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Late-Glacial bifacial microblade core technologies in Hokkaido: an implication of human adaptation along the northern Pacific Rim

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Abstract

The wedge-shaped microblade core technology found along the northern Pacific Rim has been regarded as a trait of hunter-gatherer adaptation during the Late Glacial and initial Holocene. Having recognized variable microblade core reduction methods among the technocomplexes in Hokkaido, by employing an optimization model in lithic technology, the present paper addresses the question of what role bifacial microblade core technologies played in foraging, through a comparative analysis of utility, cost of transportation, and failure rates between the larger (“*Sakkotsu*”) and smaller (“*Oshorokko*”) bifacial microblade core technologies in the Late Glacial Hokkaido. Results suggest that as opposed to the larger bifacial microblade core technology, the smaller bifacial microblade core technology was more effective for exploring unpredictable environment across the northern Pacific Rim.

Keywords: microblade core technology; core size; risk; cost; utility; Hokkaido

1. Introduction

Owing to its unique and standardized techno-morphological traits, wedge-shaped microblade cores have been regarded as the material signature of human adaptation across the northern latitudes ($> 40^{\circ}\text{N}$), namely regions of the northern Pacific Rim consisting of northeastern Asia (i.e., Siberia, Mongolia, China, Korea, and Japan) and northern North America (i.e., Alaska and Pacific coast of Canada) during the Late Glacial and initial Holocene (e.g., Nelson, 1938; Müller-Beck, 1967; Smith, 1974; Yi and Clark, 1985; Cheng and Wang, 1989; Ackerman, 1992; West, 1996; Kuzmin and Orlova, 1998; Dixon, 1999; Goebel, 1999; Hamilton and Goebel, 1999; Bever, 2001; Yesner and Pearson, 2002; Hoffecker and Elias, 2007; Doelman, 2008; Goebel et al., 2008; Kajiwar, 2008; Wang et al., 2009; Bae, 2010; Graf, 2010; Buvit and Terry, 2011; Elston et al., 2011; Bae and Bae, 2012; Lee, 2012; Kato, 2014; Nian et al., 2014; Wang and Qu, 2014; Wang et al., 2015; Yi et al., 2014, 2015). A battery of analytical studies on microblade assemblages particularly from the Japanese late Upper Paleolithic sites have revealed that wedge-shaped microblade cores are shaped by a series of standardized reductive processes, suggesting that Late Glacial hunter-gatherers designed complex core technology to produce highly standardized microblades (e.g., Yoshizaki, 1961; Morlan, 1967; Kobayashi, 1970; Tsurumaru, 1979; Fujimoto, 1982; Bleed, 1996, 2002b, 2003, 2011; Kimura and Girya, 2016). Among the regions along the northern Pacific Rim, Hokkaido, the northernmost Japanese island has yielded rich Upper Paleolithic microblade assemblages, characterized by highly variable microblade core technologies and represented by distinctive steps in core reduction sequences, which are known to be unique core reduction methods (Nakazawa et al., 2005, see also Bleed, 2001). In Hokkaido, bifacial wedge-shaped microblade core technology first appeared

in the Last Glacial Maximum (LGM) (Nakazawa et al., 2005; Izuho et. al., 2012), followed by the advent of variants in the ways cores and platforms were prepared during the post-LGM, ca. 18,000 - 11,500 BP (Yamada, 2006; Tsutsumi, 2011; Nakazawa and Yamada, 2015). Among the variants, large and small bifacial microblade cores called *Sakkotsu* and *Oshorokko* are distinctive microblade-core types in Hokkaido (Yoshizaki, 1961; Morlan, 1967; Tsurumaru, 1979; Bleed, 2001; Nakazawa et al., 2005). Although there is an empirically observed size difference between these two microblade core technologies, these morph-metric differences are less emphasized than techno-morphological variation in microblade core reductions. The question of why regional variation in bifacial wedge-shaped microblade core technology emerged is more critical to understand the general question of why and how the Late-Glacial hunter-gatherers successfully adapted to the rigorous climate and ecology, as well as the diverse geographic and geological conditions of the northern Pacific Rim. In order to orient the archaeological record into anthropological significance, by employing a framework of optimization theory in stone tool technology, we address the question of how the variation in bifacial microblade core reduction methods was related to hunter-gatherer foraging, by comparing utility to the cost of transportation and failure rates between the large and small bifacial microblade core technologies in the Late-Glacial microblade technocomplexes in central Hokkaido. Based on the results of these analyses, we provide an implication of the important role the wedge-shaped microblade core technology played in the human adaptation in the northern Pacific Rim during the Late Glacial (ca. 18,000 – 11,500 cal. BP) and the initial Holocene (ca. 11,500 – 8000 cal. BP).

2. Bifacial wedge-shaped microblade cores in Late-Glacial Hokkaido

2.1. A brief research history

Besides the difference in dates between the Pleistocene/Holocene sites in the Old and New Worlds, it is the morphological affinity in wedge-shaped microblade cores shared among the assemblages from both sides of the regions of the northern Pacific Rim that support the idea of human migrations from East Asia to North America through the Beringia (Nelson, 1937; Yi and Clark, 1985; Andrefsky, 1987; Hoffecker et al., 1993; Hoffecker and Elias, 2007). The peculiar morphological characteristics of wedge-shaped cores have been particularly scrutinized by Japanese archaeologists to distinguish reductive processes of microblade cores in microblade production (Yoshizaki, 1961; Kobayashi, 1970; Tsurumaru, 1979, see also Bleed, 2001). Techno-morphological studies conducted between the 1960s and the 1990s almost completely described core reduction sequences and the types of resultant microblade cores (e.g., Yoshizaki, 1961; Hayashi, 1968; Kobayashi, 1970; Anbiru, 1979; Tsurumaru, 1979; Bleed, 1993, 2002; Chiba, 1993). Based on these analytical results, it is now recognized that more than half a dozen of patterned microblade core reduction sequences are present in Hokkaido (Sato and Tsutsumi, 2007), known as the “gihō” (Bleed, 2001: 102, 2002b: 96) or “methods” (Nakazawa et al., 2005: 276). Moreover, meticulous descriptions of microblade cores have allowed us to understand prehistoric human technology by comparing reduction sequences characterized by different sequential steps and processes that reduced the mass by removing flakes, spalls, and microblades among assemblages (Bleed, 2001).

2.2 Large and small bifacial wedge-shaped cores in Late-Glacial technocomplexes in

Hokkaido

Fig. 1 illustrates core types and corresponding reduction sequences in bifacial microblade core technology. While archaeologists have made some observations on the techno-morphological differences among the bifacial microblade cores (e.g., *Sakkotsu* and *Shirataki* types) including the presence/absence of core and platform preparations after removing spalls (i.e., first spalls with trihedral sections and secondary ski spalls with trapezoidal sections [Bleed, 1993]), and blank types of bifaces (e.g., flakes, split cobbles, angular debris [Hayashi, 1968; Anbiru, 1979; Tsurumaru, 1979; Chiba, 1993]), they are generally viewed as variation in the reduction of bifacial microblade-cores that follow the processes of preparations of bifacial preforms, removing of multiple spalls along the longest axis of the biface to make the relatively flat surface of the platform, and the detachment of microblades from one end of the elongated platform, which is the specific reductive method most often known as the “Yubetsu gihō” (Yoshizaki, 1961: 15), or “Dyuktai technique” (Flenniken, 1987: 118, about the concept of “Dyuktai culture” see Yi and Clark, 1985). Similar to the reduction sequence of the *Yubetsu* method but a little different reduction sequences are also recognized in the “*Oshorokko*” method (Yoshizaki, 1961; Tsurumaru, 1979; Bleed, 2001). In *Oshorokko*-type microblade cores, a core platform is set in an oblique direction along the perimeter of a biface near the end. The size differences between these two methods, however, are implicitly incorporated into the classification procedure in determining the reductive methods of microblade cores rather than as techno-morphological traits that serve as criteria to identify distinctive reductive methods.

2.2.1. Sakkotsu and Oshorokko complexes in central Hokkaido

Because all of these methods were found separately among the assemblages, the microblade assemblages in Hokkaido are better analyzed by dividing them into the complexes represented by different microblade core reduction methods (Nakazawa and Yamada, 2015). The *Sakkotsu* and *Oshorokko* complexes are distinctive not only in the size difference of the bifacial wedge-shaped microblade cores, but also in the variation in tool compositions. The typical tool inventory for the *Sakkotsu* complex is characterized by endscrapers, sidescrapers, and burins made on flakes, and “half-oval” small bifaces, sometimes with chopping tools, while that of the *Oshorokko* complex is characterized by blade-based endscrapers, sidescrapers, and burins, often with edge-ground axes (Fig. 2). In the archaeological sites, these two complexes have neither been associated with one another in the same assemblage, nor been stratigraphically separated in the same site. Notable differences make it legitimate to view them as mutually independent complexes, and most Japanese archaeologists currently agree with the interpretation that the *Oshorokko* complex appeared later than the *Sakkotsu* complex (Yamahara, 1998; Nakazawa et al., 2005; Terasaki, 2006; Yamada, 2006; Naoe, 2014; Nakazawa and Yamada, 2015). However, the limited number of chronometric dates associated with these complexes makes it difficult to validly place them in a chronological order. The well-accepted dates obtained from charcoals from the hearth of the Kamihoronai-Moi where the *Sakkotsu*-type microblade core assemblage was recovered yielded the dates of 18,000 – 17,600 cal. BP (14650 ± 80 BP) (Nakazawa et al., 2007; Izuho et al., 2009), suggesting that the *Sakkotsu* complexes appeared at least during the early Late Glacial after the end of the LGM. In contrast, current chronologies place the *Oshorokko* complex in the terminal phase of the Upper Paleolithic, probably encompassing the Pleistocene/Holocene transition (e.g., Yamahara, 1998; Naoe, 2014).

Despite this current view, these regional, cultural chronologies based on techno-morphological traits have not been explicitly tested for their chronometric dates. Table 1 lists all of the available radiocarbon dates from the sampled sites on the southern Ishikari Lowland in central Hokkaido. The dates for the *Sakkotsu* complex are ca. 18,000 – 15,000 cal. B.P., while those of the *Oshorokko* complex are ca. 22,000 – 14,000 cal. B.P. The dates for the *Oshorokko* complex suggest that it could have lasted for several millennia after the end of the LGM. In the current cultural chronology of microblade technocomplexes that places the boundaries at the early and late Late Glacial at ca. 13,500 cal. BP, the *Sakkotsu* complex would be in the early Late Glacial and the *Oshorokko* complex would be placed in the late Late Glacial (Yamada, 2006; Nakazawa and Yamada, 2015). However, an overlap in the chronometric dates between the *Sakkotsu* and *Oshorokko* complexes does not fully support the currently accepted diachronic succession of these complexes. It may be probable that the post-LGM hunter-gatherers used these two kinds of core reduction technologies, alternating according to their needs in various situations, such as depending on environmental conditions (e.g., resource abundance or scarcity) of the Late Glacial.

The Upper Paleolithic sites are particularly concentrated on the southern part of the Ishikari Lowland where there are large amounts of pyroclastic flow-deposition from the Shikotsu Caldera and surrounding volcanoes located 10 km to the west, extending as far as 350 km², and known as the Shikotsu Volcanic Terrain (Chitose-shishi Hensaniinkai, 2010). Most of the Paleolithic sites are located on the eolian sand dunes that were created by the accumulation of wind-blown sediments from the volcanic tephra of Spfa 1, erupted at ca. 42,000 BP (Machida and Arai, 2003). In this volcanic terrain, meandering rivers spawn low-energy streams that produce little amounts of rocks and

raw materials, such that material for manufacturing lithic artifacts was scarce (Soya and Sato, 1980). Indeed, the high-quality raw materials for knapping were rarely available on the Shikotsu Volcanic Terrain. For example, the nearest source of good obsidian is Akaigawa, located approximately 80 km northwest of the study region of the Shikotsu Volcanic Terrain. The examined assemblages are from open-air sites on the Shikotsu Volcanic Terrain (Fig. 3). These are the Oruika 2 from the *Sakkotsu* complex, and Meboshigawa 2 and Osatsu 16 are from the *Oshorokko* complex. The major lithic raw materials used for the method of production of microblades (core and platform preparations and microblade detachments) are almost all obsidian, mostly from the Akaigawa source (Fig. 2-b) according to the energy-dispersive X-ray fluorescence analysis of the obsidian (Warashina, 1997). This indicates that hunter-gatherers moved to procure lithic materials and transported cores/tools to the study region.

3. Model

3.1. Risks, costs, and benefits in hunter-gatherer lithic technology

In the foraging lifeways of hunter-gatherers, stone tools and cores were also frequently provisioned to transport out for use while foraging in the landscape (Binford, 1979; Kuhn, 1994, 1995; Elston and Brantingham, 2002; Hoffecker, 2002; Graf, 2010). By the same token, it is likely that hunter-gatherers wanted to minimize the risk that is defined as the “probability that costs will exceed benefits” (Elston 1990: 154). In terms of subsistence, risk is defined as the “probability of failing to meet dietary requirements” (Torrence 1989b: 59). However, the applicability of the risk in hunter-gatherer behavior varies depending on variables in decision-makings by individual hunter-gatherer, including managing the risk of exploiting resources (Mayer 1989; Torrence, 1989b;

Elston and Brantingham, 2002), the risk of raw material availability (Bamforth and Bleed, 1995), and the risk of the uncertainty or lack of information (Fitzhugh, 2001). Because the probability of failure in the procurement and use of lithic resources indirectly incurred risks relative to subsistence needs, Elston (1990: 154) has distinguished two kinds of risk: the “venture risk” that refers to the “probability that the cost of lithic tool procurement will exceed the payoff in increased efficiency of subsistence tasks through use of lithic tools” and “contingency risk” that is the “probability of being caught short in circumstances where the supply of tools (short-term risk) and/or toolstone (long-term risk) is insufficient to meet subsistence needs.” When hunter-gatherers using microblade core technology foraged in an area with a low availability of raw materials in the study region of the Shikotsu Volcanic Terrain, it was the contingency risk rather than the venture risk that was likely to be more influential on the decision-making of organizing microblade core technology.

Having recognized that the Late-Glacial hunter-gatherers designed lithic technology to minimize the contingency risk, we employed the cost-benefit model in behavioral ecology (O’Connell and Hawkes, 1981; Stephens and Krebs, 1986; Elston, 1990; Kuhn, 1994; Kelly, 2000; Surrovell, 2009). Inspired by cost-benefit models that have been created to understand various domains in stone tools, notably use-lives, tool design, technology, and mobility (Elston, 1990; Kuhn, 1994; Elston and Brantingham, 2004; Surrovell, 2009), we were concerned about costs and benefits of microblade core technology, as well as the risk of failure in the reduction of microblade cores (Bleed, 1996, 2003). In particular, we address the question of how hunter-gatherers used the nearly identical but dimensionally different microblade core technologies for foraging in the Late-Glacial landscape of central Hokkaido. There were also concerns about the

risks, costs of transportation, and utility gained from bifacial wedge-shaped microblade core reductions.

3.2. Cost of transport and utility of bifacial microblade cores

Given that groups of Late-Glacial hunter-gatherers moved across the landscape bringing with them stone tools and cores, it is generally expected that the cost of transportation increased as the package size of the tools and cores increased (Elston, 1990; Kuhn, 1994; Beck et al., 2002; Surovell, 2009). In contrast, larger the core more is the production of the flakes. This general expectation is applicable to microblade core technology because microblades likely served as edges for composite tools (Guthrie, 1983; Dixon, 2001; Helwig et al., 2008) and were produced in batches (Bamforth and Bleed, 1995). Among the batches, only some fraction of detached microblades was actually chosen for use, implied by observations that numerous microblades without retouches and truncations are often found from microblade assemblages (e.g., Morlan, 1968; Fujimoto, 1982; Yamada, 2006). The proportions of used microblades relative to the produced microblades would vary depending on core reduction technologies, site functions, mobile strategies, and raw material availability. Although it is necessary to examine as to whether amounts of used microblades are different between the *Sakkotsu* and *Oshorokko* types, assuming that the ratios of used microblades are constant among microblades produced from different types of microblade cores, it is expected that the total amount of microblades produced from a microblade core was maximized (cf. Bleed, 1993).

While scholars studying non-human and human foragers in the framework of optimality have usually employed energy as currency (e.g., Maynard Smith, 1978; Pyke

et al., 1977; Stephens and Krebs, 1986; Kaplan and Hill, 1992), it is not determinable to what extent prehistoric hunter-gatherers optimized their behavior or how optimization behavior links to archaeological questions (Keene 1983). Indeed, archaeologists have emphasized different “currencies” in stone-tool technology, notably energy, time, raw material, information, uncertainty, and risk, depending on the context of study regions, periods, and materials (Jochim, 1983, 1989; Mayers, 1989; Torrence 1989a). Under the premise that the Late-Glacial hunter-gatherers optimized their subsistence strategies to exploit resources, the currency to be optimized was energy gained from terrestrial and aquatic resources (e.g., mobile grazers, waterfowl, fish), and therefore the stone tools particularly hunting weapons would be organized to successfully capture the hunting targets. The other limitation of using this optimality principle for the study of Late-Glacial hunter-gatherers on the Japanese Archipelago is particularly pronounced because the prey species are unknown due to the poor preservation conditions of faunal remains (Akazawa, 1999; Nakazawa, 2010). Despite these shortcomings in evaluating Late-Glacial subsistence, it is legitimate to assume that the primary function of microblades was to serve as a composite part of a composite projectile by referring to some archaeological evidence from the Late-Glacial Siberia and northern North America (e.g., Kimura 1997; Helwig et al. 2008). With this assumption as a given, it is expected that the amount of microblades produced would be roughly proportional to the amount of composite weapons. If multiple projectiles were at hand, they could have served as “back-up” weapons in the case of loss or breakage of weapons while hunting or traveling, which in turn would have decreased the risk of failure in resource exploitation (i.e., contingency risk). Thus, as the production of microblades increase, the benefit gained also increases. In this respect, we see that the currency is to maximize the

efficiency in the amount of microblades produced from a microblade core.

As mentioned above, the amount of microblades produced is proportional to the initial core size. Conversely, the greater the mass of a microblade core, the higher the calories for individual foragers. Instead of using calories that are difficult to measure in given archaeological record, we regard artifact mass as the representation of transportation cost referring to the models of artifact transportation developed by Kuhn (1994) and Surovell (2009). When a core is transported during foraging, the cost of transportation increases according to the increased mass of a microblade core. This in turn makes an individual to create a trade-off relationship between the size of a transported core and the amount of microblades produced from a core. Thereby, making it necessary to consider the “utility” (Kuhn 1994: 427) that is regarded as the reducible portion of a core since the core has little utility as it is discarded after the removal of flakes. In our further examination, a general reductive method of microblade cores represented by the *Yubetsu* method follows these redundant steps: the removal of one to multiple spalls along the longest axis to prepare long and narrow platforms that are along the parallel line of the biface, followed by the detachment of microblades (Fig. 1, see also Nakazawa et al., 2005). Therefore, the benefit of a bifacial microblade core can be viewed as proportional to the mass of a biface. In his sophisticated simulation model of a bifacial core, Surovell (2009: 159) suggests that the utility of a bifacial core is “proportional to its volume of usable stone.” This implies that the large bifacial wedge-shaped cores have more benefit than the smaller cores. If so, it is predictable that the payoff gained from the larger cores in a mobile context would be more efficient than transporting smaller cores. Thus, it is again questionable as to why the Late-Glacial hunter-gatherers developed two kinds of reduction methods and prepared large and

small bifaces.

4. Materials and methods

4.1. A comparison of size among bifacial microblade cores

Before assessing the cost-benefit ratio of microblade core technologies, it is necessary to identify to what extent there were core size differences between the two bifacial microblade core technologies. Since techno-morphological variation in stone tools and cores is potentially influenced by the availability of lithic raw material, including lithology, package size, quantity, quality, and accessibility (e.g., Straus, 1980, 2006; Bamforth, 1986; Elston, 1990; Rolland and Dibble, 1990; Andrefsky, 1994; Kuhn, 1995; Brantingham et al., 2000; Blades, 2001), all of the specimens in the instant study are from the sites located on the Shikotsu Volcanic Terrain in central Hokkaido (Fig. 3). The size of a microblade core is represented by the maximum length of a microblade core (b in Fig. 4).

4.2. Analysis of the cost-benefit ratio of microblade cores

The prediction of transportation cost and utility of microblade cores was tested against the archaeological data from the Late-Glacial microblade technocomplexes (i.e., *Sakkotsu* and *Oshorokko*) from the Shikotsu Volcanic Terrain. Having been inspired by the pioneering model developed by Elston and Brantingham (2002), and taking advantage of volumetric changes in a microblade core from a bifacial preform clarified by core reduction sequences among the Japanese microblade technocomplexes (e.g., Yoshizaki, 1961; Morlan, 1967; Anbiru, 1979; Tsurumaru, 1979; Bleed, 1993, 1996; Nakazawa et al., 2005), we provide a cost-benefit model for a wedge-shaped microblade

core.

In principle, utility of a wedge-shaped microblade core (UT) is defined as the original core volume (OC) minus the wastes from core platform preparations (i.e., spalls) (PP), platform maintenance (e.g., trimming flakes laterally removed from platform to core surface) (PM), unsuitable/unusable microblades (UBM) and core remnant (CR). Therefore,

$$UT = OC - (PP + PM + UBM + CR)$$

In evaluating this formula, it will be further necessary to analyze refitted specimens and conduct experiments. While our data sets are specifically on the core remnants (CR), a total amount of removals in platform preparations (PP and PM) are somewhat estimable from the observations on core morphologies as well as using metric attributes. Here, the utility of bifacial microblade cores is defined as the amount of microblades removed from a core regardless of the extent to which removed microblades were actually used or not. Because the width of a bifacial wedge-shaped microblade core platform is mostly equal to the maximum thickness of the microblade core (Tsurumaru, 1979), it is legitimate to assume that the microblade core is reduced to half of the initial size of the microblade core. As illustrated in Fig. 4, the total amount of microblades detached is estimated as the sum of Volume 1 (V_1) and Volume 2 (V_2). Thus, the utility of a microblade core preform (i.e., a biface) is given as

$$Utility = V_1 + V_2$$

V_1 is the portion that was lost by removing microblades. Because the thickness of a core surface of a microblade core is usually at the thickest portion of a microblade core (Tsurumaru, 1979), the longest dimension of V_1 is at least half the length of the original biface, estimated to be the platform length (b in Fig. 4). V_2 represents the mass

defined as the volume between the core surface and perimeter of original bifacial blank.

These volumes are estimated as follows.

$$V_1 = a \times b \times c/2$$

$$V_2 = 0.5 \times a \times c \times e/2$$

$$\text{where } e = \cos\Theta \times d$$

Since e is not given as a landmark on a microblade core, it is calculated by using d and Θ . d is the distance of a microblade core surface given as the length between α and β (Fig. 4). c is the distance of a vertical line perpendicular to e passing through α and the point on the estimated perimeter of core bottom. Because the bifacial microblade cores were wedge-shaped, the numerators given by the multiplications of the metric attributes are divided in half to estimate accurate volumes (i.e., V_1 and V_2).

The transportation cost (TC) is given as the estimated total volume of a core blank that was likely transported along the foraging. The transported forms of cores or core blanks are obviously invisible. However, the refitted specimens of *Sakkotsu* and *Oshorokko* microblade cores have some spalls removed from the bifacial cores (Fig. 5). This suggests that the wedge-shaped microblade cores were reduced from the bifaces after they were transported into the sites. In the microblade core reductions, it is generally expected that a bifacial blank is reduced by almost half to prepare a platform, especially for the *Sakkotsu* type. Thus, its original bifacial preform is twice the size of a microblade core with platform (as illustrated in the area within the dotted line in Fig. 4). The TC for the *Sakkotsu*-type (TC_S) represented by a bifacial core preform, assuming that a whole biface was transported and gradually reduced as producing microblades across landscape until the core was eventually discarded. This is indicated from some refitted specimens (Fig. 5). Given this situation, transportation cost is measured by the

mass of a whole bifacial core preform minus the portion provided for microblades. The estimated transportation cost for the *Sakkotsu*-type microblade core is given as

$$\begin{aligned} TC_S &= V_1 \times 4 - (V_1 + 0.2 V_1) \times 0.5 \\ &= 3.4V_1 \end{aligned}$$

where the usable mass for microblade production is the sum of the whole of V_1 and V_2 represented as 20% of V_1 portion of the microblade core that are exclusively reduced without producing wastes. Assuming that the portion of microblade removals would be consistently reduced along the foraging, cost of transportation diminishes as foraging proceeds. As the trade-off between utility and cost of transportation in foraging is generally expected, we correct the usable mass by dividing it into half.

On the other hand, unlike the *Sakkotsu*-type, a platform for the *Oshorokko*-type microblade core is set in an oblique direction along the perimeter of a biface near the end (tip), and there are fewer spalls removed than for the *Sakkotsu*-type (Fig. 1). Having estimated that the removed spalls to make platform (PP) is 25% of a microblade core size, less amount of spalls removed to make a platform makes TC for the *Oshorokko*-type (TC_O), given as

$$\begin{aligned} TC_O &= V_1 \times 2 + (V_1 \times 2 \times 0.25) - (V_1 + 0.2 V_1) \times 0.5 \\ &= 1.9V_1 \end{aligned}$$

Measurements of *Sakkotsu* microblade cores were collected from the Oruika 2 assemblage (Hokkaido Miazobunkazai Center, 2005) by the first author, and those of the *Oshorokko* microblade cores were taken from the assemblages of Meboshigawa 2 (Chitose-shi Kyoikuiinkai, 1983) and Osatsu 16 (Hokkaido Bunkazaihogo Kyokai, 1997) by the second author (Akai, 2005). Potential inter-observer errors in measurements have been minimized by sharing the definition in metric attributes.

4.3. An assessment of failure rates using an event-tree analysis

Besides the cost-utility analysis of microblade cores, the failure rate is assessed using selected assemblages from the Shikotsu Volcanic Terrain. Taking advantage of the refitting analysis that is a routine step in lithic analysis in Japanese Paleolithic archaeology (Bleed, 2002a), we examine to what extent the microblade core preforms failed to manufacture microblades as they were reduced using an event-tree analysis (e.g., Bleed, 1991, 1993, 1996, 2002b). The event-tree analysis is an analytical method to evaluate the risk involved in making stone tools and its management in studying the steps in a “technological system” (Bleed 1993: 27). Besides the analysis of bone bead production in the North American Plains assemblage (Bleed, 1991) and Folsom projectile points of the North American Paleoindian (Winfrey, 1990), the event-tree analysis has been effectively used to estimate failure rates for late Upper Paleolithic wedge-shaped microblade assemblages in regions of the Japanese Archipelago (Bleed, 1993, 1996, 2002b). Risk in the microblade core technology is evaluated through the failure rate of microblade production that is quantitatively assessed by the number of broken or unworked specimens left from the steps in microblade core reductions. Here because the refitted specimens for the microblade assemblages are also available, we used both the refitted and the non-refitted specimens for the analysis, using the samples of the Oruika 2 assemblage (Hokkaido Miazobunkazai Center, 2005) for the representative sample of the *Yubetsu* method and the Meboshigawa 2 assemblage (Akai, 2005; Chitose-shi Kyoikuiinkai, 1983) for the *Oshorokko* method.

5. Results

5.1. Size difference in bifacial microblade cores

Even though the local availability of raw material is low in the Shikotsu Volcanic Terrain, variations in the size of microblade cores are notably present. Table 2 summarizes the size (maximum length) of the *Sakkotsu*- and *Oshorokko*-type microblade cores, in the Oruika 2 and Meboshigawa 2 assemblages. The mean size for the *Sakkotsu*-type microblade cores (97 mm) is more than twice that of the *Oshorokko*-type microblade cores (43 mm). While the sample size of the *Sakkotsu*-type is smaller than that of the *Oshorokko*-type, the 95% confidence interval around the means for the size in the *Sakkotsu*-type microblade cores (43-151 mm) is also greater than that for the *Oshorokko*-type microblade cores (23-63 mm), reinforcing the size difference, i.e., the larger size of the *Sakkotsu*-type and smaller size of the *Oshorokko*-type. Table 3 also shows the estimated amount of microblades produced from a microblade core, comparing the *Sakkotsu* and *Oshorokko* types. The estimated amount of microblades produced given simply as the fraction of microblades to microblade cores for the *Sakkotsu* microblade assemblage of Oruika 2 is 42 and that of the *Oshorokko* microblade assemblage of Meboshigawa 2 is 19. The estimated production of microblades for the *Sakkotsu*-type microblade cores is twice that of the *Oshorokko*. In sum, the results of comparisons of core sizes and the amount of microblades produced suggest that the productivity of microblades is twice as much for the larger bifacial microblade cores of the *Sakkotsu*-type than for the *Oshorokko*-type smaller bifacial microblade cores. Nevertheless, this is a gross estimate of the productivity of microblades, since utility and transport efficiency of microblades may have potentially varied between different core reduction technologies, to which further examination will be necessary.

5.2. Utility to cost for bifacial microblade core technologies

Ratios of utility to cost are calculated for all of the microblade cores, using the above proposed equation and measurements (Fig. 4). As the Oruika 2 is the only microblade assemblage with the *Sakkotsu*-type microblade cores in the study region of the Shikotsu Volcanic Terrain (Hokkaido Miazobunkazai Center, 2005), only six microblade cores were available for comparison, as opposed to a total of 107 cores from the Osatsu 16 and Meboshigawa 2 assemblages with the *Oshorokko*-type microblade cores. Although this discrepancy in sample size may make a difference in the results, the comparison of utility to cost of microblade cores between the *Sakkotsu*- and *Oshorokko*-types is pronounced. As exhibited in Table 4, the mean ratio of utility to cost for the *Sakkotsu*-type microblade cores (0.12) is approximately 40% of the *Oshorokko*-type microblade core (0.29). There is a significant difference in the ratios of utility to cost between these groups (Mann-Whitney U test: $U=759$, $p < 0.001$).

5.3. Failure rates

Tables 5 and 6 summarize the results of the event-tree analysis for the *Sakkotsu* and *Oshorokko* microblade core reductions, according to the analytical procedure of Bleed (1993, 1996, 2002b). The bifacial microblade preforms are sequentially reduced from the nodule/gravel, bifacial preforms, to microblade cores. Between the bifacial preforms and microblade cores, a few to several spalls (first and ski spalls) were removed to prepare a core platform. While there is no evidence of core platform rejuvenation in the examined *Sakkotsu*-type microblade cores from the Oruika 2 (Table 5), there are a total of ten rejuvenated spalls identified in the *Oshorokko*-type microblade cores of the

Meboshigawa 2 (Table 6). In the *Sakkotsu*-type microblade core reduction, there are eight spalls consisting of two first spalls and six second spalls. These core preforms with removals of spalls were abandoned without detaching microblades. One of them is broken and the other two are intact. In the *Oshorokko*-type microblade core reductions, there are 11 spalls consisting of one possible ski spall and 10 platform rejuvenation spalls. There are a total of 16 microblade cores, consisting of 15 intact (complete) cores and one failure core (a core broken during the reduction). The failure rates based on the event-tree analysis of the microblade cores and spalls from the assemblages of the *Sakkotsu* and *Oshorokko*-type microblade cores are 7 % (1/16) and 4 % (1/27), respectively. In contrast, the case studies of the event-tree analysis on the wedge-shaped microblade core reductions in the Araya, Kakuniyama, and Fukui assemblages in the Japanese Upper Paleolithic in the northern Honshu Island have shown failure rates in microblade production varying from 9 % to 17 % (Bleed, 1993, 2002b). The microblade cores from the Araya and Kakuniyama assemblages are the variant of *Sakkotsu*-type. The microblade cores from the Fukui assemblage are wedge-shaped specifically called as the “Saikai gihō” (Aso, 1965, see also Hayashi, 1968), a method resemble to the *Yubetsu*. Despite nearly identical core reduction technologies between the northern Honshu Island and Hokkaido, the failure rates for the microblade assemblages for the *Sakkotsu* and *Oshorokko* microblade cores are judged to be low, lower than the northern Honshu microblade assemblage of Araya (11%, Bleed, 2002b: 97-98) where the principal raw material (i.e., hard shale) was likely transported from a remote outcrop (> 150 km) (Sawada, 2014).

6. Discussion and conclusions

Although local lithic raw material availability is identical for the two bifacial microblade core technologies, there is a notable size difference between *Sakkotsu* and *Oshorokko* bifacial microblade cores. However, in the actual consumption of microblade cores, there seems to be some effect arising from raw material availability. Scarcity of lithic materials in the study region of the Shikotsu Volcanic Terrain can explain relatively low failure rates observed in both the Oruika 2 and Meboshigawa 2 assemblages. In other words, high success rates under conditions of low availability of lithic raw material were a likely solution to avert the contingency risk. Even though failure rates in the production of microblades were found to be low in both core technologies, a remarkable difference in the utility to cost ratio between the *Sakkotsu*-type and *Oshorokko*-type microblade core technologies is present, with lower utility to cost ratio for the *Sakkotsu* microblade core technology (SMT) than for the *Oshorokko* microblade core technology (OMT). This suggests that the goal of foragers employing the SMT was to maximize the amount of microblade production. Contrary to the SMT, the OMT is characterized by its lower production rate of microblades and higher utility to cost of transport, implying that the goal in the management of *Oshorokko* core technology was to minimize the cost of transportation.

Based on these contrasted differences in the goals for the larger and smaller bifacial microblade core technologies, we can deduce advantages, problems, potential solutions, and risks unique to the systems of bifacial microblade core technologies (Table 7). The advantage in using the larger bifacial cores was to reduce the risk of failure. As shown in No.1 in Fig. 5, a broken biface can be transformed into a smaller biface that was intended to serve as a microblade core preform. Moreover, thinning flakes obtained during the shaping of a biface could provide tool blanks such as scrapers

and retouched flakes. Under the use of the SMT, the potential problem was the increased cost of transport because of the need for large bifacial preforms. Increased transportation costs can gradually incur foraging inefficiency, which can be solved by placing caches of large bifaces (e.g., Yamahara, 1996) on regular foraging routes. For example, besides complete bifacial preforms, intact cores (bifacial preforms with spalls removed as in Oruika 2, see Table 5) could have served as sources of new bifacial microblade cores. Another solution to reduce the cost of transport is to minimize the number of bifaces transported along the foray and occasionally visit the sources (both primary outcrop(s) and secondary deposits such as river beds and gravels) to transport portable bifacial core preforms. However, these solutions restrict foraging routes. Occasionally, hunter-gatherers had to procure lithic materials and visit caches, while foraging over greater range of the landscape to search for food resources. This would have resulted in increasing the venture risk. Such foraging strategies could only be effective in predictable environments under which available resources were either geographically fixed or predictable, even if they fluctuated seasonally. Conversely, it is expected that the employment of large microblade core technology became inappropriate when the diet breadth changed in response to changes in abundance and kinds of prey species due to climatic changes, or natural disasters (e.g., volcanic activities, earthquakes, natural fires) that could make it difficult for hunter-gatherers to access previously known lithic sources.

In contrast, using the OMT, the goal of hunter-gatherers was likely to minimize the cost of transportation. Because of the small size, it was necessary to abandon the smaller amount of waste formed during core platform preparation. However, this method also has the risk of failure. If a knapper failed to properly prepare a core

platform, unlike the SMT, there was little chance to wholly reshape the bifacial preform due to the small size, thus increasing the chance of needing a complete replacement of core preforms (i.e., correctly execute the steps of platform preparation, microblade detachments, and platform rejuvenations). Although it may have increased the cost of transport, one possible solution to reduce the failure rate in this microblade production would be to bring multiple microblade core preforms or the failure rate could be reduced by increasing the skill of the knappers. The former explanation is somewhat compatible with the situation that the large number of the *Oshorokko*-type microblade cores is from the Osatsu 16 and Meboshigawa 2. Enhancing knapper skills evidently required significant time for them to learn and practice to become proficient much less exceptional (e.g., Bamforth and Finlay, 2008; Bleed, 2008; Ferguson, 2008) as it involves complex and unrecoverable steps to achieve microblade production that required time to teach all of the steps of microblade production, regardless of the modes of transmission such as vertical, horizontal and oblique (e.g., Cavalli-Sforza and Feldman, 1981; Hewlett and Cavalli Sforza, 1986; Hewlett et al., 2011).

Although faunal assemblages are rarely preserved in Upper Paleolithic sites in Hokkaido, foragers using the SMT could have been residually mobile mainly to chase mobile games (e.g., reindeer) that were predictable in their perceived landscape, similar to the late Upper Paleolithic foraging society in Siberia (Goebel, 2002). On the other hand, mobile strategy for the foragers using OMT is still obscure, while their group size were likely larger than that of SMT as indicated by extensive and dense lithic scatters notably represented in Osatsu 16 (Hokkaido Bunkazaihogo Kyokai, 1997; Nakazawa, 2016). Large group size also necessarily maintained a base camp where transmission of technological skills among group members through one-to-many relationship

(Cavalli-Sforza and Feldman, 1981) may have been facilitated.

Having found these two core technologies in the landscape of the Late-Glacial Hokkaido and surrounding northern Pacific Rim, using the large bifacial microblade core technology represented by the SMT would have been efficient as long as the hunter-gatherers could maintain ample knowledge and access to information about their foraging landscape. In contrast, use of the small microblade core technology represented by the OMT would have been effective in foraging that required long-distance traveling and/or under conditions of low availability of lithic materials. Given the predictable risk involved in each of the core technologies (Table 7), the potential contingency risk is lower in the OMT than in the SMT, as long as the hunter-gatherers using OMT could maintain social ties that facilitated the transmission of knowledge of how to operate that particular lithic technology. Considering the Late-Glacial hunter-gatherer colonization to higher latitudes ($> 50^{\circ}\text{N}$) in the northern Pacific Rim (notably to Beringia and northern Siberia), the OMT could be expected to be useful to cope with unpredictable environments particularly fluctuations in the abundance of available prey, kinds of species, and lithic raw material availability. In other words, once hunter-gatherers acquired complex skills to manipulate small bifacial microblade cores, it would have at least given them the option to migrate into unexplored lands of the northern Pacific Rim. Our comparison of large and small bifacial core technologies in terms of utility, cost, and risk is preliminary and require testing the distance of transportation by obtaining lithic sourcing data as well as performing experiments in evaluating the utility. Nevertheless, results of this paper imply that there are dichotomous characteristics among the bifacial wedge-shaped microblade core technologies. It is hypothesized that once the Late-Glacial hunter-gatherers solved their problems of foraging across

Hokkaido, that knowledge would have been spread and shared with neighboring hunter-gatherer societies in northeast Asia (e.g., northern Japan, the Russian Far East, and Korea) through emergent Upper Paleolithic social and economic networks (Kuzmin and Glascock, 2007; Izuho and Hirose, 2010; Kuzmin, 2010; Yakushige and Sato, 2014; cf. Wobst, 1974), presumably enhanced by regional demographic increases during the post-LGM (Nakazawa and Yamada, 2015). Moreover, variations in microblade core technologies among regional hunter-gatherer societies could have been emerging coupled with an extensive paleo-ecogeographic variation in the northern Pacific Rim and complex social systems (e.g., symbolic and ritual activities), to which continuous international/multi-regional comparisons are required.

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Captions of figures

Fig. 1. Reduction sequences of bifacial microblade cores and corresponding types of wedge-shaped microblade cores. *Yubetsu* method has resulted in microblade cores of *Sakkotsu* type. Schematic illustration of reduction sequences is modified from Nakazawa et al. (2005)

Fig. 2. Stone tool components of the *Sakkotsu* and *Oshorokko* complexes in central Hokkaido. Tools for the *Sakkotsu* are from the Oruika 2 (Hokkaido Miazobunkazai Center, 2005), and those of the *Oshorokko* are from the Meboshigawa 2 assemblages (Chitose-shi Kyoikuiinkai, 1983). 1-3: *Sakkotsu*-type microblade cores, 4-6: microblades, 7-8: burins, 9: endscraper, 10: biface, 11: sidescraper, 12: chopper, 13-15: *Oshorokko*-type microblade cores, 16-18: microblades, 19-20: endscrapers, 21-22: sidescrapers, 23: burin, 24: projectile point (medial fragment), 25: ground axe

Fig. 3. (a) Map of northern Pacific Rim and Hokkaido inside square, (b) Map of Hokkaido and the Shikotsu Volcanic Terrain in central Hokkaido inside square, with showing the Akaigawa obsidian source as black dot (c) Map of Shikotsu Volcanic Terrain and locations of sites examined in the text: (1) Oruika 2, (2) Meboshigawa 2, (3) Osatsu 16.

Fig. 4. A schematic wedge-shaped microblade core, designating the metric attributes to estimate volumes. Definitions of alphabets are mentioned in text.

Fig. 5. Refitted examples of the bifacial wedge-shaped microblade cores. 1: Refitted first spall and broken biface to the bifacial preform of microblade core, 2: A second spall with bifacial thinning flakes, 3: *Oshorokko*-type microblade core with first spall, 4: *Oshorokko*-type microblade core with platform

rejuvenation spall and microblades. 1 and 2 are the Oruika 2 (Hokkaido Miazobunkazai Center, 2005), 3 and 4 are from the the Meboshigawa 2 (Chitose-shi Kyoikuiinkai, 1983, and Akai, 2005).

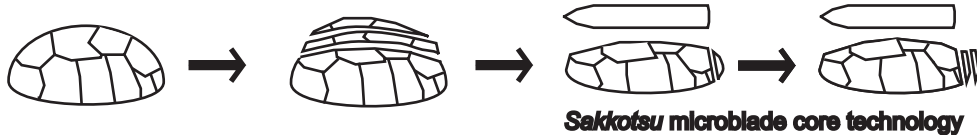
Bifaical Preform

Platform Preparation

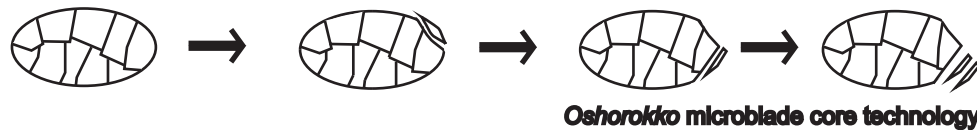
Core-Surface Preparation

Microblade Detachment

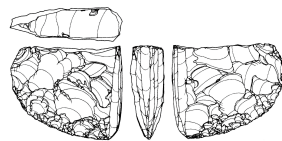
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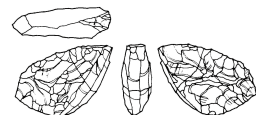
Oshorokko method



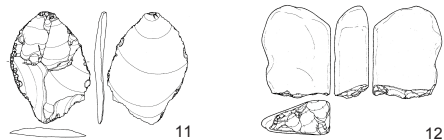
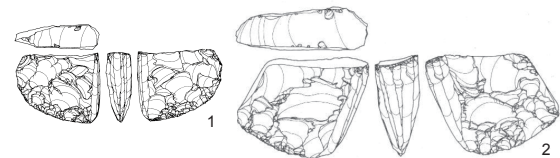
microblade core types



Sakkotsu



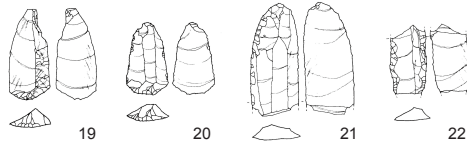
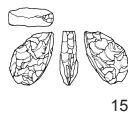
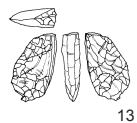
Oshorokko



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No. 1-11

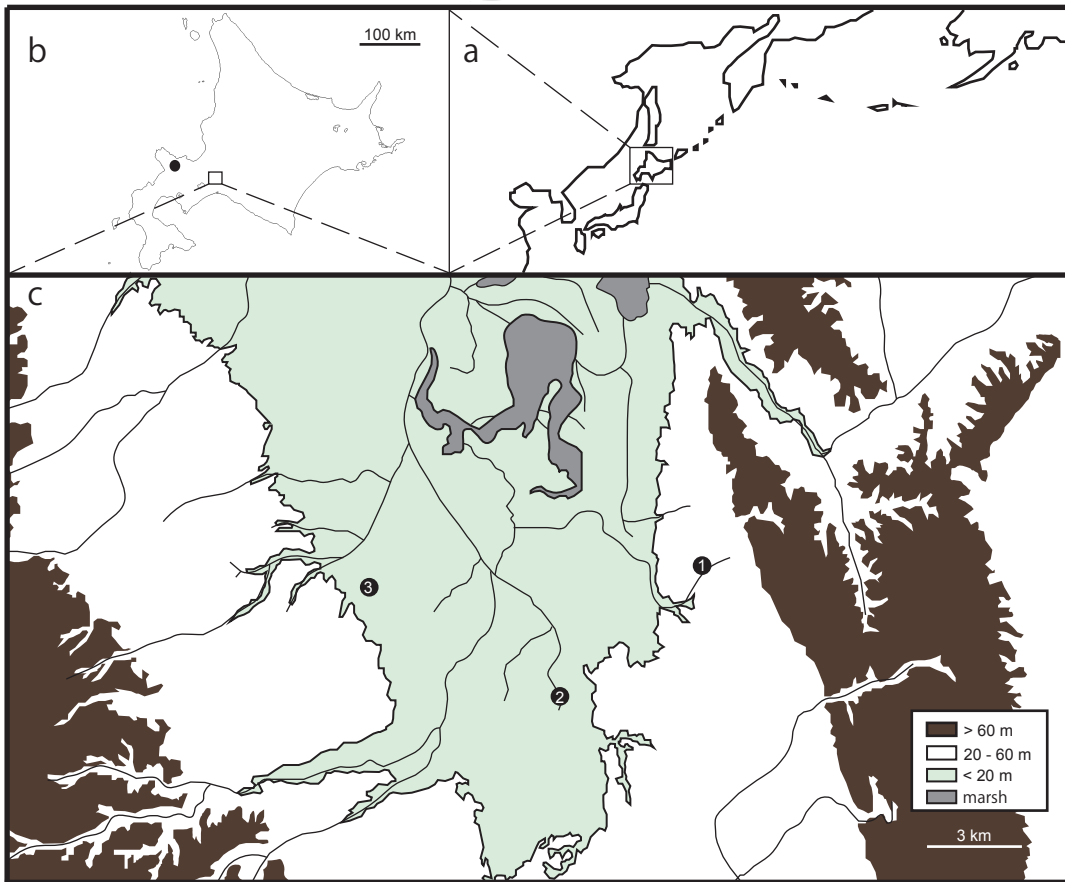
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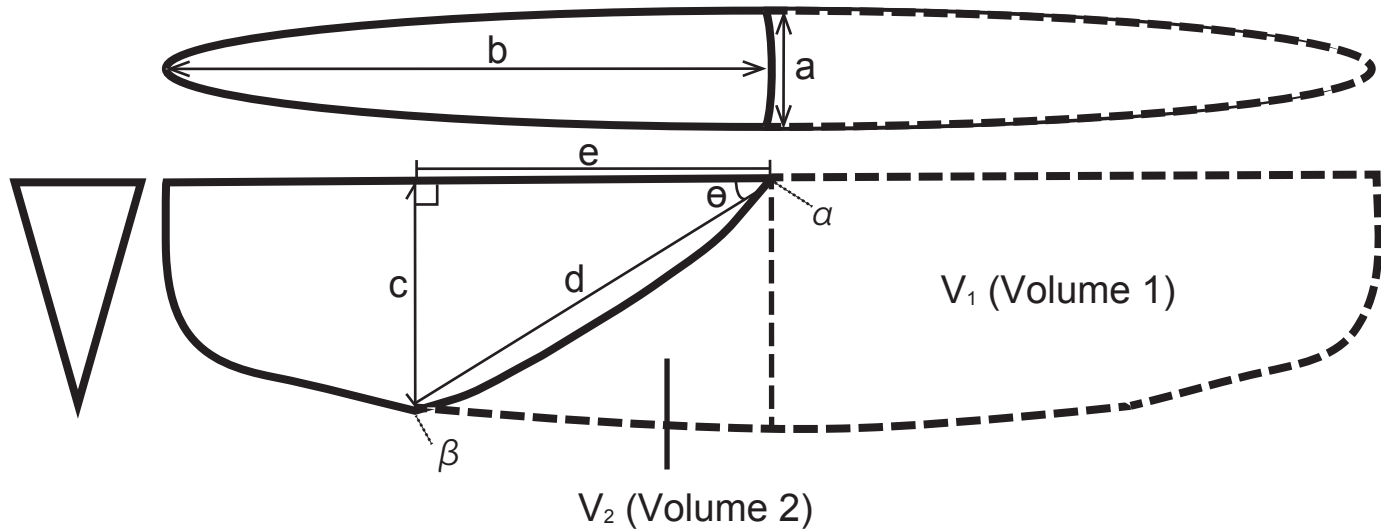
Sakkotsu complex

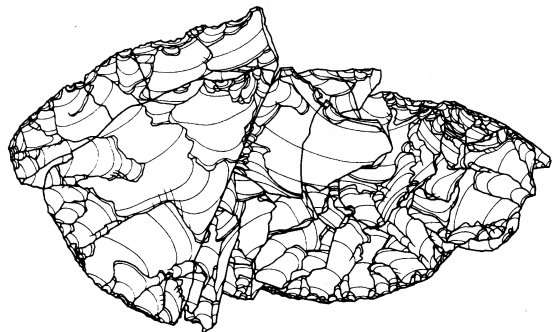
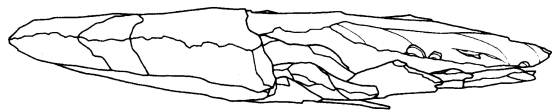


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Oshorokko complex







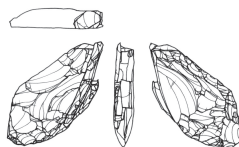
1



2



3



4

5 cm

Complexes	Assemblages	Laboratory Numbers	Materials Dated	¹⁴ C Ages BP	cal. B.P.
Sakkotsu	Oruika 2	PLD-3358	charcoal	14690±70	18030-17709
Sakkotsu	Oruika 2	PLD-3359	charcoal	12740±60	15386-14933
Sakkotsu	Oruika 2	Beta-174529	charcoal	14630±50	17962-17678
Oshorokko	Kiusu 5	INAA-72130	charcoal	18570±80	22636-22276
Oshorokko	Kiusu 5	INAA-72131	charcoal	18500±70	22546-22196
Oshorokko	Kiusu 5	INAA-72132	charcoal	18350±70	22419-21963
Oshorokko	Shukubaigawa-ueda	PLD-6858	charcoal	14725±45	18078-17741
Oshorokko	Shukubaigawa-ueda	PLD-6859	charcoal	14750±45	18111-17777
Oshorokko	Shukubaigawa-ueda	PLD-6860	charcoal	14120±45	17405-16990
Oshorokko	Shukubaigawa-ueda	PLD-6861	charcoal	12330±40	14628-14099

Table 1. Radiocarbon dates from the Sakkotsu and Oshorokko assemblages in the Ishikari Lowland, central Hokkaido. Dates are calibrated by OxCal ver.4.2.

Core type	Assemblage	N	Mean	95% CI
Sakkotsu	Oruika 2	7	97	43-151
Oshorokko	Meboshigawa 2	21	43	23-63

Table 2 A comparison of maximum dimension of wedge-shaped microblade cores

Complex	Assemblage	Count		Ratio
		microblades (a)	microblade cores (b)	a/b
Sakkotsu	Oruika 2	460	11	42
Oshorokko	Meboshigawa 2	320	17	19

Table 3 A comparison of estimated amount of produced microblades between the Sakkotsu and Oshorokko complexes

Core type	N	Mean	SD
Sakkotsu	6	0.27	0.03
Oshorokko	107	0.44	0.02

Table 4 A comparison of utility to cost in the large and small microblace core technologies

Steps of core reduction processes	Cores	# of cores		Spalls	# of Spall		Intact cores	Failed cores	Total
		Refitted	Not refitted		Refitted	Not refitted			
	Microblade cores	4	1	-	-	-	5	0	5
detachment of microblades	↑	-	-	-	-	-	-	-	-
	Biface after removal of ski spalls	2	1	-	-	-	2	1	3
removals of 2nd spalls	↑	-	-	ski spall	4	2	-	-	6
	Biface after removal of 1st spall	0	0	-	-	-	0	0	0
removal of 1st spall	↑	-	-	1st spall	0	2	-	-	2
	Bifacial preform	0	0	-	-	-	0	0	0
removals of biface-thinning flakes	↑	-	-	-	-	-	-	-	-
	Nodule/gravel	0	0	-	-	-	0	0	0
Total							7	1	16
								Failure rate (%)	7

Table 5 Event summary of microblade core reductions in Oruika 2.

Steps of core reduction processes	Cores	# of cores		Spalls	# of Spall		Intact cores	Failed cores	Total
		Refitted	Not refitted		Refitted	Not refitted			
	Microblade cores	1	15	-	-	-	15	1	16
detachment of microblades	↑	-	-	-	-	-	-	-	-
	Rejuvenate platform	0	0	ski spall	1	9	-	-	10
detachment of microblades	↑	-	-	-	-	-	-	-	-
	Biface after removal of ski spalls	0	0	-	-	-	0	0	0
removals of 2nd spalls	↑	-	-	ski spall	0	1(?)	-	-	1
	Biface after removal of 1st spall	0	0	-	-	-	0	0	0
removal of 1st spall	↑	-	-	1st spall	0	0	-	-	0
	Bifacial preform	0	1	-	-	-	1	0	0
removals of biface-thinning flakes	↑	-	-	-	-	-	-	-	-
	Nodule/gravel	0	0	-	-	-	0	0	0
Total							16	1	27
								Failure rate (%)	4

Table 6 Event summary of microblade core reductions in Meboshigawa 2.

	<i>Sakkotsu</i> microblade core technology (SMT)	<i>Oshorokko</i> microblade core technology (OMT)
Core size	Large	Small
Goal	Maximize amount of microblades produced	Minimize the cost of transport
Advantage	Reduce the risk of failure	Reduce the cost of transport
	Bifacial thinning flakes can provide tool blanks	
Problem	Increase cost of transport	Increase risk of failure
Solution	Create cash	Bring multiple cores
	Regularly obtain raw materials	Increase a knapper's skills
Potential	Foraging routes tend to be restricted	Require time to transmit knapping skills
Risk	Easy to fail in unpredictable environment	

Table 7 Goal, problem, solution, and potential risk in the *Sakkotsu* and *Oshorokko* microblade core technologies.