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Portable-XRF Analysis of Archaeological Obsidian from Rebun Island, Japan

by

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Abstract

Ongoing excavations on Rebun Island have demonstrated the prehistoric use of obsidian persistently from the Middle Jomon (5400−4300 cal.YBP) to Okhotsk (1500−750 YBP) periods. Since obsidian does not occur naturally on Rebun Island, only the transportation of raw materials and/or finished tools over great distances accounts for their presence there. Previous research in northeast Asia has shown that movement of obsidian from various sources on Hokkaido played a vital role in the entire lithic industry since the Paleolithic. As cultures varied in Northern Japan from the Middle Jomon to the Okhotsk periods, the patterns of source exploitation are also believed to have changed. This expectation is tested by evaluating the sources of archaeological obsidian recovered from three archaeological sites on Rebun Island (Uedomari 3, Kafukai 1, and Hamanaka 2) through portable-XRF. This method provides new insights into the dynamics of resource procurement and distribution among Middle Jomon to Okhotsk hunter–gatherers on Rebun Island.

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Chapter One – Introduction

1.1 Thesis Scope

The examination of prehistoric exchange networks continues to be a main focus of archaeological research in the 21st century. Furthermore, advances in the technology used by archaeologists to analyze archaeological materials have helped the examination of prehistoric mobility, and prestige economies and kinship structures within the context of exchange networks. This is partly demonstrated by the increased use of portable X-ray fluorescence (PXRF) devices by archaeologists in recent years (for a discussion on the increased use of PXRF in archaeology see Frahm 2012, 2013; Frahm and Doonan 2013; Shackley 2010; Speakman and Shackley 2013). Geochemical analyses of obsidian artifacts have produced sound examinations of prehistoric exchange networks (see Eerkens et al. 2008; Frahm and Feinberg 2013; Golitko et al. 2012; Phillips 2010, 2011). Furthermore, the use of PXRF in obsidian provenance research has been demonstrated to be compatible with other geochemical methods of analysis such as neutron activation analysis (NAA) and inductively coupled mass spectrometry (ICP-MS) (see Craig et al. 2007; Forster and Grave 2012; Nazaroff 2010; Phillips and Speakman 2009; Sheppard et al. 2011; Williams et al. 2012). Therefore, determining the provenance of archaeological obsidian through PXRF provides an opportunity to examine prehistoric exchange networks over space and time.

Hokkaido is the most northerly region of the Japanese archipelago and contains an archaeological record associated with both Pleistocene and Holocene hunter-gatherers. In Hokkaido, obsidian was a commonly used raw material for the production of lithic tools, given the abundance of obsidian sources in this region (Hall and Kimura 2002; Izuho and Hirose 2010; Izuho and Sato 2009). Previous provenance studies have identified the location of Hokkaido obsidian sources, as well as their chemical compositions (Hall and Kimura 2002; Izuho and Hirose 2010; Izuho and Sato 2009; Kuzmin and Glascock 2007; Kuzmin et al. 2012; Phillips 2010, 2011, Phillips and Speakman 2009). Although these studies have demonstrated the widespread prehistoric use and distribution of Hokkaido obsidian objects throughout Northeast Asia[1], little research has focused on the geological provenance of archaeological obsidian collected from Rebun Island, Hokkaido, Japan (see Tomura et al. 2003). Rebun Island is located 50km northwest of Hokkaido and displays a similar cultural history. Therefore, Rebun Island was likely an important territory for prehistoric peoples in Hokkaido, and those who migrated between Northeast Asia and eastern Japan.

This thesis aims to explore two questions that are relevant to the long term goals of the Baikal-Hokkaido Archaeology Project (BHAP). The first question aims to assess the applicability of PXRF technology for the analysis of archaeological obsidian collected from prehistoric sites on Rebun Island. The second question aims to examine changes in obsidian source use on Rebun Island through the analysis of obsidian artifacts dating from the Middle Jomon (5400−4300 cal. YBP) to Okhotsk (1500−750 YBP) periods. This is conducted through the analysis of archaeological materials collected from three sites on Rebun Island: the Middle Jomon site Uedomari 3, and the Okhotsk sites Kafukai

[1] Northeast Asia in this thesis refers to the Japanese regions of Hokkaido and northern Honshu, and the eastern territories of Russia: Amur River Basin, Primorskii Krai, Eastern Siberia, Kamchatka, and Kuril Islands.

1 and Hamanaka 2 (Nakatani). Through the examination of these two questions this thesis will help position the use of PXRF analysis in future BHAP research initiatives and situate Rebun Island within the broader context of obsidian provenance research in Northeast Asia by expanding the current body of research.

There are several chronological notations used in this thesis to define geological eras and archaeological ages. Geological eras are noted as mya for million-years-ago. Archaeological ages that are uncalibrated are noted as YBP for uncalibrated years-before-present, whereas calibrated archaeological ages are noted as cal. YBP. Historical dates are noted in this thesis as years AD.

1.2 Thesis Content

In addition to this introduction, this thesis contains six chapters which serve to examine the prehistoric use of obsidian on Rebun Island. Chapter two contains an overview of the geographic and environmental context of Hokkaido and Rebun Island. This is presented through an examination of the geological structures, topography, and environmental history of these two islands.

Chapter three includes an examination of the cultural history of Hokkaido and Rebun Island. Here, information on the Jomon, Epi-Jomon, Okhotsk, and Satsumon cultures is provided. The Jomon period is divided into its recognized phases; Incipient, Early, Middle, Late, and Final. Whereas the following three cultural periods are examined as complete cultural phases. In these sections the cultural traits, subsistence patterns, and material cultural of these prehistoric groups are presented. These materials are examined to lay the foundation for a discussion of the prehistoric exchange networks found between Hokkaido and Rebun Island.

Chapter four contains an overview of the methods of obsidian provenance studies in archaeology. This chapter also describes the formation processes of obsidian as well as its geochemical structures. This section is followed by a discussion of the benefits and limitations of non-portable methods of geochemical analysis, and PXRF, as well as a discussion of the compatibility of results between these methods. Chapter four also contains the description of the materials and methods used in this thesis.

Chapter five supplies the background information on previous obsidian provenance research in Northeast Asia. A review of this research is provided to situate Rebun Island within the broader context of prehistoric exchange in Northeast Asia. Therefore, this chapter contains a discussion of the prehistoric transportation of obsidian in Hokkaido, Honshu, Sakhalin, the Kuril Islands, Kamchatka, and the Amur River Basin and Primorskii Krai.

Chapter six is a discussion of results beginning with the examination of the compatibility of the PXRF results produced in this thesis to non-portable geochemical methods of analysis, and previously published data. The main focus of this chapter is on the results and findings of the PXRF analysis of archaeological obsidian collected from the Middle Jomon site of Uedomari 3, and Okhotsk sites Kafukai 1, and Hamanaka 2 (Nakatani).

Chapter seven presents the conclusions of this thesis and its contribution to the current body of research surrounding obsidian provenance studies in Northeast

Asia. Recommended studies for future obsidian provenance research on Rebun Island are also provided

Chapter Two – Geographic Context of Hokkaido and Rebun Islands

2.1 The Japanese Archipelago

The Japanese Archipelago consists of 3,900 islands, four of which are considered the main islands: Kyushu, Shikoku, Honshu, and Hokkaido (Sakaguchi 1980: 3). Japan is divided further into regional geographical units known as Hokkaido, Tohoku, Kanto, Chubu, Kinki, Chugoku, Shikoku, Kyushu, and Ryukyu (Figure 1.1) (Sakaguchi 1980: 5). The Japanese Archipelago is often described as central, western, and northern (or eastern) Japan (Sakaguchi 1980: 4). Central Japan includes the area to the east of the Chubu region at the Tsugaru Bay−Ise Bay divide, and to the west of the Kanto region (Sakaguchi 1980: 4). Western Japan includes all regions to the west of the Tsugaru Bay−Ise Bay divide, and includes Shikoku, Kyushu, and the Ryukyu Islands (Sakaguchi 1980: 4). Northern Japan spans from the western boundary of the Kanto region to Cape Soya, all the way to Hokkaido Island.

Hokkaido and the Tohoku region of Honshu are also often referred to as eastern Japan (Nakamura 1980: 186). This is because the Japanese conceptually divide Japan into the west and the east, rather than north and south. The divide between eastern and western Japan is not only treated as a geographical divide, it also is perceived as a cultural divide that began during Japanese prehistory (Nakamura 1980: 186, 188). Regional dialects, geological structures and climate are seen to culturally differentiate Japan from the west and the east (Nakamura 1980: 193). The Fossa Magna is a tectonic depression located in central Honshu that divides Japan into these two halves (Nakamura 1980: 185-187). In the west, Paleozoic (541−252.2 mya) and Mesozoic (252.2−66 mya) formations are typical, while later Tertiary (65−2.6 mya) and Quaternary (2.6 mya to present) formations are more frequently found in the east (Nakamura 1980: 187). The areas of Japan discussed in this thesis are identified by geographical region (i.e., Hokkaido, Kanto, etc.), by island, and western, central and eastern Japan. Although several regions of the Japanese Archipelago are mentioned in this thesis, the subsequent sections of this chapter focus on the geological structures, topography, and environmental history of Hokkaido and Rebun Island.

2.2 Geological Structures

As mentioned, Hokkaido is the most northern island of the Japanese archipelago which borders the Sea of Japan, the Pacific Ocean, and Sea of Okhotsk. Hokkaido is located between N45º31'48" – N41º23'24" and E139º23'24" – E145º49'48", and 77,981.87 km² in area (Figure 1.2). The geographical territory of Hokkaido also includes the islands of Rebun, Rishiri and Okushiri. Rebun Island is situated between N45º30'36"− N45º16'12" and E140º56'42" – E141º04'30" in the Sea of Japan. Rebun Island is located 50km northwest of Hokkaido. It is about 82 km² in area and stretches roughly 20km north to south, and 8km east to west (Sato et al. 1998: 58). Although Hokkaido and Rebun are situated in close proximity to one another their geological structures differ.

Hokkaido is located on top of two tectonic formations, the Kuril Arc, and the Northeast Japan Arc. The continual subduction of the Pacific Plate beneath the

North American Plate also influences the movements of the Kuril and Northeast Japan Arcs (Izuho and Sato 2007: 114). The tectonic activity between the Kuril and the Northeastern Arcs is known to have contributed to the geological formation of Hokkaido (Moriya 1985; Izuho and Hirose 2010: 9). The formation of the Kuril and Northeastern Japan Arcs began during the Palaeogene period (65−23 mya), while the collision of these two plates against one another began after the Neogene period (23−2.5 mya) (Izuho and Hirose 2010: 10). In central Hokkaido the boundary between these two plates resulted in the formation of two large volcanic regions. Since the beginning of Quaternary period (2.6 mya to present), 46 volcanoes have formed in Hokkaido, albeit, 29 remain morphologically intact as lava domes, cinder cones, and calderas (Moriya 1985: 2-3). The majority of Hokkaido's volcanoes is associated with the Kuril Arc in the eastern region of the island where felsic volcanic rocks, such as rhyolites, and dacites are found at the earth's surface (Takanashi et al. 2012: 53). Volcanic activity in this region has been dated by potassium-argon (K-Ar) and fission-track methods to 14−2 mya. Basalts and andesites compose a predominant portion of the parent geological materials which are found throughout Hokkaido (Izuho and Sato 2007: 114; Takanashi et al. 2012: 53). Geochemical and geomorphological analyses have determined that basaltic magmas were responsible for melting of crustal materials during the middle Miocene which gave rise to the formation of rhyolitic magmas in Hokkaido (Takanashi et al. 2012; Yamashita et al. 1999). The many crypto-crystalline materials such as chert, siliceous shale, and jasper, as well as metamorphic and igneous materials such as jade, andesite, and obsidian materials are native to Hokkaido (Izuho and Sato 2007: 114-115). Formations of these materials are found throughout Hokkaido and are a result of the dynamic processes of volcanism found in this region.

The geological structures of Rebun Island were formed by Cretaceous (145−66 mya) and Miocene (23−5.3 mya) magmatism (Hirahara and Shuto 2008). The formation ages for these periods have been evaluated on Rebun Island with K-Ar dating techniques. The magmatism associated with the current geomorphology of Rebun Island is believed to have occurred between 28−18 mya with the spreading of the Sea of Japan (Hirahara and Shuto 2008: 413). On Rebun Island, magmatic activity occurred again from 14−9 mya, contributing to its current geological structures. The different geological formations on Rebun Island are identified as the Motochi, Kafuka, Meshikumi, and Hamanaka. These formations contain deposits of mudstone, sandstone, conglomerate, and siltstone (Hirahara and Shuto 2008: 414). Andesite, dolerite, dacite, porphyrite intrusions are also found in these formations and are associated with the different stages of Miocene magmatic activity on Rebun Island (Hirahara and Shuto 2008: 414). The rhyolitic volcanism associated with formation of Hokkaido is absent from Rebun Island, and, therefore, Rebun Island lacks obsidian deposits. Given the specific focus on obsidian in this thesis, a more detailed discussion of the formation processes and geochemical structures of this material are provided in chapters four and five.

2.3 Topography

Hokkaido Island features several mountainous and lowland areas. Mt. Ashai (2,290m) is highest point in Hokkaido. There are three mountain ranges in Hokkaido: the Hidaka Mountains in the southern portion of central Hokkaido; the Ishikari Mountains in north-central Hokkaido; and the Kitami Mountains in northern Hokkaido (Izuho and Sato 2007: 115). In northeastern Hokkaido the Akan-Shiretoko volcanic zone also contains points of high elevation. In western and southern Hokkaido there are several large volcanoes such as Yotei Zan, Uzu Zan, Tarumae San, and Komaga Take. Miocene volcanism in Hokkaido created several large calderas, which after eruption filled with water forming crater-lakes. Such lakes are found in central and northern Hokkaido. The Ishikari lowlands are located in central Hokkaido and surround the capital city of Sapporo (Izuho and Sato 2007: 116).

There are four watersheds in Hokkaido that are separated by the mountain chains mentioned above (Oguchi et al. 2003). These watersheds drain into the Sea of Okhotsk in the north, the Pacific Ocean to the east, and south, and into the Sea of Japan on the west. There are many rivers and streams in Hokkaido which drain these watersheds. However, the largest rivers in Hokkaido are the Ishikari River (268km) on the west coast, the Teshio River (256km) on the northwest coast, and the Tokati River (156km) on the east coast (Figure 1.2) (Geological Survey Institute, Japan 1977). The Yubetsu River (87km) located in northeastern Hokkaido is also of notable importance to the geography and prehistory of this region. Heavy storms produced by the polar front and typhoons during the winter and late summer months, repeatedly contribute to the dissolution of sediments in steep regions creating landslides in watershed areas throughout Japan, including Hokkaido (Oguchi et al. 2003: 6).

The topography of Rebun Island features many low mountain formations, with steep cliffs along its coasts. Large sand dunes lay on top of the underlying geological formations of Rebun Island. These dune formations were deposited during the Last Glacial Maximum (LGM) when the continental shelf was exposed. The highest point of Rebun Island is Mt. Rebun (490m), which is located at the center of the island. Lowland areas are situated along the northern and east coasts of Rebun Island. The landscape of the western Rebun contains many steep cliffs which drop off into the Sea of Japan. The largest rivers on Rebun Island are the Kafukai River (~1km), the Osawa River (~2km), and Oshionnai River (~1.5km). The Kafukai River drains to the Sea of Japan on the east coast of Rebun Island. The Osawa River drains into Funadomari Bay in the north of Rebun, while the Oshionnai River drains into Rebun's only freshwater lake, Lake Kushu (Sato et al. 1998: 58). Lake Kushu is separated from Funadomari Bay by a sandbar and dune formation (Figure 1.3) (Sato et al. 1998: 59). Sediment and diatoms drawn from lake coring samples suggest that Lake Kushu began to form between 7000 and 5800 YBP (Sato et al. 1998: 62). Between 4900 to 3200 YBP freshwater conditions were permanently established in Lake Kushu (Sato et al. 1998: 63). A peat moor, wetland is found around the southern perimeter of Lake Kushu (Sato et al. 1998: 59). The formation periods of Lake Kushu are attributed to changes in global sea levels during the Holocene.

Changes in sea-level during the Holocene are also responsible for reshaping the coastlines of Japan, as well as Hokkaido and Rebun Island. Rapid changes in global sea levels are associated with global deglaciation that occurred during the Holocene, 12,000 to 6000 YBP (Sato et al. 1998: 57). In Japan, only the alpine areas in Honshu and Hokkaido were glaciated (Tsukada 1986: 22). The Holocene marine transgression which occurred from 6500 to 5000 YBP is associated with increases in global sea-levels that were a result of increased tectonic activity (Sato et al. 1998: 58). Sea-levels during this time were seen to be roughly 6m higher than they are at present (Habu 2004: 44). From 5000 to 4000 YBP and 3000 to 2000 YBP sea-levels began to fall as colder climates began to occur (Sato et al. 1998: 58). These changes in sea-levels are known in Japan as the 'Middle Jomon minor regression' and the 'Yayoi regression' (Sato et al. 1998: 58). Sea-levels during these time periods were roughly 3m lower than they are at present (Habu 2004: 44).

2.4 Environmental History

The climate of Hokkaido is described as being a cool-temperate zone (Igarashi et al. 2011: 1102). In Hokkaido, the climate is influenced by the surrounding tropical and arctic sea-currents; the warm Tsushima Current from the Sea of Japan, and the cold Oyashio Current from the Pacific Ocean (Igarashi 2013: 139; Leipe et al. 2013: 160). The average warm summer month temperatures in Hokkaido are around 21.1ºC, whereas during the cold winter months, the temperature is roughly -3.7ºC (Leipe et al. 2013: 155). Three primary vegetation types are presently established in Hokkaido (Leipe et al. 2013: 154). Southwestern Hokkaido consists of a temperate deciduous forest containing Japanese beech (*Fagus crenata*) (Igarashi 2013:139; Leipe et al. 2013: 154). Central and northern Hokkaido consist of a boreal-coniferous forests containing Jezo spruce (*Picea jezonsis*), Glehn's spruce (*Picea glehnii*) and Sakhalin fir (*Abies sachalinensis*), and a temperate broad-leaved forests containing Mongolian oak (*Quercus mongolica var. grosseserata*), Painted maple (*Acer mono*), and Erman's birch (*Betula ermanii*) (Igarashi 2013:140). There are many plant species that contributed to prehistoric subsistence in Hokkaido. These plant species include millets, fruits, and some types of nuts. Given this, a more detailed discussion of these plant species and their prehistoric utility is provided in the next chapter.

Rebun Island is associated with subarctic and marine climates (Sakaguchi 2007b: 33). Despite its northern location, sea-ice does not form around Rebun Island because the warm Tsushima Current of the Sea of Japan travels past Rebun, preventing sea-ice from accumulating (Keally 1990: 20; Sakaguchi 2007b: 33). Seasonal temperature variation on Rebun Island is similar to that of Hokkaido. Summers are characterized as dry, while winters are cold and stormy (Keally 1990: 20; Sakaguchi 2007b: 33; Sato et al. 1998: 58). The vegetation of Rebun Island is described as a mixed broad-leaved and coniferous forest which is similar to the neighbouring island Rishiri (Igarashi 2013: 141-142; Keally 1990: 19). Bamboo grasses grow throughout Rebun Island on top of the dune formations. The central region of Rebun Island is dominated by a mixed forest environment which contains firs (*Abies sachalinensis*), spruce (*Picea jezoensis*), and birch (*Betula ermanii*). However, additional research is still required to examine the prehistoric vegetation of Rebun Island (Keally 1990: 19). Nevertheless, climate fluctuations have been documented in these regions through paleoenvironmental reconstructions for the Holocene.

In Hokkaido, the Pleistocene-Holocene environmental transition affected the native fauna and flora, as well as prehistoric peoples (Koizumi et al. 2003; Nakazawa et al. 2011). At the beginning of the Holocene (12,900 to 11,600 cal. YBP), a global cooling event known as the Younger Dryas also affected plant and animal species found in Hokkaido (Nakazawa et al. 2011). Fluctuations between warmer and colder environments are known to have continued into the Mid-Holocene (6000 to 2000 YBP) (Igarshi 2013; Igarashi et al. 2011; Koizumi et al. 2003; Leipe et al. 2013). Through the use of pollen chronologies and diatom analyses, researchers have been able to document climatic and environmental changes from the Mid-Holocene period in Hokkaido (Habu 2004: 42; Lutaenko et al. 2007: 345).

Researchers have described the period from 8000 to 5000 YBP as the climatic optimum in Hokkaido (Lutaenko et al. 2007: 345). During this time, oak became established throughout Hokkaido as the northward trajectory of the warm Tsushima Current helped increase the range of the cool-temperate forest in Japan (Lutaenko et al. 2007: 345). By 5000 YBP, cooler climates reoccurred in Hokkaido (Lutaenko et al. 2007: 345). This has been demonstrated by the expansion of spruce and fir species in Hokkaido and through diatom analyses which support a cooling trend in northern Japan from 4650 and 1800 cal. YBP (Igarashi 2013: 149; Koizumi et al. 2003: 149; Lutaenko et al. 2007: 346). From 1732 to 1246 cal. YBP, a cold period known as the ‘Kofun cold stage’ occurred in northern Japan (Koizumi et al. 2003: 154). During the Kofun cold stage, the amount of annual sea-ice increased on the Sea of Okhotsk (Koizumi et al. 2003: 149). From roughly 1300 cal. YBP onward, limited levels of sea-ice accumulation was found in the Sea of Okhotsk (Koizumi et al. 2003:154). However, a ‘late ice-age’ occurred in Hokkaido from 400 to 200 cal. YBP, and is associated with cooler annual temperatures than at present (Koizumi et al. 2003: 155).

The wildlife of Hokkaido provided prehistoric hunter-gatherers with a variety of subsistence options. However, the accessibility and use of animal food resources in Hokkaido are shown to have varied throughout prehistory (Habu 2004; Imamura 1996; Nishimoto 2000; Yamaura 1998). Regardless, essential terrestrial and aquatic species known to contribute to prehistoric subsistence are listed here to provide the necessary dietary context for the hunter-gatherers who occupied Hokkaido and Rebun Island. In Hokkaido, terrestrial mammals include: sika deer (*Cervus nippon*), and bear; Hokkaido brown bear (*Ursus arctos*), rabbit (*Lepus timidus ainu*), fox (*Vulps vulps schlenki*), marten (*Martes zibellina*), and otter (*Lutra lutra whieteyi*) are also found in prehistoric faunal assemblages (Ohyi 1981: 720). In coastal areas, sea birds were also found to be a part of hunter-gatherer diets: cormorant (*Phalacrocarx*), Great albatross (*Diomedea*), and various water fowl species (Ohyi 1981: 720). Domesticated boar (*Sus scrofa inoi.*)

and dog (*Canis familiaris*) were also included in hunter-gatherer diets later in prehistory.

Aquatic subsistence resources were also an important component of hunter-gatherer diets in Hokkaido. Most notably, sea mammals, which include seals, sea lions, whales, and dolphins, were eaten by hunter-gatherers in this region. Seal species include fur seal (*Callorhinus ursinus*), harbor seal (*Phoca vitulina*), ringed seal (*Pusa hispida*), ribbon seal (*Histriophoca fasciata*), and bearded seal (*Erignatus barbatus*) (Ohyi 1981: 720). Remains of the Steller sea lion (*Eumetopias jubata*), and Japanese sea lion (*Zalophus californianus japonicus*), were also frequently featured in prehistoric faunal assemblages in Hokkaido (Ohyi 1981: 720). Many species of the Cetacea family were exploited by coastal hunter-gatherers in Hokkaido and on Rebun Island: white-sided dolphin (*Lagenorhyncus obliquidens*), common porpoise (*Phecoena phocoena*), Dall's porpoise (*Phocoenoides dalli*), pilot whale (*Globicephala melaena*), false killer whale (*Pseudorca crassidens*), sperm whale (*Physeter macrocephalus*), humpback whale (*Megaptera novaeangliae*), sei whale (*Balaenoptera borealis*), minke whale (*Balaenoptera acutorostrata*), and right whale (*Eubalaena glacialis*) (Ohyi 1981: 721).

Several salmon and trout species were frequently exploited by coastal and inland prehistoric peoples in Hokkaido (Imamura 1996: 76-77). Additionally, pelagic and demersal fishes were also eaten by hunter-gatherer groups. Some of these pelagic species include herring (*Clupea pallasi*), Atka-mackerel (*Pleulogramus azous*), cod (*Gadus macrocephalus*), and Salmon shark (*Lamuna* *ditropis*) (Ohyi 1981: 720). Common demersal fishes include scorpion-fish and flounder. Sea-urchin (*Srongilocentrotus interomedius* and *S. nudus*) is also frequently recovered from prehistoric shell-middens on Rebun Island (Ohyi 1981: 719).

Chapter Three – Archaeological Context of Hokkaido and Rebun Islands

3.1. The Holocene Cultural History of Hokkaido and Rebun Island – An Overview

Holocene hunter-gatherers left behind an archaeological record that continues to be an interesting discussion topic in archaeology. In Hokkaido, Holocene hunter-gatherers were proceeded by hunter-gather groups who arrived to Japan during lower sea-levels (30,000 cal. YBP) (Imamura 1996; Kikuchi 1986; Kobayashi 2004; Mizoguchi 2002). Northern and Southern migration routes have been discussed for the initial prehistoric colonization of the Japanese Islands during the Pleistocene (Aikens and Higuchi 1982; Hanihara 1991; Imamura 1996; Kikuchi 1986; Ono 1999). However, recent genetic studies have demonstrated that a Northeast Asian ancestry is more likely for the hunter-gatherer groups who arrived to Japan by 20,000 cal. YBP (Adachi et al. 2009; Hanihara and Ishida 2009).

The procession of prehistoric immigration to Hokkaido from Northeast Asia, as well as from the southern Japanese islands created cultures in Hokkaido that were distinct compared to those found in the other Japanese islands (Kikuchi 1986: 149). The primary attributes which are used to differentiate Holocene hunter-gatherers in Hokkaido from those in the rest of Japan include the emphasis on marine based subsistence, and the stockier body proportions of these Hokkaido hunter-gatherers which are typically associated with arctic peoples (Akazawa 1986; Befu and Chard 1964; Chisholm et al. 1992; Fukase et al. 2012; Minagawa and Akazawa 1992; Okada 1998a; Okada 1998b; Temple and Matsumura 2011; Yamaura 1998). The hunter-gatherer groups found in Hokkaido during the

Holocene are the Jomon (from the Incipient to Final phase) (16,000−2500 cal. YBP), Epi-Jomon (2500−2300 cal. YBP), Okhotsk (1500−700 YBP), Satsumon (1400−800 YBP), and Ainu (800−83 YBP). The Yayoi culture (2800 to 1700 cal. YBP), known for intensifying rice cultivation in southwestern Japan, did not spread to Hokkaido (Aikens and Higuchi 1982: 241; Matsui and Kanehara 2006: 260). Past environmental conditions are believed to have prevented the expansion of Yayoi rice agriculture in Hokkaido (Imamura 1996: 198; Nakamura 1980: 184). This allowed hunter-gatherer life styles to persist in Hokkaido well into the historic Ainu period (Aikens and Akazawa 1996: 225). Although rice cultivation never arrived to Hokkaido prehistorically, plant husbandry is known to have begun here during the early phases of Jomon (Bleed 1989; Bleed and Matsui 2010; Crawford 1997, 2008, 2011; Crawford and Takamiya 1990; Crawford et al. 1976; Kidder 1968). This finding has called to question the appropriateness of applying the term *hunter-gatherers* to prehistoric groups in Hokkaido (Crawford 2008). Conversely, some scholars posit that these agricultural practices should not be considered when discussing prehistoric agriculture in Japan (Matsui and Kanehara 2006). Regardless, the cultural groups discussed in this thesis are referred to as hunter-gatherers. The use of this definition here also aims to include the assertion that prehistoric groups in Hokkaido also practiced some form of plant husbandry and or agriculture that contributed to their overall subsistence.

The Holocene cultural history of Rebun Island is similar to that of Hokkaido. The habitation of Rebun Island is thought to date back to the late Pleistocene (20,000 cal. YBP), although only sites dating to the Jomon period, Epi-Jomon, Okhotsk, Satsumon and Ainu cultures have been confirmed (Nishimoto 2000; Sakaguchi 2007a: 29, 2007b: 33). The most extensive occupations of Rebun Island were during the Late Jomon, Epi-Jomon and Okhotsk periods (Sakaguchi 2007a: 29, 2007b: 33). The productive marine environment around Rebun Island which was abundant in fish and shellfish, sea mammals including seals, sea lion, whale and dolphin, would have attracted prehistoric hunter-gatherers to this region (Keally 1990: 23; Nishimoto 2000; Sakaguchi 2007b: 33; Yamaura 1998: 323). Albatross and seagulls were also hunted prehistorically on Rebun Island; however, the use of native plant and terrestrial animal resources is believed to be limited given the low biodiversity of the island (Keally 1990: 23; Nishimoto 2000: 278; Sakaguchi 2007b: 33).

The Middle Jomon occupation of Rebun Island at Uedomari 3 is believed to have been a permanent settlement (Keally 1990). Whereas the archaeological and faunal assemblages dated to the Late Jomon period suggest that the island was occupied by hunter-gatherer groups who traveled from southern Hokkaido during the later spring and early summer for hunting seals and constructing ceramics out of local clays (Nishimoto 2000: 278-279; Yamaura 1998: 323). Obsidian materials recovered from sites on Rebun Island support the connection between Rebun Island and southwestern Hokkaido during the mid Holocene (Tomura et al. 2003). However, additional research is needed to expand this argument for the Middle Jomon period of Rebun Island. During the Okhotsk period it is thought that Rebun again became permanently settled (Ohyi 1981: 723; Sakaguchi 2007b: 33). Obsidian has also been recovered from Okhotsk sites on Rebun Island but the provenance of these materials has yet to be determined. Only cultural materials from the Middle Jomon and Okhotsk periods are examined in this thesis. The background archaeological context for the Jomon (from the Incipient to the Final phase), Epi-Jomon, Okhotsk and Satsumon periods is provided given their relevance to the examined archaeological materials. The archaeological sites examined in this chapter are all from Rebun Island and include: Uedomari 3, Kafukai 1, and Hamanaka 2 (Nakatani).

3.2. The Jomon Period

The Jomon period has been demonstrated archaeologically to have survived for roughly 10,000 years in the Japanese archipelago, making the it the most distinct and cohesive cultures in Japanese prehistory (Habu 2004: 3; Imamura 1996). Jomon culture is most widely known for the development of elaborate ceramic technologies. Until recently, Jomon ceramics were established as the oldest in the world (Habu 2004; Kobayashi 2004). The word Jomon means cord-marked. This name references the cord-marked impressions made on the ceramics by Jomon artisans (Esaka 1986: 223). Current archaeological, genetic, and osteological evidence suggests a Northern ancestry for all Jomon peoples, dating to 20,000 cal. YBP. (Adachi et al. 2009; Habu 2004; Hanihara and Ishida 2009; Kikuchi 1986; Temple and Matsumura 2011). Jomon culture is thought to have replaced their Paleolithic ancestors at the end of the LGM upon its arrival to Hokkaido (Hanihara and Ishida 2009: 312; Y. Ono 1999: 32). The use of watercraft in Japan likely dates back to the Pleistocene since the movement of obsidian during this period has been identified between Honshu Izu Islands which are located 200km south of Tokyo on the Pacific Ocean (Yamaura 1998: 325). Additionally, the remains of paddles and possibly a canoe have been recovered from the Torihama site in Honshu, on the Sea of Japan, which date to the Early Jomon (Ikawa-Smith 1986: 203).

The Jomon period is divided into a few discrete cultural periods: Incipient, Initial, Early, Middle, Late, Final, and Epi. The inception dates of each of these periods differ by region in Japanese archipelago. In Hokkaido, a reservoir effect has made calibrating ^{14}C ages difficult (Habu 2004; Omoto et al. 2010). Currently, the established start dates for the periods of Jomon in Hokkaido are as follows: Incipient 16,000 cal. YBP, Initial >10,000 cal. YBP, Early 7000 cal. YBP, Middle 5400 cal. YBP, Late 4300 cal. YBP, Final 3200 ca. BP, Epi 2400 cal. YBP (Omoto et al. 2010: 8). It should be noted here that the Epi-Jomon phase (also known as Zoku-Jomon), is only found in the Aomori Prefecture of northern Honshu, the coastal areas of Hokkaido, and the Kuril Islands (Aikens 1982: 241; Phillips 2010; Yamaura 1998). The Epi-Jomon continued hunter-gatherer life styles in these regions that was reminiscent of those seen during the previous phases of the Jomon period, while rice cultivation began in Kyushu and Honshu (Aikens 1982: 96; Ono 1999: 33). Therefore, Epi-Jomon is treated separately from the rest of the Jomon period in this chapter.

The Incipient Jomon marked the development of seasonal task-specific settlements in Japan (Mizoguchi 2002:76-77). In Hokkaido, the production of ceramic technology began towards the end of the Incipient stage with shell incised, flat-based pottery (Kobayashi et al. 1992: 88-89). During this early stage of Jomon, group mobility remained high with few traces of dwellings (Imamura 1996: 56, 88; Lutaenko et al. 2007: 363). This is believed to indicate a focus on family units rather than larger groups (Mizoguchi 2002: 77). Jomon dwellings typically are rectangular, semi-subterranean pit-houses that have two to three rows of posts to support a roof (Lutaenko et al. 2007: 363). The lithic technology of the Incipient stage is composed of slender and tanged spearheads, triangular shaped arrowheads, as well as end scrappers, and chipped stone axes (Imamura 1996: 45, 88). Although wild boar did not exist in Hokkaido until the Late and Final Jomon, deer hunting is known to have persisted in Hokkaido since the Incipient stage of Jomon (Imamura 1996: 88; Kobayashi 2004: 88).

Increases in population and site size have been attributed to the broadening of the Jomon diet to include more plant and marine resources. This began by the end of the Initial period, and beginning of the Early period of Jomon (Imamura 1996: 88). This has been demonstrated by examining the differences seen in lithic assemblages recovered from inland and coastal sites, in addition to the accumulation of shell middens during these periods (Habu 2004: 72-73; Imamura 1996: 88-89; Okada 1998b: 336). Sea levels during the Early Jomon period are estimated to be 5m higher than present (Bleed et al. 1989:111). During this time, Early Jomon sites were situated on terraces that would have provided a suitable location for habitation (Crawford et al. 1976: 145, 1997: 94; Bleed et al. 1989: 114). Plant remains recovered from the Initial period sites in the Kameda Peninsula of Hokkaido are composed of herbaceous annual plants, in addition to shrub and nuts (Crawford et al. 1976; Crawford 2011: 337). In this region, annual plants, fruits from trees and shrubs become more common in Initial Jomon diets (Crawford 2011: 337). However, the use of plant resources, especially nuts, are seen to be much lower in Hokkaido than in central and western Japan (Crawford 1997: 94, 2008: 452, 2011: 337; Habu 2004; 78).

The toolkit that emerged during the Early stage of Jomon in Hokkaido carried through to the Late and Final stages of Jomon, and into the Epi-Jomon, Okhotsk, Satsumon and Ainu cultures (Lutaenko et al. 2007: 364; Okada 1998a: 342). This toolkit included open socket toggle harpoons, fishnet sinkers, fishhooks, stone knives, chipped and polished axes and adzes (Lutaenko et al. 2007: 364; Matsui 1995: 332; Okada 1998a: 342). The use of open-socket toggle harpoons is unique to the hunter-gatherer groups found in Hokkaido (Matsui 1995: 332). The origins of the open socket toggle harpoon found in Hokkaido are thought to derive from the Amur Basin where sturgeon and carp were fished by earlier coastal adapted groups (Yamaura 1998: 325). This material culture supports the emphasis on a marine diet that emerged in Hokkaido during the Early period of Jomon (Matsui 1995: 332). Excavations of the shell midden site Kitakogane in southern Hokkaido, have demonstrated that fish, shellfish, as well as sea mammals (i.e., fur seals) were important to the Early Jomon diet (Minagawa and Akazawa 1992: 61).

Regional ceramic styles began to emerge by the Early period of Jomon (Kikuchi 1986: 156; Kobayashi et al. 1992; Lutaenko et al. 2007: 364: Okada 1998a: 341). Cord-marked and pointed base styles of pottery continued in

Hokkaido during the Early Jomon period (Kobayashi et al. 1992: 89). Later, the development of cylindrical pottery shapes in Hokkaido became known as the Ento type which is generally found in southern Hokkaido, while the Hokuto type is typically found in the north (Kobayashi et al. 1992: 89). This cylindrical ceramic style persisted into the Middle Jomon period where it was elaborated further (Crawford and Takamiya 2008: 638; Kikuchi 1986: 157).

The Middle stage of Jomon is often treated as the pinnacle phase of Jomon throughout the Japanese archipelago (Imamura 1996: 93). Middle Jomon groups are known to have developed the ornate flame rim pottery style that became typical of Jomon ceramic technology in the subsequent periods (Kobayashi 2004: 42; Lutaenko et al. 2007: 366). The utilization of ceramics is also thought to have changed during the Middle Jomon period as ceremonial activities became more widely practiced (Imamura 1996: 95; Kobayashi 2004: 42; Lutaenko et al. 2007: 366) Thus, the use of ceramics in funerary practices and other ritual activities discontinued the production of ceramics solely for utilitarian purposes such as cooking and food storage (Kobayashi 2004: 42−49). Changes in ceremonial practices during the Middle Jomon are also represented in the construction of a large number of anthropomorphic ceramic figurines (i.e., dogu), and stone rods (i.e., sekibo) (Habu 2004: 144; Imamura 1996: 95−100; Lutaenko et al. 2007: 366; Nagamine 1986; Underhill and Habu 2006: 139).

In Hokkaido, the maritime economy that developed during the Early Jomon continued to flourish during Middle Jomon (Matsui 1995: 332−333; Okada 1998a: 336). During the Middle Jomon period in eastern Japan and Hokkaido the number and size of occupation sites and shell middens significantly increased (Habu 2004: 73; Imamura 1996: 93; Lutaenko et al. 2007: 365−366; Matsui 1995; Okada 1998a: 342; Okada 1998b: 336; Twiss 2008; Underhill and Habu 2006: 139). Shell midden and site densities in eastern Japan are found to be four times greater than western Japan (Okada 1998b: 336). This trend has been attributed to the productive marine and deciduous forest environments in eastern Japan and Hokkaido (Habu 2004: 60; Okada 1998b: 336). This trend gave rise the “salmon hypothesis”. This hypothesis supports the view that the incorporation of salmon into the diets of prehistoric peoples in eastern Japan supported larger populations than those who did not have access to additional salmon stocks throughout the year (Habu 2004: 60; Imamura 1996: 75−76; Okada 1998b: 336). Shell middens produced during the Middle Jomon period are found in coastal areas, as well as several kilometers inland if coastal areas were inhabitable (Matsui 1995: 330; Okada 1998a: 342). Sea mammal hunting became an essential component of subsistence during the Middle Jomon period in Hokkaido (Okada 1998a: 342; Yamaura 1998: 325). It has been suggested that during spring and summer months Middle Jomon groups resided on the coasts producing large shell middens, while during the fall and winter months these groups travelled inland to access salmon streams and deer runs (A Okada 1998: 342; Yamaura 1998: 323). Dietary analyses of Jomon populations in Hokkaido and Honshu have established that the protein sources for these two regions differed prehistorically (Habu 2004:74-74; Minagawa and Akazawa 1992). Through stable isotope analysis of Middle Jomon skeletal remains, Minagawa and Akazawa (1992) confirmed that $\delta^{13}C$ signatures were more elevated in Honshu when compared to the remains analyzed from Hokkaido. This indicates plant, and terrestrial mammal proteins made up a large portion of the Middle Jomon diet in Honshu. Moreover, elevated $\delta^{15}N$ signatures in the remains analyzed from Hokkaido suggest marine resources were more important in Hokkaido diets. Although marine and terrestrial animals composed large portions of Middle Jomon diets in Hokkaido, plant foods were also an essential component of their subsistence (Yamaura 1998: 325).

Roughly two-hundred plant species of potential dietary use are represented in Middle Jomon paleobotanical assemblages recovered in Hokkaido (Crawford 2006: 87). The most frequently recovered plants remains from Middle Jomon sites in Hokkaido include barnyard millet and grass, knotweed, elderberry, grapes, and sumac (Crawford 2006: 87). The domestication of barnyard millet began to appear during the Middle Jomon period in the Kameda Peninsula of southern Hokkaido (Crawford 2011: 333). In this region of Hokkaido, paleobotanical analyses have shown a 20% increase in the size of seeds over time suggesting prehistoric selection for larger grades (Crawford 2011: 333). This evidence supports the position that the hunter-gatherers of Hokkaido practiced plant husbandry by the Middle Jomon period at the latest.

Cultural innovation continued into the Late Jomon period with the construction of communal cemeteries demarcated by stone circles (Ikawa-Smith 1992; Kobayashi 1992, 2004; Sakaguchi 2011). In Hokkaido, the Late Jomon period is described as peak of Jomon culture in this region (Kato et al. 2008: 1032). During Late Jomon, stone circle cemeteries are found in central and northern Hokkaido, including on Rebun Island (Sakaguchi 2011). Archaeologists developed several theories to explain the emergence and decline of this cultural phenomenon in Hokkaido. These theories center on the social-political complexity of Late Jomon culture and the paleoenvironmental pressures that were believed to have been present during the mid-Holocene (Ikawa-Smith 1992; Kobayashi 1992, 2004; Sakaguchi 2011). Sakaguchi (2011) demonstrated that the proportion of grave goods recovered from inner and outer graves found in communal cemeteries in Hokkaido varied. Inner graves showed a higher proportion of exotic and prestige items when compared to the assemblages recovered from graves found outside the communal cemetery. Sakaguchi (2011) also noted that the differences in assemblage variability were more pronounced at larger cemeteries suggesting that these areas served as important centers of exchange. Sakaguchi (2011) says that increased levels of socio-political complexity are likely to have contributed to the construction of these sites since degrading environmental conditions would not be favorable in the construction of monumental sites, given the level of organization and resources needed to orchestrate their construction. Moreover, recent paleoenvironmental reconstructions have demonstrated that the climate during the Late Jomon period was warmer compared to earlier periods (Sakaguchi 2011: 278).

Evidence for long-distance exchange during the Late Jomon strengthens the argument for increasing levels of social-political complexity during this time period. During Late Jomon, central Hokkaido became a centralized point of influence given the presence of complex stone circle cemeteries found in this region, and mixing of cultural materials derived from Honshu, northeastern Hokkaido, and Sakhalin (Kato et al. 2008; Sakaguchi 2011). The distribution and use of ceramic styles in Hokkaido during the Late Jomon appear to be directly influenced by the ceramic styles of the Tohoku region of northern Honshu (Kikuchi 1986: 157). Jade pendants recovered from the Funadomari cemetery on Rebun Island have been sourced to the Niigata Prefecture of Honshu (Oxenham et al. 2006: 37). Additionally, bitumen used in the crafting of bone tools at Funadomari have been sourced to deposits located in both Sakhalin and Honshu, about 1500km away from Rebun Island (Kato et al. 2008). Furthermore, obsidian artifacts dated to the Late Jomon period on Rebun Island have been sourced to the Akaigawa deposit, roughly 400km from Rebun Island in central Hokkaido (Nishimoto 2000; Tomura et al. 2003). Therefore, Late Jomon groups in Hokkaido and Rebun Island were incorporated into the socio-political and economic sphere of influence of Northeast Asia, central Hokkaido, and central Japan. The diminished role of communal cemeteries during the later part of the Late Jomon and Final Jomon reflects a decline in the social-political organization between groups in central Hokkaido and Honshu. The decline of Jomon culture has been linked to the arrival of Yayoi peoples to Japan. As Yayoi and Jomon groups intermixed in western Japan, kinship structures, and exchange structures would have either been modified or have collapsed (Aikens and Higuchi 1982; Crawford 1992: 127, 2011; Hudson 1999, 2004; Kobayashi 2008; Kobayashi et al. 1992).

Final Jomon marks the end of Jomon period in Japan. During the Final Jomon, site density and site size are seen to decrease throughout Japan (Crawford and Takamiya 1990:892-893; Lutaenko et al. 2007: 367; Twiss 2008). Colder climates during the late-Holocene have been linked to the decline in Final Jomon productivity (Koizumi et al. 2003: 154; Lutaenko et al. 2007: Okada 1998b: 336; Sakaguchi 2011: 278; Yamaura 1998: 325). In Hokkaido, Final Jomon diets continued to include marine resources, terrestrial game and plant materials (Crawford 2011; Okada 1998a; Okada 1998b; Yamaura 1998). However, the number of shell midden sites dated to the Final Jomon supports the decline in the overall productivity of Final Jomon and potentially of the marine environments which they relied upon for subsistence (Okada 1998a: 342; Okada 1998b: 336). Additionally, there is a decline in the number of residential sites associated with Final Jomon groups on Rebun Island (Sakaguchi 2007a: 27, 2007b: 33). Although the Jomon culture had substantially declined during this time, Tohoku style ceramics, and jade from Honshu continued to be represented in Final Jomon assemblages in Hokkaido indicating continued ties to central Japan (Kikuchi 1986: 158; Kobayashi 2004:164).

By the Final Jomon phase in Hokkaido, Yayoi peoples had already lived in Japan for roughly 400 years. Carbonized rice grains found in Late and Final Jomon sites from Kyushu to northern Honshu have shown that rice was known to Jomon peoples before the arrival the Yayoi groups (Hudson 1999: 108). Thus incorporation of Jomon into Yayoi is thought to have been a gradual process of cultural assimilation (Hudson 1999; Kobayashi 2008). In Honshu, the blurring of

Yayoi and Final Jomon ceramic styles display the multidirectional cultural transmission between Yayoi and Jomon peoples (Hudson 1999: 118−123). When Yayoi peoples spread into the Tohoku region of Honshu, the Jomon culture was nearly disbanded throughout the Japanese archipelago (Crawford 2011; Crawford and Takamiya 1990: 894−895). Final Jomon groups who were not incorporated into the Yayoi culture likely spread to Hokkaido where their culture changed into a distinct hunter-gatherer group, the Epi-Jomon.

3.3. The Epi-Jomon

As previously mentioned, the Epi-Jomon culture is found in the Aomori prefecture of northern Honshu, Hokkaido, and the Kuril Islands (Okada 1998b; Yamaura 1998). Epi-Jomon peoples perpetuated the hunter-gatherer life styles practiced by their Jomon predecessors in Hokkaido while Yayoi peoples became established throughout Japan (Crawford and Takamiya 1990: 896). Early Epi-Jomon is contemporary to the later portion Final Jomon in Hokkaido (Crawford and Takamiya 1990: 896). Epi-Jomon is thought to have begun in the Oshima Peninsula of southern Hokkaido (Crawford and Takamiya 1990: 896; Okada 1998a: 342; Kikuchi 1986: 158). Epi-Jomon differs from the proceeding Jomon groups in their material culture and subsistence economy (Crawford 1992: 121). Epi-Jomon sites are generally defined by the presence of Esan and Ebetsu type pottery (Crawford and Takamiya 1990; Okada 1998a; Okada 1998b). Esan pottery is found from the beginning of Epi-Jomon in southern Hokkaido and is associated with the production of shell midden complexes (A. Okada 1999: 342). Ebetsu pottery appeared at latter half of the Epi-Jomon and is associated with riverine fishing sites throughout Hokkaido (Okada 1998a: 346).

Epi-Jomon subsistence is thought to be primarily derived through hunting and fishing. Evidence of this is seen in the faunal remains excavated from Epi-Jomon shell midden sites, and in the sea mammal carvings and hunting iconography represented in Epi-Jomon material culture (Okada 1998b: 336−337; Yamaura 1998: 325). Additionally, few cultigens have been recovered from Epi-Jomon sites supporting the position that sea mammals were the primary source of subsistence for these prehistoric peoples (Crawford 2011; Crawford and Takamiya 1990). The lack of evidence to support the use of plant husbandry by Epi-Jomon peoples does not indicate that plant materials were unused by Epi-Jomon peoples. On the contrary, shrub and vine fruits, as well as nuts, and camp follower species (i.e., edible plant species that accumulate near areas of anthropogenic activity) have been found at Epi-Jomon sites (Crawford 2011: 338). Nonetheless, Epi-Jomon culture is treated as less complex than Final-Jomon groups.

The large residential and task specific camps seen during the Jomon period did not carry on into the Epi-Jomon era (Crawford 1992: 121, 2011: 338). Only small short-term habitation sites are associated with the Epi-Jomon occupation of Hokkaido (Crawford 2011: 338; Crawford and Takamiya 1990: 896). Cemeteries, including burials in shell-middens are also associated with Epi-Jomon (Crawford and Takamiya 1990: 896). Cultural materials produced by the Tohoku Yayoi such as metal tools, glass beads, pottery are often found in Epi-Jomon assemblages in

Hokkaido (Crawford 2011: 338; Crawford and Takamiya 1990: 896; Hudson 2004: 293; Imamura 1996: 199-201). Additionally, shells used in bracelets recovered from an Epi-Jomon site in southwest Hokkaido have been identified as tropical cone shell species native to the Ryukyu island chain of southeast Japan (Hudson 2004: 293). Epi-Jomon pottery has been recovered from Yayoi sites in Tohoku showing multidirectional exchange between these groups (Crawford 2011: 338). However, there are few examples of Epi-Jomon artifacts in Yayoi assemblages.

The importation of new material culture elements into Hokkaido is believed to have contributed to the destabilization of central regions of influence during the Late and Final Jomon (Crawford 1992: 127; Hudson 2004: 293). The residual evidence of this decline is thought to be demonstrated by the scarcity of well established Epi-Jomon sites, and lack of a more defined material culture in Epi-Jomon assemblages (Crawford 1992: 121). It is still unclear what brought about the end of the Epi-Jomon culture in Hokkaido. However, it is likely that interaction between Epi-Jomon and Yayoi peoples in northern Honshu and Hokkaido contributed to the formation of the Satsumon culture. Prior to the end of Epi-Jomon, the Okhotsk Culture appeared in northern Hokkaido.

3.4. The Okhotsk Culture

The Okhotsk culture is well known for its maritime adaptation with specific specialization on open-sea and costal marine mammal hunting on the Sea of Okhotsk (Ackerman 1982; Befu and Chard 1964; Deryugin 2008; Hudson

2004; Ohyi 1975; Moiseyev 2008; Okada 1998a; Okada 1998b; Ono 2008; Sakaguchi 2007a, 2007b; Yamaura 1998). Archaeological remains of the Okhotsk culture are found on Sakhalin Island, the coast of northern Hokkaido, and the Kuril Islands. The cultural ancestry of the Okhotsk is from the Amur River of Northeast Asia (Deryugin 2008; Matsumura et al. 2009; Moiseyev 2008; Sato et al. 2009; Ohyi 1975). The earliest evidence of the Okhotsk culture appeared on Sakhalin Island by AD 500 (Befu and Chard 1964; Ohyi 1975). From there, Okhotsk peoples spread to Rebun Island, Rishiri Island, the north coast of Hokkaido, and on to eastern Hokkaido and the Kuril Islands (Ohyi 1975). Keally (1990) suggests that the Middle Jomon peoples who occupied Rebun Island travelled north to Sakhalin Island where thousands of years later their descendants formed into the Okhotsk Culture. However, there is little evidence to support this hypothesis.

Similarly to the treatment of Jomon, the Okhotsk culture is divided regionally and temporally on the basis of ceramic styles. In Hokkaido, the Okhotsk pottery styles include Towada (AD 500 to AD 600), Kokumon (AD 700), Chinsemon (AD 750 to AD 800), Haritsukemon (AD 800), Somenmon (AD 850), Motochi (AD 900 to AD 1000), and Tobinitai (AD 1050 to AD 1300) (Deryugin 2008: 60). On Rebun Island, pottery of the Enoura B and Enoura A (AD 700 to AD 800) types associated with Okhotsk occupations in Sakhalin are found at the Kafukai 1 site (Oba and Ohyi 1981: 716). Deryugin (2008) argues that only ceramics associated with the Enoura type should be treated as Okhotsk cultural materials. However, prior to Deryugin's (2008) publication all of the aforementioned ceramic types are treated as Okhotsk materials. Until additional research is conducted on this topic all the ceramic styles mentioned here should continue to be regarded as Okhotsk[2].

The Okhotsk people are known to have imported domesticated pigs and dogs to Hokkaido from Sakhalin (Befu and Chard 1964: 3; Nishimoto 2000: 281; Ohyi 1975: 138). As Okhotsk groups expanded into eastern Hokkaido pig breading was abandoned since an abundance of riverine fishes, deer, and other terrestrial resources provided ample subsistence in this region (Hudson 2004: 296; Ohyi 1975: 141; Yamaura 1998: 327). Moreover, the shift towards the incorporation of terrestrial resources in the diets of eastern Okhotsk groups is thought to be a result of the limited access to fur seal populations in this region (Ohyi 1975: 141). Although, remains of barley, millets, buckwheat, elderberries, and walnuts have been recovered from Okhotsk sites, little is known about Okhotsk horticultural practices throughout the Sea of Okhotsk region (Crawford 2011: 339; Hudson 2004: 296).

During its early stages, the Okhotsk culture was confined to the peripheral regions of Hokkaido while Epi-Jomon groups were still established in central and southern Hokkaido (Okada 1998a: 346). Furthermore, it is suspected that earliest stage of Okhotsk (Towada) did not have direct access to obsidian resources found in eastern and central Hokkaido; Shirataki and Oketo (Personal Communication T. Amano, 2012). However, in later stages of the Okhotsk culture obsidian artifacts made from Shirataki, and Oketo materials became more widely used

[2] Motochi and Tobinitai are regarded as Okhotsk ceramic types that share characteristics of Satsumon ceramic styles given the acculturation of Okhotsk by Satsumon peoples in Hokkaido by AD 900.

(Personal Communication T. Amano, 2012). This trend has been demonstrated for the eastern Okhotsk groups who inhabited the southern Kuril Islands (Phillips 2010; Phillips and Speakman 2009). Exotic exchange items in Okhotsk assemblages are rare (Befu and Chard 1964: 8; Hudson 2004: 302). Artifacts crafted out of iron and bronze were shaped into harpoon heads, adzes, bells, and buckles (Yamaura 1998: 330). The metals used to produce these artifacts are derived from Honshu and China. Therefore, some form of long-distance exchange must have existed between the Okhotsk and other groups. However, metal tools at Okhotsk sites in Hokkaido are infrequent. This suggests that the Okhotsk were not engaged in extensive long-distance exchange networks, or in the production of specialized goods for exchange (i.e., pelts from fur seals) as previously believed (Hudson 2004: 302-303).

Okhotsk culture amalgamated with the proto-Ainu Satsumon culture by AD 1200 in eastern Hokkaido and the southern Kuril Islands (Deryugin 2008: 62; Hudson 2004). Before the dissolution of the Okhotsk culture in Hokkaido two ceramic types were developed by Okhotsk peoples that display the influence of Satsumon styles. Tobinitai ceramics type emerged in eastern Hokkaido, whereas the Motochi ceramic type appeared only on Rebun Island (Ohyi 1975; Deryugin 2008). Hudson (2004) notes that although the Satsumon assimilation of the Okhotsk culture was most likely a “gradual and structural” process, evidence of warfare between Satsumon and Okhotsk groups in northern Hokkaido suggests resistance of this cultural change. Okhotsk groups who did not become acculturated by Satsumon likely retreated back to Sakhalin (Hudson 2004: 303)

3.5. The Satsumon Culture

The name Satsumon is derived from pottery impressions made on the clay's surface with wooden implements (Crawford and Takamiya 1990: 899). The Yayoi of northern Honshu and the Epi-Jomon culture in Hokkaido are both thought to contribute to the formation of Satsumon (Crawford 2011: 338; Okada 1998b: 337). Genetic and archaeological evidence has demonstrated that Satsumon peoples are ancestors to the Ainu (Crawford 2011: 338; Sato et al. 2009; Yamaura 1998: 325). Regardless of its origins, Satsumon developed in Hokkaido under the influence of the historic Kofun culture of Japan (Hudson 2004; Okada 1998a: 346). The southern Kofun influence began to homogenize subsistence practices and material culture in Hokkaido during the Satsumon period via agriculture, and exchange networks.

The practice of intensified plant cultivation and widespread use of iron tools by Satsumon peoples distinguish this culture from its predecessors in Hokkaido (Crawford 2011: 338; Okada 1998a: 342). Remains of barley, millets, wheat, flax, melon, soybeans, and hemp are frequently recovered through floatation indicating that plant cultivation contributed to Satsumon diets (Crawford 2011: 338). Satsumon peoples situated themselves adjacent to riverine areas in central Hokkaido where they had access to salmon, trout, and terrestrial game. Dried salmon was used by Satsumon peoples for exchange with Kofun societies in Honshu (Hudson 2004: 293). Seal hunting was also practiced by Satsumon groups who occupied coastal regions in Hokkaido (Okada 1998a: 346). This sea mammal hunting adaptation was possibly incorporated from the Epi-

Jomon period, or it was potentially learned from the Okhotsk groups that of northern Hokkaido. After Satsumon, the Ainu became the last hunter-gatherer groups to occupy Hokkaido after its modernization in 1868.

3.6. Archaeological Context of the Uedomari 3 Site

Uedomari 3, is one of four Middle Jomon sites found on Rebun Island, and is situated on top of a terrace that overlooks the shoreline on the northeast coast of Rebun Island (Figure 2.3) (Keally 1990: 20). The site was excavated in 1984 by the Hokkaido Archaeological Resources Center and has been dated to about 4950−4470 YBP (Keally 1990: 21; Sakaguchi 2007a: 29). Since no English summary is provided with the Uedomari 3 site report, Keally's 1990 publication on the site will be relied upon for the necessary archaeological context.

The primary settlement component of Uedomari 3 contained 5 dwelling pits (8 to 12m in diameter, 50cm deep), 14 small pits, 1 stone-encircled hearth, 57 fireplaces, 2 refuse areas, one of which was used primarily as a stone working area (Keally 1990: 21). The Uedomari 3 assemblage contains some 20,000 ceramic fragments, 3,200 lithic tools, 80,000 lithic flakes and pebbles (Keally 1990: 21). As previously mentioned, the rich marine environment of Rebun Island provided substantial resources for the Middle Jomon occupants. By screening the excavated sediments bones from salmon, rockfish, greenlings, cod, Pacific herring were recovered from the site (Keally 1990: 23). The remains of sea lions (i.e., the Steller sea lion *Eumetopais jabatus*), and fur seal (*Callorhinus ursinus*) were also recovered (Keally 1990: 23). In Keally's (1990) summary of the site report he notes that no mollusc shells were excavated. Additionally, very few bird bones were recovered, Remains of seeds and nuts were not mentioned in the report (Keally 1990: 24). This is unsurprising given that toolkit recovered from Uedomari 3 is predominantly composed of spear and arrow heads used for hunting sea mammals, and net weights for fishing (Keally 1990: 24-25). Moreover, Keally (1990) does not mention floatation techniques were used by excavators to recover any potential plant remains. Therefore, there remains the possibility that the occupants of Uedomari 3 utilized plant resources.

Keally (1990) suspects that Uedomari 3 was a permanent occupation site on Rebun Island since there would have been adequate local resources to sustain a population over the winter. Salmon could have been harvested from September to January during the spawning season then stored over the winter (Keally 1990: 26). Local fishes such as the rockfish and greenlings would have also been abundant during the spawning season but also available throughout the year (Keally 1990: 26). Sea lions and seals would have been available through the winter and spring months and are known to provide enough nourishment for northern hunter-gatherer-fisher groups to subsist on throughout the year (Keally 1990: 27). Keally (1990) notes that this rigid dependence on marine resource differentiates Uedomari 3 from other Middle Jomon sites in Hokkaido that contain Ento Upper style ceramics.

The raw materials used to produce the lithics found at Uedomari 3 are marine shale that can be collected locally from Funadomari Bay on Rebun Island, andesite, chert, mudstone, and obsidian. The presence of obsidian at Uedomari 3 demonstrates the presence of long-distance exchange or direct procurement since no deposits of obsidian are found on Rebun Island (Keally 1990: 28). The closest source of obsidian is the Nayoro deposit in northwest Hokkaido about 170km away from Rebun Island (Keally 1990: 28). The largest sources of obsidian in Hokkaido are Shirataki, Oketo, Akaigawa, and Tokachi. These sources are located 200 to 400km from Rebun Island. Therefore, the importation of these obsidian materials to Rebun Island likely coincides with the transport of the Ento style ceramics to Uedomari 3. Keally (1990) suggests that these Ento Upper ceramics were imported to Rebun Island along with other exotic materials, since many of the pots show signs of repair. Keally (1990) also posits that clays on Rebun Island were not suitable for the production of these large ceramics. This position differs from Nishimoto (2000), and Hall et al. (2002) who have suggested that clays derived from Rebun and Rishiri Islands were used in the production of ceramics from the Late and Final Jomon, Epi-Jomon and Okhotsk periods.

3.7. Archaeological Context of the Kafukai 1 Site

The Okhotsk site of Kafukai 1 is located at the mouth of the Kafukai River on the east coast of Rebun Island where the village Kafukai is also located (Figure 2.3) (Ohyi 1981: 711) [3]. The site is located on a sand dune formation and is about 7500m² in area (Ohyi 1981: 711). Two sites are found in the village of Kafukai; Kafukai 1 and Kafukai 2. Kafukai 1 contains archaeological materials dating to

[3] The Kafukai is referred to as the *Kabukai* in earlier academic literature published on the site and Rebun Island. However they are the same site. This was confirmed through the geographic references of the site location in both spellings, and by Hiroko Ono at the Hokkaido University Museum.

the Okhotsk and later Satsumon periods, while Kafukai 2 contains Susuya-type ceramics which are typically found on Sakhalin, and predate the Okhotsk culture (Ono 2003; Ohyi 1981: 711)[4]. Only the Okhotsk materials from Kafukai 1 are examined here. The English summary of the Kafukai report (Ohyi 1981) will be used here to provide the archaeological context for Kafukai 1. The site was excavated from 1968 to 1971 by members of the Research Institute for the Study of North Eurasian Culture on Rebun, Faculty of Literature, Hokkaido University (Ohyi 1981: 711). Kafukai 1 is a well stratified site containing a shell-midden and complex faunal assemblage, semi-subterranean pit-houses, human burials, and an artifact assemblage that contains materials which span from the early to late Okhotsk periods (Ohyi 1981). Therefore, Kafukai 1 continues to be an important site for researching the expansion of the Okhotsk culture from Sakhalin to Hokkaido.

The shell-midden layers found at Kafukai 1 contain the remains of sea-urchin, herring, cod, Atka-mackerel, rockfish, and salmon shark (Ohyi 1981: 719). Remains of sea birds, dogs, boars, brown bear, rabbit, deer and reindeer, seals (fur seal, ribbon seal, harbor, ringed seal, and bearded seal), sea lions (Steller sea lion and Japanese sea lion), dolphin (white-sided dolphin, common porpoise, and Dall porpoise), and whale (pilot whale, false killer whale, sperm whale, humpback whale, sei whale, minke whale, and right whale) were also recovered from the excavations at Kafukai 1 (Ohyi 1981: 721). Brown bear, deer and reindeer are not native to Rebun Island, thus their presence in the Kafukai 1

[4] Kafukai 1 was previously known as Kafukai A, but as the number of sites grew on Rebun Island it was later renamed (Personal communication with Hiroko Ono 2013).

assemblage reflects the transport of these animal remains to Rebun from Hokkaido and Sakhalin (Ohyi 1981: 721). Despite the large number of faunal remains recovered from this site, fishing is estimated to have composed 80% of the total caloric intake of the Okhotsk peoples at Kafukai 1 (Ohyi 1981: 721). Analyses of the fish remains have demonstrated that herring, Atka-mackerel, and cod were prominent subsistence elements for the Okhotsk people at Kafukai 1 (Ohyi 1981: 719). No plant remains were recovered from Kafukai 1 to indicate what portion of the Okhotsk diet was composed of plant resources (Ohyi 1981: 722).

The pit-houses found at Kafukai 1 had hexagonal or rectangular floor plans that are typically associated with Okhotsk dwellings. These dwellings contained hearth features, post holes, and the remains of bear and seal. Bear skulls were found in four of the six pit-houses excavated at Kafukai 1. In all these cases, the skulls were positioned side-by-side at the back of the dwelling on the living floor (Ohyi 1981: 713-714). The number of bear skulls in each dwelling ranged from two to five. Seal skulls recovered from pit-house no. 2 were found in the same position as the bear skulls also retrieved from this dwelling (Ohyi 1981: 713). Given that bears are not native to Rebun Island, the presence of bear remains at Kafukai 1 reinforces the ceremonial importance of bear to the Okhotsk peoples (Masuda et al. 2001; Ohyi 1981: 720). Additionally, mtDNA analysis of these bear skulls has revealed that three of the bears' lineages are derived from central and southwestern Hokkaido (Masuda et al. 2001). Masuda et al. (2001) suggest that Okhotsk peoples exchanged with Epi-Jomon groups in central

Hokkaido for these juvenile bears. The presence of the seal skulls indicates the importance of sea mammal hunting at Kafukai 1. This notion is also supported by the presence of a stone cache structure at Kafukai 1 that contained the bone elements of at least seven pilot whales (Ohyi 1981: 721). The human burials found at Kafukai 1 only contain infants and children (Ohyi 1981: 715). Therefore, adults must have been buried elsewhere on Rebun Island or in a different context (Ohyi 1981: 715). Based on dwelling size, occupational sequences, and the assemblage it is estimated that five families could have occupied Kafukai 1 at a time over the course of its use (Ohyi 1981: 715).

The artifact assemblage of Kafukai 1 contains ceramics, lithic materials, as well as bone, antler, and metal tools. In total, 89,924 pottery sherds were recovered during the excavation of this site (Ohyi 1981: 715). Ceramics from the Enoura type A and B were found at Kafukai 1 from the lower cultural deposits with Towada type ceramics found in later occupational sequences (Ohyi 1981: 716). Additionally, Ohyi (1981) notes that the change from the early to late Okhotsk phase at Kafukai 1 displays a continuous and gradual change over time. Since no other cultural groups breached the Okhotsk continuity at Kafukai 1 it can be assumed that the Okhotsk maintained a control over the occupation Rebun Island and Kafukai during their residency. The toolkit recovered from Kafukai 1 is indicative of the emphasis on fishing and sea mammal hunting since more than half of the artifact assemblage is composed of arrow, spear and harpoon heads, and no medium or large sized terrestrial game could have been hunted on Rebun Island (Ohyi 1981: 716). A total of 737 formed lithic tools, 336 cores, and 6,992 flakes were recovered from the site (Ohyi 1981: 716). Although a number of the lithics recovered from this site are made of obsidian, there is no mention of lithic material types in the English summary. Ohyi (1981) notes that size of the lithic assemblage found at Kafukai1 is comparatively smaller than those documented at other sites in northeast Asia. Ohyi (1981) says that metal tools may have already begun to replace flaked-stone implements, as fewer and fewer lithic tools were recovered from the later occupation layers at the site.

The bone and antler tool assemblage contains the typical open-socket toggle harpoon heads associated with the Okhotsk and the other maritime adapted cultures of Hokkaido (Ohyi 1981: 717). Digging tools and needle cases were also crafted out of bone and antler (Ohyi 1981: 718). Only 16 metal artifacts were found at Kafukai 1 during the 1968−1971 excavations (Ohyi 1981: 718). These tools included iron knives, point tips, a needle, and fish hook, and bone disk with a bronze cover plate (Ohyi 1981: 718). However, it is suspected that the Okhotsk culture did not possess the knowledge of how to refine metals from native ores, and only reshaped existing metal artifacts into desired forms (Ohyi 1981: 719).

Since the ecosystem surrounding Rebun Island would have provided Okhotsk peoples with enough resource to survive the winter, spring and summer months, Ohyi (1981) posits that Kafukai 1 was occupied by Okhotsk groups continuously throughout the year. Both the faunal assemblage and the associated seasonal availability of fishes and sea mammals around Rebun Island demonstrate that 80% of the Okhotsk caloric supply could have been obtained during the winter months and stored, while 20% of the Okhotsk diet would have been supported by subsistence resources acquired during the spring and summer months (Ohyi 1981: 723). Nevertheless, it is also suggested that the number of individuals occupying Kafukai 1 varied throughout the year (Ohyi 1981: 723). This assertion is similar to Keally's (1990) evaluation of the seasonality of the Middle Jomon occupation of Uedomari 3, and Nishimoto's (2000) evaluation of the Okhotsk site Hamanaka 2, location R. Therefore, it is possible that Okhotsk peoples were able to reside on Rebun Island throughout the year in a similar fashion to the Middle Jomon groups.

3.8. Archaeological Context of the Hamanaka 2 (Nakatani) Site

Hamanaka 2 (Nakatani) is situated to the west of Osawa River which drains into Funadomari-Bay on the northern end of Rebun Island (Sakaguchi 2007a: 29) (Figure 2.3). Hamanaka 2 is a multi-component site spread between various locations in the village of Hamanaka (Sakaguchi 2007a: 29). Excavations at these locations have been carried out intermittently by Japanese archaeologists since the 1990's. These pervious excavations have uncovered cultural materials dating from the Late and Final Jomon periods, as well as the Epi-Jomon and Okhotsk cultures (Nishimoto 2000; Sakaguchi 2007a, 2007b). Hamanaka 2 (Nakatani) is located on a sand dune terrace about 150m south of the shoreline. In 2011 the BHAP excavated two trenches totaling 48m^2 that revealed cultural materials associated with the Okhotsk Culture. Given the recentness of the excavation at Hamanaka 2 (Nakatani), the analysis of the excavated materials is in progress. Therefore the information provided here is only an initial assessment of the site.

At Hamanaka 2 (Nakatani), Okhotsk cultural materials were recovered from a well stratified shell midden complex. The remains of fishes (herring, and cod), sea mammals (seal, whale, and dolphin), shellfish (sea-urchin), birds, dogs, and pigs were identified. These faunal remains are similar to those found at Kafukai 1. At least five dog burials were found at Hamanaka 2 (Nakatani). Overturned pots were found overtop several of these graves suggesting the ritual sacrifice of dogs at the site. At Hamanaka 2 location R, Nishimoto (2000) notes that 50 dog skulls were found within $1m^2$, indicating the place of a dog butchering site or dog ceremony. Hamanaka 2 (Nakatani) was likely a processing and cooking camp given the distribution of these faunal remains within the site and the presence of a large stone circled hearth containing fire cracked rocks.

The artifact assemblage includes ceramics, lithic workshops, and bone tools. Excavation revealed a large number of ceramic artifacts that varied in completeness. The flaked and ground stone tools were primarily crafted out of agate, marine shale, and silicified mudstones can be found locally on Rebun Island. Although very few obsidian materials were recovered during the excavation of Hamanaka 2 (Nakatani). Similarly to Kafukai 1, the bone tool assemblage contained harpoon heads, needle cases, and digging tools. Ceramics from Hamanaka 2 location R are associated with early and late Okhotsk groups (Sakaguchi 2007a: 30). Given the proximity of these sites to each other, it is likely that the ceramics recovered from Hamanaka 2 (Nakatani) also reflect these phases of the Okhotsk culture.

One intact human infant burial was also found within the midden. Additional bone fragments found throughout the midden are also thought to be human remains. Roughly one hundred meters to the east of Hamanaka 2 (Nakatani), a large Okhotsk cemetery containing twenty-two individuals was previously excavated in Hamanaka (Sakaguchi 2007b: 42). This cemetery may have severed as the main burial ground for adult Okhotsk peoples on Rebun Island given the lack of adult burials at Kafukai 1, and its central location between Cape Sukoton and Cape Sukai (Nishimoto 2000: 281).

The pattern of refuse found at Hamanaka 2 (Nakatani) suggests the site was a processing site for fishes, shellfish, and sea mammals. Additionally, this is supported by the lack of identified dwelling features in the 2011 BHAP excavation of Hamanaka 2 (Nakatani). As mentioned in the provided Kafukai 1 summary, Nishimoto (2000) notes that Hamanaka 2 location R was likely settled throughout the year. Therefore, the Okhotsk groups who utilized Hamanaka 2 (Nakatani) as a processing camp may have resided in Hamanaka 2 location R. Further excavations are needed to expand the 2011 trenches in order to fully assess the residency of Okhotsk peoples at Hamanaka 2 (Nakatani).

3.9. Summary

The well preserved remains of Holocene hunter-gatherers in Hokkaido and on Rebun Island provide researchers with a broad overview of prehistoric life styles in this region. The early Jomon complexes found in Hokkaido developed a subsistence economy that included the exploitation of marine resources. As the Jomon culture developed in the Middle phase, marine mammal hunting other aquatic resources became more common in Hokkaido diets when compared to rest of Japan. This growing dependence on marine resources created a unique northern character in the prehistoric peoples of Hokkaido. When the Jomon period ended in Japan, hunter-gatherer life styles continued to persist in Hokkaido with the Epi-Jomon culture. The pinnacle of the maritime adaptation in Hokkaido occurred during the Okhotsk period. Succeeding groups of Satsumon and Ainu are shown to have continued to incorporate marine resources into their diets but are not known to have harvested sea mammals to the same extent as the Okhotsk. Additional research is needed to explore the dynamics of cultural change that took place during the Jomon period (from the Incipient to Final period), Epi-Jomon, Okhotsk and Satsumon cultures. Lithic provenance studies in archaeology provide researchers with the opportunity to explore changes in prehistoric resource procurement in the context of mobility, exchange, and prestige economies. Since obsidian is not native to Rebun Island or the neighbouring Rishiri and Sakhalin, its analysis provides a unique opportunity to evaluate the extent of prehistoric resource procurement and cultural contact in this region. Therefore, the analysis of obsidian materials recovered from the sites Uedomari 3, Kafukai 1 and Hamanaka 2 (Nakatani) provides a chance to examine change in obsidian resource procurement of the Middle Jomon, and Okhotsk groups who inhabited Rebun Island.

Chapter Four – Methods of Obsidian Provenance Studies in Archaeology

4.1. Overview

Archaeologists engaged in provenance studies strive to determine the location from which raw materials were obtained. Determining provenance aids in situating an artifact within the broader context of prehistoric resource procurement, mobility, and exchange (Rapp and Hill 2006; Price and Burton 2011). In archaeology, provenance studies have steadily increased over the last 30 years as the use of geochemical methods of analysis has grown (Shackley 1998a, 2008:196). Before the widespread use of geochemical methods, archaeologists relied upon visual methods to distinguish an artifact's provenance (Odell 2000: 272). The instrumental methods of geochemical analysis used by archaeologists include NAA, laser-ablation inductively coupled mass spectrometry (LA-ICP-MS), proton-induced gamma ray emission spectrometry (PIGME or PIXE), electron microprobe analysis (EMPA), X-ray diffraction (XRD), wavelength and energy-dispersive X-ray fluorescence (XRF). Instrumental methods of analysis are commonly used to learn the origin of metal objects (Pollard and Heron 2008; Constantinescu et al. 2012), ceramics (Neff 1998; Hall et al. 2002; Foster et al. 2011), and lithic materials (Herz 2001; Rapp 2002; Odell 2003; Rap and Hill 2006). Nonetheless determining provenance fundamentally rests on the recovery of suitable materials from an archaeological context.

Lithic workshops are frequently the only remaining evidence of prehistoric activity recovered from an archaeological site making their analysis germane to the study of human prehistory (Hughes and Smith 1993: 80; Glascock et al.

1998:16; Herz 2001: 449). Lithic materials lend themselves to provenance analyses because their geochemical signatures indicate their derived geological source. A growing body of research has demonstrated the potential for lithic provenance studies in archaeology, however, there remain several factors that potentially confound accurate source determination: raw material type, sourcing and sampling methods, and secondary-depositional processes (Hughes 1998; Luedtke 1992; Rapp and Hill 2006; Shackley 1998a, 1998b) Consequently, several scholars have called to question the appropriateness of the term ‘sourcing’ given that only the approximate geographic region of origin can be assigned (Hughes 1998; Shackley 1998a, 2008). This issue has been defined by Shackley (1998a) as the ‘sourcing myth’ in archaeology.

Chemical heterogeneity found in many lithic materials and their parent geological structures make it difficult to identify accurately prehistoric localities of procurement (Shackley 1998b, 2008:196). This is especially true for siliceous-sediments such as chert and flint where depositional conditions during their formation were not consistent over space or time (Luedtke 1992: 57; Rapp and Hill 2006; Shackley 2008). Moreover source deposits can cover large geographical areas affecting a researcher’s ability to correctly differentiate between intra and inter source variations (Hughes 1998; Luedtke 1992; Rapp and Hill 2006; Shackley 1998a, 1998b). Secondary-depositional processes, such as glacial transport and alluvial systems, are responsible for displacing raw materials from their primary sources and thus creating secondary deposits (Shackley 1998b). These factors require archaeologists to have suitable knowledge of the geological variability within a source to determine the impacts of their sampling biases (see Shackley 1998b for methods on source sampling). The difficulty in determining provenance for chert and flint materials presents a daunting challenge for archaeologists without any immediate solution. In contrast, obsidian provenance studies have developed over the years allowing archaeologists to glean variety cultural information from human prehistory (Shackley 2012).

4.2. Obsidian Provenance Studies and the Archaeological Record

Obsidian is a naturally occurring volcanic glass that was selected by prehistoric peoples for its predictable fractural properties which produce the sharpest cutting edge in nature. Obsidian artifacts are found in archaeological assemblages dating from the Pleistocene and continue throughout the Holocene (Glascock et al. 1998: 16; Phillips 2011: 115 Rapp 2002: 80). The prehistoric use of obsidian is seen to be ubiquitous in regions were sources occur (Hughes and Smith 1993: 80). Groups that resided on the peripheries of these areas traveled long distances to procure these materials directly or developed intricate exchange systems that were linked to kinship structures and prestige economies (Beck and Jones 1990; Peterson et al. 1997). Geological sources of obsidian are restricted to regions of volcanic activity that have occurred after the Cretaceous Periods (145–65 mya) (Phillips 2011: 116). Presently, obsidian deposits are located in volcanic areas bordering the Pacific Ocean (i.e., the so called Pacific “ring-of-fire” including Northeast Asia), East Africa, the Mediterranean basin, Iceland, Ascension Island, and Canary Islands. Obsidian resources are found in primary and secondary deposits (or sources) (Glascock et al. 1998; Hughes 1998; Hughes and Smith 1993). Primary sources of obsidian are typically distributed around their parent volcanic foundations in lava domes, flows, and pyroclastic bomblets (Glascock et al. 1998:16). Single volcanic episodes may produce multiple primary source formations spanning 10 to 100km² (Hughes 1998: 104; Hughes and Smith 1993: 81). Redeposition and erosion of primary obsidian source materials produces secondary deposits (Glascock et al. 1998; Hughes and Smith 1993; Shackley 2005). However, primary or secondary sources that were used prehistorically may be clandestine to researchers in the present as depositional processes have obfuscated their provenance.

Archaeological obsidian was first incorporated into provenance studies in the late 1950's and early 1960's. Academic interest in this topic has grown with each passing decade (Hughes and Smith 1993; Shackley 2008). Chemically, obsidian is a relatively homogeneous when compared to other lithic materials such as chert or flint. This allows researchers to determine provenance through geochemical analysis with a high degree of certainty (Phillips 2011: 115). Petrographic and other visual identification methods have also been used to identify provenance of obsidian artifacts and raw materials, however, with varying degrees of success (Braswell et al. 2000; Cho et al. 2010; Herz 2001; Negash and Shackley 2006; Reedy 2008). Obsidian typically occurs in black, grey or brown colours, but red and green formations are also known (Herz 2001: 453). Given that differently coloured obsidians may have identical geological origins, it is unreliable to base provenance on visual methods alone (Negash and Shackley

2006: 4). Geochemical studies on archaeological obsidian provide researchers with a strong platform to begin exploring exchange relationships, subsistence and settlement patterns of prehistoric societies given the finite number of obsidian sources that would have been accessible prehistorically (Phillips 2011: 115; Shackley 2005: 7-8). Nonetheless, there remains the potential for misidentification of archaeological obsidian due to chemical variability within a source, sourcing methods, and secondary-depositional processes (Hughes 1998). Researchers have dealt with these issues by examining the formation processes and geochemical structures of obsidian deposits in order to develop source standards that safeguard the reproducibility and accuracy of provenance results (Hughes and Smith 1993: 80).

4.3. Obsidian Formation Processes

The processes that dictate the formation of obsidian are derived from silicic, rhyolitic volcanic activity[5] (Eichelberger 1995; Hughes and Smith 1993). Temperatures ranging from 750° to 1200°C in a rhyolitic magma are needed to produce obsidian (Eichelberger 1995: 48; Herz 2001: 453). Additionally, rhyolitic magmas must possess a silicon (Si) content in excess of 70% to form toolstone-quality obsidian (Eichelberger 1995; Shackley 2005). With these conditions, obsidian occurs when rhyolitic magma is rapidly cooled (or quenched) upon reaching the earth’s surface and contacting rocks, air and water (Hughes and Smith 1993: 80; Shackley 2005: 14; Reedy 2008: 9; Phillips 2011:115). Rapid

[5] Obsidian and other volcanic glasses may also form in silica rich basaltic lavas that rapidly cooled. However obsidian is more typically associated with rhyolitic volcanism given higher silica content present in these magmas.

cooling of rhyolitic magmas leaves obsidian devoid of a crystalline structure. Not all rhyolitic volcanoes demonstrate the required conditions to produce obsidian, or form obsidian that is of artifact quality (Shackley 2005: 14). In order to produce artifact-quality obsidian, the parent magma melt must have a low water concentration (< 1%), or have been degassed before eruption (Eichelberger 1995; Herz 2001; MacKenzie et al. 1982; Shackley 2005:14). High concentrations of SiO_2 and Al_2O_3 in rhyolitic magma lead to the formation of lava domes rather than lava flows normally seen in basaltic or andesitic magmas (Shackley 2005: 14). Albeit, obsidian is also known to appear in rhyolitic lava flows (Hughes and Smith 1993: 81). Rhyolitic lava domes typically have a crystalline interior with outer regions having glass materials (Hughes and Smith 1993: 81; Phillips 2011: 115; Shackley 2005: 15). The outermost zones are composed of pumice, and porous glasses produced by degassed magmas (Phillips 2011:115). Deposits of artifact-quality obsidian are normally found beneath the porous glass region adjacent to the crystalline interior of the volcano, albeit, spines of dense obsidian that have protruded to the surface (Hughes and Smith 1993: 82; Phillips 2011:115). Obsidian that appears in the upper regions of the lava flow or dome may exhibit a variety of colours and textures compared to deeply bedded deposit (Hughes and Smith 1993: 81).

Obsidian is unstable at surface temperatures and pressures gradually absorbing water through cracks that formed in obsidian flows (Hughes and Smith 1993: 80; Phillips 2011: 16; Shackley 2005: 14). Obsidian that is reheated by magma or hot water transported by natural cracks in an obsidian flow may spontaneously crystallize creating vitrophyic fabrics or chalcedony geodes and strata within deposits (Shackley 2005: 14). As these processes occur, obsidian devitrifies into lower quality hydrated glass, perlite, and pitchstone (Phillips 2011: 116). The devitrification of obsidian outcrops over time is responsible for the absence of obsidian in geological deposits older than the Cretaceous Period (Phillips 2011: 116).

4.4. Obsidian Geochemical Structures

The geochemical identity of an obsidian deposit is developed during the formation of its parent magmatic material (Tykot 2004: 422). Here major and minor elements are incorporated into the melt from the crust surrounding the magma chamber (Tykot 2004: 422). Obsidian is primarily composed of silicon dioxide (SiO_2 70–57%), aluminum oxide (Al_2O_3 10–15%), sodium oxide (Na_2O), potassium oxide (K_2O 2–5%), calcium oxide (CaO 1.5%), iron oxide (Fe_2O_3 3–5%), and water (H_2O 0.1-0.5%) (Glascock et al. 1998: 18; Phillips 2011: 117; Pollard and Heron 2008: 80). These compounds make up the major elemental composition of all obsidian materials and can be used to source obsidian based on their percentages. Although, obsidian deposits are more accurately differentiated from one another by examining the trace elements present in a given sample (Merrick and Brown 1984; Phillips 2011: 118).

The trace elements found in obsidian occur through the maturing of the parent volcanic material. Continual incorporation of crustal materials into buried lava constantly changes the physical structure of a lava between solid and liquid phases (Pollard and Heron 2008: 80; Tykot 2004: 422). Solid and liquid lavas differ in their trace elemental concentrations based on the size and ionization (i.e., energy) of specific *compatible* and *incompatible* elements (Shackley 2005: 10). Compatible elements form with solid crystallized lavas, whereas incompatible elements form with liquid glassy lavas (Phillips 2011: 17; Pollard and Heron 2008: 80; Shackley 2005: 10). The elements that are absorbed into solid lavas include chromium (Cr), cobalt (Co), and nickel (Ni), while rubidium (Rb), strontium (Sr), cesium (Cs), barium (Ba), and zirconium (Zr) are absorbed during liquid phases (Phillips 2011: 117; Shackley 2005: 10;). As a magma continues to transform concentrations of trace elements are seen to change over time creating chemical variation within a source (Pollard and Heron 2008; Shackley 2005). Chemically different deposits that were derived from a single magma chamber are caused by magma mixing and the incorporation of new crustal materials into a melt (Shackley 2005: 11). This requires focus on specific elemental concentrations to distinguish between sources.

There are a large number of elements that can be analyzed by researchers using geochemical instruments to differentiate one obsidian from one another: Na, Mg, Al, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Ni, Cu, Zn, As, Rb, Sr, Y, Zr, Nb, Sn, Sb, Cs, Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Hf, Ta, Pb, Th, and U. Concentrations of titanium (Ti), iron (Fe), manganese (Mn), rubidium (Rb), strontium (Sr), yttrium (Y), zirconium (Zr), and barium (Ba) are normally used to describe obsidian sources and artifacts. Presently, NAA, LA-ICP-MS, PIXE-PIGME, and XRF are the most frequently used methods to determine provenance for archaeological obsidian, albeit, LA-ICP-MS and XRF have seen a sharp growth in applications in recent years (Shackley 2005, 2008)[6]. Each of these methods differs in their analytical approach and ability to identify and quantify relevant trace elements (Shackley 2008). Regardless, with proper instrument calibration these methods have been demonstrated to be directly comparable (Glascock 2011; Foster and Grave 2012; Williams et al. 2012). A review of the aforementioned instrumental methods of geochemical analyses is provided in the following section.

4.5. Non Portable-Instrumental Methods of Geochemical Analysis

The incorporation of instrumental methods of geochemical analysis into obsidian studies revolutionized the field by allowing archaeologists to accumulate a wide range of quantifiable data from the archaeological record. (See Freund 2012; Shackley 2012). As the use of instrumental analyses in archaeology has evolved over time, so too has the precision and effectiveness of methods and equipment. Microprocessors, personal computers and portable equipment now permit researchers to conduct non-destructive analyses in situ, removing the need to transport samples back to a laboratory (Shackley 2008, 2012). However, non-portable instruments are needed to generate the standards to which all portable devices are compared.   With this in mind, it is necessary for archaeologists to

[6] EMPA is also used to determine provenance for obsidian samples, However, this method cannot typically characterize elements below 100ppm which is essential for the detection of trace elements such as Sr. Given this, EMPA is not discussed in this thesis (See Merrick and Brown 1984).

choose a suitable method of analysis, be it NAA, LA-ICP-MS, PIXE-PIGME, or XRF.

Due to its ability to characterize the greatest number of elements compared any other geochemical method of analysis NAA has historically been the method of choice for geologists and archaeologists alike for geochemical characterization studies, including obsidian sourcing (Glascock et al. 1998: 20; Glascock and Neff 2003: 1516; Shackley 2005:89-90). Additionally, the high precision of these instruments have been used to develop geological standards for obsidian sources. Hence, NAA has been demonstrated to be an effective method of geochemical analysis for determining provenance of archaeological obsidian (Izuho and Sato 2007; Kuzmin and Glascock 2007; Kuzmin et al. 2008; Shackley 2005). NAA involves the irradiation of a sample by neutrons to make the sample radioactive (Glascock and Neff 2003: 1516). The decay of radioactive isotopes (i.e., gamma rays) that are emitted from the sample after irradiation are measured to determine the elemental concentrations found within the sample (Glascock and Neff 2003: 1516; Malainey 2011: 428; Pollard et al. 2007: 123). A spectrometer is used to determine the energy or frequency of the gamma rays emissions to characterize the elemental structure of a sample (Malainey 2011: 429).

To determine the trace elements of an artifact a powder sample of $\leq$ 100mg is removed from the interior of an object (Glascock and Neff 2003: 1522; Malainey 2011: 429; Pollard et al. 2007: 128). Samples are then placed inside a nuclear reactor to be irradiated and characterized (Pollard et al. 2007: 128). Samples are irradiated twice for five seconds each time, decayed for 25 minutes, and counted for 12 minutes (Glascock and Neff 2003: 1552). After irradiation samples may remain radioactive for years (Pollard et al. 2007: 128). Some of the disadvantages of NAA include the accessibility of nuclear reactors, the cost of analysis per-sample, as well as the inability of NAA to characterize Ba, Sr, and Zr as accurately as LA-ICP-MS or XRF (Malainey 2011: 432; Odell 2003: 33-34; Shackley 2008: 203).

LA-ICP-MS is a newer method of analysis compared to NAA or XRF but has shown comparable accuracy in obsidian provenance research (Gratuze 1999; Pollard and Heron 2008; Reepmeyer et al. 2011; Speakman and Neff 2005; Williams et al. 2012). Similarly to NAA, LA-ICP-MS analytical range is useful for determining provenance from a small sample size < 1mm (Phillips 2011; Scharlotta et al. 2011; Shackley 2005). Traditional ICP-MS required samples to be converted into a solution in order to be analyzed (Pollard et al. 2007: 196). With LA-ICP-MS samples or entire artifacts can be analyzed, provided artifacts and samples fit within the 6−4cm chamber of the unit and possess a microscopically flat surface to allow the laser to maintain focus during ablation (Pollard et al. 2007: 197). Samples are viewed under a video microscope that is connected to a computer that plots a series of lines or points that are to be ablated by the laser (Phillips 2011: 122; Speakman and Neff 2005: 1).

During LA-ICP-MS analysis, samples are ablated using an ultraviolet laser; a moveable stage and optical microscope allow the laser to be directed to specific regions of a sample, creating a 5−400μm laser scar (Pollard et al. 2007: 197−198). Argon (Ar) is then used as a carrier to transport samples' elemental concentrations into the plasma torch where it is ionized at high temperatures and injected into the quadrupole mass selector (Pollard et al. 2007: 198). The one of limitations of LA-ICP-MS is data quantification, because results can be obfuscated by instrument drift that requires frequent calibration (Phillips 2011: 122). In addition, LA-ICP-MS is a destructive method of analysis. Complete artifacts or portions thereof must be scarified in order to be analyzed as the sampled portions of artifacts will be left damaged by the laser ablation scar.

PIXE-PIGME techniques are *non-destructive* methods of analysis similar to XRF that produce rapid quantification of results with high degrees of precision and accuracy. PIXE-PIGME has been used to determine provenance of archaeological obsidian since the 1980s (See Duerden et al. 1980 and Ambrose et al. 1981). Given that PIXE and PIGME share similar techniques of analysis they are often used in conjunction (Odell 2003: 37). Sample preparation prior to analysis typically includes a washing with a solvent in an ultrasonic bath to remove dirt from surfaces (Bird et al. 1997: 62). Samples may be mounted outside the vacuum chamber of the instruments removing the need to damage artifacts for analysis (Pollard et al. 2007: 117). During PIXE analysis a beam of protons are used to excite inner shell electrons of an element to vacate their position (Pollard et al. 2007: 116). Secondary X-rays or Gamma rays produced from bombardment with a proton beam are used to characterize samples (Odell 2003: 35). These characteristic X-rays are measured to determine the abundance of a specific element within a sample when the vacancy is filled by an electron that moves from an adjacent electron shell to stabilize the atom (Pollard et al. 2007: 117).

PIGME operates by using a beam of protons or other particles to excite the nucleus rather than the electrons of an atom (Pollard et al. 2007: 117). As the nucleus de-excites the characteristic gamma rays are measured to identify the elemental composition of a sample (Pollard et al. 2007: 117).

Elements lighter than calcium (Ca) can be analyzed with these methods at an accuracy of 0.5−5ppm for PIXE and 10−100ppm for PIGME (Pollard et al. 2007: 117). Therefore these techniques can provide a high degree of certainty for identifying the provenance of archaeological obsidians (Ambrose et al. 1981; Bellot-Gurlet et al. 2005; Bird et al. 1997; Odell 2003: 37; Seelenfreund et al. 1996). The limitations for using PIXE-PIGME to determine provenance of an artifact include access to instruments and the operation costs per-sample (Sheppard et al. 2010: 21). Additionally sample size may impact quantification of results as only a small portion of a sample is analyzed with the proton beam rather than complete samples (Odell 2003:37; Sheppard et al. 2010: 21).

The incorporation of XRF spectrometry into archaeological research coincided with the birth of provenance studies in archaeology in the late 1950's early 1960's (Phillips 2011: 118). The widespread use of XRF analysis in obsidian provenance research has been in part due to its low operation costs, accessibility and *non-destructive* protocol. More importantly, XRF results have been shown to be consistent with those derived from NAA or LA-ICP-MS (Glascock 2011; Knight et al. 2011; Shackley 2005). In practice, XRF operates by causing electrons in the K, L, and M shells of an atom to vacate their location by exciting them with X-rays emitted from an X-ray tube or radioactive source

(Pollard et al. 2007: 101). Two processes occur when samples are bombarded with X-rays: absorption and scattering (Pollard et al. 2007: 101). Absorption is responsible for the ejection of electrons from their constituent electron shells, producing vacancies that are in filled by a neighbouring electron (Pollard et al. 2007: 101). Secondary X-rays are then produced when an electron from one of the adjacent shells moves to fill the void left by the ejected electron. These secondary (fluorescent) X-rays are characteristic of their parent elements found within a sample and are measured in electron volts (eV) (Phillips 2011: 119; Pollard et al. 2007: 101).

Scattering processes are identified as *coherent* and *incoherent*. Coherent scattering refers to the reflection of wavelength energies into the X-ray detector that are identical to the secondary X-rays produced during fluorescence Pollard et al. 2007: 101). Incoherent scattering (i.e., Compton scattering) produces longer wavelength energies that create background noise at lower energy levels that can obscure XRF results (Pollard et al. 2007: 101). Computer software is then used to generate a visual representation of the elemental spectrum characterized by the XRF and remove incoherent scattering effects.

There are two types of XRF instruments available to archaeologists: wavelength dispersive XRF (WDXRF) and energy dispersive XRF (EDXRF) (Phillips 2011: 118). Both methods of XRF can be used non-destructively to characterize samples (Shackley 2005: 96; Suda 2012).WDXRF measures the wavelength of electromagnetic waves produced by secondary X-rays that are characteristic of specific atomic energies (Philips 2011: 119; Pollard et al. 2007:

101; Suda 2012: 2−3). The characteristic X-rays emitted from the sample are dispersed onto a crystal that separates secondary radiation into component wavelength intensities which are in turn recorded by a detector (Pollard et al. 2007: 104). Crystals are used as a dispersion device because the spacing of their atomic structure of a crystalline material is similar to the wavelengths produced by X-rays (Pollard et al. 2007: 104−105). Changes to the angle of the crystal permit the detection of different elements as only one wavelength can be detected at a time (Phillips 2011: 119). WDXRF is responsive to elemental concentrations lower than 0.01%, making it an order of magnitude more sensitive than EDXRF instruments (Phillips 2011: 119; Pollard et al. 2007: 105). Regardless, WDXRF is used less frequently than EDXRF given longer sampling times, operating costs, and lack of portable devices (Phillips 2011: 119; Pollard et al. 2007: 105; Shackley 2005: 95).

EDXRF operates by irradiating samples with photons emitted from an X-ray tube to cause the electrons found within a sample to emit secondary X-rays (i.e., fluoresce) (Davis et al. 1998: 160). EDXRF units detect and count individual characteristic photon energies emitted from a sample with a solid state semiconductor diode (Phillips 2011: 119; Pollard et al. 2007: 102). Photon energies are measured simultaneously and appear as peaks within an energy spectrum (e.g., 20−40keV). These energy peaks are next used to determine elemental concentrations of an unknown sample in parts per-million (ppm) (Phillips 2011: 119). The detection of specific elements is determined by the energy output of the instrument (e.g., 15−120keV). The elemental spectrum that can be captured through EDXRF ranges from Sodium (Na) to Uranium (U), (Phillips 2011: 199). Although, instrument sensitivity for the light and heavy elemental spectrum is limited for EDXRF analyses (Pollard et al. 2007: 104).

The primary limitation of EDXRF technology is the inability to characterize as many elements as NAA or LA-ICP-MS consequently making EDXRF less sensitive than these two methods. As well, accurate determinations are dependant sample size (≥3mm thickness, ≥10mm diameter) (Davis et al. 1998: 174). These size constraints are termed as the 'infinite thickness' required for complete X-ray absorption by a sample. Surface irregularities may also hinder proper characterization of elements since fluorescent X-rays rapidly disperse in air at a rate equal to the square distance between the X-ray source and the detector (Philips 2011: 119). Lastly, standard laboratory XRF units (EDXRF or WDXRF) units are not easily transported to the field, preventing researchers from conducting analyses in the field. Given this inconvenience archaeologists interested in obsidian provenance studies have begun to use portable-XRF (PXRF) instruments typically used for characterizing industrial metals as well as geological samples.

4.6 Portable X-ray Fluorescence Spectrometry

As the accuracy and reliability of PXRF units have improved over the years, their use for determining obsidian source provenance in archaeology has also grown. Furthermore, governmental legislations regarding the export of cultural property have become more stringent. Thus researchers need to conduct all analyses within their host country, creating a necessity for portable devices. PXRF has existed in one form or another for several decades as portable desktop units and now as hand-held devices (Shackley 2010: 18) (see Speakman and Shackley 2013). The increased use of this technology in archaeology for obsidian provenance research began in the mid-1990's but has shown a marked increase in use with each passing year (Craig et al. 2007; Frahm 2013; Glascock et al. 2011; Jia et al. 2010; Knight et al. 2011; Shackley 2010; Sheppard et al. 2010, 2011; Speakman and Shackley 2013; Williams 2012; Williams-Thorpe et al. 1995). PXRF analyzers operate using the same principles as EDXRF providing researchers with a practical, portable, and non-destructive method of analysis. The elemental sensitivity for PXRF devices varies between production companies, and can be affected by the calibration package employed by their users (Frahm 2013; Goodale et al. 2012; Speakman 2012; Speakman and Shackley 2013). PXRF units are typically fitted with battery packs, miniaturized X-ray tube and thermoelectrically-cooled detectors making them a wholly portable device (Phillips 2011: 120). Spectral outputs can be recorded on a personal digital assistant (i.e., PDA) device, or uploaded directly to a laptop computer allowing archaeologists to analyze samples in minutes. For a comprehensive review of recent archaeological applications of PXRF devices see Speakman and Shackley 2013.

The increased use of PXRF for the characterization of archaeological obsidian has created valid concern among some researchers regarding the validity and reproducibility of results generated by portable, handheld units (Foster and

Grave 2012; Frahm 2013; Goodale et al. 2012; Liritzis and Zacharias 2011; Speakman and Shackley 2013; Shackley 2010). Because of this, systematic comparisons between PXRF instruments and NAA, LA-ICP-MS, PIXE-PIGME, and laboratory ED and WDXRF (hereafter LXRF) units were conducted to demonstrate the ability of PXRF units to produce results compatible to these other geochemical techniques (Craig et al. 2007; Foster and Grave 2012; Nazaroff et al. 2010; Philips and Speakman 2009; Williams et al. 2012). To illuminate the compatibility of PXRF in obsidian provenance research, brief reviews of the aforementioned comparative studies are provided below.

Craig et al. (2007) compared ppm results derived from PXRF to those produced by LXRF for the analysis of Andean archaeological obsidian. The elements selected for comparison were Mn, Fe, Rb, Sr, Zn, and Zr. The authors found a significant difference in elemental concentration values between the two methods by conducting an element by element paired *t*-test set at a 95% confidence interval for all elements analyzed except for Mn. Despite this, both methods were capable of differentiating between sources, and assigning artifacts to their geological point of origin by normalizing the ratios of elements between each instrument (Craig et al. 2007: 2019-2020). Normalization helps to correct variations in elemental concentration values permitting for inter-instrument comparisons. This is achieved by applying a calibration curve of geological standards to instrument results to account for X-ray drift over time and incoherent scattering effects. These factors are defined in greater detail several recent studies (Foster and Grave 2012; Goodale et al. 2012; Nazaroff et al. 2010; Speakman and

Shackley 2012; Shackley 2010). Through applying a normalization curve, PXRF was found to be directly comparable to LXRF and successful in determining the provenance of archaeological obsidian.

Philips and Speakman (2009) present their findings from an analysis of archaeological obsidian collections from the Kuril Islands. In this study, PXRF was used as the primary mode of analysis, while LA-ICP-MS was used to characterize samples that were too small for PXRF. Artifacts were analyzed for K, Mn, Fe, Ga, Th, Rb, Sr, Y, Zr, and Nb. Philips and Speakman's results produced through PXRF and LA-ICP-MS were directly compared to those published in previous studies that employed NAA (see Glascock et al. 2006 and Kuzmin et al. 2000, 2002). PXRF results were calculated as ratios to the Compton peak of rhodium and converted to ppm using a linear regression calibration that had been established from 15 well characterized obsidian samples previously analyzed by NAA and LXRF (Philips and Speakman 2009: 1258). This data correction method was also used by Craig et al. (2007) and Foster and Grave (2012). The results of Philips and Speakman's work demonstrate the use of PXRF as an accurate method of geochemical analysis for obsidian studies.

Nazaroff et al. (2010) compared the results of PXRF to LXRF for archaeological obsidian samples from the Mayan Lowlands in Belize. In this study Fe, Rb, Sr, Y, Zr, and Nb were used to discriminate between source groups. Similarly to Craig et al. (2007) both methods successfully attributed the samples to the same sources, although, there was a significant discrepancy between ppm values for the elements examined (Nazaroff 2010: 891-894). Through a systematic comparison of instruments via a *k*-means cluster analysis, Nazaroff et al. (2010) were able to obtain directly comparable quantitative results. Lastly, Nazaroff et al. (2010) determined that their results generated by PXRF were not compatible to those produced by LXRF without statistical evaluation given that the low accuracy of the PXRF results in this study was attributed to systematic error, opposed to random error. Despite this, PXRF was able to attribute samples properly to their appropriate geological source.

Foster and Grave (2012) used a PXRF device to characterize curated obsidian artifacts from the Levant. The goal of their research was to examine the practicality of PXRF scanners in museum based research by comparing results generated from their device to source results produced by ICP-AES (atomic emission spectroscopy)/ICP-MS, LA-ICP-MS, and PIXE, which the authors term *legacy data*[7]. The elements examined included Fe, Rb, Sr, Y, Zr, and Nb. Results from the PXRF device were normalized with proprietary calibration data to convert intensity peaks into numerical results (Foster and Grave 2012: 730). Multivariate statistical analyses were used to compare the generated results using Principle Component Analysis (PCA) and Canonical Variate Analysis (CVA). The findings presented in their study show that *legacy data* can be used as reference material from which PXRF results can be compared. Furthermore, their study strengthens the argument for the use of PXRF devices in obsidian provenance research.

[7] In Foster and Gave (2012) legacy data refers to elemental concentration values that have been previously generated by instrumental methods to determine source standards for a given region.

Williams et al. (2012) provide another comprehensive assessment of the viability of PXRF by comparing ppm results for archaeological obsidian collected from Wari sites in Peru between PXRF and LA-ICP-MS, and NAA data generated from a previous study. K, Ca, Ti, Mn, Fe, Zn, Sr, Zr, and Nb were selected for comparison between the instrumental methods. Mn, Sr, and Rb were specifically used to differentiate between obsidian sources. Similarly to the aforementioned studies, Williams et al. (2012) used calibration software to normalize their data. The results presented in Williams et al. (2012) show a lower accuracy for Mn and Sr in PXRF data compared to LA-ICP-MS. However, the PXRF unit was shown to differentiate correctly between sources, although not as accurately as LA-ICP-MS or NAA. The authors note that INAA and LA-ICP-MS are crucial for the identification of patterns and for differentiating precisely between sources (Williams et al. 2012: 84). Nonetheless, PXRF is again demonstrated to be a reliable method of analysis for determining provenance of archaeological obsidian.

The primary deficiencies seen in the PXRF units used in these studies were instrument sensitivity and accuracy. Compared to non-portable geochemical methods of analysis PXRF was shown to produce ppm counts much lower than those produced by NAA or LA-ICP-MS. Furthermore, direct comparisons between other geochemical methods are potentially inappropriate given the lower detection limits of PXRF. Therefore, the use of calibration curves and multivariate analysis are necessary in obsidian provenance studies to help correlate results generated by different instruments or methods (see Glascock et al. 1998 for an indepth explanation of multivariate methods in obsidian provenance research). Despite these drawbacks, the results produced by PXRF and all other methods of geochemical analysis are subjected to refinement of source standard and technological improvements. Therefore, additional research is required to enhance the precision of the instrumental methods used in obsidian provenance studies.

4.7 Summary

Provenance studies in archaeology have been substantially advanced over the last decade through the integration of geochemical methods of analysis. The field of obsidian studies in archaeology has benefited greatly from this development given the success of geochemical characterizations archaeological obsidian. The presence of well-defined obsidian in an archaeological context provides archaeologists with an invaluable resource through which to explore dynamics of mobility and exchange through geochemical analysis. NAA, LA-ICP-MS, PIXE-PIGME and LXRF remain the most commonly used instrumental methods of characterization for archaeological obsidian given their reliability and compatibility. However, portable units provide an opportunity for archaeologists to analyze materials while in the field, and have been shown to produce results consistent with their laboratory based counterparts (Craig et al. 2009; Foster and Grave 2012; Knight et al. 2011; Nazaroff et al. 2010; Phillips and Speakman 2009).

4.8 Materials and Methods

4.8.1 Sample Selection

The obsidian artifacts that are used in this thesis were supplied by the Japanese colleagues of the Baikal-Hokkaido Archaeology Project (BHAP) located at Hokkaido University. The collections used here were recovered during previous excavations at the Uedomari 3 Site (1984), Kafukai Site (1968-1971), and Hamanaka 2 Site (2011). A total of 104 artifacts were analyzed by PXRF: 51 from Uedomari 3; 50 from Kafukai 1; and 3 from Hamanaka 2[8]. In addition to the scanned artifacts, a reference collection of 23 source samples from Hokkaido were analyzed at the Asahikawa City Museum (Table 4.1). The reference collection contains samples of obsidian from primary and secondary source deposits throughout Hokkaido (Figure 4.1). Two reference samples from the collection at the Asahikawa City Museum were not scanned (Kushiro-Shitakara and Kushiro-Kutyorogawa) since the size of these samples fell below the infinite thickness limits required for accurate source characterization by PXRF.

All sampled artifacts required no preparation prior to analysis as their curation had left them free of significant amounts of dirt or other contaminates. Samples were selected for analysis based on their size (i.e., approximately 5mm in width and 10mm in diameter) for PXRF analysis. Many of the artifacts analyzed were bifacial tools (projectile points and knives) and unifaces (scrapers and utilized flakes) that did not possess a morphologically flat surface. Given this, an attempt was made to scan all artifacts at the widest and thickest

[8] Only 3 obsidian artifacts of suitable size were recovered from the 2011 BHAP excavations at Hamanaka 2.

location..Reference samples that did not possess a morphologically flat surface or a face without cortex were modified using a geological hammer. Reference samples were selected for analysis following the same size decimation as used for the analyzed artifacts.

4.8.2 Portable-XRF Equipment

For this thesis a Bruker AXS Tracer III-SD handheld X-ray fluorescence spectrometer was supplied by the Canadian Foundation for Innovation (CFI) grant awarded to the BHAP. The Bruker AXS Tracer III-SD is equipped with a rhodium X-ray tube and a 10mm² silicon drift detector with a resolution of 145 eV FWHM for 5.9 KeV X-rays at 200,000 counts per second (Speakman 2012: 3). The spot size of the X-ray is less 10mm in diameter (Speakman 2012: 3). Results from the PXRF unit were displayed on a HP laptop supplied by Bruker AXS running S1PXRF software.

4.8.3 Scanning Procedure

The PXRF was setup in the Bruker designed desktop stand, and was operated remotely by laptop. The PXRF unit was powered by an AC adapter for all analyses. All artifact and reference material analyses were conducted at 40keV, 30µA using the Bruker AXS supplied green filter (0.3047-mm aluminum, 0.0254-mm titanium, 0.1523-mm copper). This filter was designed to focus X-ray energies for the analysis of obsidian materials (Speakman and Shackley 2013: 1437). Additionally, all samples were scanned for a live-time count of 300s. A live-time count of 300s was also used by Nazaroff et al. (2010) and Forster and Grave (2012). Higher live-time counts allow for greater detection of elemental concentrations when samples sizes approach the limits of infinite thickness. The elements Mn, Fe, Zn, Ga, Rb, Sr, Y, Zr, and Nb were quantified for all samples on the Kα shell, while Th was calculated for the Lα shell. All results were calculated as ratios for the Compton peak of Rb and converted to ppm using the proprietary obsidian calibration supplied by Bruker AXS. This calibration was prepared using 40 obsidian samples characterized by NAA and LA-ICP-MS at the Missouri University Research Reactor (MURR) (Speakman 2012: 3).

During analysis of archaeological and reference material a control sample of obsidian (JPN1) collected from the Shirataki-A source (Hokkaido) was also scanned to evaluate instrument drift and precision, since no geological reference material produced by the United States Geological Survey (USGS) or the National Institute of Standards and Technology (NIST) were available for analysis at the time of my data collection. This sample was scanned in approximately the same location each time using the same procedures as during analysis of all artifacts and reference materials. This sample was also analyzed three times by quadrupole ICP-MS at the University of Alberta Earth and Atmospheric Sciences Department and by NAA at the University of Alberta Slowpoke Nuclear Reactor Facility. These additional characterizations aim to create a standard of reference that will be used to evaluate the accuracy of the PXRF device used in this thesis. Flakes were removed from around the edges of JPN1 with a deer antler billet. Flakes were then ground using an agate mortar and pestle with an acetone solution.

Agate was used to avoid trace elemental contamination from the grinding process. The acetone solution was used to expedite the grinding process and is not believed to contribute any contaminating agents to the powdered samples (personal communication with A. Locock, 2013). For ICP-MS analysis, three 100mg aliquots were used to characterize sample JPN1. Additionally, three 100mg aliquots were used to characterize sample JPN1 by NAA. A U.S. Geological Survey (USGS) reference standard was also analyzed by ICP-MS and NAA to compare inter-instrument consistency. This reference standard is known as RGM-1.

4.8.4 Analytical Procedure

The analysis of ppm results from the scanned obsidian materials was conducted using GAUSS software with the statistical routine package MURR. The MURR statistical package was developed by Hector Neff and Michael Glascock at the Missouri University Research Reactor specifically for archaeometric analyses. These statistical routines are designed to apply statistical analyses to sets of chemical data in order to determine artifact provenance, or describe a geological source (Glascock et al. 1998: 22−37). The statistical analysis conduced on all geological reference material and archaeological materials bivariate analysis. Bivariate plots are two dimensional charts used to differentiate sources and artifact visually from one another. In this thesis, this is done by plotting Sr and Zr, Sr and Rb, and Rb and Zr against one another. In the MURR software package, confidence ellipses may be drawn at various intervals to establish group membership (i.e., individual sources). These ellipses are calculated in the MURR software by the Mahalanobis distance from a group's centroid (i.e., the average ppm values of an individual source) (Glascock et al. 1998: 27). In this thesis, all confidence ellipses drawn in the bivariate plots use a 95% confidence interval to account for $\pm 2\sigma$. However, if obsidian sources share the same chemical ranges, their ellipses will overlap. Thus, close comparisons of the ppm concentration values for the examined elements are also used to differentiate sources from one another, and to make source assignments for individual artifacts.

Chapter Five – Review of Archaeological Obsidian Provenance Studies in Northeast Asia

Given the previous research on obsidian provenance conducted in these areas, the regions of principal concern in this study are Hokkaido, Honshu, Sakhalin, the Kuril Islands, Kamchatka, Amur River Basin and Primorskii Krai,. Several provenance studies have also identified exchange networks from the Amur River Basin and Primorskii Krai from the Korean peninsula (Cho et al. 2010; Doelman et al. 2008. 2012; Glascock et al. 2011). However, Korean sources are not discussed in this chapter given the geographical and cultural separation between Rebun Island and the Korean peninsula.

Rebun Island and the closest neighbouring islands, Rishiri and Sakhalin, do not have any natural sources for obsidian. Therefore all archaeological obsidian found on Rebun Island is the product of long-range transport by prehistoric peoples. Hokkaido sources are suspected to comprise all obsidian materials used by northern hunter-gatherer populations on Rebun Island (Sakaguchi 2007a, 2007b; Tomura et al. 2003). However, there remains the potential for long-range transport of Eurasian materials through exchange to Rebun Island. In order to situate the research presented in this thesis within the broader context of obsidian provenance in Northeast Asian a background section on the movement of obsidian resources in this region is provided below.

5.1 Hokkaido

Hokkaido is located at a junction of the northeast Japan and the Kuril volcanic arc (Phillips 2011: 126). Obsidian sources in Hokkaido are primarily found in the Eastern part of the island and are associated with the Kuril volcanic arc (Izuho and Hirose 2010). Fewer sources are found in the Western portion of Hokkaido associated with the Northeast Japan volcanic arc (Izuho and Hirose 2010: 12). The formation ages for obsidian sources on Hokkaido range from the Pliocene to the early Pleistocene (i.e., 3−1 mya) (Izuho and Hirose 2010: 12). The prehistoric use of Hokkaido obsidian began in the Upper Palaeolithic (30,000 cal. YBP) with the production of tools on obsidian gravels (Izuho and Hirose 2010: 17). Direct use of primary source material coincides with the manufacture of microblade and stemmed point technology at the Shirataki source in Northern Hokkaido and their export to Sakhalin Island (Izuho and Hirose 2010: 18). Hokkaido sources continued in use throughout the Jomon, Okhotsk periods (Izuho and Hirose 2010; Kuzmin et al. 2012).

There are currently 21 chemically distinct known sources of obsidian in Hokkaido (Izuho and Hirose 2010: Izuho and Sato 2007). The Shirataki, Oketo, Akaigawa, and Tokachi volcanic areas comprise the four largest primary source deposits of obsidian in Hokkaido. For a list and a map of the Hokkaido obsidian sources examined in this thesis see table 4.1, and figure 4.1. Primary contexts for several other sources have yet to be identified (Izuho and Sato 2007; Phillips 2011). Secondary sources in these areas are situated in riverbeds and terrace deposits (Izuho and Hirose 2010: 13).

Over the last decade there have been a number of provenance studies examining the geochemical structure of Hokkaido sources (Glascock et al. 2000; Glascock and Kuzmin 2007; Hall and Kimura 2002; Izuho and Hirose 2010; Izuho and Sato 2007; Kuzmin 2006, 2010, 2011; Kuzmin et al. 2002, 2012; Phillips 2010, 2011; Phillips and Speakman 2009; Tomura et al. 2003; Wada et al. 2003, 2006). The instrumental methods of analysis have included NAA, LA-ICP-MS, EPMA, XRF and PXRF. These methods have been demonstrated to be successful in properly differentiating between Hokkaido sources and archaeological materials. However, few studies have been published on the geochemistry of archaeological obsidian from Rebun Island (Suzuki and Tomura 1992, cited in Kuzmin et al. (2012); Tomura et al. 2003).

Tomura et al. (2003) used NAA to characterize 83 obsidian samples from the Hamanaka 2 site on Rebun Island. The sampled assemblages were associated with the Late and Final Jomon and Epi-Jomon periods. Tomura et al. (2003) noted a change in obsidian source use from the Late Jomon to Epi-Jomon on Rebun Island. The obsidian samples from the Late Jomon assemblage were primarily derived from the Akaigawa source, while during Final Jomon and Epi-Jomon periods the assemblages showed an increase in the use of central Hokkaido source, Oketo (Tomura et al. 2003: 197). By the Epi-Jomon period nearly all the samples were composed of Oketo and Shirataki obsidian, with a minor portion of the samples sourced from the Akaigawa deposit. This characteristic source selection during the Epi-Jomon period was also reported after on Rishiri Island by Wada et al. (2006) who used EPMA to characterize 72 obsidian artifacts dating to the Epi-Jomon period. They determined that three Hokkaido sources were represented in the analyzed assemblage: Shirataki 75%, Oketo 21%, and Asahikawa 4%. These findings are similar to those presented in Tomura et al. (2003) and help to illuminate changes in resource procurement from the Late Jomon to Epi-Jomon periods in Hokkaido and Rebun Island.

The most recent obsidian provenance study in Hokkaido by Kuzmin et al. (2012) used NAA to differentiate between the Shirataki and Oketo sources and sub-sources. Moreover, this study aimed to provide a synthesis of obsidian provenance research in Northeast Asia. Their research also examines the dispersal of Hokkaido obsidians throughout Northeast Asia via prehistoric transport, and exchange networks at distances ranging from 250 to 1200km, during the Upper Palaeolithic to Paleometal period (Kuzmin et al. 2012: 8). Their study incorporated samples and results from previous studies by Hall and Kimura (2002), Kuzmin et al. (2002) and Kuzmin and Glascock (2007) to create a comprehensive data set that can be used for future comparative analyses of archaeological obsidian in Northeast Asia. The results presented in this article were found to be in good agreement with the XRF results produced by Hall and Kimura (2002), as well as the NAA results published in Kuzmin et al. (2002), and Kuzmin and Glascock (2007) (Kuzmin et al. 2012: 7). The results published in Kuzmin et al. (2012) will be used as a framework of reference for the results presented in this thesis.

5.2 Honshu

The movement of obsidian resources between Honshu, the largest Japanese Island, and Hokkaido and Rebun has yet to be fully explored. Honshu is located to the South of Hokkaido, situating it in the Pacific volcanic rim. Honshu is separated from Hokkaido by the 30km Tsugaru Strait, and boarders the Sea of Japan on the west, and the Pacific Ocean on the east. Honshu contains roughly 30 known sources of obsidian. The highest densities of sources are found in northern Honshu in the Aomori and Shizuoka Prefectures (Tsutsumi 2010). Widespread movement of obsidian resources is known to have occurred during the Upper Palaeolithic and Jomon periods (Izuho and Sato 2007; Tsutsumi 2010). However, the presence of siliceous shale resources in Aomori may have diminished the need for obsidian resources by prehistoric peoples in this region (Tsutsumi 2010: 27−28). Obsidian from the Shirataki source in Hokkaido was recovered from the Sannai Maruyama site in the Aomori Prefecture, showing contact between Hokkaido and Honshu (Warashina 2005, cited in Kuzmin et al. 2012). Furthermore, the Epi-Jomon culture of Hokkaido is known to have had contact with its contemporary cultures on Honshu in order to acquire iron tools, glass and stone beads (Hudson 2004: 293).

Tomura et al. (2003) included source material from two obsidian sources in the Aomori Prefecture (Kizukuri and Fukaura) in their examination of archaeological obsidian from Hamanaka 2 (Rebun Island). However, no artifacts from the assemblages analyzed were sourced to these deposits in Honshu. The lack of data regarding the exchange of obsidian between Honshu and Hokkaido likely reflects a lacuna of research into this matter rather than the lack of such movement in the past. Although Tomura et al. (2003) published the concentration values for the two obsidian sources in the Aomori Prefecture, these elements do not match those examined in this thesis. Therefore, comparisons between northern Honshu sources and the artifacts analyzed in this thesis were not possible. However, Published data on obsidian sources in central Honshu by Suda (2012) will be used as a framework of comparison for the archaeological obsidian examined in this thesis. This will help to explore the potential for the transport of obsidian between central Honshu, Hokkaido, and Rebun.

5.3 Sakhalin

Sakhalin Island is located to the Northwest of Hokkaido and is surrounded by the Sea of Okhotsk on the West and Sea of Japan on the East. La Pérouse Strait separates Sakhalin and Hokkaido by roughly 40km. Sakhalin is geologically positioned on the Pacific volcanic belt, but contains no natural source of obsidian (Kuzmin et al. 2002, Kuzmin and Glascock 2007). Andesitic basalts and dacites dominate the volcanic rocks of Sakhalin, however artifact quality glasses have yet to be found in these formations (Kuzmin and Glascock 2007: 102-103). The shortage of suitable lithic materials made it necessary for prehistoric groups to acquire high quality lithic materials from Hokkaido.

The transportation of Hokkaido obsidian to Sakhalin began at 19,000−18,000 YBP (Kuzmin et al. 2002, 2012). By the Neolithic and Early Iron Age obsidian from Hokkaido was widely used by prehistoric peoples throughout

Sakhalin (Kuzmin 2006a, 2006b: 172; Kuzmin et al. 2002: 747). Fluctuations in sea levels before, during, and after the Last Glacial Maximum changed the coastlines between Sakhalin and Hokkaido. Initial transport of obsidian to Sakhalin during the Upper Palaeolithic would not have required the use of watercraft as sea levels were 120m lower than present (Kuzmin and Glascock 2007: 111). However, watercraft would have been necessary in subsequent epochs as rising sea levels spaced Sakhalin and Hokkaido further apart. Nevertheless, Hokkaido obsidian has been recovered from archaeological sites dating to the Paleometal or Early Iron Age demonstrating the use of watercraft by these cultures (Kuzmin, 2006b, 2011; Kuzmin and Glascock 2007).

Kuzmin and Glascock (2007) provide a comprehensive overview of the presence of Hokkaido obsidian in Sakhalin. Archaeological obsidian from Sakhalin and source material from Hokkaido were analyzed with NAA to form data set of 182 samples of which 137 were previously used in Kuzmin et al. (2002). The artifacts used in their sample were taken from each of the prehistoric phases represented on Sakhalin: 15% for the Palaeolithic, 35% for the Neolithic, and 50% for the Paleometal period (Kuzmin and Glascock 2007: 105-107). Four Hokkaido sources were shown to correspond to the archaeological material analyzed from Sakhalin: Shirataki-Akaishiyama, Shirataki-Hachigozawa, Oketo-Tokoroyama, Oketo-Oketoyama, and Akaigawa (Kuzmin and Glascock 2007: 109). Obsidian from the Shirataki source is seen to dominate the sampled assemblages dating from the Palaeolithic and Neolithic, while the Oketo-Oketoyama source is shown to surpass Shirataki in use during the Paleometal period. Given the geographic proximity of Sakhalin and similar cultural occupational sequences these results provide and an interesting framework of reference for Rebun materials.

5.4 The Kuril Islands

Although the Kuril Islands do not contain any known sources of obsidian, recent archaeological survey and excavation in this region has demonstrated the widespread use of Hokkaido and Kamchatka obsidians. The Kuril Island archipelago is found to the Northeast of Hokkaido stretching towards the Kamchatka peninsula. The Kuril Islands divide the Sea of Okhotsk from the Pacific Ocean. The Southern islands Kunashir, Iturup, Urup, and the Northern islands Onekotan, Paramushir, and Shumshu, are larger than the central islands Chirpoi, Simushir, and Shiashkotan (Phillips and Speakman 2009: 1256). The environment of the Kuril Islands likely discouraged continuous occupation throughout the year (Kuzmin et al. 2012b: 236). The southern Kuril Islands were first occupied during the Early Jomon 6210−5660 YBP (Kuzmin et al. 2012b). The recurrent occupation of the southern Kuril Islands by prehistoric peoples is understood to have begun by 4000 YBP (Phillips and Speakman 2009: 1257).

Recent archaeological focus on the Kuril Islands has shown the use of Hokkaido sources throughout the island chain (Phillips 2010, 2011; Phillips and Speakman 2009). Phillips and Speakman (2009), and Phillips (2010) determined that artifacts linked to Hokkaido sources were commonly used in the Southern islands while Kamchatka sources were dominant in materials collected from the central and Northern islands. Nonetheless, Hokkaido materials were seen to be distributed throughout the Kuril Islands, reaching the most Northern island Shumshu (Phillips 2010: 127). The Hokkaido sources that were identified in these studies were Shirataki-Akaishiyama, Shirataki-Hachigozawa, Oketo-Tokoroyama, and Oketo-Oketoyama. Five Kamchatka sources were also identified, along with two unknown groups that are potentially derived from unknown Kamchatka sources (Phillips 2010: 127).

Phillips (2011) identified the Toachi-Mitsumata Hokkaido source in his subsequent Kuril Island study. However this assertion conflicts with his results published in 2010 which are based on the same set of data (Kuzmin et al. 2012a: 11). The discrepancy between results published in Phillips (2010) and (2011) have come under scrutiny in Kuzmin et al. (2012a) who claim that the Toachi-Mitsumata source was not used by prehistoric peoples outside of Hokkaido. Since Phillips (2011) did not provide the geochemical data for his assertion, the presence or absence of this source in Kuril Islands has yet to be determined (Kuzmin et al. 2012a: 11). Since samples from the extensive geochemical work on Sakhalin have been yet to be sourced to the Toachi-Mitsumata deposit, Kuzmin et al. (2012a) believe it is unlikely that Toachi-Mitsumata obsidian is represented in the Kuril Islands. Consequently, additional research in the Kuril Islands and surrounding regions of Northeast Asia is required to assert the use of Toachi-Mitsumata obsidian outside of Hokkaido.

5.5 Kamchatka

The Kamchatka peninsula of Eastern Siberia contains obsidian sources that were utilized by prehistoric peoples during the Pleistocene and Holocene (Glascock et al. 2006; Grebennikov et al. 2010; Kuzmin 2010, 2011; Kuzmin and Glascock 2007; Kuzmin et al. 2008; Phillips 2010, 2011; Phillips and Speakman 2009: Speakman 2005). The Kamchatka Peninsula is located at a boundary between the Pacific and Eurasian tectonic plates (Grebennikov et al. 2010: 89). The thirty distinct sources of obsidian have been identified in Kamchatka are found in three geographic regions: Central and Eastern Range; and the Southern portion of the peninsula (Glascock et al. 2006: 74). All sources in Kamchatka belong to Neogene (23−2.6 mya) and Quaternary (2.6 mya to present) formations (Glascock et al. 2006; 89). During the Neolithic, obsidian was transported at distances up to 470km, and up to 560km during the Paleometal period (Glascock et al. 2006: 80).

As mentioned, Kamchatka sources are shown to have been used by the prehistoric groups who inhabited in the Kuril Islands (Phillips 2010, 2011; Phillips and Speakman 2009). Therefore, there remains the potential that Kamchatka obsidian was moved also through the Kuril Islands into Hokkaido. Grebennikov et al. (2010) conducted the most recent study of archaeological obsidian using NAA to characterize archaeological obsidian identifying 16 sources in Kamchatka. Only 37 of the 444 samples analyzed could not be assigned to any known sources. Given the high attribution of artifacts to source samples, the results included in Grebennikov et al. (2010) provide a strong data set for comparison between Hokkaido sources. Additionally, the source data published in Grebennikov et al. (2010) will be used in this thesis to identify any potential archaeological obsidian samples from Rebun Island.

5.6 The Amur River Basin and Primorskii Krai

The regions of the Amur River Basin and Primorskii Krai of Eastern Russia boarder neighbouring countries North Korea and China to the West, and geographically the Sea of Japan to the East. These regions were occupied by prehistoric groups during the Upper Paleolithic, Neolithic, and Paleometal periods (Doelman et al. 2008, 2012; Glascock et al. 2011: Garkovik et al. 2005; Kluyev and Sleptsov 2007; Kuzmin 2011; Pantyukhina 2007). In this region obsidian materials were commonly used during the Upper Paleolithic and Neolithic since the introduction of metal tools during the Paleometal periods made lithic materials redundant (Glascock et al. 2011: 1838).

Two known primary sources of obsidian exist between these regions: the Basaltic Plateau source in Primorskii Krai and the Obluchie Plateau source in the Amur River Basin (Doelman et al. 2008, 2012; Glascock et al. 2011). The Samarga source is known as secondary deposit that has been chemically identified in the Amur River basin, yet a primary source location has yet to be defined (Glascock et al. 2011: 1837). Recently, geochemical evidence has demonstrated the prehistoric transportation of Hokkaido obsidians to the Amur River Basin (Glascock et al. 2011; Kuzmin et al. 2012). Kimura (1995) originally predicted an 'obsidian path' leading from Hokkaido through Sakhalin into the Amur River

Basin; however, this theory was not originally validated through geochemical analysis (Kuzmin et al. 2012: 10−11). The transport route of obsidian materials from Hokkaido to the Amur River Basin ranged from 900 to 1000km (Glascock et al. 2011: 1836). Conversely, there remains the potential that Amur River Basin and Primorskii Krai obsidian materials were moved to Hokkaido.

Glascock et al. (2011) carried out a geochemical analysis of archaeological obsidian from the Amur River Basin using NAA and EDXRF. Ceramic analysis first established the connection between the cultural groups of the Amur River Basin and Primorskii Krai which was later confirmed with the analysis of archaeological obsidian (Glascock et al. 2011: 1837-1838). The sources that were chemically characterized were Obluchie Plateau, Basaltic Plateau, Samarga, and Shirataki-Akaishiyama. The Basaltic Plateau source was the most frequently represented group, followed by the Obluchie Plateau, Shirataki-Akaishiyama, and Samarga the least (Glascock et al. 2011: 1836). The presence of Hokkaido obsidian in the analyzed assemblages demonstrates the long distance transport of these materials throughout Northeast Asia. The NAA and XRF results presented by Glascock et al. (2011) will also be used as a reference of Amur River Basin and Primorye obsidians in this thesis.

5.7 Summary

The growth in Hokkaido obsidian characterization studies over the last decade has allowed researchers to pattern the extensive use of Japanese obsidian in Northeast Asia. As archaeological obsidian recovered in Honshu, Sakhalin

Island, the Kuril Islands, and the Amur River Basin has been sourced to Hokkaido deposits, the cultural connections between these regions are undeniable. Outside of Hokkaido, Hokkaido obsidian is most commonly seen in assemblages recovered from Sakhalin and the Kuril Islands (Kuzmin et al. 2002, 2012; Kuzmin and Glascock 2007; Phillips 2010). The sources that were most commonly represented throughout Northeast Asia are derived from the Shirataki and Oketo sources. However, within Hokkaido itself, Akaigawa and Asahikawa are more common (Izuho and Sato 2007; Izuho and Hirose 2010; Hall and Kimura 2002). As of yet, obsidian from Kamchatka, the Amur River Basin and Primorskii Krai have not been identified in archaeological contexts in Hokkaido. Nonetheless, there remains the potential for obsidian from these regions to enter the archaeological record of Hokkaido given the history of cultural contact between these areas.

The results published in Kuzmin et al. (2012) will be used as a framework of reference for sources in Hokkaido, data presented by Suda (2012) will be used as a reference for central Honshu sources, and measurements taken by Grebennikov et al. (2010) and Glascock et al. (2011) will be used for Kamchatka, the Amur River Basin, and Primorskii Krai. Given Rebun Island’s proximity to Hokkaido and Sakhalin it is possible that prehistoric groups used Rebun as a meeting point, or stepping stone between Japan and continental Asia. Therefore, the results presented in this thesis will situate Rebun Island within the broader context of obsidian transport in Northeast Asia.

Chapter Six – Results and Discussion

6.1 Data Evaluation

The PXRF analysis of archaeological obsidian recovered from Middle Jomon and Okhotsk period sites on Rebun Island demonstrates that several Hokkaido obsidian sources were used during these times. In order to explore the archaeological significance of these findings, the precision and accuracy of these results must first be examined. The PXRF device used in this study displayed a high instrument precision throughout the analyses of all reference and cultural materials. This is demonstrated by the low relative standard deviations (RSD < 5%) for the examined elements in control sample JPN1 (Table 6.1). However, these results do not provide data on the accuracy of the PXRF device. Therefore, sample JPN1 was also analyzed three times by both ICP-MS and NAA to determine the accuracy of the PXRF device used in this study. In tables 6.2−6.4 the data from the ICP-MS and NAA (long irradiation) analyses of JPN1 are provided. A United States Geological survey (USGS) reference standard (RGM-1) was analyzed by both ICP-MS and NAA to examine inter-method variability (Table 6.5). Although many elements are quantified through ICP-MS and NAA, only Rb, Sr, and Zr are of principal concern given the uniqueness of the ppm concentration values of these trace elements in obsidian sources and given their successful use in previous PXRF studies to determine artifact provenance (Craig et al. 2007; Ferguson 2012; Nazaroff 2010; Phillips and Speakman 2009; Sheppard et al. 2011). Additionally, all ppm concentration values are rounded to the nearest whole number when possible.

Comparisons of accuracy between ICP-MS, NAA, and PXRF are evaluated using a relative percent difference (RPD). This quantitative ranking scheme is borrowed from the United States Environmental Protection Agency (EPA) publication: XRF Technologies for Measuring Trace Elements in Soil and Sediments (Billets 2006). RPD is calculated by the following formula: $RPD = \frac{(Lm-Pm)}{average\ (Lm,Pm)} \times 100$ where Lm = mean laboratory measurement, Pm = mean portable measurement (Billets 2006: 26). If the portable measurement (Pm) is larger than laboratory measurement (Lm), then the RPD is calculated as follows: $RPD = \frac{(Pm-Lm)}{average\ (Lm,Pm)} \times 100$. Accuracy is quantified by a RPD for the elements as either excellent (RPD less than 10%), good (RPD between 10% and 25%), fair (RPD between 25% and 50%), and poor (RPD greater than 50%) (Billets 2006: 26). Given the limitations of PXRF analyses, all ppm element concentrations values with a comparative RPD of 0% to 25% are considered acceptable for the purpose of this thesis and are therefore compatible to results produced by ICP-MS and NAA (personal communication with A. Locock and J. Duke, 2013).

Several differences are noted between the ppm concentration produced by ICP-MS and PXRF (Table 6.6 and Figures 6.1–6.3). The ICP-MS results of reference standard RGM-1 for Rb are 14% greater than the recommended value established by the USGS for this sample. Thus, the ICP-MS value for Rb can be corrected using the recommended ppm value of Rb in the RGM-1. Corrections are conducted by calculating the difference between the lower ppm concentrations of the recommend value of Rb, for RGM-1, and the higher ppm value of Rb obtained by ICP-MS for RGM-1. The difference between these two values is then multiplied by the ppm concentration of Rb in sample JPN1 that were produced by ICP-MS. Through correction, the ICP-MS data for Rb fall within the ±1σ of the PXRF data. Therefore, the corrected ICP-MS results for Rb are in excellent agreement with those produced by PXRF (RPD of 4%). Additionally, the Sr results from the ICP-MS and PXRF analyses of JPN1 are also within ±1σ of one another. Therefore, Rb and Sr are demonstrated to have consistent accuracy between ICP-MS and PXRF analyses. Ultimately, these PXRF and ICP-MS data are seen to be in excellent agreement in the ppm concentration for Rb, good agreement in the concentrations for Fe, Sr, Y, and Zr, fair agreement for the concentrations of Mn and Th, and poor agreement for the concentrations of Zn, Ga, and Nb.

The results of the NAA of JPN1 are seen to be in excellent agreement with the PXRF results for Rb and Zr, and good agreement for Sr (Table 6.6 and Figures 6.1−6.3). Although both the Rb and Zr results from NAA and PXRF are shown to be in excellent agreement, they fall outside of ±1σ; Rb falls within ±2σ, while Zr falls within ±3σ. However, the concentration for Sr falls within ±1σ. The elements Mn, and Ga were not analyzed with NAA during the long irradiation. Additionally, the elements Y and Nb cannot be detected through NAA. The concentration values produced by NAA for Fe are found to be in good agreement with those produced by PXRF (RPD of 11%). However, Th is found to be in poor agreement given a RPD of 67%. Regardless, the results of the PXRF and NAA analyses for Rb, Sr, and Zr is found to be compatible. Furthermore, the NAA results produced at the University of Alberta for JPN1 are seen to be in good agreement with the NAA results published by Kuzmin et al. (2012) for the source Shirataki-A (Akaishiyama Summit Lava).

Between ICP-MS and NAA, the results for JPN1 are found to be in excellent agreement for Rb (RPD of 1%) and Sr (RPD of 0%) (Table 6.6 and Figures 6.1− 6.3). However, the RPD of Zr is 27%. Although this RPD would be considered unacceptable for comparisons with PXRF analyses, for ICP-MS and NAA this comparison is acceptable. The higher ppm concentration value for Zr obtained by NAA can be attributed to the limitations of this technique in accurately characterizing Zr within samples. Conversely, the low ppm concentration value for Zr in JPN1 produced through ICP-MS analysis may be the product of poor digestion of the powered aliquots of JPN1 in the solution used during ICP-MS analysis. Nonetheless, the ICP-MS and NAA data are found to be in excellent agreement for Fe, Th, Rb, and Sr, and fair agreement for Zn and Zr.

Although the PXRF analysis of JPN1, and the reassessment of this sample by ICP-MS, and NAA, the elements Rb, Sr, and Zr are in good agreement, the results for Mn, Fe, Zn, Ga and Th display poor agreement. Variations in ppm concentration values between these three methods were anticipated given the limitations and biases inherent to each of these geochemical methods. Ferguson (2012) notes that the obsidian calibration file supplied by Bruker tends to 'over-count' ppm concentration values for elements lighter than Rb when a sample falls below infinite thickness, or fails to completely cover the path of the X-ray emitted by the PXRF device. Since the calibration applies the same correction to all elements examined regardless of actual concentration values, elements lighter than Rb, and heavier than Nb, are overcorrected when the calibration is applied (Ferguson 2012: 416). Given that the PXRF ppm concentration values for elements Mn, Fe, Zn, Ga, and Th are consistently higher than the ICP-MS and NAA results over time, the higher ppm concentration values seen in JPN1 for these elements are attributed to this calibration effect. Regardless, the multiple tests conducted on JPN1 through PXRF, ICP-MS and NAA are seen to be in good agreement with one another for Rb, Sr, and Zr. Thus, the PXRF device is shown to have an acceptable accuracy for the characterization of these elements, and therefore has an acceptable accuracy for determining the provenance of archaeological obsidian.

6.2 Reference Materials

Table 6.7 provides the results from the PXRF analyses of the obsidian reference materials. Concentration values from previous provenance studies on the four main Hokkaido sources of obsidian are displayed in Table 6.8. These previous studies list the concentration values for the Shirataki, Oketo, Akaigawa, and Tokachi sources and sub-sources. However, ppm concentration values for smaller primary and secondary source deposits of obsidian that are examined in this thesis have yet to be published for compatible methods such as XRF, NAA, ICP-MS and PIXE/PIGME. The ppm concentration values produced by PXRF in this study are found to range from excellent to poor agreement with the previously published source values for elements Rb, Sr, and Zr based on RPD calculations

(Table 6.9). However, the results presented in this thesis for the analyzed reference material frequently fall within ±1σ, or ±2σ, of the previously published values for Hokkaido obsidian sources. Thus, the ppm concentration values produced by PXRF in this study are found to be in good agreement with previously published data.

It should be noted here that Shirataki-B as characterized by Kuzmin and Glascock (2007), Phillips and Speakman (2009), Phillips (2010), and Kuzmin et al. (2012), is treated as the second primary source of obsidian found at the Shirataki formation, and it is referred to as Hachigozawa in these studies. In this thesis, Shirataki-B is known as Horoka-Yubetsu and Tokachi-Ishizawa given their identification as such, and their nearly identical chemical structure. Material from Tokachi-Ishizawa was used by Hall and Kimura (2002). Kuzmin et al. (2012) have identified Tokachi-Ishizawa as a secondary source deposit of Hachigozawa obsidian. Given that the geochemical structures of these three obsidians are identical in their ppm concentration values for Rb, Sr, and Zr, they are treated as the same source material in this thesis.

Although the PXRF device used in this thesis demonstrates an appropriate precision and accuracy for obsidian provenance research, several Hokkaido sources display similar ppm concentrations making it difficult to differentiate these sources chemically from one another. Sources which overlap in ppm concentrations for Rb, and or Sr, and or Zr, can be distinguished in some cases by examining other elements such as Mn, Fe, Zn, and Y. When a majority of elements overlap, including Rb, Sr, and Zr, sources cannot be differentiated from one other. Thus, artifacts attributed to these overlapping sources are treated as potentially derived from either source. Further differentiation of these sources and archaeological materials would require additional analyses by more precise methods such as laboratory XRF, NAA, ICP-MS, and PIXE/PIGME, or by adjustments to the calibration files supplied by Bruker. However, these approaches fell outside the scope of this thesis. Overlap between several Hokkaido obsidian sources is also noted by J. Ferguson (a researcher at the MURR archaeometry lab) who analyzed the same reference materials from the Asahikawa City Museum in Hokkaido with PXRF (Personal communication with J. Ferguson 2013). A discussion of the range overlap found between obsidian sources in Hokkaido, and sub-sources is provided below. Sources Shirataki-A1 and Shirataki-A2 could not be differentiated by their ppm concentration values. Difficulty in the differentiation between these two sub-groups of Shirataki-A is also identified by Hall and Kimura (2002). Moreover, Shirataki-B1 and Shirataki-B2 could not be differentiated. Concentration overlap between samples Shirataki-A1 (Summit Lava) and Shirataki-B2 (Tokachi-Ishizawa) is identified for Sr although, these deposits can be differentiated from one another based on their Rb and Zr values. Obsidian from Shirataki-A and Shirataki-B are chemically different from Akaigawa, Tokachi-Mitsumata, Tokachi-Shikaribetsu, Oketo-Tokoroyama, Kitatokoroyama, and Oketo-Oketoyama.

The materials analyzed from Oketo-Tokoroyama and Oketo-Kitatokoroyama could not be differentiated based on the methods used in this thesis. Therefore, artifacts attributed to Oketo-Tokoroyama or Oketo-

Kitatokoroyama could have been derived from either source. However, Oketo-Tokoroyama and Oketo-Kitatokoroyama are found to be chemically distinct from Oketo-Oketoyama through PXRF analysis. Furthermore, Oketo-Tokoroyama, Oketo-Kitatokoroyama, and Oketo-Oketoyama are found to be chemically distinct from Shirataki-A, Shirataki-B, Akaigawa, Tokachi-Mitsumata, and Tokachi-Shikaribetsu.

The Akaigawa material is found to be chemically distinct from Shirataki-A and Shirataki-B, as well as Oketo-Tokoroyama, Oketo-Kitatokoroyama, Oketo-Oketoyama, and Tokachi-Shikaribetsu. However, Akaigawa is found to overlap with the source materials analyzed from Tokachi-Mitsumata and Monbetsu when Rb, Sr, and Zr, concentration values are compared. When Mn and Fe ppm concentration values are compared, Akaigawa, Tokachi-Mitsumata, and Monbetsu are seen to be chemically distinct. In addition to the overlap seen within the four primary sources for obsidian in Hokkaido there are several overlapping ranges displayed in the smaller primary and secondary sources.

Sources Ikutahara-1 and Ikutahara-2 are seen to be chemically indistinguishable from one another for most elements examined; except Fe. Sources Asahikawa-Syunkodai and Tokachi-Shikaribetsu overlap for elements Rb, Sr, and Zr. However, these sources can be differentiated by examining Mn and Zn ppm concentration values. The Nayoro source is found to overlap with materials from Toyoura for the elements Sr and Zr, although, these two sources are distinguishable based on Rb values. Additionally, it should be noted that the source material from Nayoro was only analyzed twice rather than three times because of researcher error. Although source overlap presented initial confusion in the differentiation of sources when comparing Rb, Sr, and or Zr values, direct comparisons of ppm concentration values for each of the elements examined aided in the differentiation of overlapping sources in most instances.

6.3 Archaeological Materials

The PXRF analysis of archaeological obsidian recovered from the Middle Jomon site Uedomari 3 on Rebun Island revealed the prehistoric use of four Hokkaido obsidian sources (Shirataki-A [n=21], Shirataki-B [n=8], Akaigawa [n=19], and Rubeshibe-Iwayama [n=3]) (Table 6.10). No trends between artifact type and lithic sources are found for the Uedomari 3 assemblage. Comparisons between the Uedomari 3 artifacts and published values for obsidian from the Primorskii Krai (Table 6.11), Kamchatka (Table 6.12), and central Honshu (Table 6.13) reveal that all artifacts analyzed from Uedomari 3 are derived from Hokkaido sources. Given that no compatible data produced by XRF, NAA, ICP-MS, or PIXE/PIGME were found for northern Honshu obsidian sources, comparisons between the ppm concentration results from the Uedomari 3 artifacts and northern Honshu obsidian sources were not possible.

Regardless, all obsidian artifacts analyzed from Uedomari 3 in this study are seen to be derived from Hokkaido obsidian sources based on the good agreement between these artifacts and Hokkaido obsidian source data. The Uedomari 3 artifacts were then plotted in bivariate charts for Sr and Rb, Sr and. Zr, and Rb and. Zr (Figures 6.4‒6.6). Ellipses are drawn around individual sources at a 95% confidence interval, and account for ±2σ from the groups' average. Individual source assignment for this assemblage is displayed best in the bivariate analysis of Rb and Zr, and Sr and Rb. Clusters of artifacts within and around source ellipses are used to assert source assignment. These analytical procedures were repeated for the Kafukai 1 and Hamanaka 2 assemblages.

For the Okhotsk culture, material analyzed from the sites Kafukai 1 and Hamanaka 2 (Nakatani) five Hokkaido obsidian sources are identified (Table 6.14): Shirataki-A [n=13], Shirataki-B [n=29], Oketo-Tokoroyama or Oketo-Kitatokoroyama [n=7], Akaigawa [n=2], and Toyoura [n=1]. All three artifacts from Hamanaka 2 (Nakatani) are attributed to the Shirataki-B deposit, and are included in the total with the Kafukai 1 assemblage. As with Uedomari 3 assemblage, no trend was found between artifact types and lithic sources for the Kafukai 1 and Hamanaka 2 (Nakatani) assemblages. Comparison of the ppm concentration values for Rb, Sr, and Zr in the Kafukai 1 and Hamanaka 2 (Nakatani) assemblages to the published ppm concentration values for obsidian from the Primorskii Krai, Kamchatka, and central Honshu are seen to be dissimilar (Tables 6.11−6.13). Additionally, as with the artifacts from Uedomari 3, no comparison was possible between northern Honshu source material and Kafukai 1 and Hamanaka 2 (Nakatani). All obsidian artifacts from Kafukai 1 and Hamanaka 2 (Nakatani) are attributed to Hokkaido obsidian sources based on the agreement between these data and the Hokkaido source data. Bivariate plots produced from the Kafukai 1 and Hamanaka 2 (Nakatani) data for Sr and Rb, Sr and Zr, and Rb and Zr are presented in Figures 6.7 to 6.9.

Several artifacts from the Kafukai 1 assemblage were difficult or impossible to assign to an individual source. Artifacts KAF32 and KAF45 are seen to group together in the cluster analysis of the Kafukai 1 assemblage. However, when initially plotted the bivariate chart for Sr and Zr, KAF45 is plotted at a distance from the Akaigawa source group. Given that the source material from Akaigawa and Monbetsu are seen to overlap for several elements, source assignments for artifacts that fall between the compositional ranges of two sources prove difficult. However, given the overall compositional similarity of KAF45 to the Akaigawa, the provenance of artifact KAF45 is attributed to Akaigawa. Nonetheless, further analysis of KAF45 by NAA or ICP-MS may prove otherwise. Based on the low ppm concentrations of all elements examined for artifact KAF02 it is evident that this artifact is not made of obsidian (Table 6.14). Although KAF02 is identified as obsidian in the Kafukai 1 site report it could not be assigned to a source given its dissimilar chemical composition relative to all other obsidian materials examined in this thesis.

The difficulty found in accurately assigning several artifacts in the Uedomari 3, Kafukai 1 and Hamanaka 2 (Nakatani) assemblages to source materials is likely the result of infinite thickness errors that occur when thin or irregularly shaped specimens fail to absorb and reflect sufficient X-rays back to the PXRF device. This issue was noted earlier in this chapter in reference to over-counting errors produced when samples approach or fall below the required infinite thickness limits of PXRF. Therefore, the ppm concentration values seen in specimens UEDO3, UEDO37, KAF 15, KAF24, and KAF45 may represent this type of sampling error. However, since a small amount of reference material from the Asahikawa City Museum was used to define each source there remains the potential that the chemical variability present in each source was not completely identified in this study.

6.4 Data Analysis

The results from the PXRF analysis of archaeological obsidian collected from Uedomari 3, Kafukai 1, and Hamanaka 2 (Nakatani) demonstrate a change in obsidian source use taking place from the Middle Jomon to Okhotsk period on Rebun Island. Variations in Hokkaido obsidian source use have been suggested to have begun during the Paleolithic period as prehistoric groups developed exchange networks, and modified mobility patterns to acquire obsidian resources (Hall and Kimura 2002; Izuho and Hirose 2010; Izuho and Sato 2009; Kuzmin et al. 2012). On Rebun Island, changes in Hokkaido obsidian source use have been identified for the Late Jomon, Final Jomon, and Epi-Jomon periods (Tomura et al. 2003). The research presented in this thesis serves to extend the current knowledge of obsidian resources use on Rebun Island to the Middle Jomon and Okhotsk periods. Since all obsidian artifacts examined in this thesis are seen to originate from Hokkaido, both Middle Jomon and Okhotsk peoples on Rebun Island had access to non-local resources. These materials were either acquired through direct procurement or down-the-line trading (Renfrew and Bahn 2008). Although Middle Jomon and Okhotsk groups found at Uedomari 3, Kafukai 1, and Hamanaka 2 (Nakatani) had access to Hokkaido obsidian as either raw materials or finished tools, there is difference between these two cultures in the proportions of obsidian derived from northeastern and central Hokkaido (see Table 6.15 and Figure 6.10). Moreover, differences are also seen in the use of specific deposits within these regions (e.g., deposits Shirataki-A and Shirataki-B are found in the same region).Therefore, differences in obsidian source use are attributed to culture change in Hokkaido from the Middle Jomon to Okhotsk periods. Moreover, changes in prehistoric resource procurement patterns are evident given the differential use of specific Hokkaido sources over time.

The Middle Jomon occupants of Uedomari 3 are demonstrated to have had access to obsidian resources from both northeastern and central Hokkaido (Figure 6.10). However, northeastern obsidians are seen to represent a greater proportion of the obsidian used by the Middle Jomon peoples at Uedomari 3 (Figure 6.10). The predominance of Ento Upper series ceramics at Uedomari 3 demonstrates cultural continuity between the Middle Jomon peoples of Uedomari 3 and contemporaneous Upper Ento bearing groups found in southwestern Hokkaido (Keally 1999). Although the peoples of Uedomari 3 are seen to belong to the Ento Upper series culture, the presence of other ceramic styles at Uedomari 3 (Rouletted series) also demonstrates a connection to Middle Jomon cultures found in northeastern Hokkaido (Keally 1990: 28). Given the combination of ceramic styles and obsidian sources at Uedomari 3, it is suspected that this site served as an important place for both Ento Upper series and Rouletted series Middle Jomon groups located in Hokkaido.

The Okhotsk peoples who occupied Kafukai 1 and Hamanaka 2 (Nakatani) are shown to have had access to obsidian sources from both northeastern and central Hokkaido. However, most of the artifacts analyzed from Kafukai 1 and Hamanaka 2 (Nakatani) are made of obsidian from northeastern Hokkaido (Figure 6.10). Therefore, the Okhotsk people who occupied Kafukai 1 and Hamanaka 2 (Nakatani) may have had limited exchange with groups found in central Hokkaido. Given the low proportion of central Hokkaido obsidian in the Kafukai 1 assemblage it is likely that these obsidians were acquired through down-the-line trading (Renfrew and Bahn 2008). Conversely, the predominance of northeastern Hokkaido obsidians in both Kafukai 1 and Hamanaka 2 (Nakatani) possibly reflect direct procurement, or well established exchange networks between Okhotsk peoples on Rebun Island and other groups found along the north coast of Hokkaido.

As mentioned previously, three juvenile bear skulls recovered from Kafukai 1 have been shown to originate from central or southwestern Hokkaido based on mtDNA analysis. Masuda et al. (2001) suggest that Okhotsk people exchanged with contemporaneous Epi-Jomon groups in central Hokkaido to acquire these bears for the Okhotsk bear ritual. Therefore, the obsidian from the Akaigawa and Toyoura deposits found at Kafukai 1 were possibly acquired through exchange between Epi-Jomon groups and Okhotsk groups in central Hokkaido.

A pattern of prehistoric resource procurement for Rebun Island is elucidated when the results of this thesis are examined in conjunction with the results produced by Tomura et al. (2003) for the Late and Final Jomon, and Epi-Jomon periods of Rebun Island (Table 6.16 and Figures 6.11a, 6.11b). The compositional analysis of archaeological obsidian from Hamanaka 2, Rebun Island, by Tomura et al. (2003) demonstrates a significant use of central Hokkaido obsidian (i.e., the Akaigawa deposit) during the Late Jomon period (Figures 6.11a and 6.11b). However, by the Final Jomon and Epi-Jomon periods the use of Akaigawa obsidian diminishes (Figures 6.11a and 6.11b). Tomura et al. (2003) suggest that Late Jomon people from central Hokkaido travelled to Rebun Island along the Sea of Japan. Therefore, the obsidian artifacts analyzed in Tomura et al. (2003) are most likely the product of direct procurement. However, by the Final Jomon period, the movement of obsidian between central Hokkaido and Rebun Island may have become less important as exchange networks between Rebun Island and northeastern Hokkaido became more established (Figures 6.11a and 6.11b) (Tomura et al. 2003: 197). By the Epi-Jomon period, the presence of central Hokkaido obsidian is limited (Figures 6.11a and 6.11b) (Tomura et al. 2003: 197). Conversely, the movement of obsidian from northeastern Hokkaido to Rebun Island became more developed, given the larger proportion of Shirataki and Oketo obsidians recovered from the Epi-Jomon layers at Hamanaka 2 (Tomura et al. 2003: 197). On Rishiri Island, located between Rebun and Hokkaido, Wada et al. (2006) note a similar trend for the archaeological obsidian analyzed from the Epi-Jomon period. As previously noted, the analysis of archaeological obsidian collected from the excavation of an Epi-Jomon site at the Rishirifuji town hall display a high proportion of Shirataki and Oketo obsidian:

roughly 75% and 21% of all obsidian artifacts analyzed, respectively (Wada et al. 2006: 27). The remaining 4% of the obsidian artifacts were determined to be derived from the Akaigawa, Asahikawa and Rubeshibe deposits (Wada et al. 2006: 27). Therefore, Epi-Jomon peoples on Rebun and Rishiri Islands may have had direct access to the Shirataki and Oketo sources.

As mentioned in Chapter three, the Late Jomon period in Hokkaido is seen as the peak of Jomon socio-political complexity for this region given the presence of elaborate exchange networks, and monumental stone circle cemeteries (Kato et al. 2008; Sakaguchi 2011). Additionally, it is suggested that central Hokkaido became an epicenter for Late Jomon culture in Hokkaido (Kato et al. 2008; Sakaguchi 2011). Therefore, the large proportion of Akaigawa obsidian artifacts recovered from Hamanaka 2 dating to the Late Jomon period reflects the influence of central Hokkaido during this period. Given the strong cultural connection between Rebun Island and central Hokkaido during the Late Jomon period, as demonstrated by the large proportion of central Hokkaido obsidian at Hamanaka 2, and the large Late Jomon cemetery at Funadomari on Rebun Island, it would be expected that alterations to the socio-political dynamics of Jomon culture in central Hokkaido by the Final Jomon period likely impacted the socio-political dynamics of Jomon culture on Rebun Island. This hypothesis would help explain the limited number of Final Jomon sites on Rebun Island.

The decline of Jomon culture by the Final Jomon period has been linked to arrival of Yayoi people to the Japanese archipelago (Crawford 2011; Hudson 2004). Since cultural contact between central Hokkaido and northern Honshu was established from the Middle to Final Jomon periods, it is likely that the decline of Jomon culture in Honshu by the Final Jomon period was linked with the decline of Final Jomon culture in central Hokkaido, and subsequently, Rebun Island. Given that Epi-Jomon culture perpetuated hunter-gatherer life-ways in Hokkaido after the Jomon culture ended throughout the Japanese archipelago, exchange networks that were established between Rebun Island and northeastern Hokkaido during the Final Jomon period were possibly continued during the Epi-Jomon period. This would explain the similar proportion of northeastern Hokkaido obsidian found on Rebun Island during the Epi-Jomon period. However, this hypothesis cannot be extended to the Okhotsk period.

During the early phases of the Okhotsk migration to Hokkaido, Okhotsk groups may not have had direct access to obsidian sources in Hokkaido, given the prominence of Epi-Jomon culture in regions containing obsidian deposits. In later phases, as the Okhotsk culture expanded along the Sea of Okhotsk coast of Hokkaido to the Kuril Islands, obsidian from Shirataki and Oketo would have become more accessible to Okhotsk people. As the Okhotsk culture developed in this region, Epi-Jomon groups became more centralized in southwestern and central Hokkaido. The presence of several Okhotsk sites along the Sea of Japan coast of Hokkaido and on Okushiri Island in southwestern Hokkaido would have put Okhotsk groups in direct contact with Epi-Jomon peoples in this region. Thus, exchange likely occurred between these two cultures. Given the limited number of foreign artifacts recovered from Okhotsk assemblages, exchange between the Okhotsk and other contemporary cultures is thought to be limited (Befu and

Chard 1964; Ohyi 1975, 1981). This notion is reflected in the minimal proportion of central Hokkaido obsidian in the Kafukai 1 assemblage. Nonetheless, perishable items including plant and animal materials may have been exchanged between Epi-Jomon and Okhotsk people. However, their representation in the archaeological record is limited given poor preservation of these materials.

In conclusion, culture change in Hokkaido included changes to obsidian resource procurement strategies from the Middle Jomon to Okhotsk periods on Rebun Island. For the Middle Jomon period, it is likely that central Hokkaido began to play an important role in socio-political dynamics of Rebun Island given the significant proportion of obsidian from this region recovered at Uedomari 3. The growing centralization of Hokkaido during the Middle Jomon period came to fruition during the Late Jomon period. This is believed to be reflected in the research of Tomura et al. (2003) who identified a predominance of central Hokkaido obsidian at Hamanaka 2 on Rebun Island. However, the decline of the Jomon culture and exchange economy by the Final Jomon period forced subsequent prehistoric groups in northern Hokkaido and Rebun Island to alter their patterns of resource procurement, or develop entirely new procurement strategies to acquire obsidian.

6.5 Summary

The PXRF device used in this thesis has been demonstrated to have an acceptable precision and accuracy for the characterization of obsidian materials based on the good agreement of these data with established laboratory methods of geochemical analysis, and previously published data for Hokkaido obsidian sources. Furthermore, these data can be used to determine the provenance of archaeological obsidian collected from Rebun Island, Hokkaido, Japan. Source overlap was initially problematic for differentiating sources. Nonetheless, close examination of ppm concentration values helped distinguish individual sources in most instances. Moreover, adjustments to the calibration file supplied by Bruker would likely improve the differentiation and characterization of Hokkaido source materials.(Personal communication with J. Ferguson 2013). However, additional instruction is needed before these adjustments can be made to the existing calibration file and applied to this research.

Results from the analysis of archaeological obsidian from the Middle Jomon and Okhotsk periods on Rebun Island demonstrate changes in obsidian source use from the Middle Jomon to the Okhotsk period. These changes are suspected to be a result of culture change in Hokkaido between the Middle Jomon and Okhotsk period. Given the peripheral location of Rebun relative to Hokkaido, the prehistoric communities found on Rebun were likely quite sensitive to alterations in exchange networks between these two islands. Therefore, determining the provenance of archaeological obsidian recovered from sites on Rebun Island is seen as a useful aid in illuminating changes in prehistoric resource procurement patterns, as well as exchange networks in Hokkaido. Finally, these results are also found to extend the body of knowledge surrounding the prehistoric transportation of and use of obsidian materials derived from Hokkaido sources for Rebun Island, as well as Northeast Asia.

Chapter Seven – Conclusions

7.1 Summary of Research and Comments

This thesis has been successful in achieving its two research aims: testing the applicability of PXRF analyses of archaeological obsidian on Rebun Island, and identifying changes in obsidian source use dating from the Middle Jomon to Okhotsk periods by analyzing archaeological obsidian from three sites Uedomari 3, Kafukai 1, and Hamanaka 2 (Nakatani) on Rebun Island. This research extends the current body of knowledge of obsidian provenance research on Rebun Island to the Middle Jomon and Okhotsk periods, where no data had previously existed. The identified changes in obsidian source use on Rebun Island from the Middle Jomon to Okhotsk periods are attributed to culture change in Hokkaido between these times. At Uedomari 3, Middle Jomon people had access to obsidian resources from both central and northeastern Hokkaido. However, northeastern Hokkaido obsidian (i.e., Shirataki) composes a majority of obsidian materials analyzed from Uedomari 3. A significant amount of the analyzed artifacts from Uedomari 3 were also produced on central Hokkaido obsidian (i.e., Akaigawa). For the Okhotsk culture, northeastern Hokkaido obsidian is also demonstrated to compose a majority of the obsidian materials analyzed from Kafukai 1 and Hamanaka 2 (Nakatani). However, by the Okhotsk period the use of central Hokkaido obsidian sources is nearly absent. Therefore, it is posited that the Okhotsk culture never had direct or indirect access to obsidian sources located in central Hokkaido.

Hokkaido and Rebun Island share a unique prehistory relative to the other Japanese Islands. This is demonstrated by the continuation of hunter-gatherer life styles in Hokkaido after the arrival of the Yayoi to western and central Japan by 2800 YBP and evidence of cultural affiliations to both central Japan and Northeast Asia. These ties are demonstrated to have arisen through centuries of cultural contact, and exchange between these two regions. It must also be said that the unique geography, geology, and environment of Hokkaido contributed to the unique prehistory of this region.

Although Rebun Island is geographically peripheral to Hokkaido, it was undoubtedly incorporated into Hokkaido's sphere of influence during prehistory. This is best demonstrated between the shared cultural histories of these two islands, as well as through the exchange networks discussed in this thesis. Given the proximity of Rebun Island to Hokkaido, as well as Northeast Asia, it is likely Rebun Island served as a gateway between these two regions. Hirth (1978) discusses the significance of gateway communities in prehistory. Since, gateway communities are typically situated on the peripheries of cultural spheres of influence and serve as loci for exchange, and cultural contact between neighbouring groups this model may apply to Rebun Island (Hirth 1978). This model may be supported given Rebun's geographical location, and the presence of exotic exchange items such as obsidian, jade, and bitumen recovered from archaeological sites on Rebun Island that are derived from both the Japanese archipelago as well as Northeast Asia. Given that the transportation of cultural materials coincides with the movement of people over a landscape, it is likely that long distance exchange networks between prehistoric communities in Rebun and Northeast Asia were established to facilitate and perpetuate contact between cultures. Although this thesis has helped to illuminate some of the dynamics of prehistoric exchange within this region, additional research is still needed to fully develop the the applicability of the gateway community model to the prehistory of Rebun Island.

Along with the archaeological findings, this thesis demonstrates that changes in the prehistoric use of obsidian sources can be identified through PXRF. PXRF provides a unique opportunity to analyze archaeological obsidian while in the field, with compatible accuracy to other established methods of geochemical analysis. However, the successful implementation of this technology is dependent on several factors. These factors concern the proper utilization of scanning methods with PXRF to ensure that results are accurate and compatible with other geochemical methods of analyses (i.e., reproducible). As Shackley (2010), and Speakman and Shackley (2013) have noted, archaeologists are frequently keen to incorporate new methods of analysis into their research, although, potentially without sufficient knowledge to execute these methods appropriately. The scanning procedures which are essential to the proper utilization of PXRF for obsidian provenance research include the selection of appropriately sized artifacts, the duration of scan times, the energies to capture relevant trace elemental spectra, and the calibration of the PXRF instrument. However, each of these steps are easily achieved if attention is given to avoid instrument as well as researcher error.

Several scholars have critiqued Shackley (2010) and Speakman and Shackley (2013) for their harsh assessment of the widespread use of PXRF devices in archaeology. Shackley and Speakman's disdain regards the relative precision and accuracy of PXRF devices compared to established laboratory methods of geochemical analysis, as well as the training of the individuals who utilized this technology (see Ferguson 2012 and Frahm 2013). Although proper protocol is necessary to employ PXRF in obsidian provenance studies, the use of this technique in archaeology will not advance unless researchers attempt to explore all potential applications of this technique to their research. The ensuing debate between the validity of PXRF is comparable to the earlier debate in the discipline surrounding the "sourcing myth" in archaeology (see Shackley 1998a and Hughes 1998). The methods used in archaeology have changed over time to incorporate new practices and perceptions to further the analysis of the archaeological record. Therefore, the use of PXRF in obsidian provenance studies will continue to develop over the coming years as more archaeologists incorporate this technology into their research.

7.3 Recommendations for Future Research

The continued examination of archaeological obsidian excavated from Rebun Island will undoubtedly be an important avenue of research for the BHAP in the years to come. However, there are several directions which this research would benefit to explore in the future. This primarily includes the PXRF analysis of archaeological obsidian associated with the three other Middle Jomon sites on

Rebun Island: Uedomari 1, Funadomari, and Kafukai, as well as characterization of archaeological obsidian associated with Late and Final Jomon sites. Future analysis of archaeological obsidian collected from Jomon sites on Rebun Island will help elucidate the changes in obsidian source use in Hokkaido during the Jomon period. This will also help to define the directionality of exchange networks tied to Rebun Island during these Jomon cultural periods. Moreover, this research focus should include Epi-Jomon, and additional Okhotsk sites on Rebun Island to explore the collapse and establishment of post-Jomon exchange networks.

Alongside of obsidian provenance research, ceramic analyses including provenance and residue analysis would help further archaeological explorations of prehistoric exchange networks found between Hokkaido and Rebun Island. This research should focus on determining the provenance for the Ento Upper and Rouletted series ceramics found at Uedomari 3 because previous studies by Hall et al. (2002) have demonstrated that ceramic materials dating to the Epi-Jomon and Okhotsk periods were produced with local clays from Rishiri and Rebun Island. Therefore, if Epi-Jomon and Okhotsk peoples were able to produce ceramic artifact out of native clays, Middle Jomon peoples at Uedomari 3 may have reproduced Ento Upper and Rouletted series ceramics on Rebun Island rather than import these artifacts. This opposes Keally's (1990) position that local clays on Rebun Island were not suitable for the production of large ceramic vessels seen in the Ento Upper series recovered from Uedomari 3.

Although there are many avenues for future research on Rebun Island, extending this research to sites found on Hokkaido Island would also help support claims made about the prehistoric exchange networks of this region. This research should include the analysis of archaeological obsidian collected from sites along the Sea of Japan coast, and Sea of Okhotsk to examine the dispersal of obsidian source materials within these regions. Additionally, the analysis of archaeological obsidian collected from sites in central Hokkaido would also further current understandings of the movement of northeastern Hokkaido obsidian within Hokkaido.

Several technical alterations and protocol changes would also improve future obsidian provenance studies conducted by the BHAP. These include additionally analyses of obsidian source materials by PXRF and other established geochemical methods, adjustments to the Bruker obsidian calibration file, and the analysis of debitage and small obsidian artifacts. Additional characterizations of Hokkaido source materials would help to explore the true range of variation present within each of these sources. Since the PXRF device used in this thesis demonstrated good agreement with established laboratory methods of geochemical analyses, the use of this technique for additional characterizations of Hokkaido obsidian materials would be sufficient. Adjustments to the Bruker calibration file would make it easier to differentiate source deposits and individual artifacts from one another. Adjustments to the calibration file can be completed in Microsoft Excel. However, a better working knowledge of the proper protocol for these adjustments is required before they may implemented. The analysis of debitage and small artifacts by LA-ICP-MS as conducted by Phillips (2010, 2011) and Phillips and Speakman (2009) would increase the number of artifacts that could potentially be analyzed for provenance research. Furthermore, these additional analyses may help examine any potential relationships between obsidian sources and lithic production.

Table 4.1: List of the Hokkaido obsidian sources examined in this thesis, with geographic coordinates. Table supplied by Dr. M. Mukai at the Asahikawa City Museum.

Sample ID	Site ID	Sub-Region	Longitude	Latitude
JHK001	ASAHIKAWA-SYUNKODAI	KAMIKAWA BASIN	142.3601	43.8311
JHK002	ASAHIKAWA-HIGASHITAKASU	KAMIKAWA BASIN	142.3924	43.8342
JHK003	TAKIKAWA-AHINTOTSUGAWA	SORACHI PLAIN	141.8475	43.6006
JHK004	AKIAGAWA	AKAIGAWA VALLEY	140.8155	43.0388
JHK005	NAYORO	CHUREPPU HILL	142.5403	44.2781
JHK006	ENGARU-SANABUCHI	SANABUCHI RIVER	143.4729	44.0650
JHK007	OUMU	OTOINEPPU RIVER	142.8818	44.5950
JHK008	OKUSHIRI	KATSUMA MOUNTAIN	139.4592	42.1989
JHK009	TOKACHI-MITSUMATA	MINAMIKUMANESIRI MOUNTAIN	143.2026	43.4981
JHK010	TOKACHI-SHIKARIBETSU	SHIKARIBETSU RIVER	142.991	43.0801
JHK011	IKUTAHARA-1	SEYAUSHI MOUNTAIN	143.4923	43.9698
JHK012	IKUTAHARA-2	NITAPPU RIVER	143.4923	43.9698
JHK013	RUBESHIBE-IWAYAMA	IWAYMA VALLEY	143.3373	43.7607
JHK014	RUBESHIBE-KAYOKOZAWA	KAYOKO VALLEY	143.3106	43.7560
JHK015	TOYOURA	TOYOIZUMI VALLEY	140.6698	42.6045
JHK016	MONBETSU	KAMIMOBETSU VALLEY	143.3781	44.1689
JHK019	OKETO-OKETOYAMA	OKETO MOUNTAIN	143.5403	43.6969
JHK020	OKETO-TOKOROYAMA	TOKOROYAMA MOUNTAIN	143.5115	43.6850
JHK021	OKETO-KITATOKOYAMA	KITA-TOKOROYAMA MOUNTAIN	143.5153	43.6791
AK-A	AKAISHIYAMA-SUMMIT LAVA	SHIRATAKI AREA	NA	NA
AK-B	AKAISHIYAMA-UPPER LAVA	SHIRATAKI AREA	NA	NA
TI-A	HOROKA-YUBETSU LAVA	SHIRATAKI AREA	NA	NA
TI-B	TOKACHI-ISHIZAWA LAVA	SHIRATAKI AREA	NA	NA

Table 6.1: PXRF results for control sample JPN1. *JPN1* refers to the name of the obsidian control sample used in this thesis. Results are presented as ppm concentration values.

Sample JPN1	Mn	Fe	Zn	Ga	Th	Rb	Sr	Y	Zr	Nb
JPN1(test1)	616	9263	57	36	19	141	31	32	78	14
JPN1(test2)	603	9084	71	34	22	144	30	32	77	14
JPN1(test3)	615	9191	65	34	21	144	31	32	77	14
JPN1(test4)	635	9035	63	35	22	144	30	33	77	14
JPN1(test5)	585	9127	62	36	23	141	31	32	77	14
JPN1(test6)	571	9141	68	35	20	144	30	32	77	15
JPN1(test7)	610	9149	64	35	23	142	31	33	78	14
JPN1(test8)	555	9476	67	33	21	146	32	32	77	14
JPN1(test9)	621	9439	65	36	22	148	32	32	78	15
JPN1(test10)	620	9997	64	31	23	154	33	32	79	13
JPN1(test11)	659	9468	67	36	23	144	31	34	77	15
JPN1(test12)	657	9229	61	35	22	147	33	33	78	14
JPN1(test13)	607	9346	67	36	22	144	31	32	78	14
JPN1(test14)	598	9358	64	36	21	145	29	33	77	14
JPN1(test15)	601	9299	66	35	22	145	31	32	77	14
JPN1(test1a)	578	9265	66	35	21	153	31	34	79	14
JPN1(test2a)	598	9295	62	33	22	149	31	33	79	14
JPN1(test3a)	558	9237	62	35	21	149	32	32	78	13
JPN1(test4a)	606	9347	64	35	22	147	30	32	78	13
JPN1(test5a)	589	9365	68	36	22	147	32	33	80	13
JPN1(test6a)	561	9215	64	34	22	145	32	33	78	14
JPN1(test1b)	581	9422	65	36	22	149	31	33	77	14
JPN1(test2b)	592	9319	70	35	21	145	33	34	77	14
JPN1 (test A)	589	9463	66	35	23	151	30	34	79	14
JPN1 (test B)	579	9471	67	36	23	150	31	32	78	14
JPN1 (test C)	608	9370	62	35	22	148	31	33	78	14
JPN1 (test D)	583	9157	68	32	20	143	31	33	75	14
JPN1 (test E)	575	8934	67	32	20	147	31	33	75	13

	Mn	Fe	Zn	Ga	Th	Rb	Sr	Y	Zr	Nb
JPN1 Average (n=28)	598	9302	65	35	22	146	31	33	78	14
Standard Deviation	26.1	195.4	3.0	1.4	1.0	3.3	1.0	0.7	1.0	0.5
RSD%	4.30	2.10	4.60	4.10	4.50	2.20	3	2.20	1.30	3.40

Table 6.2: ICP-MS results (ppm) for control sample JPN1 and reference standard RGM-1 (Rb uncorrected)

ICP-MS Results (Rb Uncorrected)	Mn	Fe	Zn	Ga	Th	Rb	Sr	Y	Zr	Nb
RGM-1	421	13699	29.0	18.1	27.1	171	106	20.8	219	10.7
JPN1-1	365	8133	26.4	16.0	15.4	174	28.4	24.6	63.7	6.68
JPN1-2	350	7680	25.2	15.5	14.6	171	26.2	23.9	63.5	6.40
JPN1-3	365	8174	25.9	15.7	14.3	174	29.4	25.8	65.2	6.40
JPN1 Average and St. Deviation	360±9	7796±274	26±1	16±0.3	15±1	173±2	28±2	25±1	64±1	6±0.2

Table 6.3: ICP-MS results (ppm) for control sample JPN1 and reference standard RGM-1 (Rb corrected)

ICP-MS Results (Rb Corrected)	Mn	Fe	Zn	Ga	Th	Rb	Sr	Y	Zr	Nb
RGM-1	421	13699	29.0	18.1	27.1	171	106	20.8	219	10.7
JPN1-1	365	8133	26.4	16.0	15.4	153	28.4	24.6	63.7	6.68
JPN1-2	350	7680	25.2	15.5	14.6	150	26.2	23.9	63.5	6.40
JPN1-3	365	8174	25.9	15.7	14.3	153	29.4	25.8	65.2	6.40
JPN1 Average and St. Deviation	360±9	7796±274	26±1	16±0.3	15±1	152±2	28±2	25±1	64±1	6±0.2

Table 6.4: NAA long irradiation results (ppm) for control sample JPN1 and reference standard RGM-1

NAA Results	Mn	Fe	Zn	Ga	Th	Rb	Sr	Y	Zr	Nb
RGM-1	NA	12690	35	NA	14.16	147.4	99	NA	214	NA
JPN1-1	NA	8320	34	NA	11.4	149.8	29	NA	81	NA
JPN1-2	NA	8300	34	NA	11.4	151.5	26	NA	85	NA
JPN1-3	NA	8440	33	NA	11.6	152.5	30	NA	85	NA
JPN1 Average and St. Deviation	NA	8353±76	34±1	NA	11±0	151±1	28±2	NA	84±2	NA

Table 6.5: Recommended values (ppm) for USGS reference standard RGM-1

Recommended RGM-1 Values	Mn	Fe	Zn	Ga	Th	Rb	Sr	Y	Zr	Nb
RGM-1 Average and St. Deviation	280±30	12700±500	32±0	15±2	15±1.3	150±8	110±10	25±0	220±20	8.9±0.6

Table 6.6: Comparisons for specimen JPN1. Results presented as percentages for relative percent difference (RPD) values. The bracketed value in Rb represents the RPD for the corrected Rb values for ICP-MS.

Method Comparisons	Mn	Fe	Zn	Ga	Th	Rb	Sr	Y	Zr	Nb
NAA to PXRF	NA	11%	63%	NA	67%	3%	10%	NA	7%	NA
ICP-MS to PXRF	50%	15%	86%	75%	38%	17% (*4%*)	10%	14%	20%	73%
NAA to ICP-MS	NA	4%	27%	NA	3%	1%	0%	NA	27%	NA

Table 6.7: Hokkaido obsidian sources reference collection ppm concentration values collected with PXRF. The accession numbers for these reference materials are found in Table 4.1.

Reference Collection PPM Values	Mn	Fe	Zn	Ga	Th	Rb	Sr	Y	Zr	Nb
Shirataki-A Summit Lava	590±46	9491±464	66±3	35±1	21±1	149±6	31±2	32±0	80±3	13±1
Shirataki-A Upper Lava	580±21	9141±322	65±3	35±1	21±1	145±2	30±1	32±0	79±2	14±1
Shirataki-B Horoka-Yubetsu	681±51	9753±474	65±3	35±1	21±1	170±7	16±0	37±0	72±2	15±1
Shirataki-B2 Tokachi-Ishizawa	665±5	9176±146	63±2	35±1	20±2	171±6	19±9	34±0	72±4	15±1
Asahikawa-Syunkodai	736±92	12933±959	75±2	37±2	22±1	122±6	95±4	29±2	93±2	13±0
Asahikawa-Higashitakasu	810±49	16681±1063	81±9	35±2	20±1	114±5	128±5	28±1	107±0	13±0
Takikawa-Shintotsugawa	751±54	7764±289	57±3	34±1	27±1	148±2	57±0	32±0	95±0	14±1
Akaigawa	774±46	9472±673	59±3	35±6	28±2	132±6	51±3	31±2	89±2	14±1
Nayoro	471±19	11639±362	64±2	34±2	22±1	120±1	87±1	24±0	113±1	12±1
Engaru-Sanabuchi	692±31	12198±367	82±5	36±0	20±1	120±5	48±1	45±1	135±2	16±0
Oumu	351±11	10555±175	69±2	35±3	20±2	141±9	45±1	48±2	119±6	14±2
Okushiri	1019±51	6160±686	54±2	33±1	26±2	178±9	118±15	22±1	67±1	14±1
Tokachi-Mitsumata	607±10	8885±110	63±3	35±2	21±1	136±3	49±0	36±1	89±4	14±1
Tokachi-Shikaribetsu	532±23	11705±150	67±2	35±1	22±2	123±4	90±1	29±0	91±1	13±0
Ikutahara-1	467±18	13737±527	81±5	35±5	21±4	159±7	48±1	43±0	201±12	13±2
Ikutahara-2	473±14	14763±52	87±4	41±1	25±1	161±1	50±1	46±1	205±2	15±0
Rubeshibe (Iwayama)	687±12	14550±291	78±3	38±1	20±0	124±4	97±6	32±0	112±4	14±0
Rubeshibe (Kayokozawa)	733±35	16071±449	80±1	36±2	20±0	115±4	113±3	31±1	123±3	14±1
Toyoura	731±4	9745±118	57±2	31±1	20±0	90±3	88±3	29±1	110±4	13±0
Monbetsu	429±56	10120±2081	62±7	34±2	20±2	128±2	61±2	39±2	89±4	13±0
Oketo (Oketoyama)	574±39	11502±187	65±1	34±2	18±1	97±1	74±1	28±1	126±1	14±0
Oketo (Tokoroyama)	557±54	9458 ±172	57±2	35±2	23±1	136±4	64±1	29±1	102±1	14±1
Oketo (Kitatokoroyama)	540±26	9340±300	58±4	34±0	22±1	135±2	62±2	28±1	102±1	13±0

Table 6.8: Previously published data on Hokkaido sources in ppm concentrations with instrumental methods used. Concentration values for Fe converted from weight % to ppm values for Kuzmin and Glascock (2007), Phillips (2010), and Kuzmin et al. (2012).

Hall and Kimura (2002) EDXRF										
	Mn	**Fe**	**Zn**	**Ga**	**Th**	**Rb**	**Sr**	**Y**	**Zr**	**Nb**
Shirataki-A (n=31)	NA	11144±387	NA	26±7	18±2	188±7	32±2	32±2	91±4	NA
Shirataki-A (n=30)	692±56	11075±430	NA	26±6	19±2	185±6	31±2	30±1	89±3	NA
Shirataki-B (n=20)	NA	10873±819	NA	26±7	18±3	209±11	NA	37±2	76±4	NA
Oketo-Tokoro (n=20)	NA	11448±905	NA	26±9	18±2	171±9	80±5	25±2	127±5	NA
Oketo-Oketo (n=31)	Na	13002±1514	NA	23±4	15±2	127±5	97±4	22±1	160±6	NA
Tokachi-Mitsumata (n=5)	NA	15366±10360	NA	24±3	20±3	185±8	58±4	35±3	100±5	NA
Kuzmin and Glascock (2007) NAA										
	Mn	**Fe**	**Zn**	**Ga**	**Th**	**Rb**	**Sr**	**Y**	**Zr**	**Nb**
Shirataki-A (n=8)	384±6	8000±100	39±4	NA	11.1±0.1	151±2	28±4	NA	90±8	NA
Shirataki-B (n=7)	451±9	7500±200	36±4	NA	9.7±0.1	175±2	NA	NA	87±8	NA
Oketo-A (n=4)	325±5	7500±200	26±2	NA	11.9±0.1	135±1	67±11	NA	116±2	NA
Oketo-B (n=2)	385±3	8900±300	37±0	NA	9.3±0.2	99±3	79±37	NA	128±0	NA
Akaigawa (n=2)	482±4	7200±100	35±2	NA	18.4±1.4	128±2	49±21	NA	144±38	NA
Tokachi-Mitsumata (n=2)	369±6	7200±100	36±0	NA	12.1±0	139±1	42±4	NA	104±10	NA
Phillips and Speakman (2009) PXRF and LA-ICP-MS										
	Mn	**Fe**	**Zn**	**Ga**	**Th**	**Rb**	**Sr**	**Y**	**Zr**	**Nb**
Shirataki-A (n=6)	369±51	8489±1091	56±24	16±1	9±1	153±12	27±2	29±2	54±1	3±1
Shirataki-B n=7)	353±52	7326±464	36±14	15±7	7±2	168±9	9±2	33±3	44±5	4±1
Oketo-1 (n=34)	297±56	7809±560	38±13	15±1	9±2	135±7	63±3	25±1	87±4	3±1
Oketo-2 (n=2)	313±10	9379±141	39±15	14±2	6±3	92±1	75±2	21±1	111±2	2±1
Phillips (2010) LA-ICP-MS										
	Mn	**Fe**	**Zn**	**Ga**	**Th**	**Rb**	**Sr**	**Y**	**Zr**	**Nb**
Shirataki-A(n=108)	454±114	23275±130	79±35	20±4	11±2	143±26	26±4	29±6	64±10	5±1
Shirataki-B (n=79)	464±80	18167±129	67±33	19±4	10±3	160±30	11±4	33±6	54±12	5±1
Oketo-1 (n=236)	359±109	9193±392	37±10	18±2	12±1	140±12	58±7	24±3	86±6	4±1
Oketo-2 (n=22)	557±150	15842±586	62±15	25±6	15±5	178±56	82±7	32±7	117±11	6±2
Kuzmin et al. (2012) NAA										
	Mn	**Fe**	**Zn**	**Ga**	**Th**	**Rb**	**Sr**	**Y**	**Zr**	**Nb**
Shirataki-A (n=15)	384±6	7880±120	37.5±3.4	NA	11.1±0.1	150±2	28±4	NA	90±7	NA
Shirataki-B (n=11)	451±7	7430±160	35.6±3	NA	9.7±0.2	174±2	<15	NA	87±7	NA
Oketo-A (n=13)	321±4	7320±120	27±1.5	NA	11.9±0.1	135±1	74±13	NA	116±5	NA
Oketo-B (n=6)	371±13	9000±230	37.0±0.8	NA	9.3±0.1	98±2	89±23	NA	129±2	NA

Table 6.9: Relative percent difference (RPD) between PXRF results from this thesis and those previously published on Hokkaido obsidian deposits.

Thesis Compared with Hall and Kimura (2002) XRF Results	**Rb**	**Sr**	**Zr**
Shirataki-A (Akaishiyama summit)	23%	3%	13%
Shirataki-A (Akaishiyama Upper)	24%	3%	12%
Shirataki-B (Tokachi-Ishigozawa)	20%	NA	5%
Oketo-Tokoroyama	23%	22%	22%
Oketo-Oketoyama	27%	27%	24%
Akaigawa	NA	NA	Na
Tokachi-Mitsumata	31%	17%	12%
Thesis Compared with Kuzmin and Glascock (2007) NAA Results	**Rb**	**Sr**	**Zr**
Shirataki-A (Akaishiyama summit)	1%	10%	12%
Shirataki-A (Akaishiyama Upper)	NA	NA	NA
Shirataki-B (Hachigozawa)	2%	NA	19%
Oketo-Tokoroyama	1%	5%	9%
Oketo-Oketoyama	2%	7%	2%
Akaigawa	3%	4%	47%
Tokachi-Mitsumata	2%	15%	16%
Thesis Compared with Phillips and Speakman (2009) PXRF and LA-ICP-MS Results	**Rb**	**Sr**	**Zr**
Shirataki-A (Akaishiyama summit)	3%	14%	40%
Shirataki-A (Akaishiyama Upper)	NA	NA	NA
Shirataki-B (Hachigozawa)	2%	71%	48%
Oketo-Tokoroyama	1%	2%	16%
Oketo-Oketoyama	5%	1%	13%
Akaigawa	NA	NA	NA
Tokachi-Mitsumata	NA	NA	NA
Thesis Compared with Phillips (2010) LA-ICP-MS Results	**Rb**	**Sr**	**Zr**
Shirataki-A (Akaishiyama summit)	4%	18%	22%
Shirataki-A (Akaishiyama Upper)	NA	NA	NA
Shirataki-B (Hachigozawa)	7%	53%	29%
Oketo-Tokoroyama	3%	10%	17%
Oketo-Oketoyama	27%	50%	27%
Akaigawa	NA	NA	NA
Tokachi-Mitsumata	NA	NA	NA
Thesis Compared with Kuzmin et al. (2012) NAA Results	**Rb**	**Sr**	**Zr**
Shirataki-A (Akaishiyama summit)	1%	10%	12%
Shirataki-A (Akaishiyama Upper)	NA	NA	NA
Shirataki-B (Hachigozawa)	1%	30%	19%
Oketo-Tokoroyama	1%	14%	13%
Oketo-Oketoyama	1%	18%	2%
Akaigawa	NA	NA	NA
Tokachi-Mitsumata	NA	NA	NA

Table 6.10: Uedomari 3: artifact ppm concentration values

Artifact ID	Type	Source	Mn	Fe	Zn	Ga	Th	Rb	Sr	Y	Zr	Nb
UEDO1	Point	Shirataki-B	715	9652	66	39	23	180	17	38	75	17
UEDO2	Point	Shirataki-A	614	8727	74	37	25	157	33	34	81	14
UEDO3	Point	Shirataki-A	685	10271	84	40	23	169	35	35	85	16
UEDO4	Point	Shirataki-B	716	9656	65	36	22	172	16	37	72	16
UEDO5	Point	Shirataki-B	724	9709	74	35	23	175	17	38	72	14
UEDO6	Point	Akaigawa	763	9469	55	35	28	132	51	31	91	14
UEDO7	Point	Akaigawa	732	8768	65	35	27	129	50	31	85	14
UEDO8	Point	Akaigawa	768	9543	60	35	28	131	52	29	88	15
UEDO9	Point	Akaigawa	754	9242	61	38	27	130	51	31	87	14
UEDO10	Knife	Shirataki-A	613	9701	67	35	22	147	30	33	81	14
UEDO11	Point	Shirataki-A	594	9791	66	36	23	147	30	31	80	14
UEDO12	Knife	Shirataki-A	607	9539	63	35	20	147	32	33	85	14
UEDO13	Scraper	Akaigawa	767	9403	65	35	28	133	53	31	89	15
UEDO14	Scraper	Akaigawa	693	8827	53	26	22	138	52	29	88	10
UEDO15	Scraper	Akaigawa	727	9485	62	37	28	131	50	30	86	15
UEDO16	Point	Akaigawa	778	9757	62	38	27	135	54	32	90	15
UEDO17	Point	Akaigawa	755	9254	64	36	26	132	51	31	86	14
UEDO18	Point	Akaigawa	739	9542	58	36	29	135	51	31	90	15
UEDO19	Point	Shirataki-A	648	10807	66	35	21	154	32	33	81	14
UEDO20	Point	Rubeshibe-Iwayama	513	11633	66	39	23	125	94	28	118	14
UEDO21	Point	Shirataki-B	650	9503	68	37	22	171	17	38	73	16
UEDO22	Point	Rubeshibe-Iwayama	483	11919	66	38	24	126	92	27	118	13
UEDO23	Point	Shirataki-A	614	10294	69	38	23	152	33	35	81	16
UEDO24	Point	Shirataki-A	639	10605	72	40	23	157	33	34	84	16
UEDO25	Point	Shirataki-A	595	10347	64	36	23	154	33	33	80	14
UEDO26	Point	Shirataki-B	715	9889	68	37	21	173	16	37	73	16
UEDO27	Point	Akaigawa	752	9474	57	35	28	130	50	29	92	15
UEDO28	Point	Akaigawa	690	9299	54	33	28	132	51	32	89	14
UEDO29	Point	Rubeshibe-Iwayama	447	12119	65	37	24	127	92	27	116	13
UEDO30	Point	Akaigawa	793	9690	69	35	30	135	52	32	90	15
UEDO31	Scraper	Akaigawa	780	9865	64	35	27	133	52	31	91	15
UEDO32	Scraper	Akaigawa	786	9526	59	36	26	132	51	31	87	15

Table 6.10: Uedomari 3: artifact ppm concentration values continued. *Biface Frag.* refers to biface fragment

Artifact ID	Typology	Source	Mn	Fe	Zn	Ga	Th	Rb	Sr	Y	Zr	Nb
UEDO33	Point	Shirataki-A	627	10030	72	37	21	155	32	34	80	14
UEDO34	Point	Shirataki-A	583	9906	64	35	22	150	33	32	79	14
UEDO35	Point	Akaigawa	737	9311	58	34	25	132	51	30	88	15
UEDO36	Biface Frag.	Shirataki-A	636	9725	65	34	21	145	32	32	79	14
UEDO37	Point	Akaigawa	680	10343	71	45	25	154	56	40	95	17
UEDO38	Point	Shirataki-A	587	9646	94	41	22	146	32	33	85	15
UEDO39	Point	Shirataki-B	725	9506	63	38	22	180	18	39	75	16
UEDO40	Point	Akaigawa	757	9562	61	39	29	138	53	32	91	16
UEDO41	Point	Shirataki-B	746	9705	65	41	21	175	18	38	73	16
UEDO42	Point	Shirataki-A	632	10174	67	41	25	153	34	35	81	15
UEDO43	Point	Shirataki-B	696	9547	64	37	22	169	16	37	71	15
UEDO44	Biface Frag.	Shirataki-A	632	9518	61	37	21	149	32	34	79	14
UEDO45	Scraper	Shirataki-A	635	10412	63	36	22	152	32	35	83	14
UEDO46	Biface Frag.	Shirataki-A	616	10130	72	37	22	152	33	33	79	14
UEDO47	Biface Frag.	Shirataki-A	579	9537	66	35	23	144	32	32	80	14
UEDO48	Biface Frag.	Shirataki-A	594	9881	68	38	22	151	33	32	77	15
UEDO49	Biface Frag.	Shirataki-A	671	10413	70	37	23	152	33	34	83	14
UEDO50	Point	Akaigawa	716	8984	57	36	25	128	50	30	88	15
UEDO51	Point	Shirataki-A	640	10453	65	38	24	155	33	33	79	13

Table 6.11: Primorskii Krai obsidian sources. Concentration values (ppm) after Glascock et al. 2011. Concentration values in this study were produced by NAA and XRF. Concentration values of Fe converted from weight % to ppm values.

Primorskii Krai Obsidian Sources	Mn (NAA)	Fe (NAA)	Zn (NAA)	Ga (XRF)	Th (NAA)	Rb (XRF)	Sr (XRF)	Y (XRF)	Zr (XRF)	Nb (XRF)
Obluchie Plateau	967±17	63900±230	125±3	16±1	1.48±0.26	20±3	1107±162	22±1	112±6	26±2
Basaltic Plateau	1108±47	72200±240	126±21	15±1	0.77±0.19	12±2	540±84	25±1	87±5	20±3
Samarga	525±4	9700±170	32±5	14±1	8.85±0.17	104±3	226±9	12±1	114±4	7±6

Table 6.12: Kamchatka obsidian sources. Concentration values (ppm) after Grebennikov et al. 2010. Concentration values in this study were produced by NAA.

Kamchatka Obsidian Sources (Grebennikov et al. 2010)	Mn	Fe	Zn	Th	Rb	Sr	Zr
KAM-01	486±11	10777±367	34.8±2.4	3.98±0.14	60±2.2	206±20	131±9
KAM-02	587±5	13489±181	65.4±3.1	7.43±0.11	104.8±1.3	84±41	282±10
KAM-03	542±10	5761±151	34.1±2.1	7.62±0.17	74.2±1.5	111±17	126±6
KAM-04	391±18	9586±404	35.1±2.7	4.71±0.13	66.6±1.4	157±7	145±8
KAM-05	377±5	4146±99	24.5±3.7	9.27±0.05	92.2±1.5	53±6	97±5
KAM-06	755±32	5272±128	32.3±1.0	7.14±0.13	99.8±1.6	77±10	114±6
KAM-07	558±8	8548±418	34.3±4.4	4.65±0.11	70.8±1.4	354±54	133±10
KAM-08	339±12	9285±810	44.1±5.6	5.72±0.79	114±3.8	153±18	106±16
KAM-09	481±10	9397±326	35.3±2.6	3.43±0.07	50.4±0.8	119±20	145±11
KAM-10	610±22	7758±291	37.6±3	4.01±0.25	63.1±2.9	282±21	135±12
KAM-11	599±10	5441±251	34±3.2	5.6±0.1	76.9±1.4	216±24	89±5
KAM-12	657±4	7358±256	45.4±1.9	4.69±0.02	71.3±0	205±4	151±7
KAM-13	554±6	5337±0	34.8±0.4	8.97±0.02	127±0	39±0	141±5
KAM-14	539±3	5491±76	28.9±1.3	4.24±0.04	56.5±0.3	219±25	107±15
KAM-15	534±12	6411±156	31.1±2	5.41±0.18	78.9±1.4	276±25	120±6
KAM-16	395±19	4069±96	20.7±0.2	9.08±0.02	88.7±0.8	47±5	98±4

Table 6.13: Central Honshu obsidian sources. Concentration values (ppm) after Suda 2012. Concentration values in this study were produced by WD-XRF. Only the values for Rb, Sr, Y, and Zr are displayed

Central Honshu Obsidian Sources (Suda 2012)	Rb	Sr	Y	Zr
Talayama	271±8	8.2±0.4	44.4±1	87.4±2
Omegura	256±7	13.9±0.3	37.5±1	92.5±3
Wada Touge	325±6	8.2±0.2	50.7±1	90.2±1

Table 6.14: Kafukai 1 and Hamanaka 2 (Nakatani): artifact ppm concentration values. *Biface Frag.* refers to biface fragment, *Oketo-Toko./Kita.* refers to the Oketo-Tokoroyama/Oketo-Kitatokoroyama source.

Artifact ID	Type	Source	Mn	Fe	Zn	Ga	Th	Rb	Sr	Y	Zr	Nb
KAF01	Scraper	Shirataki-A	606	9347	64	35	22	147	30	32	78	13
KAF02	Scraper	Not Obsidian	107	1746	34	23	9	10	10	9	23	9
KAF03	Point	Shirataki-B	733	9792	70	40	22	176	17	39	72	15
KAF04	Point	Shirataki-B	786	10461	75	41	21	190	18	42	77	17
KAF05	Point	Shirataki-B	724	9800	71	43	22	186	16	41	79	16
KAF06	Point	Shirataki-B	793	10335	72	42	22	186	16	41	78	16
KAF07	Point	Shirataki-B	759	10802	81	45	23	194	18	40	77	17
KAF08	Point	Shirataki-B	796	11004	78	44	22	199	19	40	78	18
KAF09	Point	Shirataki-B	697	10202	72	40	21	184	15	39	78	16
KAF10	Point	Shirataki-A	655	10615	80	43	22	163	37	35	82	17
KAF11	Point	Shirataki-B	802	10348	73	43	22	182	17	39	75	17
KAF12	Point	Shirataki-A	656	10631	74	39	23	158	36	32	87	15
KAF13	Point	Oketo-Toko./Kita.	555	10231	64	43	25	151	71	30	112	15
KAF14	Biface Frag.	Oketo-Toko./Kita.	517	9403	53	37	22	138	62	29	103	14
KAF15	Point	Shirataki-B	683	9512	69	34	20	167	22	38	95	14
KAF16	Scraper	Shirataki-A	616	9933	67	37	21	152	32	32	82	14
KAF17	Point	Shirataki-B	717	9868	68	39	22	183	16	40	73	15
KAF18	Point	Shirataki-B	702	9929	68	39	22	178	16	39	72	15
KAF19	Scraper	Shirataki-B	679	9804	70	39	21	178	17	37	72	16
KAF20	Point	Shirataki-B	717	10147	72	44	21	184	17	39	76	16
KAF21	Biface Frag.	Shirataki-B	733	9702	73	40	20	178	17	38	72	16
KAF22	Point	Shirataki-B	685	9522	64	36	20	172	15	36	69	16
KAF23	Scraper	Shirataki-A	604	9798	71	36	21	151	32	33	80	14
KAF24	Point	Shirataki-A	982	13184	99	47	27	187	40	39	88	16
KAF25	Scraper	Shirataki-A	620	10039	67	35	22	145	31	32	77	15
KAF26	Point	Oketo-Toko./Kita.	597	10090	57	42	23	142	66	30	109	14
KAF27	Point	Oketo-Toko./Kita.	595	10058	61	40	23	141	66	30	107	14
KAF28	Scraper	Toyoura	711	9645	56	32	20	87	86	29	107	14
KAF29	Scraper	Oketo-Toko./Kita.	533	9023	57	34	23	135	63	28	102	14
KAF30	Point	Shirataki-B	704	9673	68	35	21	170	16	38	74	16
KAF31	Bipolar Flake	Shirataki-A	595	10069	84	35	21	144	33	32	78	14
KAF32	Bipolar Flake	Akaigawa	785	9755	62	38	27	136	52	31	89	15
KAF33	Bipolar Flake	Shirataki-B	655	9425	63	33	21	175	15	38	76	14

Table 6.14: Kafukai 1 and Hamanaka 2 (Nakatani): artifact ppm concentration values continued. *Core-RDF* refers to core reduction flake, *Bifacial-TF* refers to bifacial thinning flake, *Oketo-Toko./Kita.* refer to the Oketo-Tokoroyama/Oketo-Kitatokoroyama source.

Artifact ID	Type	Source	Mn	Fe	Zn	Ga	Th	Rb	Sr	Y	Zr	Nb
KAF34	Core Fragment	Shirataki-B	634	9348	58	34	20	171	14	36	77	16
KAF35	Core-RDF	Shirataki-B	696	9388	66	37	23	177	15	38	74	15
KAF36	Bipolar Flake	Shirataki-B	617	9420	69	38	19	176	14	37	71	15
KAF37	Core-RDF	Shirataki-B	700	9133	59	35	18	168	14	36	71	15
KAF38	Core Fragment	Shirataki-B	699	9261	64	36	22	170	16	37	75	16
KAF39	Core-RDF	Oketo-Toko./Kita.	561	9533	63	34	22	138	68	30	106	13
KAF40	Bipolar Flake	Shirataki-A	618	9691	65	37	21	150	32	32	78	14
KAF41	Core Fragment	Shirataki-A	592	8929	65	37	22	146	31	33	78	14
KAF42	Bifacial-TF	Shirataki-A	603	9729	69	38	22	158	34	34	83	15
KAF43	Bipolar Flake	Shirataki-B	720	9633	63	36	22	173	16	36	71	16
KAF44	Bifacial-TF	Shirataki-A	631	8757	68	38	22	157	34	35	84	15
KAF45	Core Fragment	Akaigawa	809	10153	67	32	26	133	60	29	91	13
KAF46	Bipolar Flake	Shirataki-B	695	9837	63	38	23	171	16	36	69	16
KAF47	Core Fragment	Shirataki-B	753	10033	66	38	21	179	16	38	73	15
KAF48	Core Fragment	Shirataki-B	708	9536	68	35	20	173	15	37	74	14
KAF49	Core-RDF	Oketo-Toko./Kita.	596	9233	61	33	21	131	64	28	100	14
KAF50	Core-RDF	Shirataki-A	688	11032	78	39	23	152	37	35	82	15
HA2-01	Bipolar Flake	Shirataki-B	695	9658	67	34	22	174	14	39	73	14
HA2-02	Bipolar Flake	Shirataki-B	706	9504	63	37	21	173	16	39	73	16
HA2-03	Bipolar Flake	Shirataki-B	686	9590	68	35	20	178	16	38	72	14

Table 6.15: Proportion of obsidian sources used during the Middle Jomon and Okhotsk periods on Rebun Island. For the Okhotsk period, the Hamanaka 2 (Nakatani) assemblage is included with Kafukai 1. Sample KAF02 is not included in the total assemblage since it is not obsidian.

Middle Jomon Period Obsidian Sources	Number	Percentage
Shirataki-A	21	42.0%
Shirataki-B	8	15.6%
Akaigawa	19	37.2%
Rubeshibe-Iwayama	3	5.8%
Total	51	100%
Okhotsk Period Obsidian Sources	**Number**	**Percentage**
Shirataki-A	13	25.0%
Shirataki-B	29	56.0%
Oketo-Tokoroyama/Oketo-Kitatokoroyama	7	13.0%
Akaigawa	2	4.0%
Toyoura	1	2.0%
Total	52	100%

Table 6.16: Obsidian sources of finds for Late and Final Jomon, and Epi-Jomon from Hamanaka 2 after Tomura et al. (2003).

Obsidian Source and # of Artifacts	Late Jomon (n)	Final Jomon (n)	Epi-Jomon (n)
Shirataki-A	1	8	2
Shirataki-B	4	1	1
Oketo	0	2	12
Akaigawa	31	3	2
Asahikawa	0	0	1

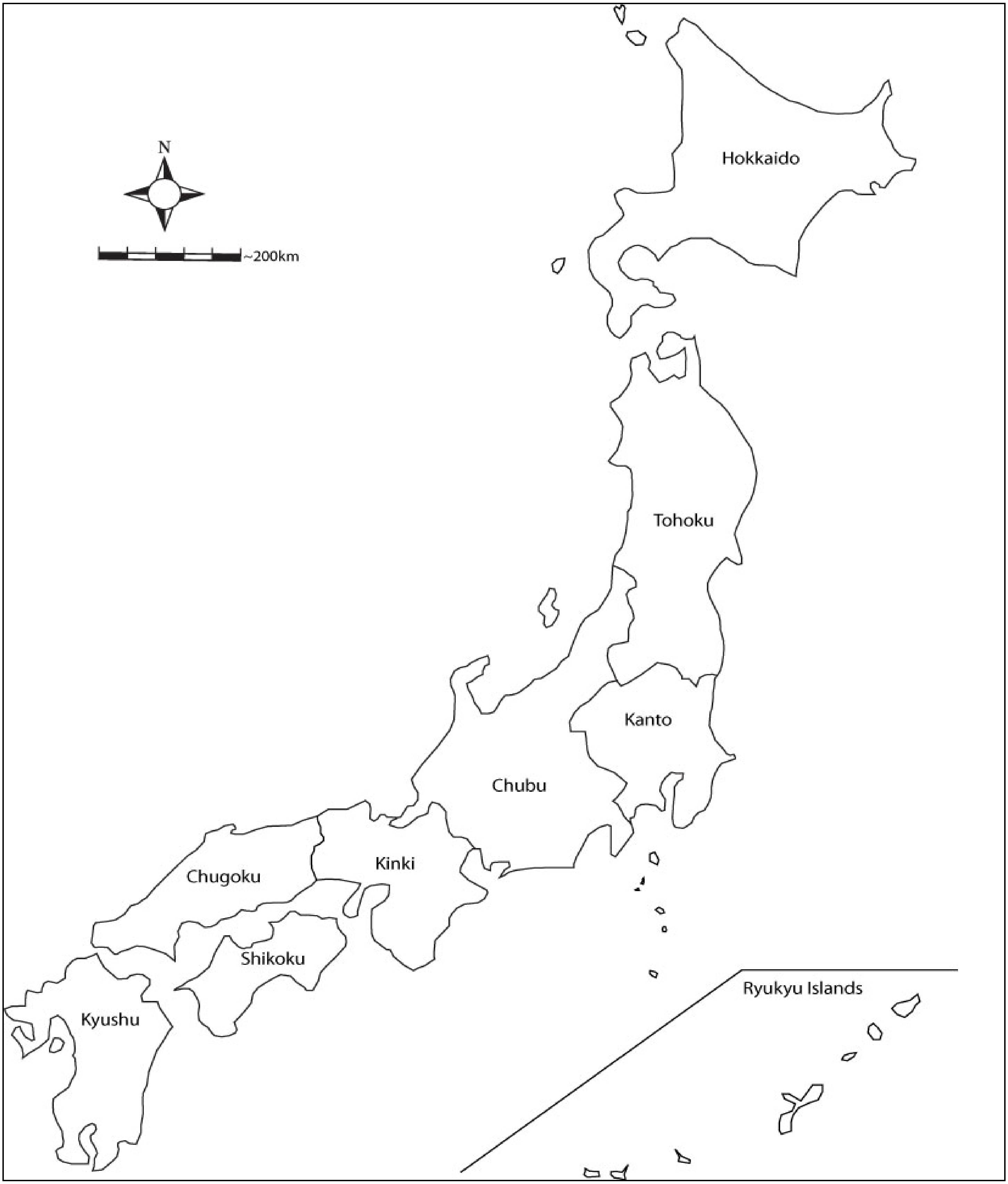

Figure 2.1: Map of the main geographical regions of Japan.

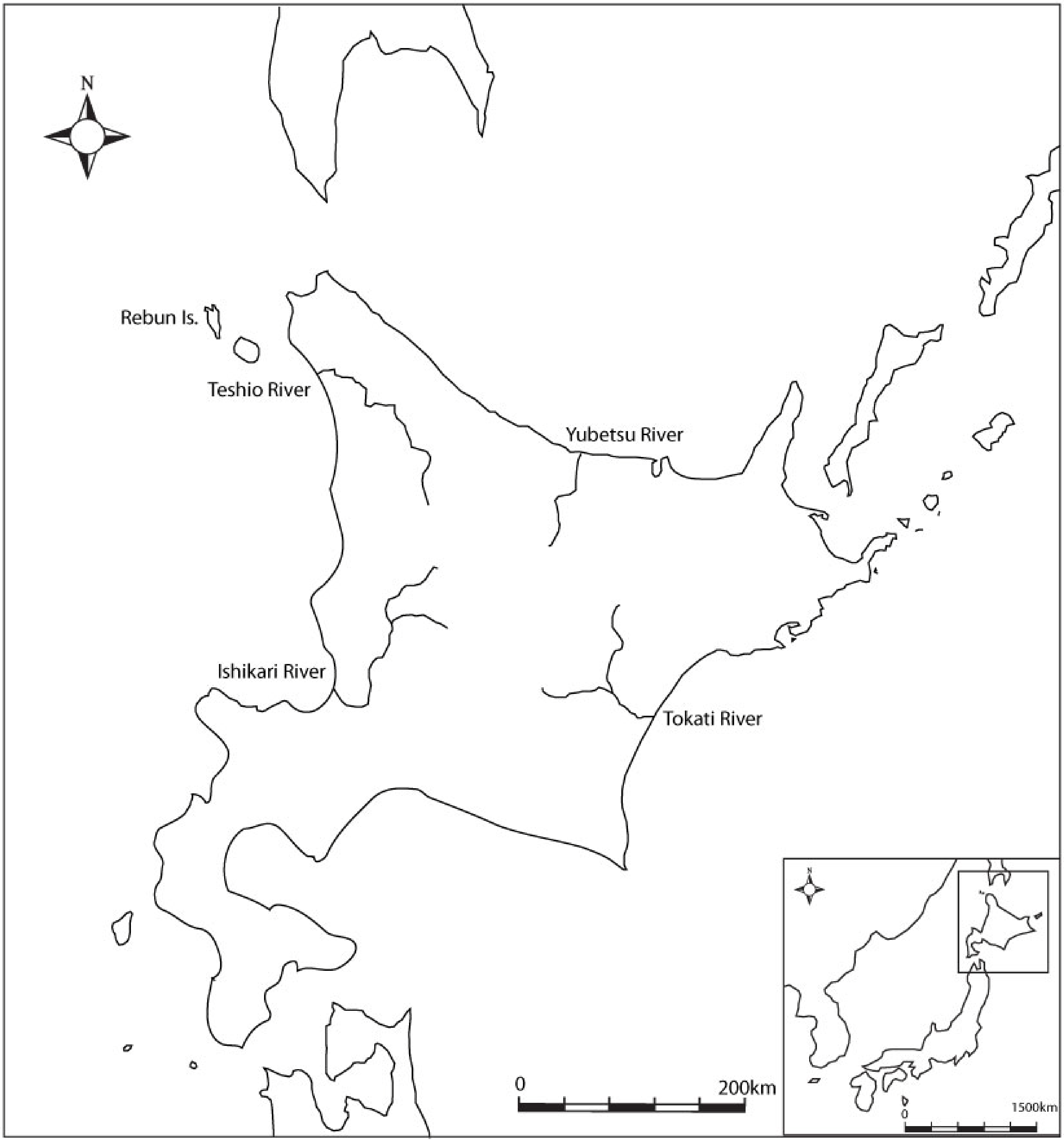

Figure 2.2: Map of Hokkaido Island, with main rivers. Map redrawn from Geological Survey Institute of Japan (1977) rivers map.

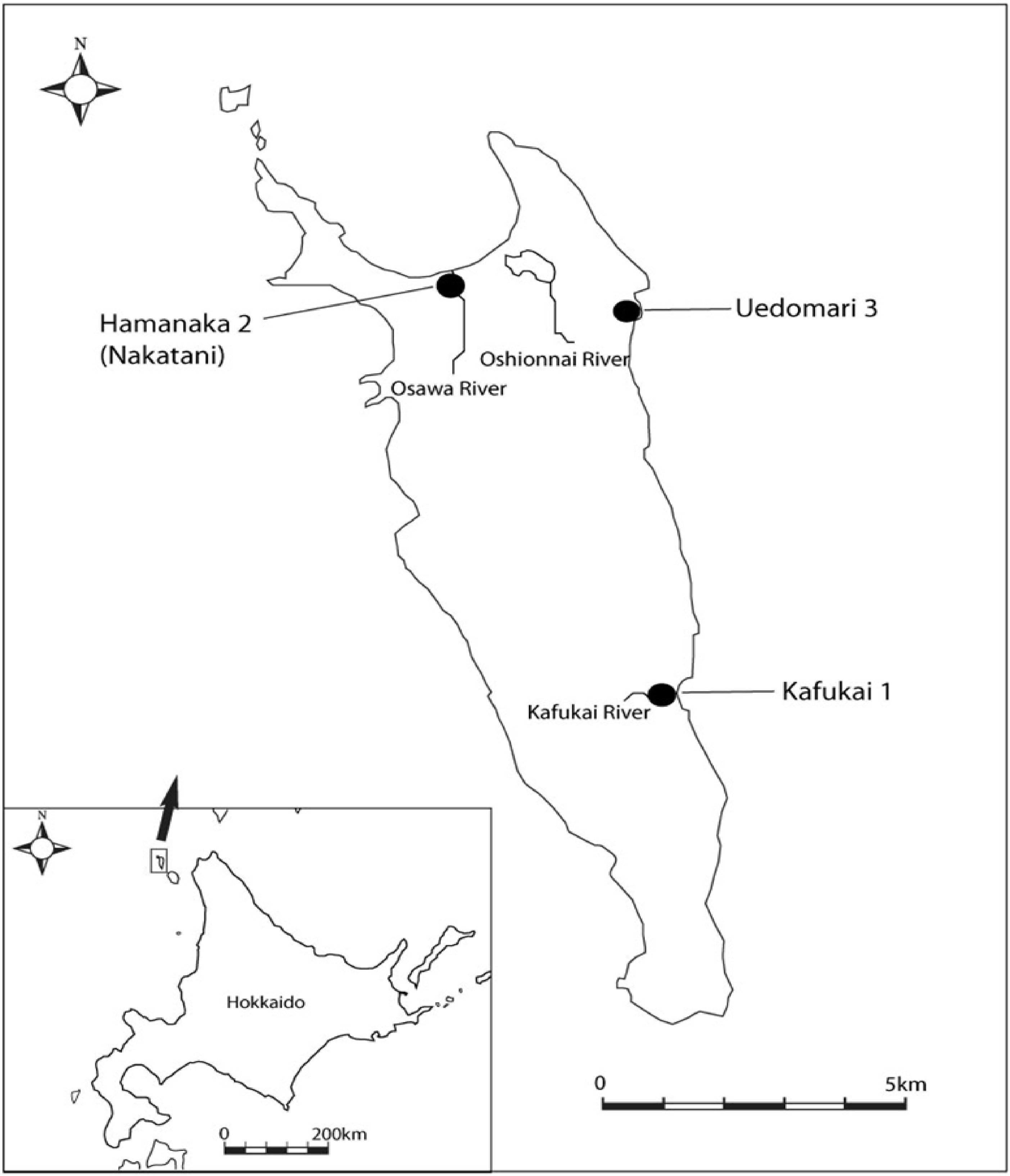

Figure 2.3: Map of Rebun Island with main rivers, and the locations of the archaeological sites discussed in this thesis. Map redrawn from Google Earth.

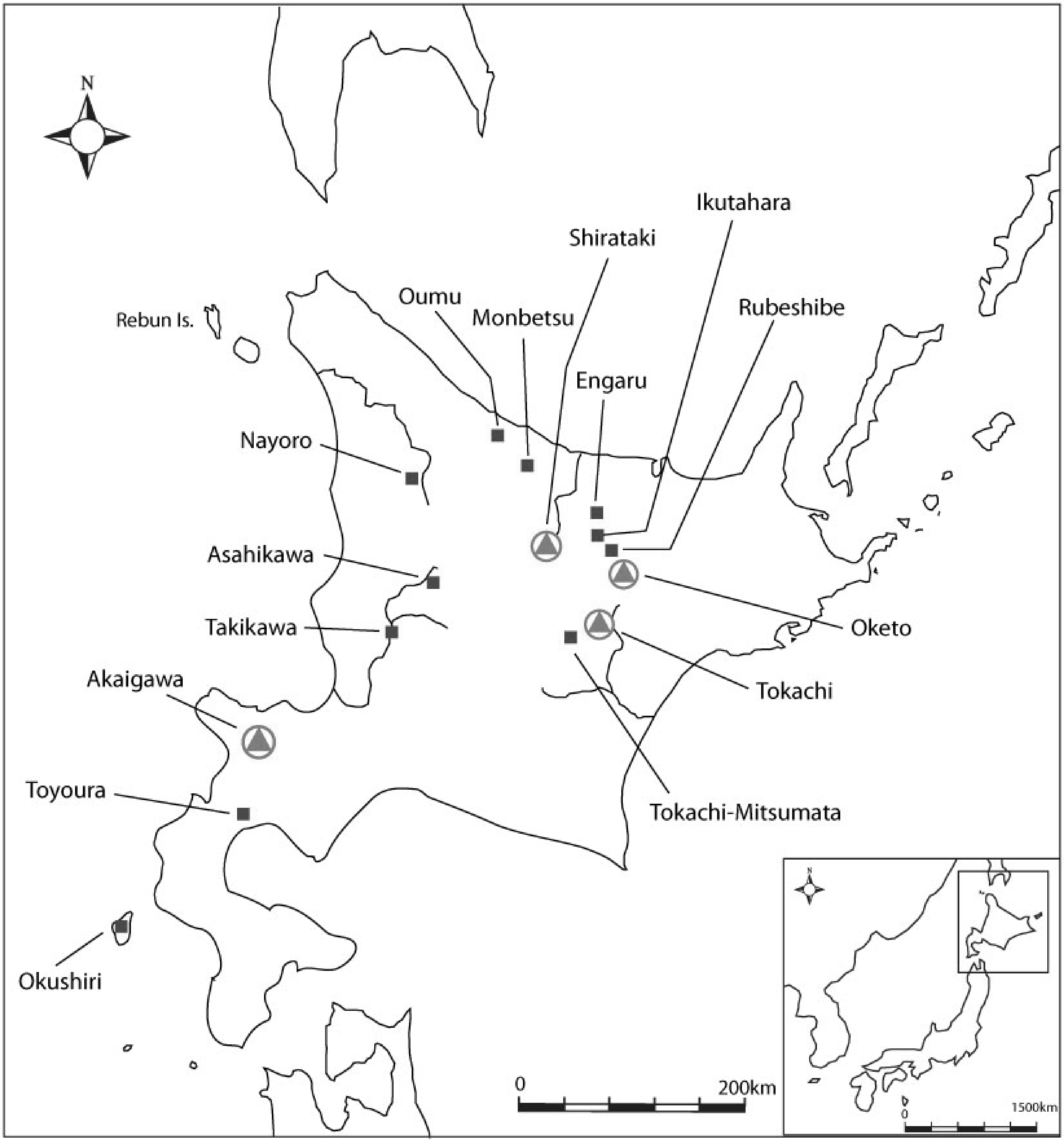

Figure 4.1: Map of the Hokkaido obsidian sources analyzed in this thesis. The symbol containing a triangle inside a circle marks the locations of the four major obsidian sources found in Hokkaido. The square symbols mark the locations of smaller obsidian sources in Hokkaido. The Hokkaido base-map is redrawn from Geological Survey Institute of Japan (1977) map. The locations of the Hokkaido obsidian sources are reproduced from the Asahikawa City Museum map of Hokkaido obsidian sources.

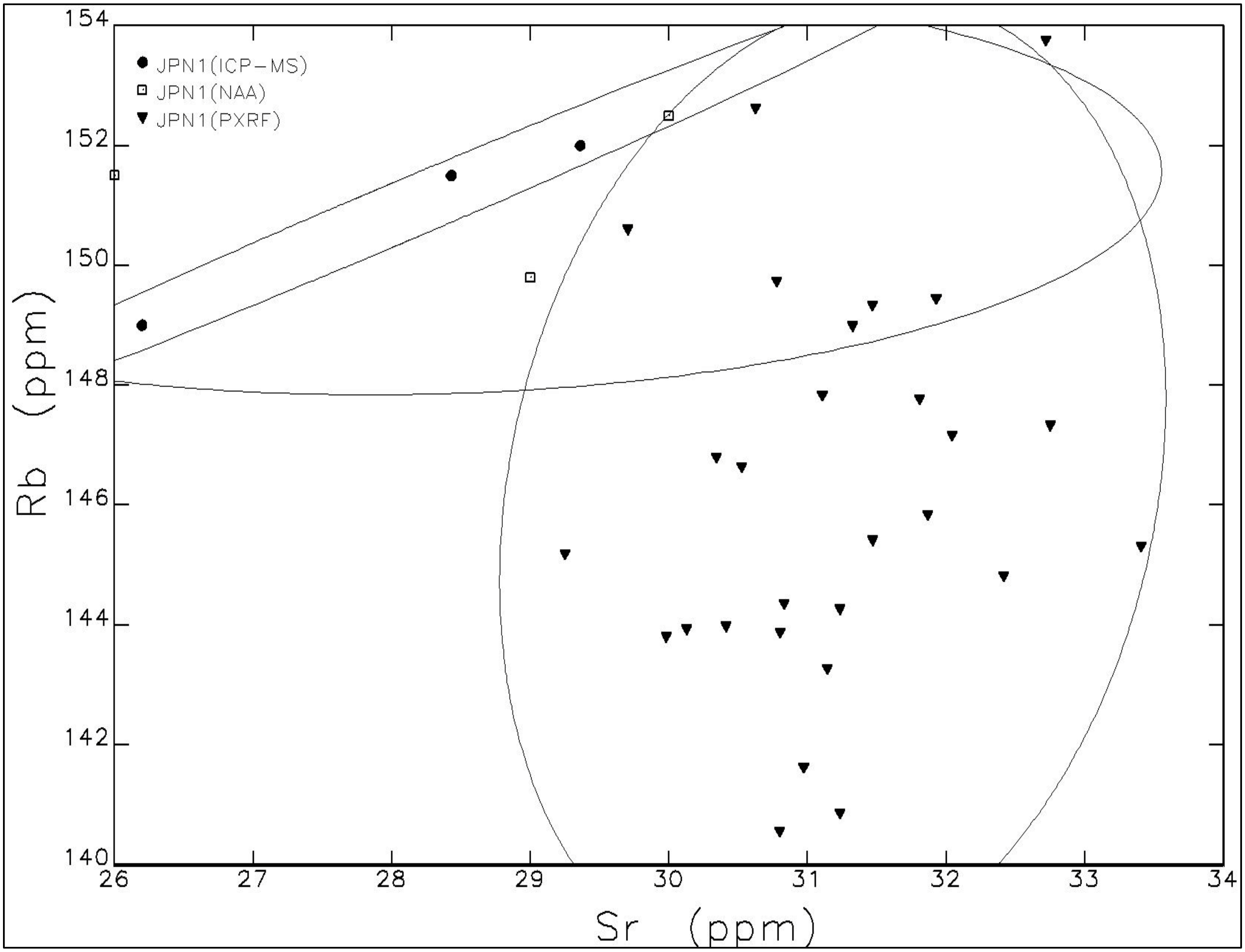

Figure 6.1: Bivariate analysis of PXRF, ICP-MS, and NAA results for specimen JPN1: Sr vs. Rb ppm concentrations.

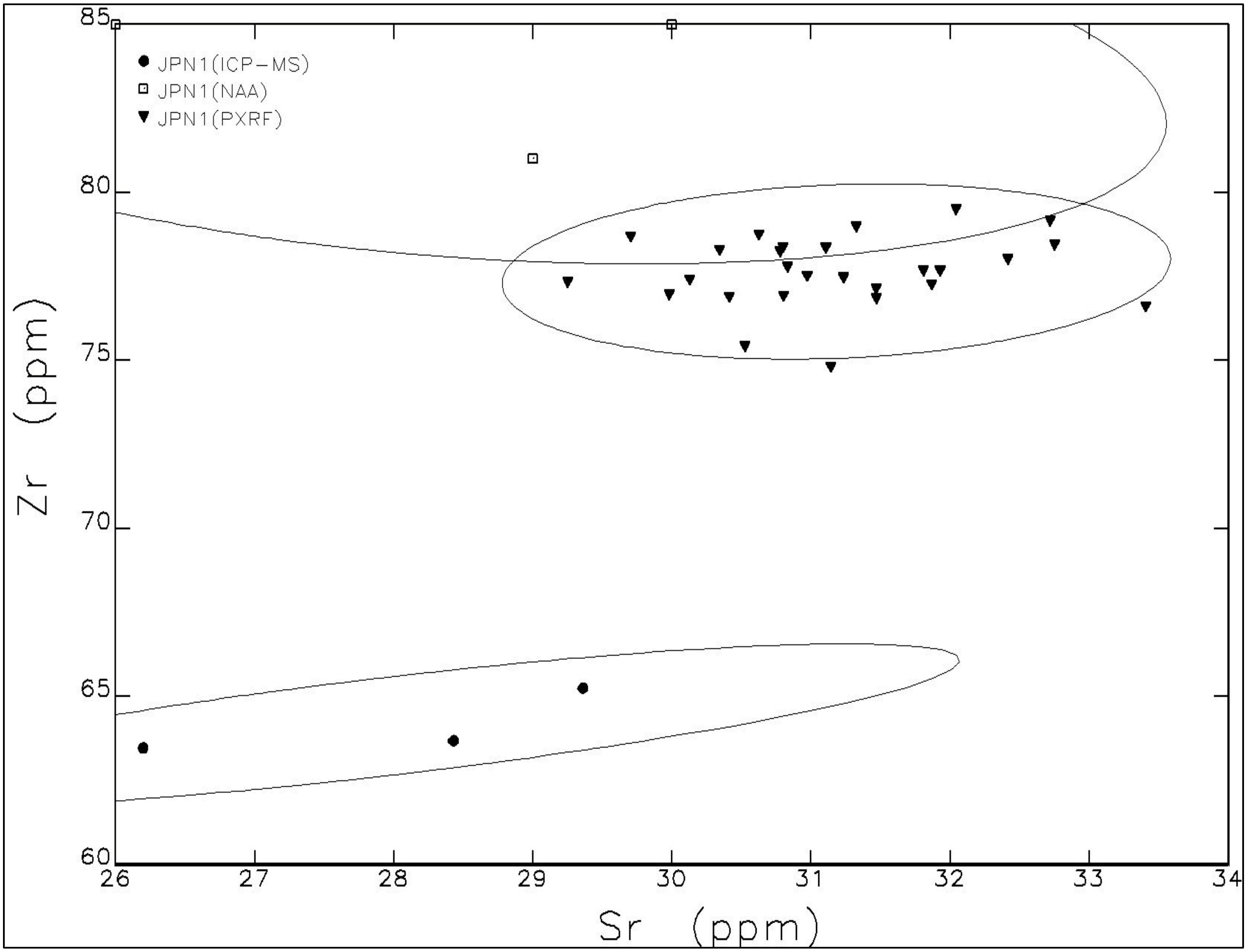

Figure 6.2: Bivariate analysis of PXRF, NAA, and ICP-MS results for specimen JPN1: Sr vs. Zr ppm concentrations

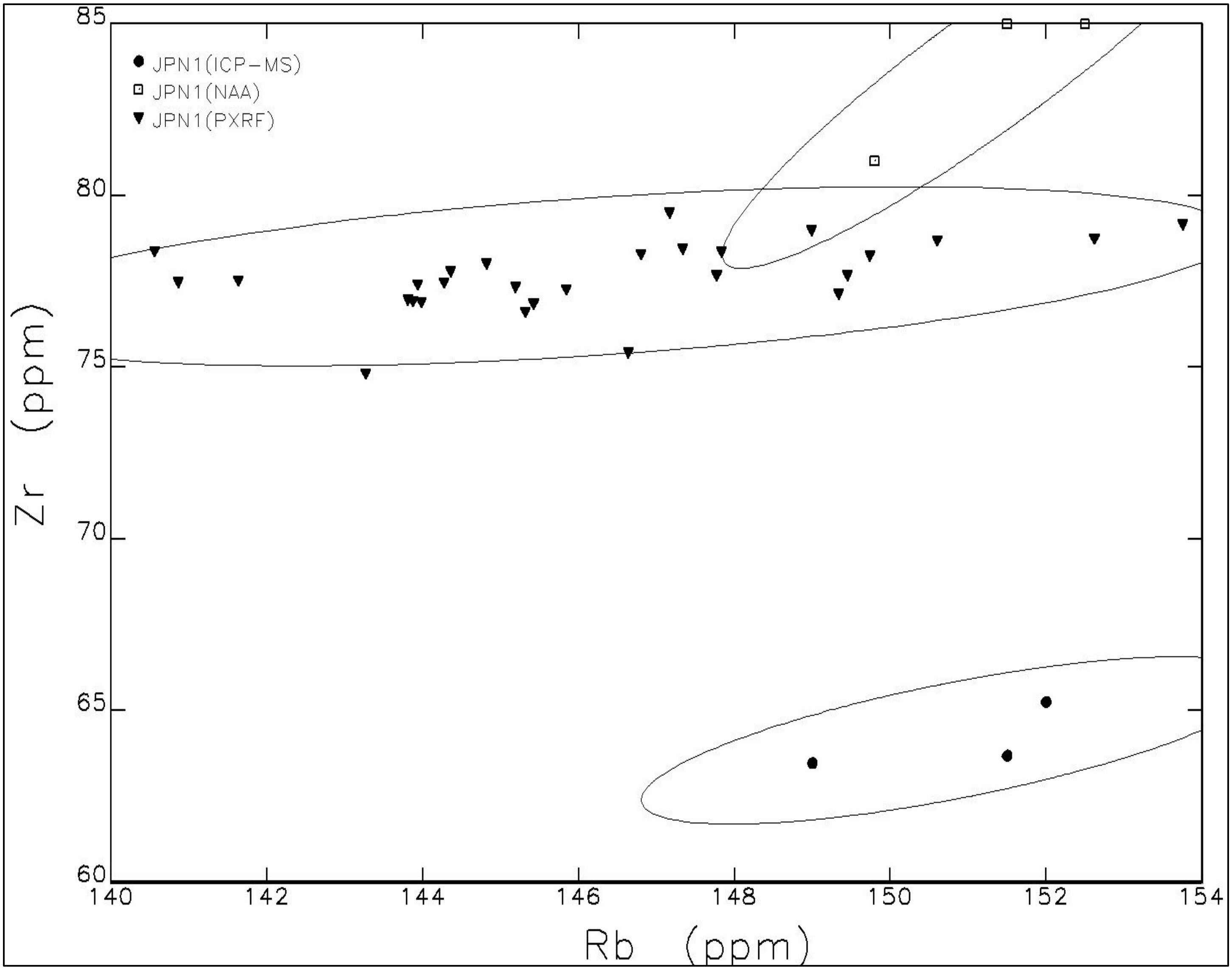

Figure 6.3: Bivariate analysis of PXRF, NAA, and ICP-MS results for specimen JPN1: Rb vs. Zr ppm concentrations

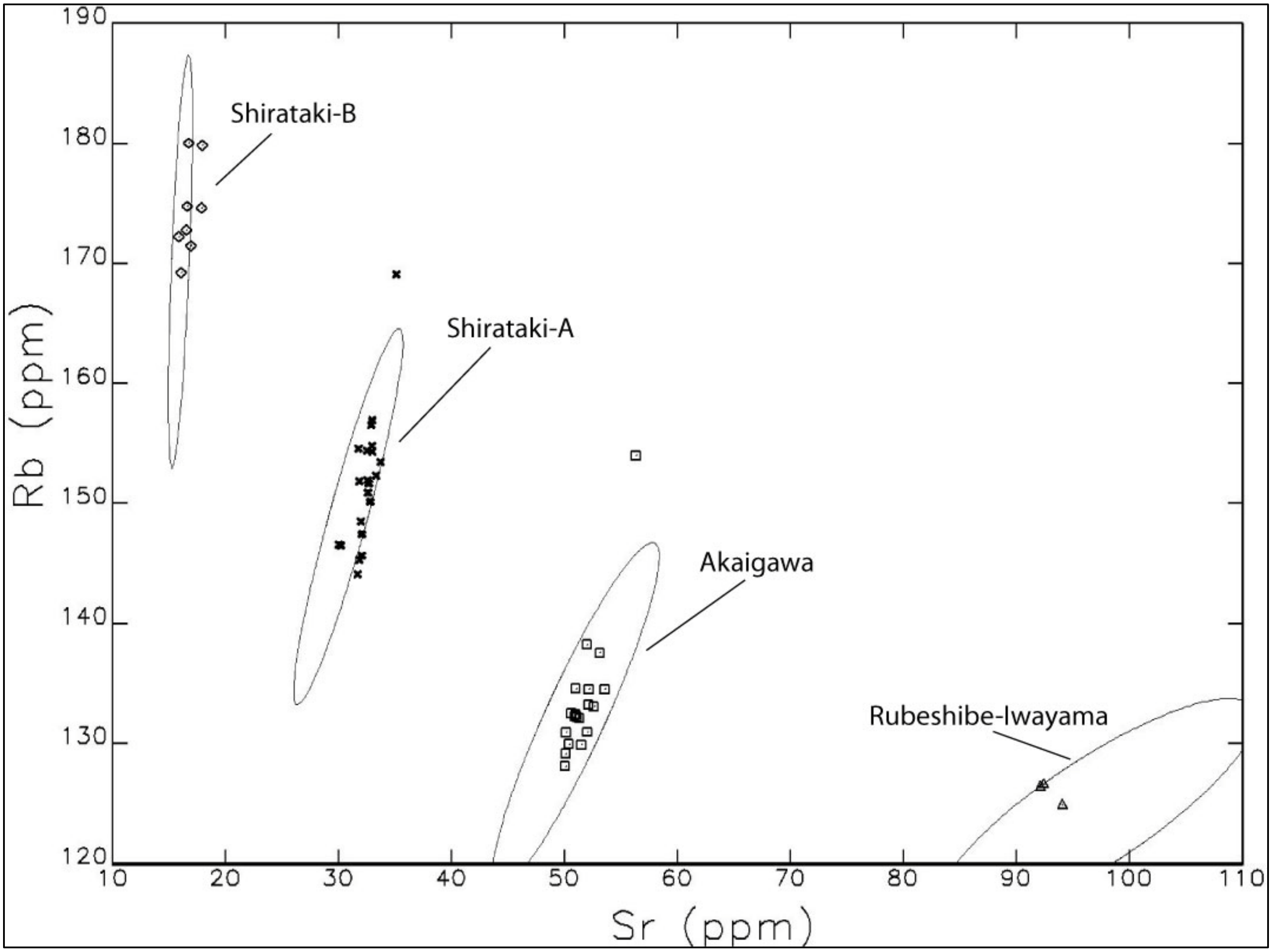

Figure 6.4: Uedomari 3: artifact bivariate plot of Sr vs. Rb ppm concentrations.

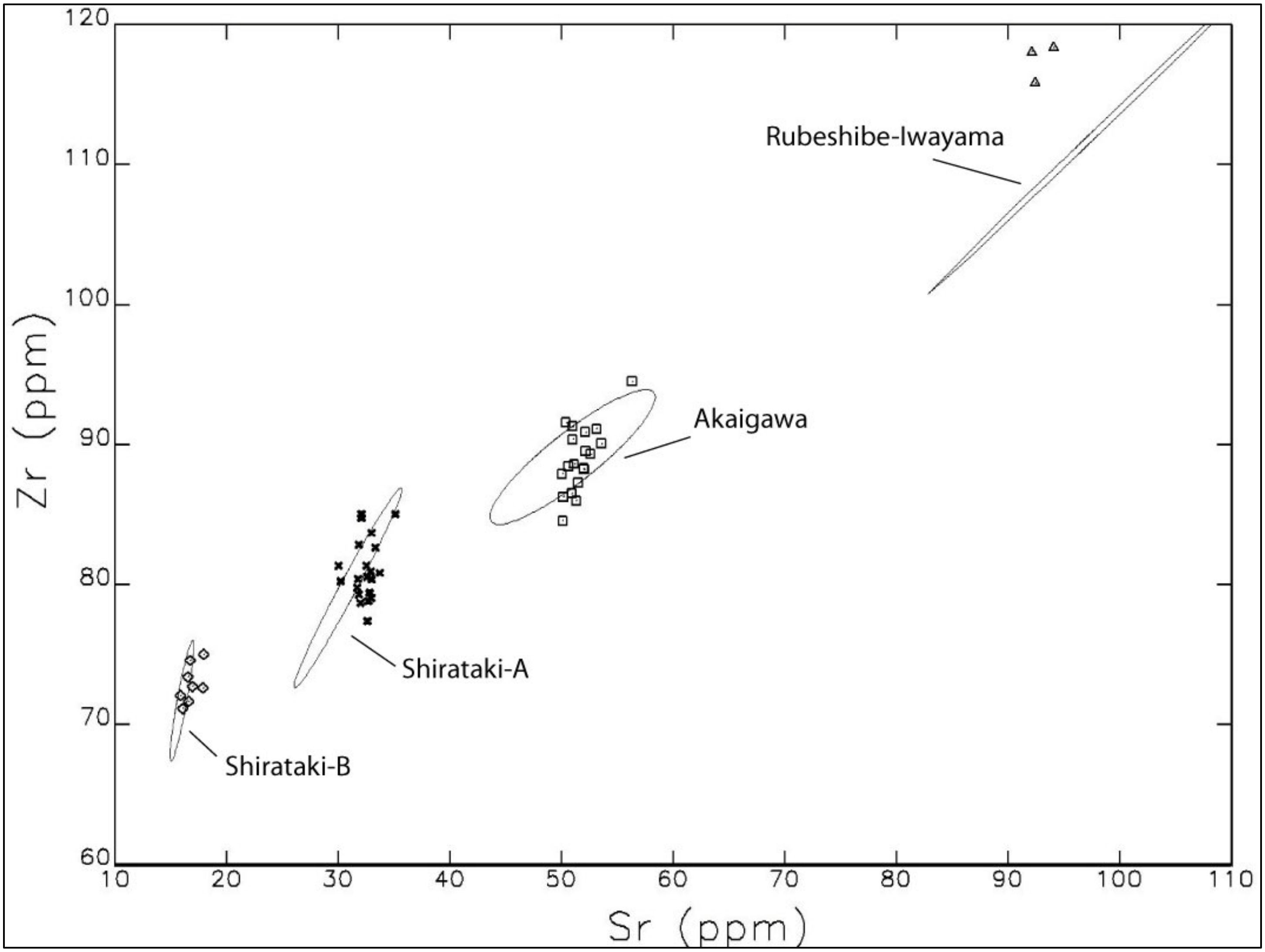

Figure 6.5: Uedomari 3: artifact bivariate plot of Sr vs. Zr ppm concentrations.

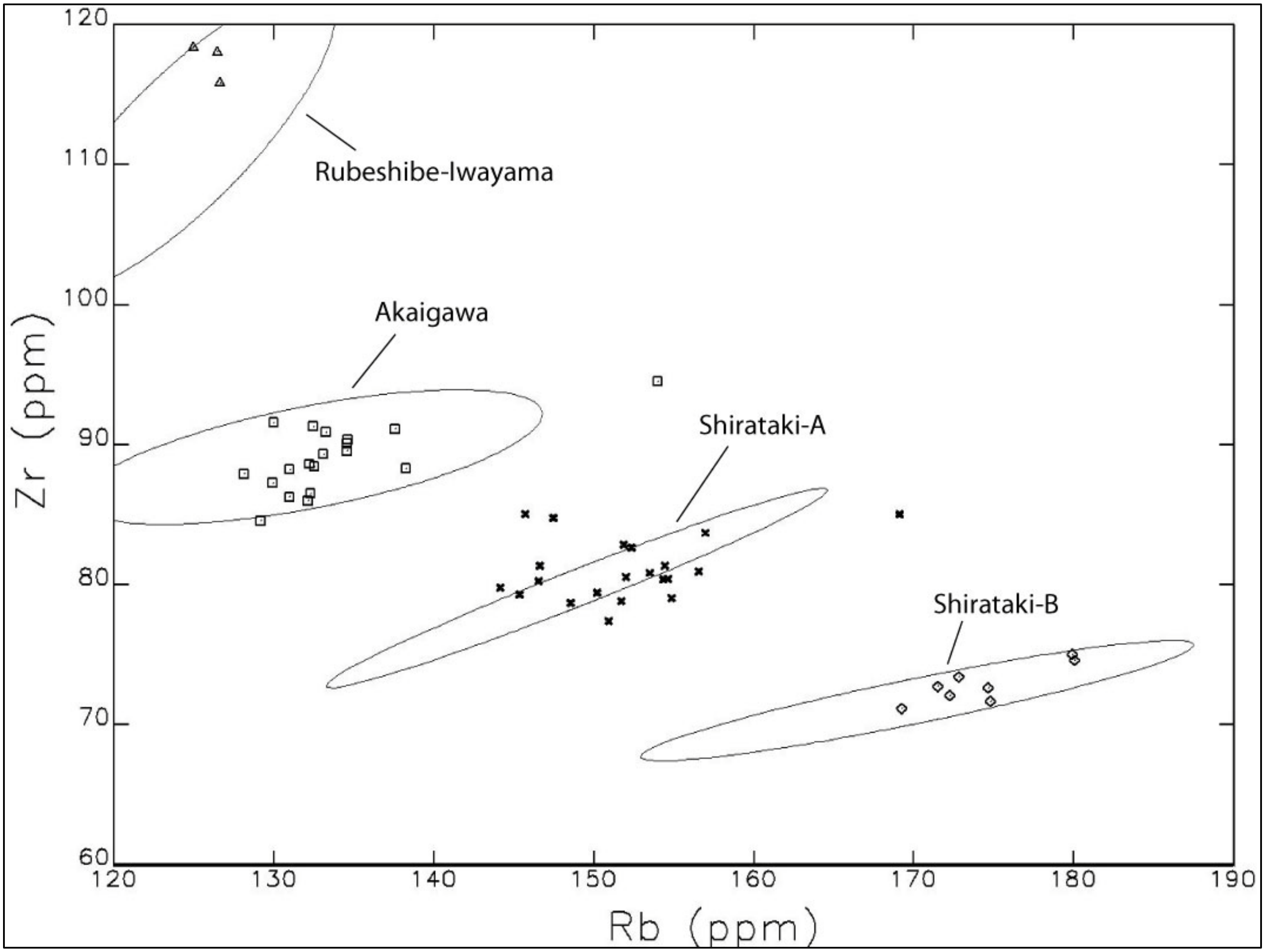

Figure 6.6: Uedomari 3: artifact bivariate plot of Rb vs. Zr ppm concentrations.

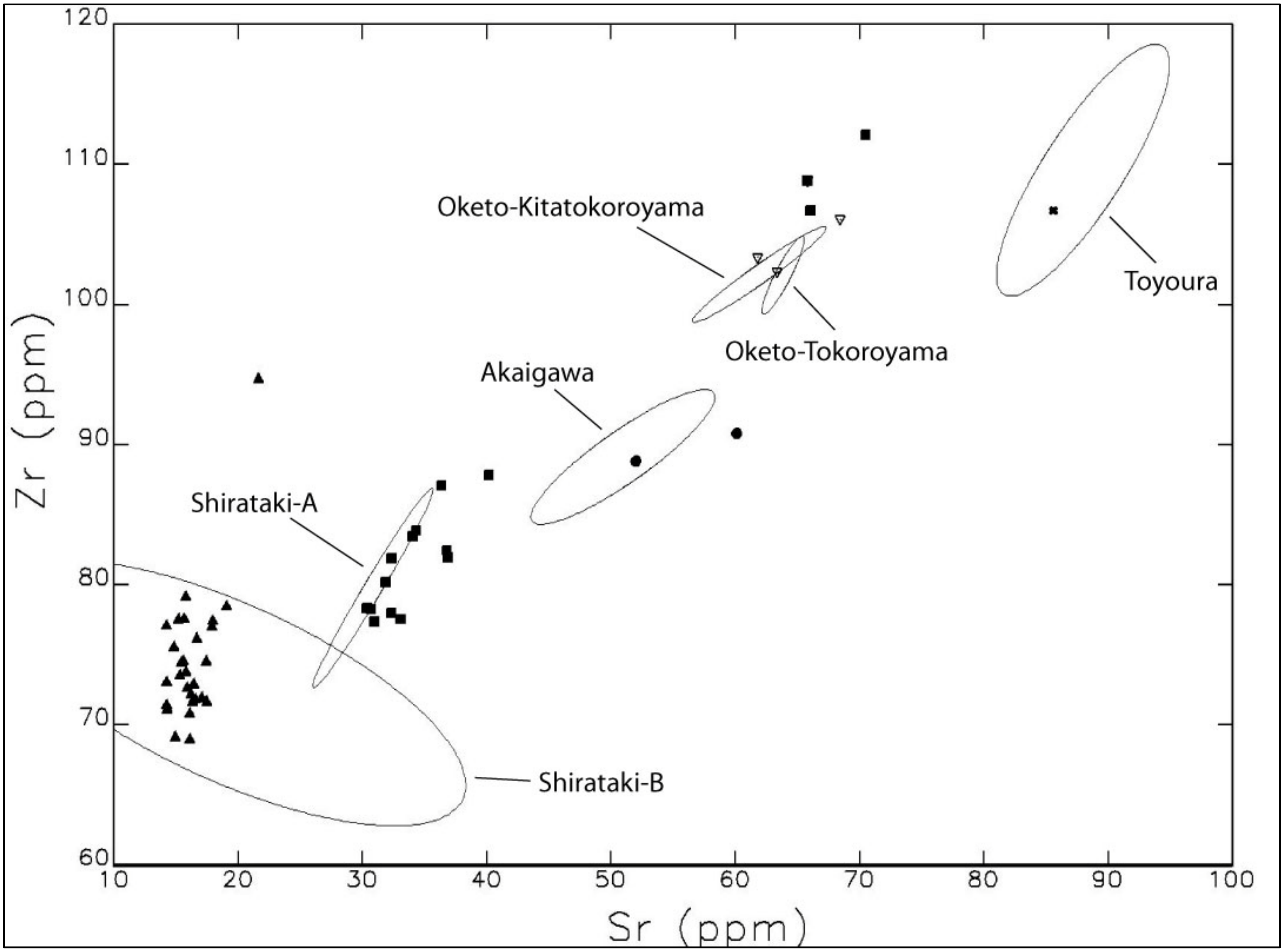

Figure 6.7: Kafukai 1 and Hamanaka 2 (Nakatani): artifact bivariate plot, Sr vs. Zr ppm concentrations.

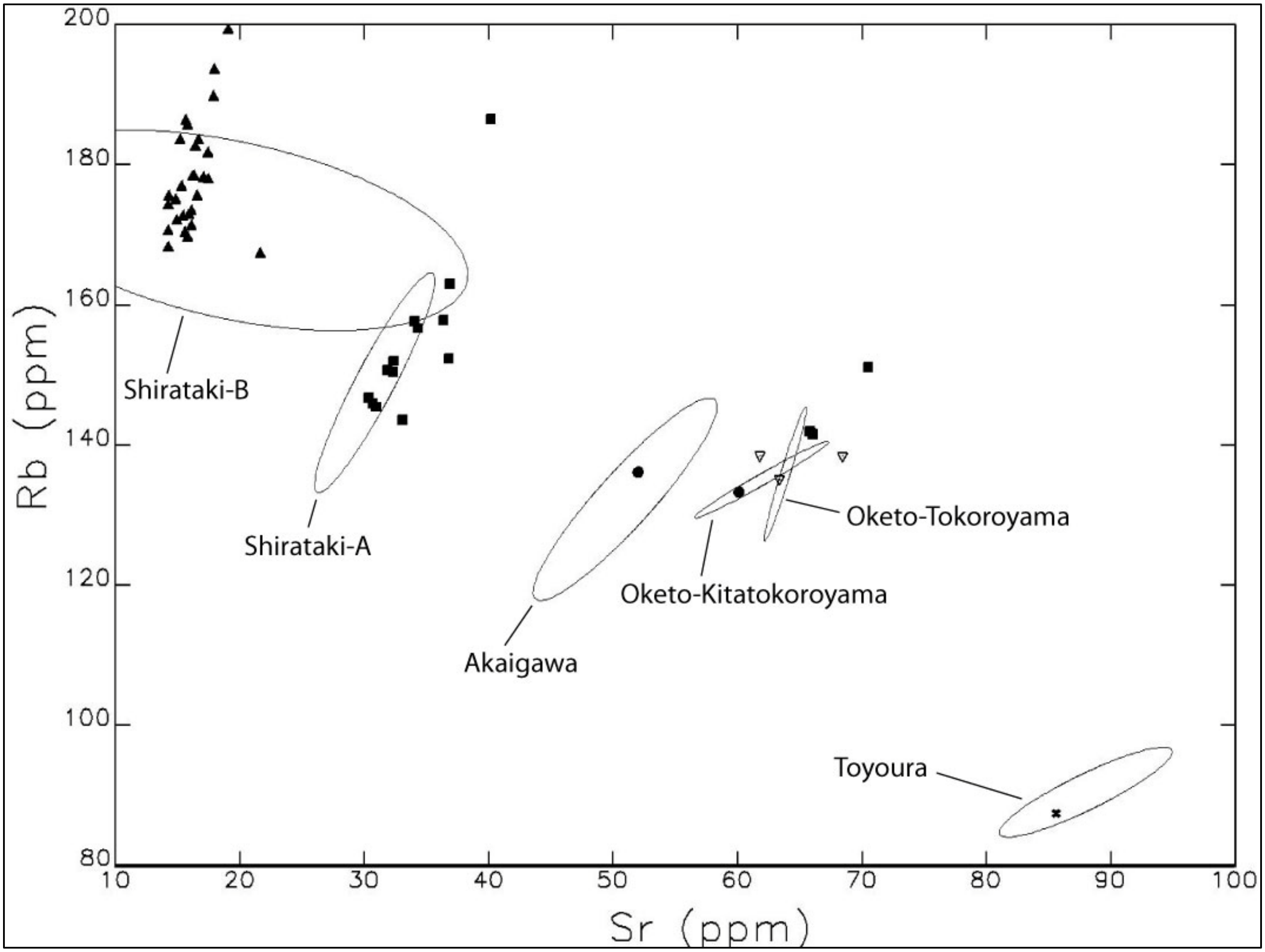

Figure 6.8: Kafukai 1 and Hamanaka 2 (Nakatani): artifact bivariate plot, Sr vs. Rb ppm concentrations.

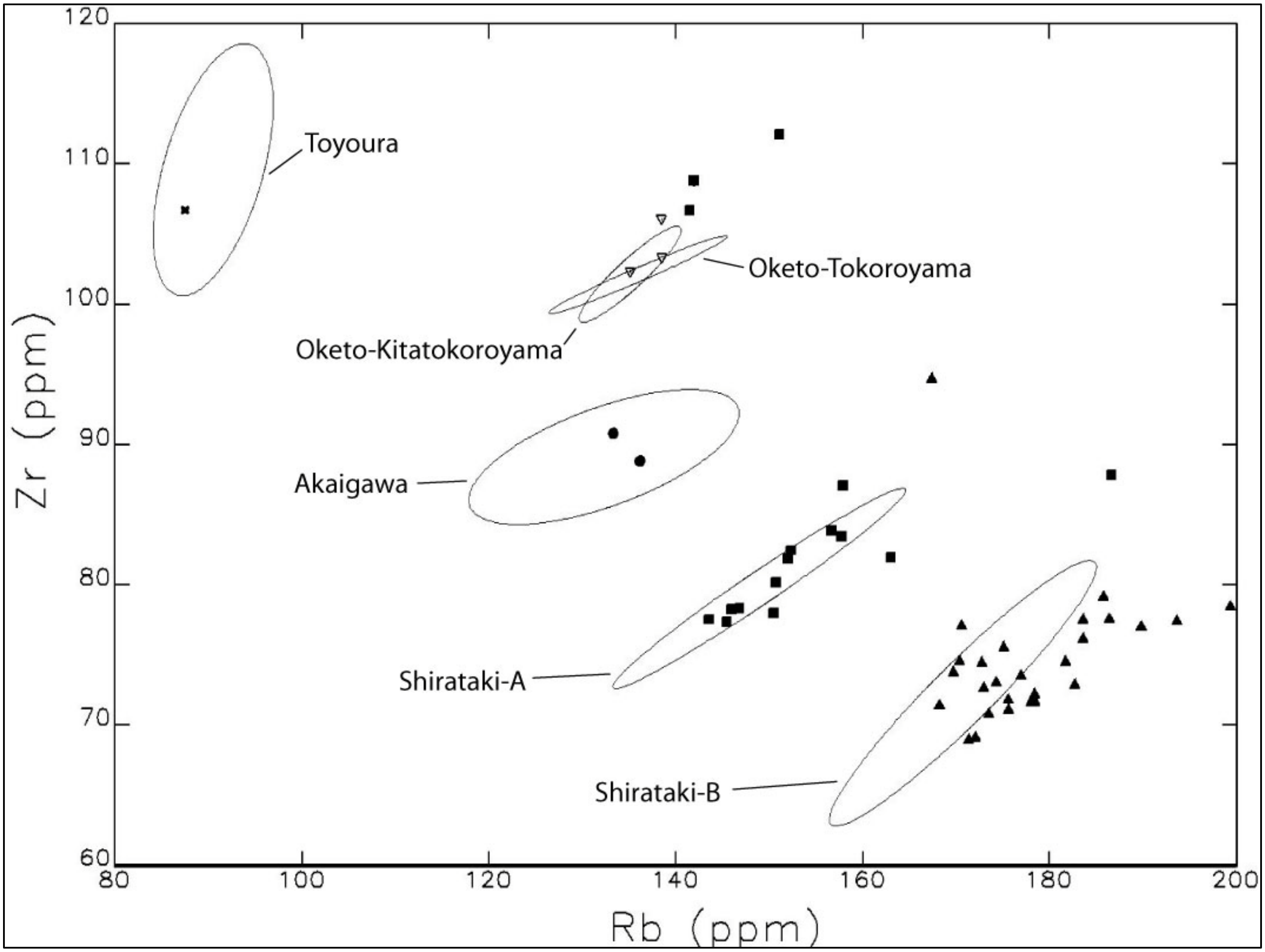

Figure 6.9: Kafukai 1 and Hamanaka 2 (Nakatani): artifact bivariate plot, Rb vs. Zr ppm concentrations.

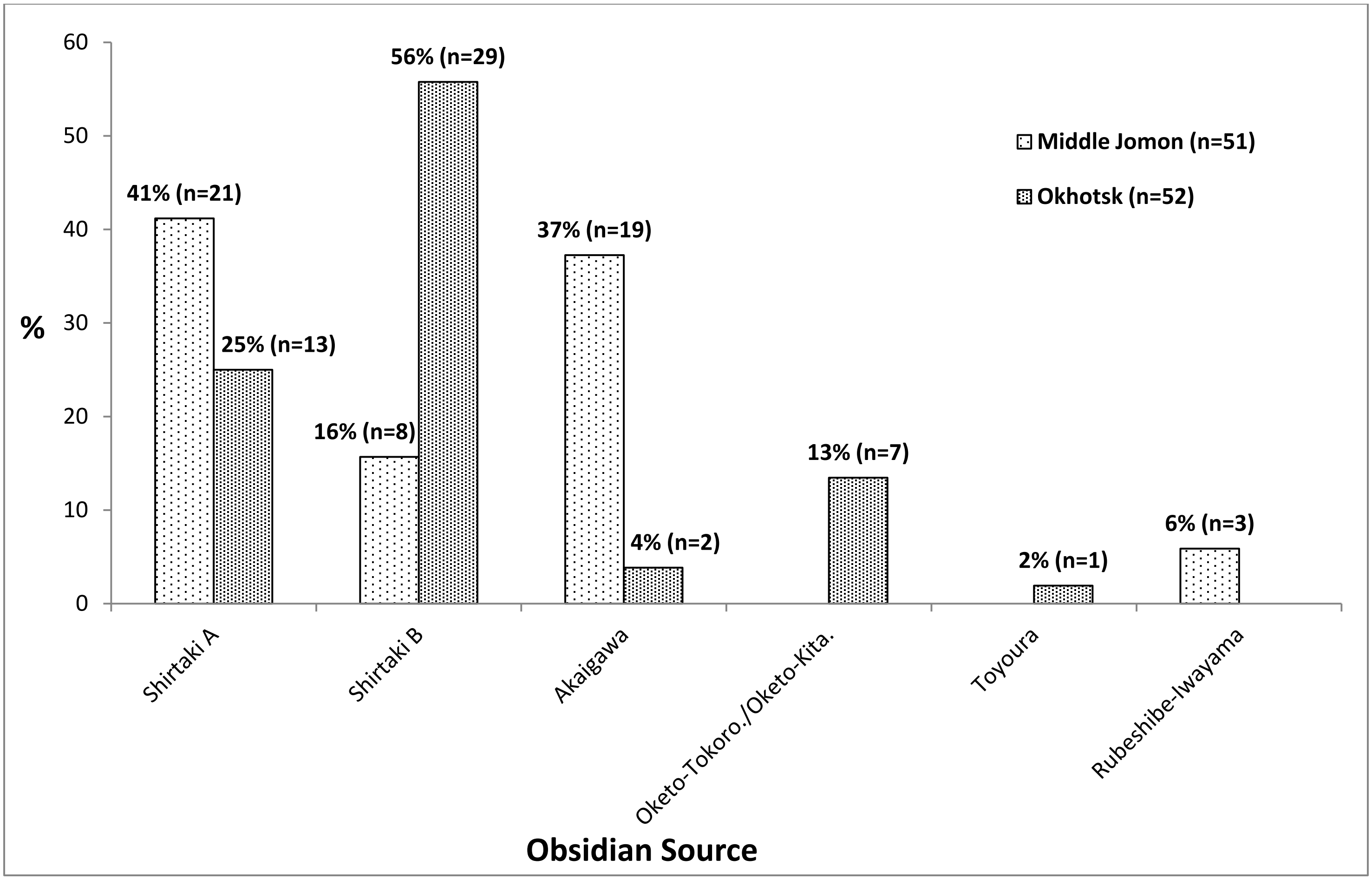

Figure 6.10: Middle Jomon obsidian source use at Uedomari 3 and Okhotsk obsidian source use at Kafukai 1 and Hamanaka 2 (Nakatani). The Hamanaka 2 (Nakatani) data are included with Kafukai 1 for the Okhotsk period. Based on data from Table 6.15.

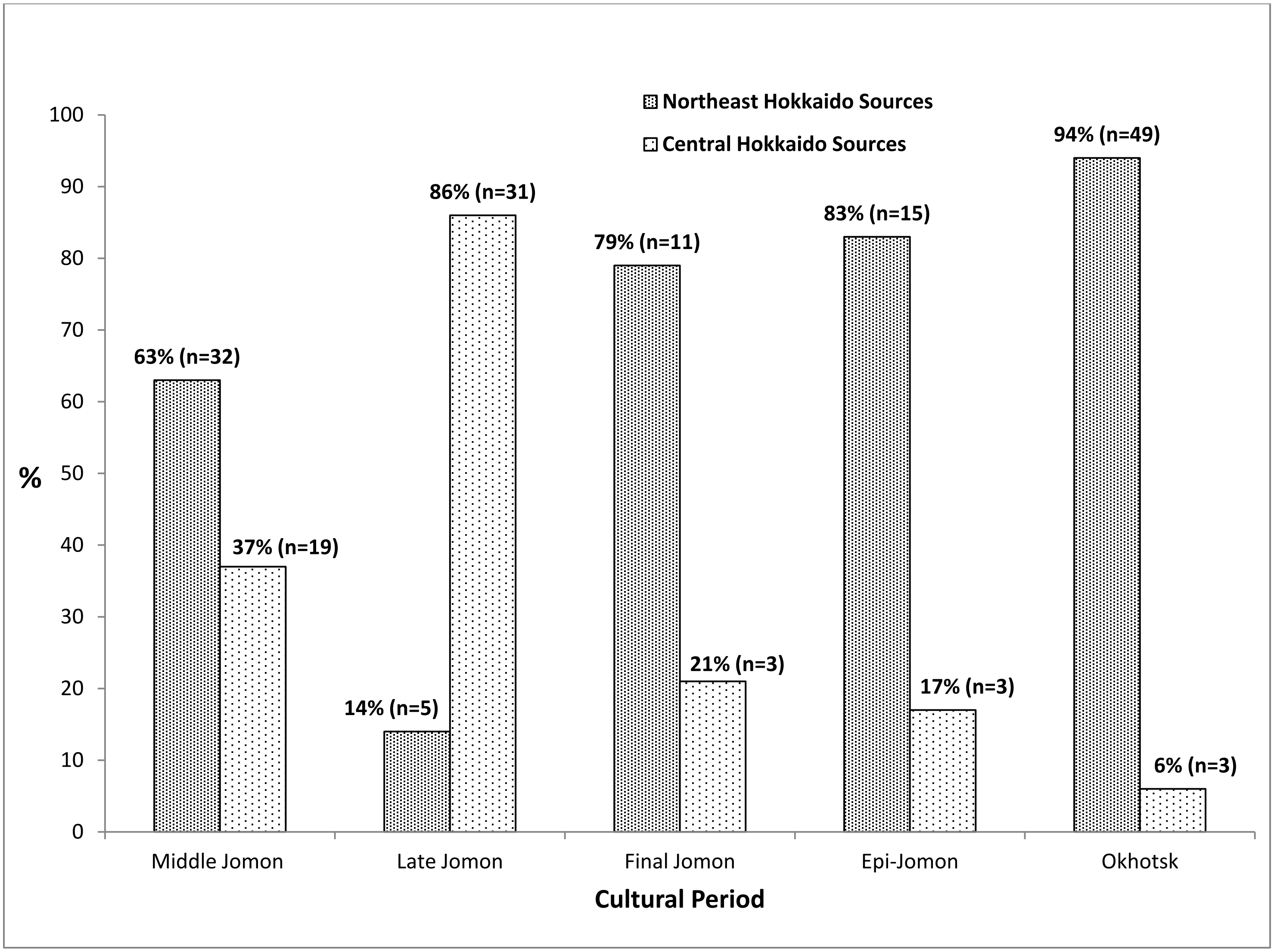

Figure 6.11a: Chart of the proportions of prehistoric obsidian use on Rebun Island from assemblages dating from the Middle Jomon to Okhotsk periods. Results are shown as a percentage of the total assemblage for each cultural period. Data for Middle Jomon and Okhotsk periods are based on data from Table 6.15. Data for Late Jomon, Final Jomon, and Epi-Jomon are after Tomura et al. 2003 (Table 6.16).

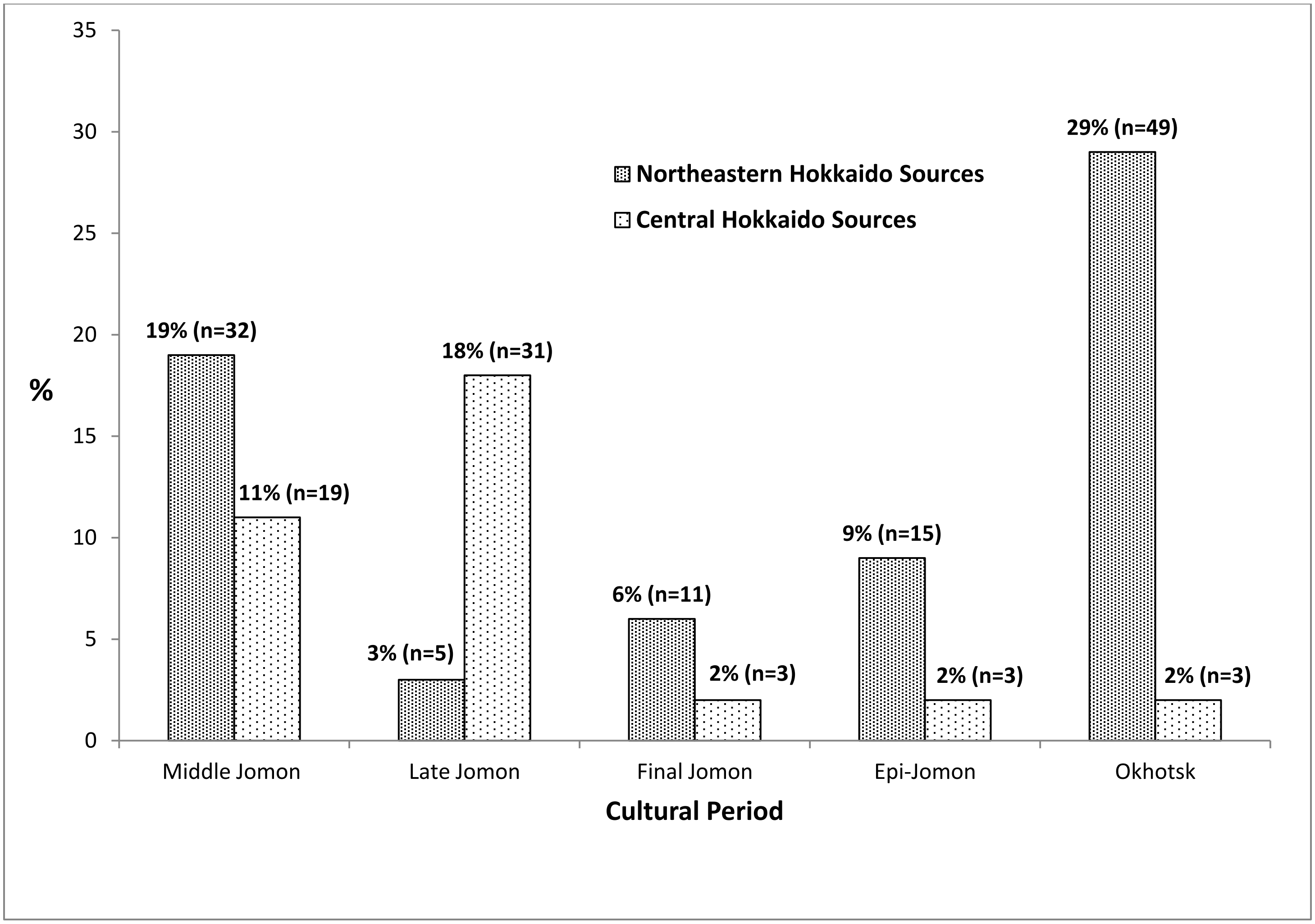

Figure 6.11b: Chart of the relative proportion of prehistoric obsidian use on Rebun Island from assemblages dating from the Middle Jomon to Okhotsk periods. Results are shown as the percentage relative to the total number of artifacts (N=171) analyzed from the Middle Jomon to Okhotsk periods. Data for Middle Jomon and Okhotsk periods are based on data from Table 6.15. Data for Late Jomon, Final Jomon, and Epi-Jomon are after Tomura et al. 2003 (Table 6.16).

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