII	Between En-a and Spfa-1	-	27,840±200	32,210-31,190	-24.6	Izuho et al. (2014)
TKa-15537	Layer VI	Between En-a and Spfa-1	Burned sediment in Artifact Cluster 1	21,480±120	26,000-25,560	-25.6	Izuho et al. (2014)

*Calibrated by Calib 7.1

Table 1 Radiocarbon dates obtained from the Kawanishi C site. All samples are charcoals and dated by AMS.

Stone artifact classes	Artifact clusters*					Total
	1	2	3	4	5	
Retouched blade	12	3	27	9	4	55
Sidescraper	11	7	45	7	12	82
Endscraper	16	9	20	8	13	66
Burin-endscraper	0	0	1	0	1	2
Burin	6	3	15	3	12	39
Burin spall	15	1	30	5	9	60
Drill	2	0	0	4	1	7
Wedge-shaped tool	1	0	0	0	0	1
Pebble tool	2	12	20	9	2	45
Hammer stone	0	0	0	0	1	1
Anvil stone	1	0	12	0	3	16
Pebble	12	89	109	50	24	284
Ocher	65	5	182	265	41	558
Flake	5023	1320	6280	3844	1643	18110
Core	0	1	0	0	0	1
Total	5166	1450	6741	4204	1766	19327

Table 2. Frequencies of stone arifact classes in the Kawanish C-L. * Division of artifact clusters is based on the visual assessment presented in Nakazawa et al. (2010).

	Edge morphology									
	retouched					unretouched				
Motion	straight	convex	concave	denticulate	burin facet	straight	convex	concave	shaggy	Total
scraping	2 (3)	**9 (17)**	0	0	1 (20)	0	0	0	0	12 (8)
whittling	**7 (9)**	4 (7.5)	0	0	3 (60)	2 (50)	0	0	0	16 (11)
scraping/whittling	2 (3)	3 (5.5)	0	0	0	0	0	0	0	5 (4)
scraping and cut/scraping	0	1 (2)	0	0	0	0	0	0	0	1 (1)
cut/saw	**52 (68)**	**29 (55)**	3 (100)	2 (100)	0	1 (25)	1 (100)	0	0	88 (61)
cut/saw, whittling	**10 (13)**	4 (7.5)	0	0	1 (20)	1 (25)	0	0	0	16 (11)
cut/saw, scraping/whittling	3 (4)	3 (5.5)	0	0	0	0	0	0	0	6 (4)
Total	76	53	3	2	5	4	1	0	0	144

Table 3-a. The frequencies of edge motions estimated by use-wear analysis in comparison with edge morphologies.

Note
/ means the edge was used either left or right motiions. For example, scraping/whittling means the edge was used either scraping or whittling.
Shaded cells represent edges more than five occurrences.
Numbers in parenthesis are percentages.

	Retouched edge morphology			
Motion	straight	convex	others	Total
scraping	2 (3)	9 (17)	1 (10)	12 (8.6)
whittling	7 (9)	4 (7.5)	3 (30)	14 (10.1)
scraping/whittling	2 (3)	3 (5.7)	0	5 (3.6)
scraping and cut/scraping	0 (0)	1 (1.9)	0	1 (0.7)
cut/saw	52 (68)	29 (54.7)	5 (50)	86 (61.9)
cut/saw, whittling	10 (13)	4 (7.5)	1 (10)	15 (10.8)
cut/saw, scraping/whittling	3 (4)	3 (5.7)	0	6 (10.8)
Total	76	53	10	139

Table 3-b. The frequencies of edge motions inferred from use-wear analysis in comparison with retouched edge morphologies.

Note

Numbers in parenthesis are percentages.

		Reduction index		Kolmogorov-Smirnov test	
Edge morphology	N	mean*	s.d.	D	p
straight	154	0.39	0.34	0.0911	0.1555
convex	130	0.59	0.32	0.1058	0.1088
concave	18	0.42	0.37	0.2035	0.4452
denticulate	7	0.59	0.34	0.217	0.8332

Table 4. Reduction indices compared among the major retouched edges. * Distributions of means are significantly different among the four classes of edge morphology (ANOVA: $F = 4.952$, $df = 3$, $p = 0.002$).

Edge morphology	Motion		
	cut/saw	whittling	scraping
straight	0.5	0.21	0.7
	0.28	0.12	0.3
convex	0.55	0.67	0.89
	0.29	0.13	0.14
concave	0.68	-	-
	0.18	-	-
denticulate	0.53	-	-
	0	-	-

Table. 5 Means and standard deviations of reduction indices in categories of edge morphology and estimated motions of use. In each cell, the upper value shows the mean and the lower one represents standard deviation.

	Motion							
Worked material	c/s	w	sc	c/s, w	c/s, sc/w	sc/w	sc, c/s	Total
DH	15	2	4	0	0	0	0	21
FH, F	12	1	3	0	0	0	0	16
FH, F, DH*	0	0	0	1	1	0	0	2
FH, F, unknown	0	0	0	2	0	0	0	2
B/A	3	0	0	0	0	0	0	3
B/A?, W?, unknown	0	0	0	0	0	0	1	1
DH, DH	0	0	0	0	1	0	0	1
DH, unknown	0	0	0	2	0	0	0	2
HM	4	0	0	0	0	0	0	4
MM	2	2	0	0	0	1	0	5
MM, MM	0	0	0	1	0	0	0	1
SM	6	4	2	0	0	1	0	13
SM, SM	0	0	0	1	0	0	0	1
unknown, SM	0	0	0	1	0	0	0	1
unknown	46	7	3	0	0	3	0	59
unknown, unknown	0	0	0	8	4	0	0	12
Total	88	16	12	16	6	5	1	144

Abbreviation	Worked material
B/A	bone and/or antler
W	Wood
DH	dry hide
FH	flesh hide
F	flesh
HM	hard material
MM	medium hard material
SM	soft material
w	whittling

Abbreviation	Motion
c/s	cut or saw
w	whittling
sc	scraping
sc/w	scraping and/or whittling

Table 6. The frequencies in estimated worked materials among different functions.

* Multiple worked materials represent that a single edge has more than one type of use-wear.

	intact	partially removed	overlapped	Total
DH	16	5	0	21
FH, F	8	8	0	16
FH, F, DH	0	1	1	2
FH, F, unknown	0	0	2	2
B/A	1	2	0	3
B/A?, W?, unknown	0	0	1	1
DH, DH	0	0	1	1
DH, unknown	0	0	2	2
HM	2	2	0	4
MM	5	0	0	5
MM, MM	0	0	1	1
SM	11	2	0	13
SM, SM	0	0	1	1
unknown, SM	0	0	1	1
unknown	18	41	0	59
unknown, unknown	0	0	12	12
Total	61	61	22	144

Table 7. The frequencies of overlapped use-ware among estimated worked materials. Abbreviations are same with Table 6.

	intact	partially removed	overlapped	Total
c/s	32	56	0	88
w	12	4	0	16
sc	12	0	0	12
c/s, w	0	0	16	16
c/s, sc/w	0	1	5	6
sc/w	5	0	0	5
sc, c/s	0	0	1	1
Total	61	61	22	144

Table 8 Frequencies of patterns in use-wears by motions

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We the authors declare that this manuscript is original, has not been published before and is not currently being considered for publication elsewhere.
We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us.
We understand that the Corresponding Author is the sole contact for the Editorial process. He/She is responsible for communicating with the other authors about progress, submissions of revisions and final approval of proofs.

Sincerely,

On behalf of all authors

Yuichi Nakazawa