The Science of Human History in Asia and the Pacific 2

Yaroslav Kuzmin

Across the Seas in Prehistoric Northeast Asia

Obsidian as a Commodity for the Study of Human Migrations

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The Science of Human History in Asia and the Pacific

Volume 2

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This series publishes research achievements that reconstruct human history in Asia and the Pacific, mainly in prehistory. Major topics covered in the series are paleoanthropology, archaeology, bioarchaeology, and human genetics, as well as zooarchaeology, archaeomethodology, environmental archaeology, geomorphology, and geochronology.

Asia occupies 30% of the earth's land area and is currently home to 60% of the world's population, who live in diverse climatic zones and landscapes. Across the adjacent vast Pacific Ocean region, many peoples have adapted to maritime, insular, and continental environments. Reconstructing humanity's past in this area in a scientific fashion is an essential aspect of world history.

The area records the history of human territorial expansion as well as diversification both physically and culturally. Asia was first occupied in the early Pleistocene, but it was modern humans who further advanced to the arctic zone and oceanic environments to colonize all of Asia as well as the Pacific region. Recent studies highlight the variability of pre-modern human groups in addition to the well-known Homo erectus that once populated the area, as exemplified by the discoveries of tiny Homo floresiensis from an Indonesian island, Neanderthals and enigmatic Denisovans from South Siberia. After the spread of modern humans, the area witnessed the development and adoption of farming and civilization in multiple locations, but also nourished distinct cultures in the particular environmental conditions afforded by the steppes, deserts, woodlands and oceanic islands. Because of this, the region is essential in understanding global issues such as human interactions with varied and changing Holocene natural environments, mechanisms of economic and sociopolitical diversification, and the emergence and development of complex societies.

Until now, much of this fascinating region remains relatively unknown in terms of the themes addressed in this series, with few cross-cutting regional studies and limited data sharing. The series promotes the publication of research that significantly advances our understanding of this important but under-studied part of the world.

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Preface

In Xanadu did Kubla Khan
A stately pleasure-dome decree:
Where Alph, the sacred river, ran
Through caverns measureless to man
Down to a sunless sea.

Samuel Taylor Coleridge, *Kubla Khan* (1816)

Obsidian is a shiny rock, beautiful, and attractive to people even today. In prehistory, this volcanic glass was a highly sought-after raw material for making stone tools, jewellery, and even mirrors—like the one which was once (most probably) owned by the famous Elizabethan polymath and *magus* John Dee (1527–1608/9), now exhibited at the British Museum. Numerous obsidian artefacts—dating from the Palaeolithic to the Bronze Age—are displayed in archaeological museums in Europe, Asia (especially in Japan), and the Americas.

John Gun, in the book called *Kublai Khan* (Bantam Press, 2006), describes the remains of Xanadu, the countryside capital-*cum*-residence of Chinese emperor Kublai Khan (1215–1294), founder of the Yuan Dynasty, in the grasslands of the modern Inner Mongolia Autonomous Region of China. Known from the famous lines of S. T. Coleridge's poem, Xanadu is described as "an imaginary wonderful place", in *The Concise Oxford Dictionary* (tenth edition, 2001). For prehistoric people, obsidian was a kind of Xanadu, walking hundreds of kilometres in their quest to obtain it. Today, for scholars who study ancient migrations, contacts, and exchange/trade, obsidian is a kind of Xanadu that provides valuable data.

For archaeologists, obsidian contains an indispensable amount of information about different aspects of the lives of prehistoric people, especially their interaction with both neighbouring and remote parts of the world. Since the early 1960s, it was proven that obsidian provenance gives precise data on where the raw material was acquired, and what the zones of immediate and distant contacts were between ancient populations. This reflects not only interactions but also migrations and exchange or even the primitive trade of obsidian as an important commodity in the prehistory of several large regions in Europe, Asia, Africa, the Americas, and Oceania. It is hard to find another rock that can serve the same purpose and allows getting the same information hidden from the naked eye of archaeologists and geologists. When the age of obsidian-bearing archaeological sites is established (mainly with the help of the radiocarbon dating method[1]), scholars can reconstruct with a high degree of confidence the spatiotemporal patterns of obsidian exploitation and derive information about the interaction between ancient people that is impossible to obtain by any other method. This is perhaps the main advantage of obsidian provenance research.

The main aim of this book is to present an updated picture of obsidian provenance in Northeast Asia, still not much known to the Anglophone world because of linguistic barriers (one should be well acquainted with the Russian, Chinese, Japanese, and Korean languages), and to some extent political issues (Russia was behind the "iron curtain" until the early 1990s, and North Korea still very tightly controls the traffic of foreign visitors). In Northeast

[1]In this book, the ages for archaeological sites and prehistoric cultural complexes are given in "years ago", corresponding to original ^{14}C values (before present, BP) that are converted to calendar time scale (cal BP) using the IntCal20 dataset (Reimer et al., 2020). Therefore, "years ago" values are equal to "cal BP" ones.

Asia, obsidian was known to explorers, travellers, and scholars since the eighteenth century, but the focus on its scientific study for understanding the place of origin and patterns of use and transport in prehistory goes back only to the very late 1960s and early 1970s. Research really took off in the 1970s in Japan and in the 1990s in other parts of this vast region. As a result, a great deal of new obsidian research was done in far eastern Russia, Korea, Northeast China, and Northeastern Siberia. Currently, ca. 3780 obsidian samples from these regions have been examined by our team and other scholars. These works shed new light on the prehistoric contacts and interactions in the vast swathes of Northeast Asia, and I believe it is worth presenting this information now to the international scholarly community in detail. As far as I know, this is the first book of its kind for the scientific audience worldwide.

Chapter 1 is an extended introduction, describing the importance and potential of obsidian provenance in archaeology and geology, and includes a brief history of early research in Northeast Asia in the 1960s and 1970s. Chapter 2 provides data on the methods currently used for obsidian sourcing, including modern analytical techniques and approaches for understanding the mechanisms of obsidian acquisition, transportation, and exchange/trade. Chapter 3 briefly introduces the main prehistoric cultural complexes of Northeast Asia, and concentrates on their periodisation, chronology, and geography. Chapters 4–7 present regional overviews for Northeast Asia, with the focus on primary obsidian sources and spatial distribution of their material in prehistory. Chapter 8 summarises the regional data and provides a reconstruction of exchange/trade networks that existed in the prehistory of Northeast Asia, and some give clues to the issue of ancient migrations and interactions. Chapter 9 contains factual data related to ancient seafaring in Northeast Asia, using obsidian as a proxy to establish the maritime skills in prehistory. Chapter 10 is a kind of conclusion, with a proposition for future research (we are still at the beginning in Northeast Asia). The Appendix consists of primary numerical data on the geochemical composition of major obsidian sources in Northeast Asia, with accompanying graphs showing the geochemical groups, each of them representing a separate source/sub-source. The lists of references includes ca. 600 articles, books, and chapters in edited volumes, published mainly in English, with some in German and French. The number of sources in Russian, Japanese, and Korean is quite restricted.

My own "obsidian story" began in 1991 upon the defence of Candidate of Sciences (more-or-less the equivalent of the Western Ph.D./D.Phil. degree) thesis on the geoarchaeology of the Stone Age complexes in Primorye (Maritime) Province of far eastern Russia. By mid-1992, I had established contacts with two leading U.S. scholars in this field, Drs. M. Steven Shackley and Michael D. Glascock, and delivered a batch of 78 samples to Steve who quickly analysed them. Later on, cooperation shifted to Michael and his laboratory. Our first personal meeting with Michael and Steve was in 2000 at the 65th Annual Meeting of the Society for American Archaeology (SAA) in Philadelphia; initial joint papers and conference presentations came out even earlier, in 1996. Afterwards, we organised a symposium at the 70th SAA Annual Meeting in Salt Lake City, entitled "Crossing the Straits: Prehistoric Obsidian Source Exploitation in the Pacific Rim", on 3 April 2005. The proceedings were published by *Archaeopress* (see Kuzmin & Glascock, 2010). In the spring of 2005, I spent three fruitful months as a visiting scholar, supported by a grant from the US Civilian Research and Development Foundation (now CRDF Global), at the Archaeometry Laboratory of the Research Reactor, University of Missouri–Columbia (Columbia, MO, USA), with Michael D. Glascock as a host.

Fieldwork on obsidian sources in eastern Russia has been conducted by geologists and myself since the late 1990s in Primorye Province, Kamchatka, and Chukotka. Being in Japan in 2003 on a fellowship of the Ministry of Education, Science, Culture and Sport (Mombu Kagakusho), I was able to visit and collect samples from several major obsidian sources—Shirataki and Oketo (Hokkaido Island), and Koshidake (Kyushu Island). In 2015, I visited the Amagi source in the Izu Peninsula (Honshu Island). This gave me the chance to be acquainted with Japanese obsidian locales. In 2002 and 2007, I went to the Chinese side of Mount Paektu (a.k.a. Paektusan Volcano), and collected pieces of volcanic glass.

Two scholars, who have conducted obsidian research for decades, were given the SAA Fryxell Award for Interdisciplinary Research: Michael D. Glascock in 2009, and M. Steven

Shackley in 2019. M. S. Shackley received in 2011 from the SAA the Award for Excellence in Archaeological Analysis. M. D. Glascock in 2011 was selected for the Pomerance Award for Scientific Contributions to Archaeology from the American Institute of Archaeology. In 2019, I received a Research Award from the 4th Shanghai Archaeology Forum, for the project "Obsidian Provenance in Northeast Asia: Gaining Solid Evidence for Prehistoric Exchange and Migrations". These examples demonstrate the importance of investigations on obsidian sources and their use for both archaeology and geoarchaeology worldwide.

In autumn 2011, our Japanese colleagues from the Centre for Obsidian and Lithic Studies, Meiji University (Tokyo), invited several scholars from Russia, the U.S.A., and South Korea to attend a prolonged field excursion/symposium. The programme included a field trip to Hokkaido Island, visiting the obsidian sources of Shirataki, Oketo, and Tokachi-Mitsumata. After that, the scientific session "Methodological Issues of Obsidian Provenance Studies and the Standardisation of Geologic Obsidian" was conducted at the Centre for Obsidian and Lithic Studies near Nagawa Town (Nagano Prefecture) on Honshu Island. Participants also visited the nearby prehistoric obsidian mines at the Hoshikuso Pass. It was a very useful event, with proceedings published by *Archaeopress* (Ono et al., 2014), and all of us learnt a great deal about obsidian provenance studies in Japan and neighbouring Northeast Asia.

However, the need of a larger—truly international—conference on obsidian was evident. It took several years, though, to become a reality.

Once (after the visit to Japan in 2011) I was flying to the island of Crete, and, when approaching Iraklion airport, I spotted a small, horseshoe-like plot of land in the Aegean Sea. Of course, this was the island of Thíra [Thera] (Santorini), famous for its tremendous volcanic eruption sometime in the seventeenth century BC (although its dating is still the subject of hot debates). A thought suddenly came to my mind: "Let's try to organise an international meeting on obsidian provenance somewhere in the Mediterranean!" Previously, such events happened very rarely. This idea was well received by several scholars who suggested (as I was originally thinking) another island in Italy, Lipari in the Aeolian Archipelago off Sicily in the Mediterranean Sea.

Finally, the First International Obsidian Conference (IOC) took place at the Regional Aeolian Archaeological Museum "Luigi Bernabò Brea" of the town of Lipari on 1–3 June 2016. It was well attended for this kind of meeting; ca. 60 scholars from 16 countries of Europe, Asia, and the Americas participated in its activities—scientific sessions and an excursion to obsidian sources (and an excellent conference dinner in truly Italian style).

This success inspired our Hungarian colleagues who took the initiative and organised on 27–29 May 2019 the Second IOC meeting in the town of Sárospatak, eastern Carpathian Mountains, with sessions at the Knights' Hall of the Rákóczi Castle (now a museum), and an excursion to obsidian sources in both Hungary and Slovakia (and cold Tokai wines from the cellar at Viničky, thanks to the owner!). Once again, we gathered around 60 scholars from 18 countries. The global disaster of COVID-19 made it impossible to get together again as expected; therefore, the Third IOC conference was conducted online on 30 April–2 May 2021, organised by our U.S. colleagues from the University of California, Berkeley.

The Fourth IOC meeting was scheduled for July 2023 at the town of Engaru, Hokkaido Island of Japan. It was a complete success, with 120 scholars from 21 countries around the globe attending the meeting (Photo 1). In fact, the area around Engaru is a real "Mecca" for obsidian-related researchers because of its proximity to the largest archaeological volcanic glass source group. Besides several scientific sessions, there was an excursion to the Shirataki cluster of obsidian sources (Photo 2), with the possibility to sample for personal use all major localities in this area. Today, all these sources are part of the Shirataki Japanese National Geopark.

Nowadays, the future of obsidian provenance research looks secure, with up to 200+ papers where this subject is considered published every year in peer-reviewed journals. I hope that readers of this book will get an understanding of what is going on in Northeast Asia, a still less-known part of the world in terms of obsidian sourcing. If so, I would feel that the task is completed. *Finis coronat opus*.

Novosibirsk, Russia/Düsseldorf, Germany — Yaroslav Kuzmin
Spring 2024

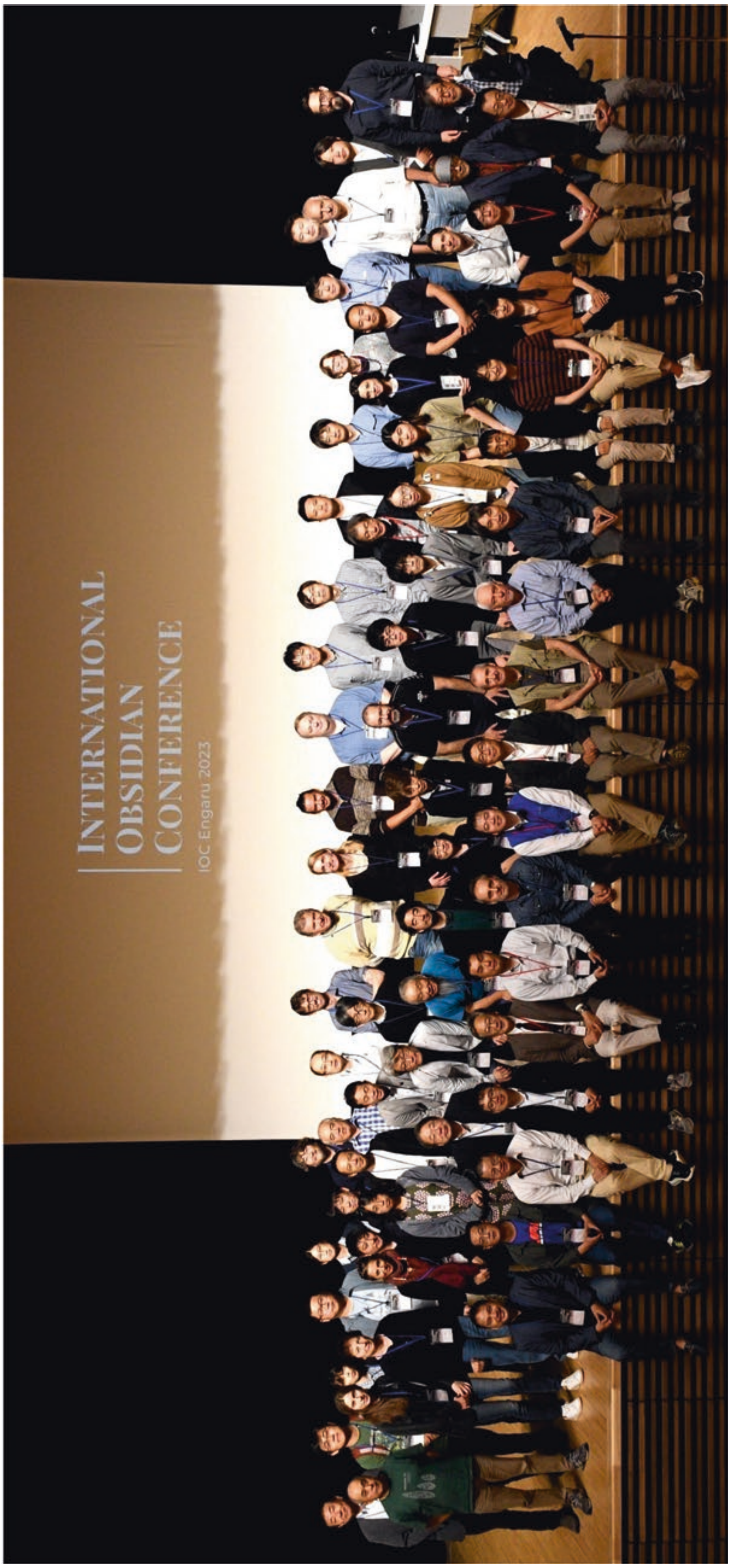

Photo 1 Participants of the Fourth International Obsidian Conference, Engaru, Hokkaido, 3 July 2023

Photo 2 Participants of the Fourth International Obsidian Conference at the Shirataki obsidian source, Hokkaido, 5 July 2023

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Acknowledgements and Declaration

I am grateful to several individuals who collaborated with me for 30+ years, beginning in 1991–1992. My U.S. colleagues Michael D. Glascock and M. Steven Shackley introduced me to obsidian provenance studies. Michael was instrumental in performing the lion's share of geochemical analyses of obsidian artefacts and source samples from eastern Russia throughout these years and interpreting them. Michael also hosted my visiting fellowship in 2005 granted by the CRDF Global. In April 2005, we chaired a symposium devoted to obsidian studies in the Pacific Rim at the 70th SAA Annual Meeting. Subsequently, a plethora of papers was published with Michael; we also co-edited two volumes published by *Archaeopress* (Oxford, U.K.) (see Kuzmin & Glascock, 2010; Ono et al., 2014).

In Russia, I was lucky to find counterparts with whom the geology of primary sources in the southern Russian Far East, Kamchatka, Northeastern Siberia, and the Chinese/North Korean border was examined. These are Vladimir K. Popov (deceased) and Andrei V. Grebennikov. We co-authored numerous papers on different subjects related to the provenance of obsidian artefacts; we also co-edited a volume (see Kuzmin & Popov, 2000). It is clear that this research would not have been possible without the close collaboration with numerous Russian archaeologists who supplied obsidian artefacts for analysis. Not being able to list all of them, I am very grateful for their cooperation. Many of them are co-authors of our joint papers.

In 2007–2024, my research was conducted at the Sobolev Institute of Geology and Mineralogy, Siberian Branch of the Russian Academy of Sciences, in Novosibirsk (Russia), and was supported by the State Assignment # 122041400252-1. I am grateful to several colleagues, friends, and the administration of this Institute for giving me the opportunity to pursue investigations on obsidian provenance in Northeast Asia.

In Japan, I was always supported by Akira Ono who introduced me to Japanese obsidian research. He invited me to Japan several times—for a short (one week) visit in 1994; for acquaintance with the Centre for Obsidian and Lithic Studies, Meiji University, in 2010; for an extended workshop in 2011; and for hosting a fellowship granted by the Japan Society for the Promotion of Science in 2015. On 29 July 2015, we conducted the Symposium "Human Behavioral Variability in Prehistoric Eurasia: Views from the Lithic and Raw Material Perspectives" at the XIX-th Congress of the International Quaternary Association (INQUA) in Nagoya (Japan); Yuichi Nakazawa was the third co-organiser of this event. The proceedings were published in the journal *Quaternary International* (Volume 442B, 2017). One of the most important events in my research was the Obsidian Workshop in Japan that took place in late October–early November 2011; it was organised by Akira Ono and Hiroyuki Sato (see Photo 3).

Other Japanese scholars who were very helpful for my research are Shigeo Sugihara, Hiroyuki Sato, Nobuyuki Ikeya, Hiroki Obata, Kazutaka Shimada, Keiji Wada, Yoshimitsu Suda, Masami Izuho, Takashi Tsutsumi, Makoto Tomii, and Masaki Naganuma. Charles T. (Tom) Keally, who is also based in Japan, introduced me to several aspects of Japanese archaeology, and I am very grateful for his assistance. Mark E. Hall, who was based in Japan in 2003, provided us with samples from the Shirataki obsidian source that were cross-analysed by Michael D. Glascock. I express my warm regards to all Japanese and Japan-related colleagues for their help.

Photo 3 Participants of the 2011 Obsidian Workshop at the Akaishiyama (Summit) outcrop (Shirataki area, Hokkaido), 30 October 2011 (*photo by* Y. V. Kuzmin, 2011). 1—Masayuki Mukai; 2—Candace C. Lindsey; 3—Michael D. Glascock; 4—Vladimir K. Popov; 5—Kyohei Sano; 6—Satoru Yamada; 7—Hiroyuki Sato; 8—Kazutaka Shimada; 9—Noriyoshi Oda; 10—Andrei V. Grebennikov; 11—Keiji Wada; 12—Jong-Chan Kim; 13—Jeffrey R. Ferguson; 14—Masami Izuho; 15—Akira Ono; and 16—Yaroslav V. Kuzmin

In Korea, I was given support by Jong-Chan Kim, who also helped to organise the joint Korean–Russian trip to the Chinese side of Mt. Paektu in summer 2007. Bok-Kyu Choi submitted some obsidian artefacts from South Korean sites that generated the first reliable data on its association with the PNK1 source (see Popov et al., 2005). Mi-Young Hong acquired and submitted the obsidian source sample that most probably comes from the greater region of Mt. Paektu; this was a crucial step in getting closer to understanding the position of this primary locale (see Popov et al., 2019). I am very grateful to these Korean colleagues for their collaboration and assistance.

In Great Britain, I was acquainted with Colin Renfrew who is a true veteran of obsidian research worldwide, and we discussed some issues related to this subject. The edited volume *Methodological Issues for Characterisation and Provenance Studies of Obsidian in Northeast Asia* (Oxford, Archaeopress, 2014) was dedicated to the pioneers, Colin Renfrew and Johnson R. Cann, commemorating the 50 years anniversary of the beginning of scientific obsidian provenance studies in 1964, after publication of their groundbreaking paper in *Proceedings of the Prehistoric Society*. Colin Renfrew also introduced me to the Shanghai Archaeology Forum and its system of awards, and supported my nomination for a Research Award of the 4th Forum that I subsequently won in December 2019. The collaboration with Clive Oppenheimer, who had an extremely rare chance to visit and work on the North Korean side of Mt. Paektu, was crucial in getting closer to understanding the exact position of this important primary obsidian locale. We also compiled an overview of obsidian research worldwide (see Kuzmin et al., 2020). Simon Kaner enthusiastically accepted the idea to publish this book with the new *Springer*'s series *The Science of Human History in Asia and the Pacific* and supported me throughout the preparation of the final version of the text. My thanks go to British colleagues for their advice and assistance.

Constant and invaluable help in editing this book and giving some advice was provided by Susan G. Keates. Some parts of the volume were read and reviewed by Akira Ono, Michael D. Glascock, Clive Oppenheimer, Nobuyuki Ikeya, Kazutaka Shimada, and Elizabeth Healey. The whole volume was reviewed by two anonymous scholars, and their comments were also useful. This book benefited from suggestions and corrections of all reviewers; however, all remaining flaws in this book belong solely to myself.

Competing Interests

Author does not declare any competing financial and/or non-financial interests in relation to the content of the book.

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Contents

About the Author

Yaroslav Kuzmin graduated from the Faculty of Geography, Moscow State University (Moscow, Russia) with B.Sc. degree (1981). Yaroslav Kuzmin is holder of the Ph.D. (1991) and D.Sc. (*Dr. habil.*) (2007) degrees in Geographical Sciences and Leading Researcher at the Sobolev Institute of Geology and Mineralogy, Siberian Branch of the Russian Academy of Sciences (Novosibirsk, Russia) (2007–today). The main area of research is the geoarchaeology of North and East Asia (Siberia, the Far East of Russia, Japan, Korea, and Northeast China), with a special focus on obsidian procurement by ancient people. Yaroslav Kuzmin is author and co-author of 250 articles and book chapters in peer-reviewed publications, including five monographs and 12 edited volumes and special issues of journals. The number of citations (by Scopus database, mid-2024) is about 4190; Hirsch index is 31. Yaroslav Kuzmin is Associated Editor of the international journal *Radiocarbon* (part of the Web of Science). Yaroslav Kuzmin is a Member of the editorial board of the journal *Prehistoric Archaeology: Journal of Interdisciplinary Research* (PAZHMI) (St. Petersburg, Russia) and Winner of the Scopus Award Russia 2015 (Earth Sciences), and the 4th Shanghai Archaeological Forum Award (2019). In 2023, Yaroslav Kuzmin was included in the top 2% of world scholars by the number of citations (Earth Sciences) according to the Scopus database. Yaroslav Kuzmin is Fellow of the Fulbright Programme (U.S.A.), Japan Foundation, Korea Foundation, Japan Society for the Promotion of Science, Soros Foundation (Russia—U.S.A.), and Civil Research and Development Foundation (U.S.A.) and leader of a number of projects funded by the Russian Foundation for Basic Research and the Russian Science Foundation (1994–2022).

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1 Obsidian as a Commodity for Studying Prehistoric Migrations, Contacts, and Exchange

Obsidian is a volcanic rock which, when broken, has a very sharp edge. It is defined in dictionaries as follows: "**obsidian** (ob-sid′-i-an) A black or dark-colored volcanic glass, usually of rhyolite composition, characterized by conchoidal fracture. It has been used for making arrowheads, jewelry, and art objects." (Bates & Jackson, 1984: 352). It has been known since antiquity, and was described by geologists in the nineteenth century (e.g., Darwin, 1844: 34–72, see also Daly, 1925; Iddings, 1885; Iddings & Pensfield, 1890).

Obsidian is part of a more general category of rocks called 'volcanic glass': "Natural glass produced by the cooling of molten lava, or some liquid fraction of it, too rapidly to permit crystallization." (Bates & Jackson, 1984: 556). Volcanic glasses can be divided into two categories: (1) basaltic and intermediate glass; and (2) silicic glass (Lajčáková & Kraus, 1993). The former glass exists mainly in rift zones, in the form of hyaloclastites—glassy clastic deposits associated with pillow lavas (Francis & Oppenheimer, 2004: 358; White et al., 2015: 367–369). The latter glass is represented by andesites and rhyolites, and is usually associated with subduction zones, especially in the Pacific Rim.

The unique feature of obsidian important for archaeology is that every primary or secondary locale has its own 'geochemical signature', and this has allowed researchers to separate different sources among the artefacts that are examined for the purpose of provenance. This was initially recognised by Cann and Renfrew (1964), and after testing was widely accepted as a basic method to identify obsidian sources.

Obsidian is formed from a glass with a very low content (or complete absence) of crystals and bubbles in quenching silicic magma (Tuffen et al., 2021). It is usually confined to the outer margins of silicic lava flows, domes, and intrusions (Castro et al., 2014); also to the outer rinds of pyroclastic ejecta. Obsidian within the lava flows is mainly associated with strata below the pumice-like rocks, which are usually deposited on the surface of the flow, or below the coarse pumice (e.g., Fink, 1983; Fink & Manley, 1987: 85; Manley & Fink, 1987). These obsidian layers of ca. 5–10 m thickness are generally the sources of high-quality raw material selected by prehistoric people. Pyroclastic obsidian originates from material that is explosively ejected from silicic vents. The size of clasts can be from a few millimetres to some metres, and can appear several kilometres away from the vent because of the strong explosion and/or the pyroclastic current.

Obsidian from the margins of silicic intrusions (dykes and sills) usually appears as a discontinuous glassy zone, with sizes up to several metres. In many cases, due to the hydration process this obsidian is turned into pitchstone (volcanic glass with abundant crystallites, a waxy dull resinous luster, and a much higher content of water than in obsidian) or perlite (volcanic glass with a higher content of water compared to obsidian, and without the sharp conchoidal fracture) (Bates & Jackson, 1984: 377, 386; Calder et al., 2015; Tuffen et al., 2021: 198, 204).

The content of silicon dioxide (SiO_2) in obsidian is usually more than ca. 66% weight (wt) which corresponds to the acidic (silicic) chemical composition (e.g., Macdonald et al., 1992; Francis & Oppenheimer, 2004: 162–165). In some cases, like in Primorye Province of far eastern Russia and the Hawaii Islands, high- and medium-quality volcanic glasses appear in the matrix of basic/intermediate composition ($SiO_2 < 66\%$ wt). The hardness of obsidian is 5–6 on the Mohs scale, and the refractive index is ca. 1.45–1.55 (Tuffen et al., 2021).

The content of water (H_2O) in obsidian is usually less than 1% wt; when it increases beyond this value, the volcanic glass becomes brittle and is called 'perlite'. It is determined as "A volcanic glass having the composition of rhyolite, a *perlitic structure*, and a generally higher water content than obsidian." (Bates & Jackson, 1984: 377). The perlitic structure is "A feature of glassy igneous rock that cracked due to contraction during cooling, the cracks

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forming small concentric pearl-like spheroids." (Bates & Jackson, 1984: 377). Typical obsidian does not have any bubbles, and its texture is very homogeneous; this makes its fracture conchoidal and the cutting edge extremely sharp. This was the main reason why this raw material was highly valued for tool-making by prehistoric people.

Obsidian sources can be divided into primary and secondary ones. The primary sources are solid rocks with obsidian, and they are located mainly in the volcanic arcs of the Pacific Rim (related to the subduction zone), the Mediterranean (associated with intra-plate "hotspots"), and in the East African Rift zone (Fig. 1.1). Some sources are situated beyond the plate boundaries, as in the Carpathian Mountains of Central Europe, in Primorye and the Amur River basin of the Russian Far East, and on the Chinese/North Korean border (PNK1 source). High concentrations of primary obsidian localities are in the Rocky Mountains (North America); Mexico and Guatemala (Mesoamerica); the Andes (South America), Kamchatka Peninsula and the Japanese Islands (Northeast Asia); New Zealand; Trans-Caucasus and Anatolia (Near East); and East Africa. Obsidian is known from Cenozoic formations, less than ca. 65 million years (Ma) old, because in older rocks due to devitrification—a very slow process of glass conversion to crystallised matter—obsidian loses its properties.

Secondary obsidian sources originate from the destruction of primary locales by different erosional factors, mainly running water and volcanic activity like the formation of pyroclastic flows (e.g., Shackley, 2005: 22–27; Kannari et al., 2014: 48–49). The distance between the primary source and occurrence of obsidian in a secondary context is usually relatively small, less than ca. 30–50 km, but in some cases, it exceeds 100 km (Church, 2000).

Today, obsidian is a subject of multidisciplinary research involving volcanologists, petrologists, geochemists, and archaeologists. Oppenheimer (2011: 111) vividly highlights this:

> … it is worth emphasising the importance of one of the most prized of rocks: obsidian. Of course, being a volcanic product, it is not so surprising that it crops up again and again in the context of 'Pompeii' style burial of ancient sites. As a material of immense aesthetic appeal – it comes in a variety of hues from pink-grey through black, sometimes with intricate banding, and always vitreous – it is loved both by volcanologists and archaeologists. Furthermore, obsidian can be geochemically fingerprinted …

The earliest documented cases of the use of obsidian as a raw material are known today from East Africa where in the Olduvai Gorge (Tanzania) and the upper Awash Valley (Ethiopia) obsidian artefacts are found at Lower Palaeolithic (a.k.a. Earlier Stone Age, according to African periodisation; Ambrose, 2012: 57) sites dating to ca. 1,700,000 years ago (Ambrose, 2012; Gallotti & Mussi, 2015; Mussi et al., 2023). In the Middle Palaeolithic of Africa (a.k.a. Middle Stone Age), the procurement of obsidian to some extent intensified, with longer distances between the sources and utilisation sites (Brooks et al., 2018). In the Caucasus region of Eurasia, the Lower and Middle Palaeolithic complexes also include obsidian items (e.g., Belyaeva, 2022; Doronicheva et al., 2019;

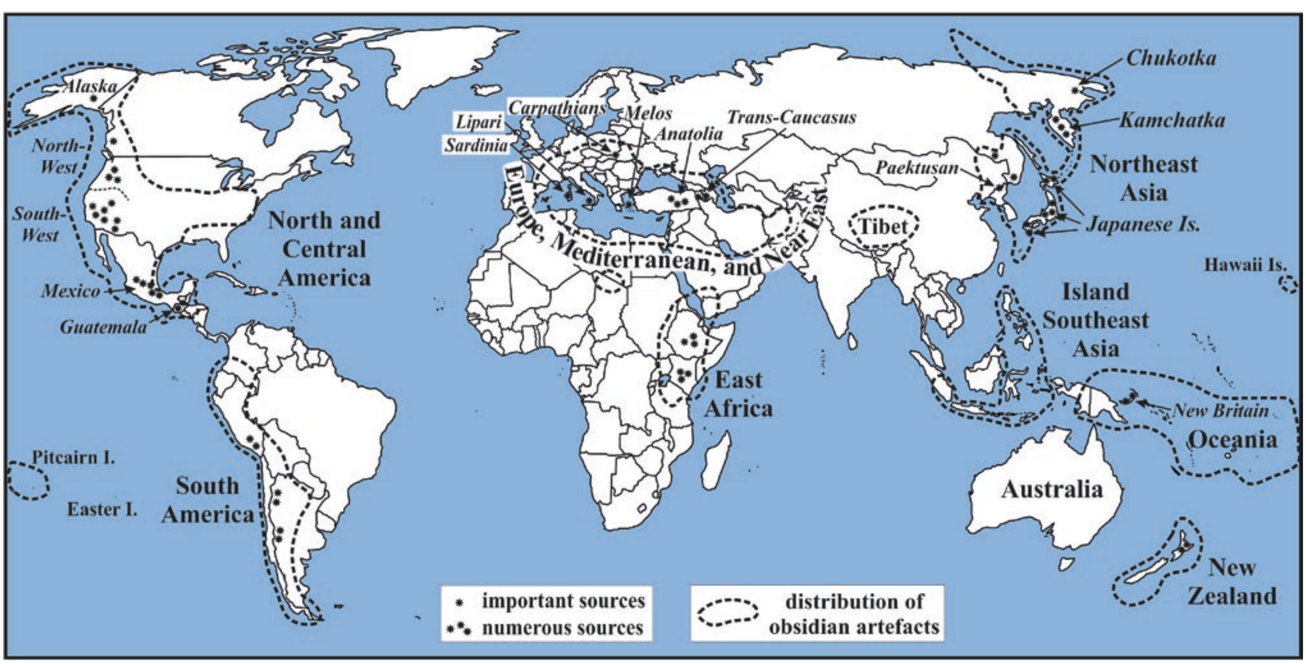

Fig. 1.1 Global summary of regions with obsidian sources and artefacts (after Kuzmin et al., 2020; modified)

Frahm et al., 2020; Le Bourdonnec et al., 2012). The most intensive procurement of obsidian for tool-making is known worldwide for the Upper Palaeolithic, since ca. 50,000 years ago (Kuzmin et al., 2020).

Studies of provenance (i.e., the determination of either primary or secondary sources) for obsidian artefacts in the modern sense began in the early 1960s, with the pioneering research of Colin Renfrew and colleagues (Cann & Renfrew, 1964; Renfrew, 1969; Renfrew et al., 1965, 1966, 1968; see also Cann et al., 1970; Renfrew & Dixon, 1976; Hallam et al., 1976) who empirically arrived at how to conduct these investigations (see Bradley, 1993: 74), and Roger Green (Green, 1962, 1964; Green et al., 1967; see also Green, 1998). It quickly became clear that identification of obsidian sources and patterns of their exploitation could be used as factual material for understanding prehistoric exchange/trade and contacts (e.g., Cann & Renfrew, 1964; Renfrew, 1969) which were 'invisible' when traditional archaeological methods and approaches were applied. This made obsidian a unique commodity for the investigation of prehistoric human contacts, migrations and movements, and interactions.

It turned out that the number of obsidian sources is generally limited to a few for each area (Glascock et al., 1998: 16), except for some regions with a high concentration (see above). For example, in Northeastern Siberia there is a single source—Lake Krasnoe—for a territory of ca. 1,600,000 km^2. The chemical composition of obsidian sources is usually homogeneous, and sources are compositionally different from each other. This is a fundamental feature of obsidian that makes it possible to separate successfully its primary locales. Geochemical analysis of the amount of trace elements, with a content of less than $n \times 10^{-4}\%$ wt (or $n \times 10^{-6}$ in absolute values called "parts-per-million" or "ppm"), allowed researchers to find a match between source and artefact—'fingerprinting' sensu Oppenheimer (2011)—using statistical methods. In this case, almost each obsidian source has its own geochemical 'portrait' or 'signature' different from even neighbouring locales (Glascock et al., 1998); this approach is now widely used worldwide (Kuzmin et al., 2020).

Cann (1983: 227) briefly summarised the advantage of obsidian sourcing for archaeology:

> Because of its superiority in use to most of other natural competitors, and no doubt because of its splendid appearance, it was traded widely from its rather few sources and may, if it can be successfully characterized, give valuable information on patterns of cultural contact through time.

Studies by C. Renfrew and R. Green inspired several scholars to continue provenance research in the Mediterranean, Near East, North America, and Oceania (Frison et al., 1968; Gordus et al., 1967, 1968; Heizer et al., 1965; Key, 1968; Parks & Tieh, 1965). Summaries of early works can be found in Taylor (1976), Cann (1983), Torrence (1986), Pollmann (1993), and Williams-Thorpe (1995). Two comprehensive bibliographies, by Skinner and Tremaine (1993) and Pollmann (1999), serve as basic depositories of information published before the late 1990s. Publications on obsidian studies really took off in the 1970s (Kuzmin et al., 2020). After fluctuations in the number of papers in the 1970s and 1980s, it continued to rise, especially since the early 2000s (e.g., Golitko, 2019; see also Freund, 2013: 782). The average number of obsidian provenance-related papers published per year is now about 180–200.

The determination of obsidian sources used by prehistoric and early historic people worldwide truly revolutionised the methods for investigating patterns of ancient contacts and trade/exchange. It became possible to establish these phenomena with a high degree of certainty not available previously when only archaeological data were employed. Instrumental geochemical analysis of obsidian artefacts with high precision and their match to a particular obsidian source serve as solid evidence for these purposes (e.g., Cann et al., 1970; Carlson, 1994; Dixon et al., 1968; Ericson, 1977; Williams-Thorpe, 1995). It is now obvious that these results are both important and useful for archaeologists who previously were often in serious doubt when subjects like prehistoric contacts and exchanges were concerned. Williams-Thorpe (1995: 234–235) pointed out the merits of obsidian provenance studies for archaeology:

> Two points emerge: first, the enormous amount of information represented here, indicating contacts of which we had no proof, and in some cases no idea, prior to the obsidian provenancing programmes—a reminder that obsidian provenancing has been a success story for archaeology as well as archaeometry. Second, although obsidian finds represent evidence for long-distance cultural contact and movement of resources (up to about 900 km in some cases), the impression … is actually one of self-contained, non-overlapping exchange regions, based on the four areas [western Mediterranean, central and eastern Europe, the Aegean, and Anatolia and the Near East] discussed in this review. Whether due to the tailing off of down-the-line type exchange networks or to the limits of nomad travel (or to other unknown factors of political or economic constraints), these obsidian transport zones rarely interacted. The limits on these zones must have had implications for the dissemination of other materials (and ideas) spread with obsidian; the obsidian itself may not have been the only, or even the major, object of the trade …

An overview of the current state-of-the-art in obsidian provenance on a worldwide scale is given by Kuzmin et al. (2020) (Fig. 1.1). In this book, the focus is on Northeast Asia (Figs. 1.1 and 1.2). This is a very vast region, stretching from the coast of the Arctic Ocean in the north to the Ryukyu Islands in the south. It includes the modern Russian

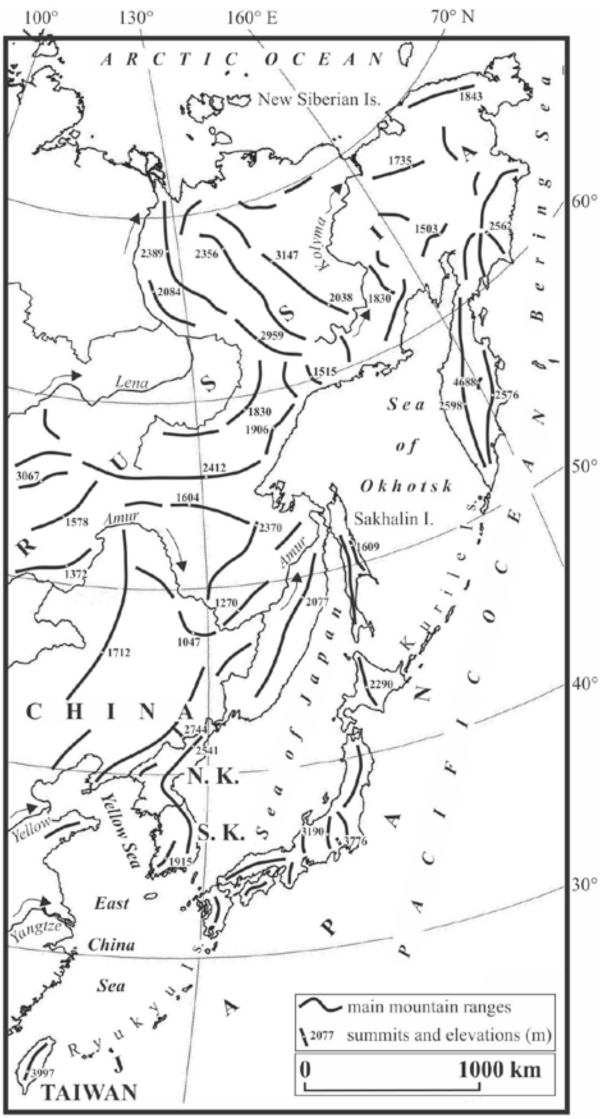

Fig. 1.2 The main physiographic features of Northeast Asia. Abbreviations: N. K.—North Korea; S. K.—South Korea

Far East and Northeastern Siberia (both are parts of Russia), Northeast China (a.k.a. Manchuria), the Korean Peninsula (both North Korea and South Korea), and the Japanese Islands. Northeast Asia belongs to the drainage basin of two oceans, the Arctic Ocean in the northern part, and the Pacific Ocean in the eastern and southern parts.

Geologically, most of Northeast Asia belongs to the Pacific Rim, with several Mesozoic and Cenozoic volcanic belts. Modern volcanic activity is related predominantly to the island arcs of Japan and the Kamchatka–Kuriles on the border of the Eurasian and Pacific plates (Hess, 2006; Oppenheimer, 2011). General data on the geology of Northeast Asia are summarised in Yang et al. (1986), Hashimoto (1991), Paek et al. (1993), Khain (1994: 281–343), Moores and Fairbridge (1997), Wakita (2013), Chough (2013), Moreno et al. (2016), and Zhai et al. (2019). Obsidian sources are plentiful in Japan and Kamchatka; in other regions, they are known in Primorye, the Amur River basin, Chukotka, and on the border between North Korea and China. Obsidian artefacts are very common in Japan and Kamchatka; they frequently occur in Primorye, Sakhalin Island, the Kurile Islands, Chukotka, the Korean Peninsula, and Northeast China. In other regions—basins of Amur, Kolyma and Indigirka rivers, and the High Arctic—obsidian items are not abundant.

The environment of Northeast Asia (terrain, vegetation, and animals) varies greatly, from the arctic zone in the extreme north (New Siberian Islands) to the subtropical zone of the central and southern Japanese Islands (Suslov, 1961; Bartz, 1972; The Association …, 1980; Yoshikawa et al., 1981; Zhao, 1986; Lautensach, 1988; Shahgedanova et al., 2002; Ivanov, 2002). The northern part is mainly mountainous, with numerous ranges in Northeastern Siberia (Shahgedanova et al., 2002) (Fig. 1.2). The Russian Far East is a combination of mountains and plains in the south, and mountains in the north (Fig. 4.1). The active volcanoes of the Kamchatka Peninsula and Kurile Islands are noteworthy (Belousov et al., 2009; Fedotov & Masurenkov, 1991). In the southern part, Northeast China consists of mountain ranges and plains; the Korean Peninsula and the Japanese Islands are distinctive for the prevalence of mountains (Fig. 1.2). Active recent volcanism is known in the main islands of Japan (Hokkaido, Honshu, and Kyushu), and on the North Korean/Chinese border (Mt. Paektu).

Studies of obsidian provenance began in Northeast Asia in the late 1960s—early 1970s in Japan (Watanabe & Suzuki, 1969; Suzuki, 1969, 1970, 1973a, 1973b; Ono, 1976; Osawa et al., 1977). In the Russian Far East, the first data on the geochemistry of obsidian artefacts were obtained in the early 1990s (Shackley et al., 1996), with more results published afterwards (Kuzmin & Popov, 2000; Kuzmin et al., 2002; see reviews: Kuzmin, 2010, 2014, 2017, 2019). In Korea, the first attempts to characterise archaeological obsidians and to establish their sources were conducted in the early 1990s (Lee et al., 1990; Sohn & Shin, 1991), but on the modern methodological level sensu Glascock et al. (1998) it began only in the mid-2000s (Kim et al., 2007; Popov et al., 2005). In the northern Russian Far East and Northeastern Siberia, obsidian provenance research was initiated in the early-mid 2000s (Glascock et al., 2006; Grebennikov et al., 2010; Kuzmin et al., 2008). In Northeast China, investigations of obsidian for archaeological purposes started in the late 2000s (Doelman et al., 2014; Jia et al., 2010, 2013). Today, source analysis of archaeological obsidian in Northeast Asia is a dynamic field, with research actively conducted in all parts of this vast region (Kuzmin et al., 2020: 46–47).

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2 Current Methods of Obsidian Provenance and Exchange Studies

Since the early 1960s, obsidian provenance has been based on the geochemical analysis of volcanic glass sources and interpretation of the results obtained for archaeological purposes. Therefore, this research consists of two steps: (1) analytical investigations of the geochemical composition of obsidian, sometimes supplemented by the determination of its geological age; and (2) studies of obsidian acquisition, use, and exchange/trade.

The ability to establish the primary source of obsidian using geochemical analysis was first clearly demonstrated by Cann and Renfrew (1964), and developed shortly afterwards (e.g., Taylor, 1976; Cann, 1983). The necessary condition to complete this task is highlighted by Glascock (2017: 305): "… for a sourcing study to be successful, the between-source difference for the raw material must be greater than the within-source variation. The hypothesis is commonly referred to as Provenance Postulate."

Wilson and Pollard (2001: 507–508) describe the main features of this postulate/hypothesis as follows:

(i) The prime requirement is that some chemical (or isotopic) characteristic of the geological raw material(s) is carried through (unchanged, or predictably relatable) into the finished object.
(ii) That this 'fingerprint' varies between potential geological sources available in the past, and that this variation can be related to the geographical (as opposed to perhaps a broad depositional environment) occurrences of the raw material. *Inter*-source variation must be greater than *intra*-source variation for successful source discrimination.
(iii) That such characteristic 'fingerprints' can be measured with sufficient precision in the finished artifacts to enable discrimination between competing potential sources.
(iv) That any observed patterns of trade or exchange of finished materials are interpretable in terms of human behaviour. This pre-supposes that the outcome of a scientific provenance study can be interfaced with an existing appropriate socioeconomic model, so that such results do not exist *in vacuo*.

In this chapter, the main approaches of the analytical examination of obsidian and ways of studying the mechanisms and causes of its procurement and movement in prehistory are presented.

It includes descriptions of different geochemical and geochronological techniques, and methods for studies of obsidian acquisition, use, and exchange.

2.1 Analytical Methods for the Determination of Obsidian Sources

Brief descriptions of the methods, currently used in order to establish the sources of obsidian, can be found in Pollard et al. (2007), Malainey (2011), Price and Burton (2012: 78–90), Glascock (2017), and Kolb (2020). Glossaries in Shackley (2005, 2011a) and Malainey (2011) are also useful. Trace elements—ones which have a concentration of less than 100 ppm—are the main subjects of quantitative geochemical analysis. The most informative are the so-called 'incompatible elements' such as Ba, Cs, Hf, Nb, Rb, Sr, Ta, and Zr; and rare-earth elements, among them—Ce, Dy, Eu, La, Lu, Ne, Sc, Sm, Y, and Yb (e.g., Cann, 1983: 238–239). The former elements tend to have higher concentrations in liquid magma (source of obsidian), and are incompatible with solid magma phases.

Knowledge of the local geology is crucial for understanding the origin of obsidian-bearing rocks. This requires acquaintance with information accumulated by regional Geological Surveys and academic researchers on the general geology, volcanology, and petrology (e.g., Fytikas et al., 1986; Keller & Seifried, 1990; Hughes & Smith, 1993; Marakushev & Mamedov, 1993; Shackley, 2005;

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Popov et al., 2005, 2019; Wada et al., 2014; Grebennikov & Kuzmin, 2017; Bačo et al., 2018; Oppenheimer et al., 2019). Shackley (2005: 100) gave a warning that quick sampling of a source, with only a few specimens collected, is no longer enough for the successful characterisation of a primary obsidian locality.

In obsidian provenance studies, a very important question is: how many samples are necessary to collect from each primary source in order to determine its geochemical signature? Shackley (2005: 99–101) proposed that at least five to ten specimens should be analysed, and he highlights that there is no "magic number" in this respect. When the geological structure of a source is complex, as it has been demonstrated (e.g., Glascock et al., 1998: 40–57; Shackley, 2005: 58–64; Chataigner & Gratuze, 2014a), and the geochemical composition of sub-sources is similar, great care should be taken in analysing the data; up to 100 or so samples may be needed from a single source cluster.

As for the number of artefacts to be analysed, this issue depends on both the task and funding. Tsutsumi (2010: 37) proposed 'exhaustive' analysis of as many items as possible; this approach allows scholars to determine primary obsidian sources that were rarely used in prehistory. The importance of the identification of rare sources lies in the fact that this information can help to understand better the patterns of exchange, trade, and migrations of prehistoric and early historic humans when other lines of evidence are absent (e.g., Bélisle et al., 2020; Reid et al., 2022).

The most commonly employed techniques for measurements of the geochemical composition of obsidian in Northeast Asia currently are (in order of both importance and frequency of use):

1. Neutron Activation Analysis (NAA) (sometimes also called Instrumental NAA [INAA]);
2. X-ray Fluorescence (XRF) analysis, including Energy Dispersive XRF (ED–XRF) and its portable variant (pXRF), and Wavelength Dispersive XRF (WD–XRF);
3. Inductively Coupled Plasma–Mass Spectrometry (ICP–MS), including Laser Ablation ICP–MS (LA–ICP–MS);
4. Proton Induced X-ray Emission (PIXE) and Proton Induced Gamma-ray Emission (PIGME [PIGE]);
5. Prompt Gamma Activation Analysis (PGAA) ;
6. Electron Probe Microanalysis (EPMA).

These methods are sometimes supplemented by two techniques for the determination of the obsidian age: (1) Fission-Track (FT) dating; and (2) Potassium–Argon (K–Ar) and Argon–Argon (^{40}Ar–^{39}Ar) dating.

The **Neutron Activation Analysis** has been in use for obsidian provenance studies since the late 1970s (e.g., Glascock & Neff, 2003). The NAA is part of a wider field of nuclear spectrometry (Glascock, 2014). The main principle of NAA is the conversion of atoms of different elements in an obsidian sample into artificially radioactive isotopes by bombarding it with low energy—about 0.025 electron-volts—thermal neutrons (velocity of ca. 2200 m/s), which are produced in a nuclear reactor by the fissioning of uranium-235 (^{235}U) during the chain reaction. As a result, a sample initially composed of stable (i.e., non-radioactive) atoms is transformed into radioactive isotopes of 'activated' elements; this is why the analysis is called 'activation'. The details of NAA procedure are described by Neff (2000) and Glascock (2011, 2020a, 2022).

When a neutron in a reactor hits the targeted nucleus (Fig. 2.1), it becomes the compound nucleus and emits instantaneously the so-called 'prompt particle' and 'prompt gamma (γ) rays'; this is an intermediate step in the reaction. The nucleus immediately changes into a radioactive state; at this stage, the sample is removed from the reactor to the laboratory. Here the process of radioactive decay occurs (although it started already inside the reactor), and radioactive nuclei emit both the beta (β) particles and the so-called 'delayed γ-rays' (Fig. 2.1). The latter is the source of information about the elemental composition of the sample. Eventually, the radioactive nuclei change to stable ones through a chain of decays with characteristic half-lives, and the emission of delayed γ-rays ceases. By measuring the energy of delayed γ-rays, it is possible to identify the chemical composition of a sample with high precision.

For measurements of the delayed γ-rays' energy, usually the high-purity germanium (HPGe) detector is used; the scheme of equipment is presented in Malainey (2011: 430). Each element has its unique energy of delayed γ-rays (Fig. 2.2), and its intensity, which originated from the element's activated nuclei, directly corresponds to its amount in the analysed sample. Along with specimens of unknown composition, the multielement calibration standard with the previously established amounts of several elements (Neff, 2000: 98) is used to determine the concentrations by measuring the number of delayed γ-rays characteristic of each element (e.g., Glascock, 2020a: 7733).

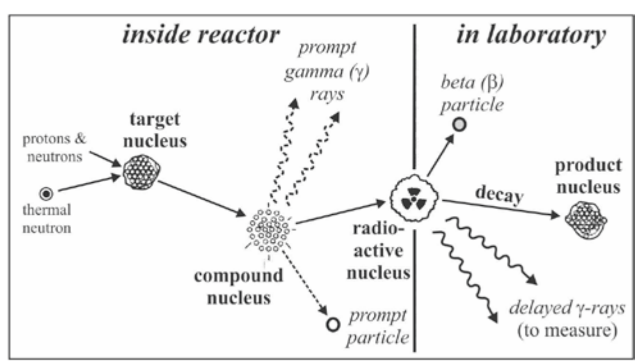


Fig. 2.1 Scheme of the NAA analysis (after Glascock, 2014; modified)

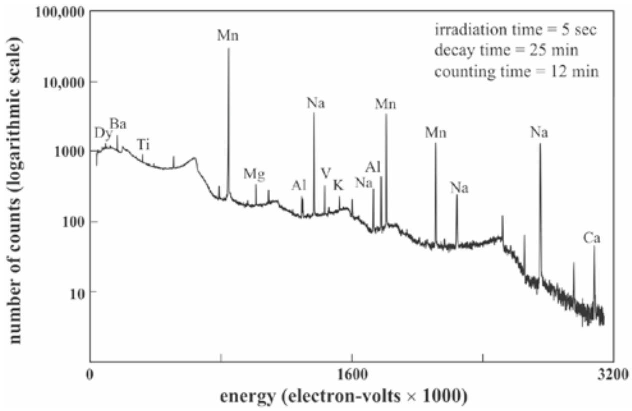


Fig. 2.2 Gamma-ray spectrum from basalt (Easter Island) after the NAA short irradiation (after Glascock, 2020a; modified)

The suitability of NAA for obsidian provenancing lies in the fact that it is free of most matrix interference effects because volcanic glass is transparent to neutrons, and most of the delayed γ-rays can penetrate through the glass without any obstacles, although some of the lowest energy γ-rays are absorbed when the sample is relatively thick. The possibility of contamination is very small because samples do not require elaborate preparation and pretreatment (Glascock & Neff, 2003).

The NAA has several other advantages (e.g., Neff, 2000; Glascock, 2020a: 7733): (1) the theory of NAA is well understood, and it is possible to take into account all methodological details; (2) the measurements have very high precision, ca. 1 ppm and below; 3) solid samples (like chunks of obsidian) can be analysed without extra treatment like dissolution; (4) the amount of material for NAA is relatively small, usually 100–200 mg, and sometimes as little as 5 mg; and (5) high potential for intercalibrating data and reliable comparison of the results obtained in different laboratories.

The main disadvantages of NAA are: (1) the method is destructive (it requires the removal of a small piece from the artefact, for example); and (2) after irradiation in the nuclear reactor the samples become radioactive, and this kind of low activity nuclear waste must be disposed of. In some cases, the radioactivity that comes from the analysed specimen is very low, and after a few months it reaches a level acceptable for radiation safety requirements allowing it to be released.

Another matter is that the number of nuclear research reactors is gradually decreasing, and less and less laboratories can perform this analysis (e.g., Bishop, 2017: 545–546; Glascock, 2020a: 7734). Today, the Archaeometry Laboratory at the Missouri University Research Reactor (MURR), located in Columbia, MO, U.S.A. (Fig. 2.3), and operative since 1988, is one of the leadership facilities which conducts the NAA on a regular basis along with other geochemical analyses (Glascock, 2020b).

In most cases, two irradiations are necessary to analyse the obsidian by NAA. The long irradiation is used to detect the content of 17 long-lived elements: Ce, Co, Cr, Cs, Eu, Fe, Hf, Ni, Rb, Sb, Sc, Sr, Ta, Tb, Th, Zn, and Zr (Glascock & Neff, 2003). The short irradiation allows researchers to determine the amount of the eight short-lived elements measured: Al, Ba, Ca, Cl, Dy, K, Mn, and Na (Fig. 2.2).

Fig. 2.3 The Missouri University Research Reactor building (photo by Y. V. Kuzmin, 2005)

Overall, at least 30–35 elements can be analysed by NAA with high precision. In many cases, the abbreviated NAA analysis, with only six elements measured (Ba, Cl, Dy, K, Mn, and Na), is enough to get reliable data on the geochemical composition of obsidian artefacts and pinpoint it to the primary sources (e.g., Glascock et al., 1994). This, however, requires prior knowledge of the content of a larger set of elements (ca. 28) for each source established by 'regular' NAA. On the other hand, Glascock et al., (1998: 60) found out that only ca. 10% of obsidian artefacts from Mexico and Guatemala—regions with a large number of primary sources—need full NAA examination.

Another important part of NAA (as well as other analyses) is the statistical evaluation of the results obtained. The approach developed by Glascock et al. (1998) is now the most widely used. It is based on the application of multivariate statistics: cluster analysis, principal component analysis (PCA), bivariate plots, and discriminant function analysis; details can be found in Glascock et al. (1998: 24–61) and Glascock and Neff (2003).

Cluster analysis measures the degree of similarity–dissimilarity between samples (i.e., distance), and the results are usually presented as dendrograms. Because this method is highly subjective, additional analyses are necessary. PCA involves a transformation of the geochemical data based on eigenvector methods to establish the magnitude and direction of maximal variance in the distribution of original data in hyperspace (Fig. 2.4a). This allows researchers to obtain a new basis for viewing the distribution of NAA measurements, in order to reveal the patterns that are invisible when the results are simply plotted. The bivariate plots, created with the help of the *GAUSS* software developed at MURR, make it possible to see the correlations between variables (i.e., chemical elements), and to identify both the sample groups and outliers (Fig. 2.4b). The discriminant function analysis can describe two processes, discrimination and classification. The former involves identifying a mathematical transformation of the original data that best reveals the differences between known geochemical groups; it is based on Mahalonobis distance. The latter includes the categorisation of a number of observations into known groups.

The application of different methods of multivariate statistics allows scholars to characterise the primary obsidian sources and to determine which sources the artefacts belong to. Examples are given in Glascock et al. (1998), using central Mexico and Guatemala as a polygon, to prove the reliability of this approach (Fig. 2.4). Constant work on standardisation and quality assurance of NAA at MURR ensures that the results obtained are secure (e.g., Glascock & Anderson, 1993).

The XRF technique has been used for obsidian provenance studies since the late 1960s (Shackley, 2005). General information about the XRF method can be found in Pollard et al., (2007: 101–109) and Shackley (2011b, 2017, 2020).

The basic idea of XRF is that samples are irradiated with photons from an X-ray tube that excites electrons in a sample's atoms. As a result, vacancies (or "holes") are created in the inner shells (K, L, M, and O) of the atoms of the surface layer (Fig. 2.5a). These vacancies are then filled with outer shell electrons and simultaneous emission of a new photon, called fluorescent X-ray. If the K-shell electron is replaced by one from the L-shell, this is called Kα X-ray, and if from the M-shell—Kβ X-ray. Similar effects occur with electrons from M, N, and O-shells, respectively. The most intensive is the Kα transition, and its secondary (fluorescent) X-rays are usually measured. The energies of secondary X-rays are specific for each element, and appear as peaks in the XRF spectrum (Fig. 2.5b). The intensity of a peak is a function of the abundance of an element in a specimen; the amplitude of a peak can be converted to units of concentration by comparing X-ray intensities with those obtained from standards.

In ED–XRF, the secondary X-ray emitted by the excited atom is considered as a particle. The energy of this X-ray is characteristic for particular atom, and for the chemical element in general. The detection system measures directly the energy spectra of the fluorescent X-rays (Fig. 2.6). The ED–XRF is not destructive, and does not require special preparation; however, it is important that the specimen has a relatively flat surface. The ED–XRF is currently widely used for obsidian provenance studies, especially for the analysis of artefacts that cannot be destroyed (Shackley, 2005, 2011b; Kannari et al., 2014).

In WD–XRF, detection and measurement of X-ray energy are separated. The fluorescent X-rays are considered as electromagnetic waves, whose wavelength is characteristic of the atom (Fig. 2.6). In this method, the relationship between the angle of the instrument and the analysed object is very important. The advantage of WD–XRF is that it is more precise than the ED–XRF. On the other hand, the WD–XRF is destructive, and the sample needs to be transformed to either powder, glass bead (by melting of the original specimen), or a polished mirror-like surface.

The pXRF as a version of ED–XRF uses a small-sized instrument (Fig. 2.7b) that can be carried to a museum, artefact repository, or primary source, in a box or a suitcase, and measurements are performed directly at the site. The particular problem with pXRF instruments is that they are not initially calibrated, and while the measurements can be internally consistent, they are not comparable with data obtained by other pXRF devices or different methods like NAA and 'stationary' XRF. Shackley (2011b) and Liritzis and Zacharias (2011) discuss this in detail. When pXRF equipment is properly used, the results are reliable and compatible with data generated by other methods (e.g., Campbell et al., 2021; Milić, 2014).

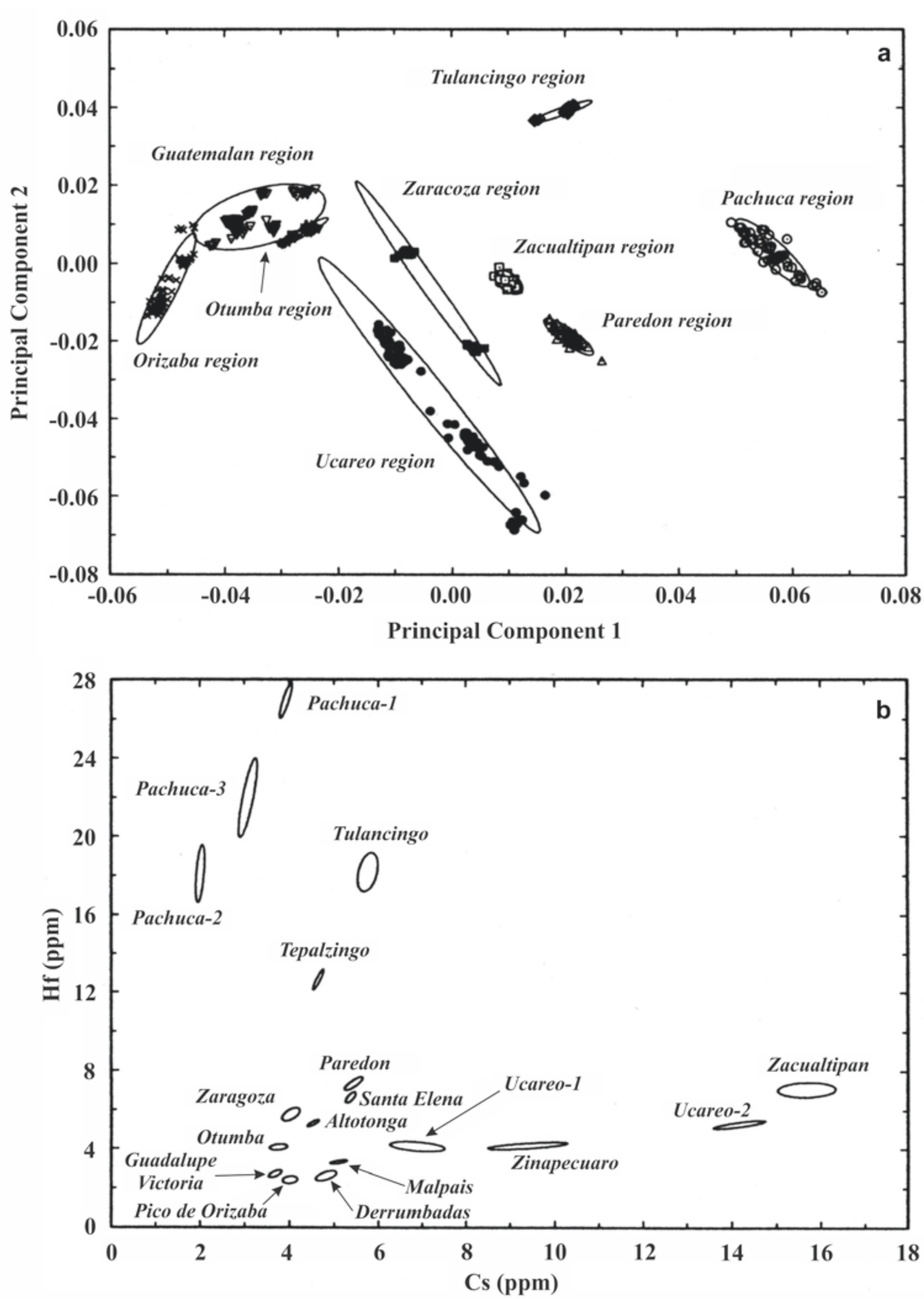


Fig. 2.4 **a** Plot of PCA showing differences between obsidian source regions in Mexico and Guatemala; **b** Bivariate plot of Cs versus Hf differentiation of the 18 compositional groups of obsidian in central Mexico, with probability ellipses at the 95% confidence level (after Glascock et al., 1998; modified)

The XRF allows researchers to measure the content of 10–15 elements, most commonly Ba, Ce, Fe, La, Mn, Nb, Pb, Rb, Sr, Ti, Y, and Zr (Shackley, 2005). The accuracy of XRF measurements depends on several factors, including surface texture, sample thickness, inhomogeneities inside the specimen, particle size, and matrix effect (Glascock, 2011). The analysis of the XRF results obtained and match of artefacts to primary sources usually follows the methodology of Glascock et al., (1998).

The advantages of XRF (Shackley, 2011) are: (1) it is non-destructive (ED–XRF); (2) sample preparations are minimal; (3) fast analysis—it takes minutes to get a result; (4) ease of use, no special training is necessary; (5) cost-effective—it is less expensive than NAA and other analyses. There are also limitations for ED–XRF: (1) sample size: it is preferable to have artefacts > 10 mm long and > 2 mm thick; and (2) limited number of elements detected.

At MURR, ED–XRF analysis of obsidian artefacts is conducted using a *ThermoScientific ARL Quant'X* spectrometer (Fig. 2.7a). It allows scientists to determine the content of 12 elements: K, Ti, Mn, Fe, Zn, Ga, Rb, Sr, Y, Zr, Nb, and Th. The *Quant'X* ED–XRF spectrometer is

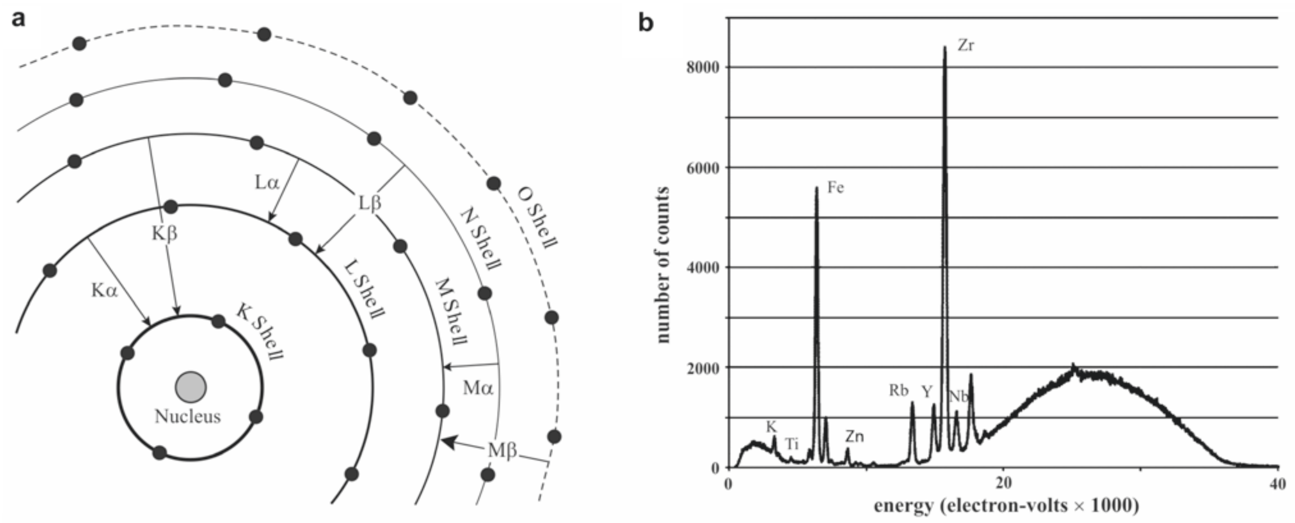


Fig. 2.5 **a** Schematic view of orbital transitions in atoms due to XRF (after Shackley, 2017; modified); **b** XRF spectrum from an obsidian sample (after Glascock, 2011; modified)

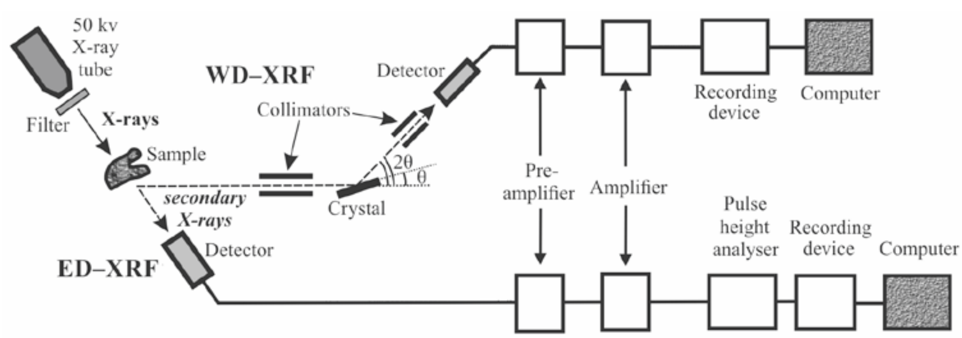


Fig. 2.6 The scheme of the ED–XRF and WD–XRF detection systems (after Pollard et al., 2007; modified)

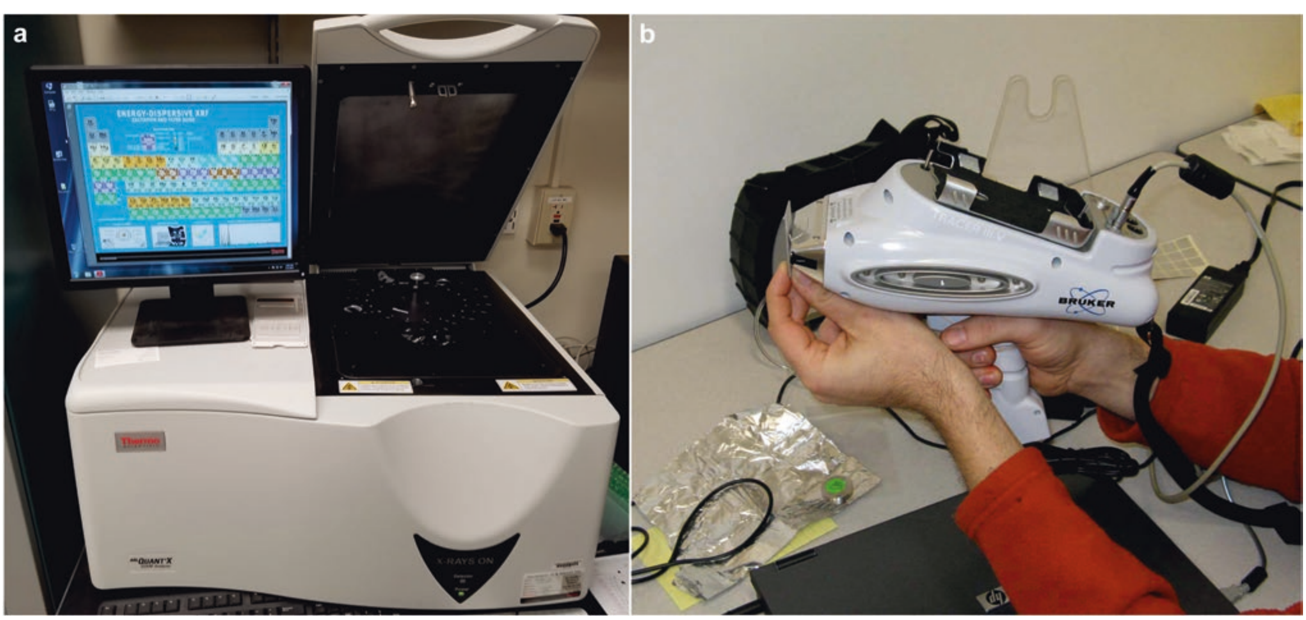


Fig. 2.7 General view of the XRF devices. **a** Stationary equipment, *ThermoScientific ARL QUANT'X*; **b** Portable equipment, *Bruker SDD* (photos by M. D. Glascock, 2017)

calibrated by measuring a set of 40 very well-characterised obsidian source samples previously analysed by NAA, ICP–MS, and XRF methods. For small samples—with dimensions of ca. 5–7 mm long and ca. 2 mm wide—the following pairs of elements and their ratios are selected for provenancing: Sr/Zr versus Y/Zr; and Nb/Zr versus Rb, because the concentrations of elements in ED–XRF are dependent on the volume of the sample that interacts with the X-rays. When the artefact is small and thin, issues related to both the thickness and cross-sectional area of the sample are very important. Thus, it is more correct to examine elements that are adjacent to one another, for example, Rb and Sr, and Y and Zr. The best way to overcome this problem is to create plots of ratios for elements that are reasonably close on the periodic table; in our case, Sr/Rb, Rb/Zr, Y/Zr, and Nb/Zr (e.g., Kuzmin et al., 2021).

Comparison of the XRF results with those obtained by NAA is a very important issue (e.g., Suda et al., 2018a). According to cross-analysis of the same specimens, the correspondence is usually very good (Shackley, 2005: 90–91; Glascock, 2011), last but not least due to the calibration of instruments to international standards. When such an exercise is performed on a more-or-less regular basis, the results of both methods can be directly compared, unlike many cases without the use of the same standards. For some elements—for example, potassium (K) in a set of source material from central Mexico—the data can be quite dissimilar, because of effects on sample differences in shape and surface which affects the low energy X-rays for K more seriously than the other elements (Glascock, 2011: 184). In most cases, the XRF allows the determination of the provenance of obsidian artefacts even in regions with numerous sources, like central Mexico. For some samples, nevertheless, additional NAA analysis is required (Glascock, 2011: 191).

Laser Ablation Inductively Coupled Plasma–Mass Spectrometry is based on ionisation of atoms by laser and analysis of ions by mass spectrometry, using a mass of the particle to separate and count it. This is relatively new technique, introduced in the 1980s—early 1990s. Detailed information on the ICP–MS and LA–ICP–MS methods can be found in Gratuze (1999), Pollard et al. (2007), Neff (2012, 2017), and Fricker and Günther (2016).

The basic principal of LA–ICP–MS is that a small portion of the sample is evaporated by laser and carried by gas (usually, argon or helium) into the plasma chamber; atoms are ionised within the plasma, and moved to the spectrometer for measurement (Fig. 2.8). Usually, the Nd-YAG solid-state ultraviolet laser is used. The laser beam ejects particles from the specimen; the laser-generated aerosol is transported to a plasma torch by a gas flow. Here the solid aerosol is vaporised, and molecules are converted to atoms. Plasma (with temperatures of ca. 6000–10,000 °C) excites the atoms, which can be identified as a mass-to-charge ratio by magnetic separation using mass-spectrometric techniques.

The LA–ICP–MS can measure the content of up to ca. 70 elements, including their isotopes that is impossible to do when NAA or XRF methods are employed. The size of the sample chamber is large enough for the majority of obsidian artefacts, usually ca. 6 cm diameter by ca. 4 cm depth. The LA–ICP–MS is practically non-destructive; the size of the "crater" created by the laser is less than 0.001 mm in diameter, and is invisible to the naked eye. Other advantages of this method are: (1) high sensitivity; the precision of measurement is less than ca. 1 ppm; (2) large number of elements analysed; (3) fast analysis, up to ca. 50 samples/day. The main disadvantage is that the LA–ICP–MS equipment is expensive, large samples can only be analysed one at a time, and the number of facilities that perform it is limited. Comparison of the results obtained by LA–ICP–MS with other methods—NAA and XRF—showed good correspondence (e.g., Gratuze, 1999). The LA–ICP–MS is still developing, with new avenues opened (e.g., Orange et al., 2016).

The **Proton Induced X-ray Emission** and **Proton Induced Gamma-ray Emission** methods are similar to XRF, and were developed in the 1970s. These techniques are based on the creation of vacancies in the inner electron shells of atoms by bombarding the sample with protons

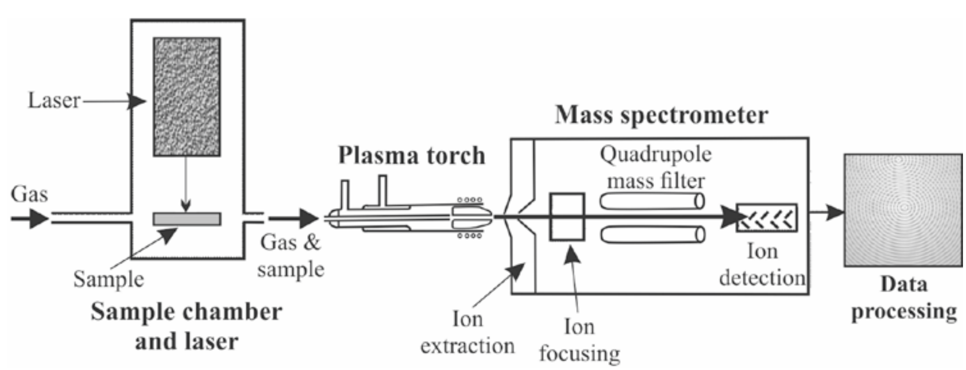


Fig. 2.8 Scheme of the LA–ICP–MS equipment (after Pollard et al., 2007; modified)

(PIXE) or γ-rays (PIGME). For the proton current in PIXE, the Accelerator Mass Spectrometer (AMS) (i.e., van de Graaf accelerator), with a voltage of ca. 2–5 MeV, is used (Summerhayes et al., 1998; Pollard et al., 2007: 116–117; Popelka-Filcoff, 2020). The detection level for light elements is high at ca. 0.5–5 ppm; for the heavier ones (above Ca), it is ca. 100 ppm. The portable PIXE equipment has now been developed for use (Pappalardo et al., 2003). For PIGME, γ-rays are emitted from the source, usually the radioactive isotope. The light elements, such as Li, F, Na, Mg, and Al, can be measured with a detection limit of ca. 10–100 ppm (Pollard et al., 2007: 117). Both methods are non-destructive. Devices for the detection of X-rays' energy from irradiated samples in PIXE and PIGME methods are very similar to those for XRF. Comparison with other analytical methods like ICP–MS showed good correspondence (Bellot-Gurlet et al., 2005).

The **Prompt Gamma Activation Analysis** is based on irradiation of the sample by a guided neutron beam, and the γ-rays originating from the radioactive capture are measured with an HPGe detector (Belgya, 2012; Jwa et al., 2018; see also Révay & Belgya, 2004). With the PGAA, it is possible to quantify most of the major components in obsidian (i.e., SiO_2, TiO_2, Al_2O_3, Fe_2O_3, MnO, CaO, Na_2O, K_2O, and H_2O), as well as some trace elements—B, Cl, Nd, Sm, and Gd, with a detection limit of ca. 1 ppm and below. The PGAA does not require removal of pieces from the investigated objects, and valuable artefacts can be studied in a non-invasive way (Kasztovszky et al., 2008). Details of PGAA can be found in a recent summary (Kasztovszky et al., 2022).

The **Electron Probe Microanalysis** (Pollard et al., 2007: 109–113; Owen, 2017) is based on the effect that a focused and accelerated beam of electrons hits the solid sample; this is similar to the underlying principal of XRF analysis, with the only difference that instead of X-rays the electrons are used to influence the specimens. As a result, it emits electrons and X-rays (Pollard et al., 2007: 110). Radiation from X-rays is measured, and its intensity is compared with analytical standards. Because each element produces X-rays with its own energy of the wavelength, it is possible to establish the composition of an obsidian specimen. The EPMA instrument consists of four parts: (1) a source of electrons; (2) an electron-optic focusing system; (3) a sample chamber; and (4) a wavelength-dispersive and/or energy-dispersive spectrometer. This method can measure the amounts of many elements, heavier than Li and with a concentration as low as ca. 100 ppm. The advantage of EPMA is that testing can be conducted in situ at a micrometre scale. The disadvantage is that for some elements the X-ray peaks overlap, and it is impossible to measure their content. Usually, samples for EPMA are polished to have a mirror-like surface cleaned with a solvent to remove any oil.

Fission-Track dating is based on the accumulation in glass of damage trails formed by the spontaneous nuclear fission decay of the ^{238}U (Kohn, 2017; see also Walker, 2005: 114–120). The nucleus of ^{238}U dissipates its considerable excess kinetic energy in the hot matrix, and this disrupts the structure and creates a linear damage trail, ca. 10–20 microns long and ca. 1–2 microns wide. After irradiation in the nuclear reactor and chemical etching, these trails become visible in an optical microscope and can be counted. The FT age depends on the density of trails, and can determine the antiquity of rocks of up to 10 million years and more.

The **K–Ar** and **^{40}Ar–^{39}Ar** dating methods are based on the radioactive decay of the "parent" isotope ^{40}K to the "daughter" isotope ^{40}Ar (Morgan, 2017; see also Walker, 2005: 58–66; Ignatiev et al., 2009). By measuring the ratio of the daughter isotope to the parent one, combined with the values of the half-life for the branched decay of ^{40}K, it is possible to calculate the time that has passed since the creation of obsidian. The ^{40}Ar–^{39}Ar method requires a very small sample, sometimes less than 1 mg, and compared to K–Ar dating it has a higher precision (Flude et al., 2018). Both methods can determine the age of rocks of up to 1 billion years and even more.

All the methods described above are constantly developing and improving, and this allows us to get more data and identify patterns of obsidian composition and chronology which were unknown before. The latest summaries can be found in Gilbert et al. (2017) and Smith (2020).

2.2 Methods of Studies of Obsidian Acquisition, Use, and Exchange

The scientific study of prehistoric strategies to obtain obsidian, including mining/collection, transportation, and exchange, began in the 1960s. C. Renfrew and colleagues made the main contribution (see Renfrew, 1969, 1975, 1977; Renfrew & Dixon, 1976; Renfrew et al., 1966, 1968; Hallam et al., 1976). The fundamental principal of this research is the law of monotonic decrement; it means that the frequency of occurrences (including obsidian) declines as one moves away from the place of origin because the transport of goods requires the input of energy, and the greater the distance the greater the amount of energy is necessary (Renfrew, 1977). The length of movement between the obsidian source and consumption site may be greater than the straight line because of terrain features like mountains, deserts, and other obstacles; the term 'effective distance' was coined to define it (Renfrew, 1977: 72).

Based on the assumption of a gradual decrease in the quantity of obsidian in a given lithic assemblage as the distance increases, the 'down-the-line' distribution with

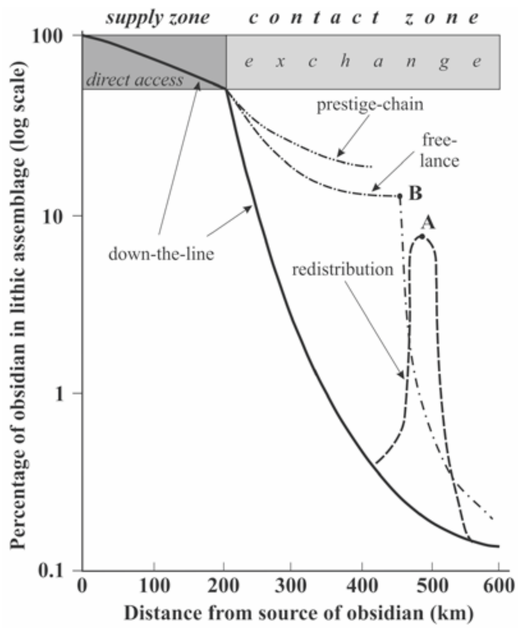
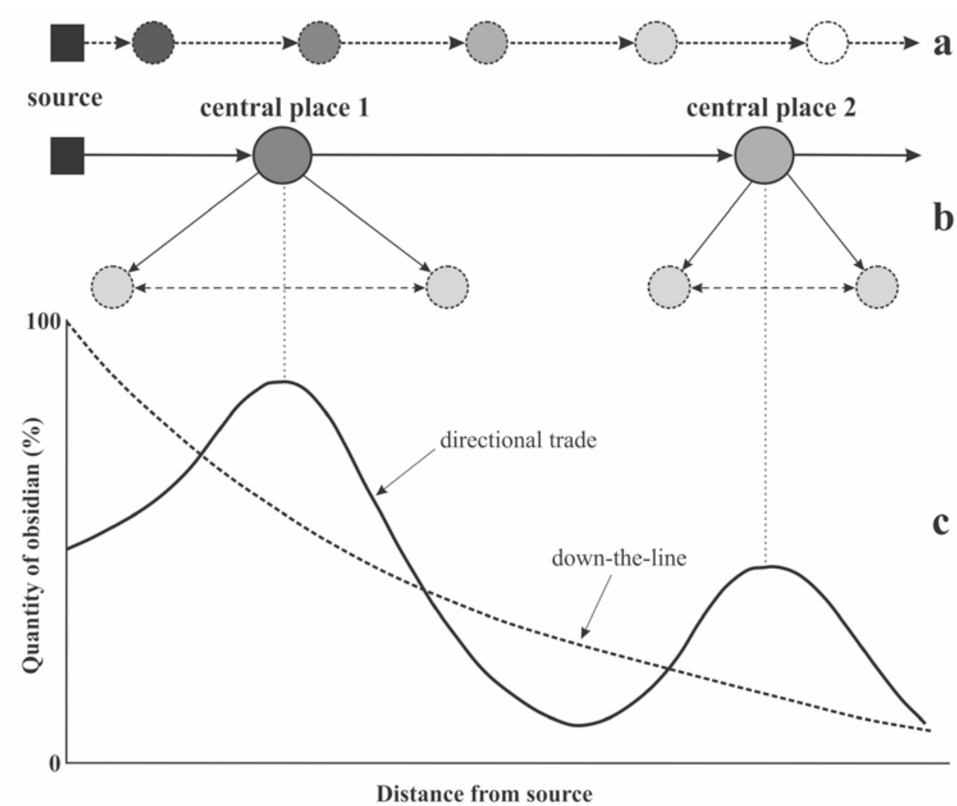


Fig. 2.9 Fall-off curves for different models of obsidian acquisition (after Renfrew, 1975; modified)

exponential fall-off was identified (Fig. 2.9). It is based on data collected by Renfrew et al. (1968) for Neolithic sites in the Near East. The mechanism of direct acquisition of obsidian from the source as the simplest way to obtain it is called 'direct access'. A 'supply zone' of ca. 250–350 km in length, within which people were able to conduct regular travel to the primary source, was determined; beyond it, the 'contact zone' includes sites where people needed to exchange obsidian in order to acquire it, without a direct journey which was too long (Fig. 2.9). The ratio of obsidian in a lithic assemblage within the supply zone was estimated at ca. 80% (Renfrew et al., 1968). Renfrew and Dixon (1976) proposed an 'interaction zone' where the amount of obsidian in a lithic assemblage from a particular source is 30% or more of all obsidian artefacts.

Therefore, a chain of settlements should have existed in prehistory with the down-the-line movement of obsidian (Fig. 2.10a). It is assumed that the larger the number of exchange acts, the smaller is the amount of obsidian passed through the sequence. Currently, the definition of down-the-line trade/exchange is: "… a process in which goods (here lithic items) move through reciprocal exchange from group to group, thus involving a series of successive exchanges of material from a point source." (Féblot-Augustins, 2008: 1187–1188). Long-distance exchange can be observed when the transportation routes exceed ca. 600–700 km. In the 1960–70s, a distance of obsidian movement in the Near/Middle East of ca. 1500 km as the crow flies was considered as the longest land transport of obsidian in the Old

Fig. 2.10 Two main models of obsidian acquisition (after Renfrew & Dixon, 1976; modified): **a** down-the-line trade; **b** central-place redistribution; **c** Graphs of distance from source versus quantity of obsidian for these models of trade/exchange



World (Renfrew & Dixon, 1976: 141). Later on, similar or even greater distances were identified: in the Near/Middle East—ca. 1600–1700 km (Barge et al., 2018); from Trans-Caucasus to Eastern Europe—ca. 2000 km (Asheichyk et al., 2018); from Mesoamerica to North America—ca. 1700–1950 km (Barker et al., 2002; Dolan & Shackley, 2021); in North America—up to ca. 2800 km (Riebe et al., 2022; Kristensen et al., 2023); and in Northeastern Siberia—up to ca. 1500 km (Pitulko et al., 2019).

When movement by watercraft is involved, the length of obsidian transportation is even greater, sometimes exceeding ca. 3500 km as the crow flies, as it is known in Oceania (e.g., Bellwood & Koon, 1989; McCoy et al., 2020; Summerhayes, 2009). Provenancing of obsidian artefacts from sites located on islands away from primary sources can contribute to understanding the patterns of prehistoric seafaring, especially in the absence of direct evidence such as remains of ancient boats. For example, in Oceania obsidian from a source in New Britain Island was brought to New Caledonia, ca. 2300 km away in a straight line, during the spread of the Lapita complex, ca. 3500–3000 years ago (Sand & Sheppard, 2000). This obsidian was transported even further, to the Fiji Islands (e.g., Best, 1987; Anderson, 2000: 120), ca. 3200 km from the source as the crow flies (see also Summerhayes, 2009). For Northeast Asia, details are presented in Chap. 9.

Another mechanism of obsidian acquisition, directional trade (involving intermediaries), also could have existed (Fig. 2.10b). In this case, on the graph of distance from source versus percentage of obsidian the peaks occur (Fig. 2.9, 'redistribution'; Fig. 2.10c). The ratio of obsidian will quickly decrease beyond the point of a regional centre in case of down-the-line transport (Fig. 2.10c). The 'central places' were the hubs of exchange activity, and they also supplied smaller settlements (Fig. 2.10b).

Two other ways of obsidian distribution from the source to sites were determined as 'free-lance trade' and 'prestige-chain trade' (Renfrew, 1975) (Fig. 2.9). In the former case, a rapid drop in the ratio of obsidian beyond the point of a settlement served by a trader is assumed. In the latter case, the decrease in the amount of obsidian is slower than in the other models because of the existence of a constant supply by redistribution and market exchange.

Using archaeological data, it was suggested that down-the-line exchange existed in egalitarian societies like the Neolithic communities of the Near East and Levant, and was based on a reciprocal type of trade (Renfrew, 1969). The central-place mechanism was observed in more centralised types of social organisations—like chiefdoms and states, especially in Mesoamerica (Pires-Ferreira, 1976; Sidrys, 1976, 1977)—and was controlled by persons of high status.

The straight distance between source and consumer site and the ratio of obsidian in a lithic assemblage (in per cent) are the most important characteristics of obsidian exchange (Renfrew et al., 1968). Other parameters were also offered to investigate obsidian acquisition, including the amount of obsidian per volume (pieces/m^3), and the mean weight of obsidian items (in grams) (Renfrew, 1969).

Although widely accepted, the mechanisms of obsidian exchange proposed by C. Renfrew were criticised (e.g., Wright, 1969; Hodder, 1982; Earle, 1982; Ortega et al., 2014). It was pointed out that the weight of obsidian is an important indicator along with the percentage of obsidian in a lithic assemblage. For some regions, even in the Near East, the supply zone concept does not work. For example, Golitko (2019: 94–94) mentioned that while for distances between source and sites of a few hundred kilometres the down-the-line model works reasonably well, it is not effective when the distance is longer, up to 700 km in some cases.

The function of sites under analysis—centres for production of flint, copper, and pottery; camps of nomadic herders; and settled farming villages—is also important because the tool types produced at sites of each category would be different. The role of nomadic and transhumant groups in long-distance movement of obsidian was underestimated (Crawford, 1978). In some cases, even for areas located within the supply zone the amount of obsidian does not fit the predicted values, as it was shown for the region of Calabria in the southernmost tip of the Apennines (Italy) (Ammermann, 1979; Ammermann & Andrefsky, 1982).

Torrence's (1986) careful analysis of the strengths and weaknesses of C. Renfrew's models for obsidian transportation and exchange, highlighted the issue related to the time required for obsidian to pass through a down-the-line chain (Torrence, 1986: 21). Another potential problem was related to the equifinality effect when different processes of obsidian movement and exchange can generate the same fall-off curve. The use of several sources by a population of the same settlement can mask the distribution of obsidian (Torrence, 1986: 23). The importance of studying the quarries (i.e., primary sources) was mentioned. The reconstruction of the ways of transportation—by land versus by the sea—is also crucial for understanding the exchange system (Torrence, 1986: 104–105). A list of measures for consumption and production of obsidian is presented in Torrence (1986: 124).

Ericson (1977) considered the spatial aspect of obsidian exchange, using the state of California (western U.S.A.) as a polygon. He first created maps with isolines (percentage of obsidian) for different time periods. After that, the three-dimensional distribution of obsidian was analysed (Ericson, 1977: 118–123). It was found that it is mostly asymmetrical which contradicts C. Renfrew's predicted fall-off curves. This emphasised that the models created by C. Renfrew are to some extent restricted to particular conditions in the Neolithic Near East, and more work is still necessary to refine them.

Findlow and Bolognese (1982) conducted a similar analysis for the state of New Mexico (U.S. Southwest). They used factor analysis to understand the role of topography in prehistoric exchange. Upon evaluation of the three-dimensional distribution of obsidian, it was concluded that down-the-line exchange was practiced relatively rarely, and that sociopolitical changes played an important role in the acquisition of this raw material. In addition, the separation between source and consumption site was important: "The greater the separation, the more likely that some form of complex exchange system will evolve." (Findlow & Bolognese, 1982: 78). In their earlier work, Findlow and Bolognese (1980) discovered that the hyperbolic model (instead of the exponential model *sensu* C. Renfrew, and the linear one) is more appropriate for the transition between simple direct access and actual exchange.

Another criterion for explaining the mechanism of obsidian exchange can be the typology of tools made of this raw material (e.g., Wright, 1969: 47; Ammermann et al., 1978: 192). If one assumes that the efforts to bring obsidian away from sources were tremendous, especially in prehistory, the transport of cores, blanks, and/or ready tools, instead of rough blocks, chunks, and pebbles with cortex, would be practical when sites are located beyond the supply zone.

In the 2000s, new methods were introduced to understand the patterns of obsidian exchange/trade. The Geographic Information System (GIS) approach was employed by Barge and Chataigner (2003), Chataigner & Barge (2008), Chataigner and Gratuze (2014b), and Barge et al. (2018). This allows researchers to take into account the topography of the region under analysis, and to calculate the cost of travel in the mountainous Trans-Caucasus. Two parameters were used, the cost-weighted distance and the least-cost route, with maps generated (Chataigner & Gratuze, 2014b). It was found that the amount of obsidian decreases sharply after the distance from the source is equal to 15 h walk (around two days, ca. 75 km). This value was considered as the maximum acceptable time for direct procurement of obsidian from primary sources (Chataigner & Barge, 2008). For sites located further away than ca. 15 h walk, acquisition of obsidian was suggested by down-the-line exchange. The overall picture can be complicated by transport of raw material by rivers away from the sources (Chataigner & Gratuze, 2014b). Barge et al. (2018) determined regional hubs for the redistribution of obsidian. These kinds of analysis are important in regions with a multitude of obsidian deposits where C. Renfrew's models cannot be used in a straightforward way.

Campbell and Healey (2018) introduced several diversity indexes for investigation of obsidian exchange/trade: richness; Chao 1 estimate; and Shannon's and Simpson's indexes. The latter two parameters are particularly useful, as they can provide ways of comparing diversity amongst obsidian sources at a particular settlement, or the degree of obsidian exploitation for different time periods at one site. The richness and Chao 1 indexes are a useful means to study the total range of sources used by ancient people, including obsidian locales that were not exploited very often. By using the Near/Middle East as a polygon, Campbell and Healey (2018) demonstrated the advantage of these indexes, especially when the intensity of the use of multiple sources needs to be examined.

The latest developments in the study of obsidian exchange/trade are presented in a series of papers published in the 2010s, where the agent-based modelling (ABM) and network analysis were employed (Ortega et al., 2014, 2016; Ibáñez et al., 2015, 2016). The essence of ABM is that it enables investigation of complex phenomena from the bottom up (Romanowska et al., 2021: 6–10; Romanowska et al., 2019). The ABM consists of three parts: (1) agents (individual, heterogeneous, and autonomous software units); (2) user-defined rules of behaviour that govern the actions and interactions of these units; and (3) spatial and temporal dimensions. The agents are commonly represented by settlements (villages or cities). They interact with each other and with their environment following a set of rules that allow population-level patterns to be generated. The major strength of agent-based models compared to other types of simulation is that the modelled human populations are heterogeneous. Agent-based models often examine processes in temporal dimension, i.e., through time, and in spatial dimension.

The ABM in conjunction with network analysis is aimed to achieve a better understanding of complex (or small-world) networks that existed in the prehistory of the Near East as one of the best-studied regions in the Old World in terms of obsidian provenance (Ortega et al., 2014, 2016). Using two basic parameters, the proportion of obsidian versus flint and the distance to the nearest obsidian source, Ortega et al. (2014) modelled the long-distance movement of obsidian that was not predicted by down-the-line exchange. In small-world networks, the links between sites are different from ones in regular (down-the-line) links. The neighbouring sites are interconnected, and some of them can interact with distant sites by establishing shortcuts instead of moving the community through all existing settlements. As a result, the relatively homogeneous Neolithic cultural sphere in the Near East is reconstructed (Ibáñez et al., 2015).

The results of small-world network modelling are presented in Fig. 2.11. According to the regular (down-the-line) model, the ratio of obsidian falls quickly to 0.5% at a

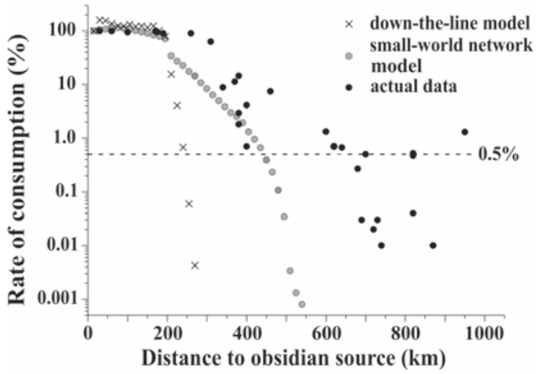


Fig. 2.11 Results of the simulation of down-the-line model, small-world type network, and actual proportion of obsidian versus flint (after Ortega et al., 2014; modified)

distance of ca. 250 km from the source. In small-world type networks, obsidian is exchanged in a more efficient way, and the 0.5% ratio can be found at a distance of ca. 450 km. The actual archaeological data fits better with the model of small-world networks than with the regular model; a ratio of 0.5% is observed at sites located at ca. 750 km distance from the obsidian source. It was found that two major variances influence the possibility of long-distance movement of obsidian: (1) rate of consumption/exchange (i.e., the quantity of the raw material used at a site versus the amount of this rock passed further on by exchange); and (2) the length of links to carry exchanges of obsidian (Ortega et al., 2014: 480). If the degree of on-site consumption of obsidian is as low as ca. 20%, and the rest (i.e., 80%) was exchanged with other sites, obsidian can be transported over very long distances—up to 900–1000 km in a straight line. Therefore, the small-world network model is more efficient than the traditional down-the-line approach, although the former is still different from the actual data by underestimating the real distances (Fig. 2.11).

In their latest paper, Ibáñez et al. (2016) improved the correspondence of their model in relation to the actual archaeological data. They concluded that a hierarchy of sites existed in the Neolithic Near East, and that some sites played a greater role in exchange than others; obsidian passed through these hubs in larger quantities. This allowed the long-distance transport of obsidian throughout the Levant in egalitarian-type Neolithic societies.

When the amount of data on obsidian provenance is plentiful (at least several hundred geochemically-characterised samples), and the chronology of sites is well-known, the social network analysis can be applied. This method for archaeology was developed in the last 10–15 years (e.g., Brughmans, 2013; Brughmans & Peeples, 2023; Knappett, 2011). G. M. Feinman and colleagues consistently applied it for obsidian research in Mesoamerica (Golitko & Feinman, 2015; Feinman et al., 2019, 2022; Feinman & Riebe, 2022). Network analysis is focused on relations between sites (“nodes”) and their connections (“edges”). Obsidian is used as a proxy measure for the degree of strength of connectedness between ancient sites (Golitko & Feinman, 2015). In order to test this assumption, the Brainerd-Robinson (BR) coefficient, which varies from 0 (completely dissimilar nodes) to 200 (complete similarity), is calculated. This coefficient is a measure of edge weight between nodes (Golitko et al., 2012). The results of the analysis are presented in Fig. 2.12a. When it is necessary to study geographical distribution, the links between sites are divided into “weak” (BR is less than 94) and “strong” (BR is equal to or greater than 94) (Fig. 2.12b). Two main parameters for network size are diameter (the longest path between nodes) and average path length (Golitko & Feinman, 2015). For the late prehistory of Mesoamerica, the temporarily defined sequence of obsidian exchanges through diverse transport routes was presented (Golitko & Feinman, 2015; Feinman et al., 2019, 2022) (Fig. 2.12). Network mapping based on assemblage similarities allow scientists to measure the generalised strengths of interconnections. For example, network analysis enabled seeing the ancient Mesoamerican economy in its dynamics (Golitko & Feinman, 2015).

The social networks revealed by obsidian provenance were compared to ethnographic data of modern hunter–gatherers (Pearce & Moutsiou, 2014). It was accepted that recent Subarctic/Continent Forest groups provide the closest analogy to the Late Pleistocene Europeans, both Neanderthals and anatomically modern humans (*Homo sapiens*). It was found that Neanderthals were able to transport obsidian up to 300 km from the sources, while modern humans exploited primary locales situated up to 400 km and even more from the utilisation sites. The larger size of social networks in the Upper Palaeolithic (associated with *H. sapiens*) is a clear phenomenon related to the development of human behaviour. Modern humans were able to maintain the social networks across the entire space of tribal home ranges. The use of obsidian as an independent proxy makes it possible to conduct this kind of research.

In rare circumstances, obsidian or obsidian-like volcanic glass can travel enormous distances by natural agents. A piece of pumice was found among drift material on the shore of the Nadikdik Atoll (Marshall Islands, Micronesia), with a large chunk of flakeable obsidian attached (Spennemann & Ambrose, 1997). The most spectacular case is the obsidian floater found on the shore of the Chatham Islands, ca. 900 km east of New Zealand (Leach et al., 2016). It was found that this piece was brought by ocean currents from very far away, McDonald Island in the Antarctic (administered by Australia), with a distance of at least 7400 km from the place where it was found. These examples (see also Boulanger et al., 2007) give us warning

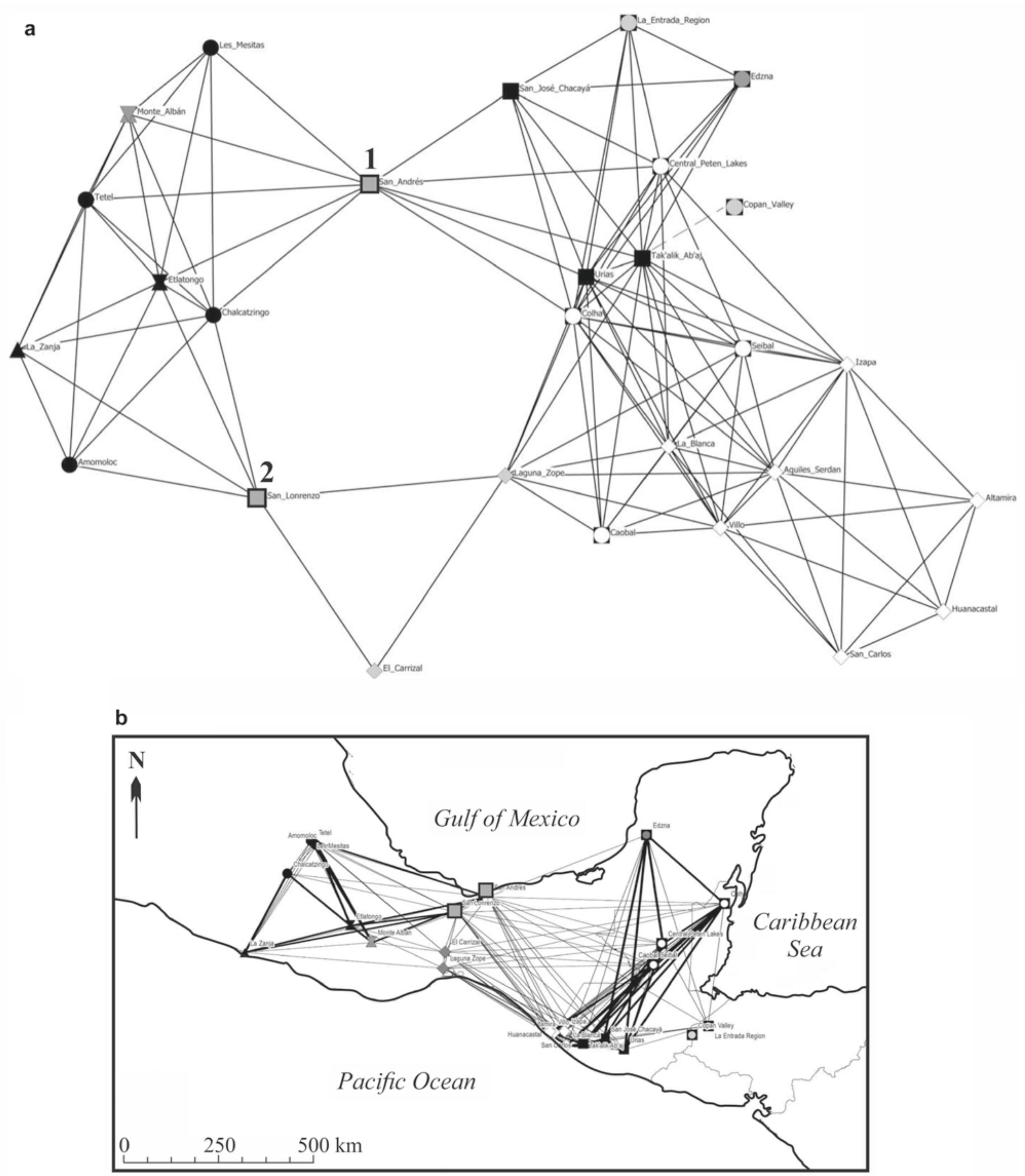


Fig. 2.12 Network graphs for obsidian assemblages in Mesoamerica, Period 3 (900–300 BC). **a** Mini-max graph, 1—San Andrés; 2—San Lorenzo; **b** Geographically-positioned sites (after Golitko & Feinman, 2015; modified)

against non-critical acceptance of unusual cases of super-long-distance transport of obsidian.

Another aspect of obsidian provenance research is the study of maritime connections between landmasses about which no direct evidence—such as the remains of seagoing vessels—is known. Anderson (2010) determined two types of movements across the sea with the help of artificial transportation: (1) simple seafaring, using log boats, rafts, and other primitive kinds of water-borne transport; and (2) sailing. While the former existed since at least the second part of the Late Pleistocene, ca. 50,000–60,000 years ago, the latter appeared only in the mid-Holocene, at ca. 6000 years ago. The crossing of open water by hominins goes back to the Early/Middle Pleistocene in Island Southeast Asia (Bednarik, 2003; Bellwood, 2013; Anderson, 2018; see review: Gaffney, 2021), but its intensification is clearly related to the spread of anatomically modern humans (*H. sapiens*) in Eurasia and Australia.

There are three main kinds of evidence for prehistoric human movement and migration between mainland and insular regions: (1) archaeological (artefacts); (2) anthropological (human remains); and (3) items of exchange (plants, animals, and raw materials) (Kuzmin, 2015). In this book, the focus is on the latter kind, and mainly on obsidian. It represents one of the most reliable methods available to archaeology to establish exchange/trade and contacts (Williams-Thorpe, 1995), and can be used to reconstruct the movements of people and commodities across the sea straits with a high degree of confidence. Therefore, obsidian can serve as a proxy for travel across wide sea spaces in antiquity.

Renfrew (1969: 160) commented on the abilities of prehistoric people to conduct long-distance trade:

> "Savages", said Lord Raglan, "never invent or discover anything." I am sure, on the contrary, that they are inventing all the time, and that trade is one of the key factors enabling these inventions to contribute to economic progress and cultural development.

It is obvious today that prehistoric trade/exchange was one of the most sophisticated strategies to obtain the necessary raw material in order to produce high-quality lithic tools, and elaborate adornments and other decorative items.

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3 Basic Information on Prehistoric Cultural Complexes in Northeast Asia

Northeast Asia as a large archaeological region was first defined by Chard (1974). Due to its vastness, the prehistoric cultural complexes vary greatly; for example, pottery is scarcely known on Kamchatka and in adjacent areas, while in Japan and the southern Russian Far East some of the oldest ceramic complexes in the world have been recorded (e.g., Barnes, 2019; Kaner, 2009; Kaner & Taniguchi, 2018; Kuzmin, 2013a, 2015a). The prehistory of Northeast Asia can be roughly sub-divided into the following periods: Upper Palaeolithic; Mesolithic (only in Northeastern Siberia); Neolithic/Jomon/Chulmun, with pottery as the main hallmark; and Palaeometal, including the Bronze Age/Mumun in Northeast China and Korea, and the Early Iron Age/Proto-Three Kingdoms/Yayoi in Northeastern Siberia, the Russian Far East, Northeast China, Korea, and Japan (see summary publications: Nelson, 1993, 1995; Dikov, 1997, 2003, 2004; Peregrine & Ember, 2002; Habu, 2004; Nelson et al., 2006; Kuzmin et al., 2007; Kiryak, 2010; Pitulko, 2013; Renfrew & Bahn, 2014; Barnes, 2015; Pitulko & Pavlova, 2016; Habu et al., 2018; Shunkov, 2022).

A remarkable feature in the late Upper Palaeolithic of Northeast Asia is the presence of pressure flaking technology (e.g., Flenniken, 1987; Inizan, 2012; Keates et al., 2019; Kuzmin et al., 2007). It allowed humans to produce narrow blades—called microblades—which were used mainly in composite tools as insets. It was a very effective hunting weapon consisting of a bone point with grooves where the microblades were inserted. Microblades in Northeast Asia appeared first in Korea at ca. 29,600–28,700 years ago. In other regions, the earliest manifestations of wedge-shaped cores and microblades are known at ca. 26,400 years ago in North China; at ca. 24,900 years ago in Japan and Yakutia (Northeastern Siberia); and at ca. 23,400 years ago in the Russian Far East (Keates et al., 2019; Kuzmin & Keates, 2021). Unfortunately, the amount of data on the earliest microblade complexes in Northeast Asia is still relatively small, and more work is needed to get a better understanding of this phenomenon. Currently, it is impossible to conclude that microblade technology spread from the 'core area' of Korea to the neighbouring regions (Kuzmin & Keates, 2021).

It should be pointed out that the term "Neolithic" in Northeast Asia does not include agriculture as one of the criteria for the beginning of this period, or in Northeastern Siberia and some parts of the southern Russian Far East where plant cultivation never existed. The definition of the Neolithic is based on the presence of pottery (e.g., Barnes, 2019; Kuzmin, 2010b). In this case, the Neolithic sensu lato in Northeast Asia emerged much earlier than in other parts of Eurasia, and the difference between the appearance of pottery and agriculture is up to 10,000 years (Kuzmin, 2013b). All pottery-containing complexes without metal items and/or their replicas are considered in this book as belonging to the Neolithic period.

3.1 Southern Russian Far East

This region (except for the Kamchatka Peninsula which is included into Northeastern Siberia; see Fig. 4.1) is the best-studied part of far eastern Russia in terms of prehistoric archaeology. The Stone Age cultural complexes are sub-divided into the Upper Palaeolithic and Neolithic (Fig. 3.1). Reliable pre-Upper Palaeolithic sites in the region in terms of chronology are still unknown. There are a few localities that contain blade assemblages (like the Geographical Society Cave in Primorye), and the majority of Upper Palaeolithic sites belong to the microblade complex (Fig. 3.2a). The lithics are represented by blade cores (discoidal and prismatic), wedge-shaped cores, blades, microblades, bifaces, knives, end scrapers, concave scrapers, *skreblos* (large crude scrapers), points, arrowheads, burins, perforators, drills, axes, adze-like tools, chisels, notches, anvils, and hammerstones (e.g., Nelson et al., 2006).

The chronology of these sites is based on the radiocarbon (^{14}C) dating method (Kuzmin, 1996, 2003a, 2006a;

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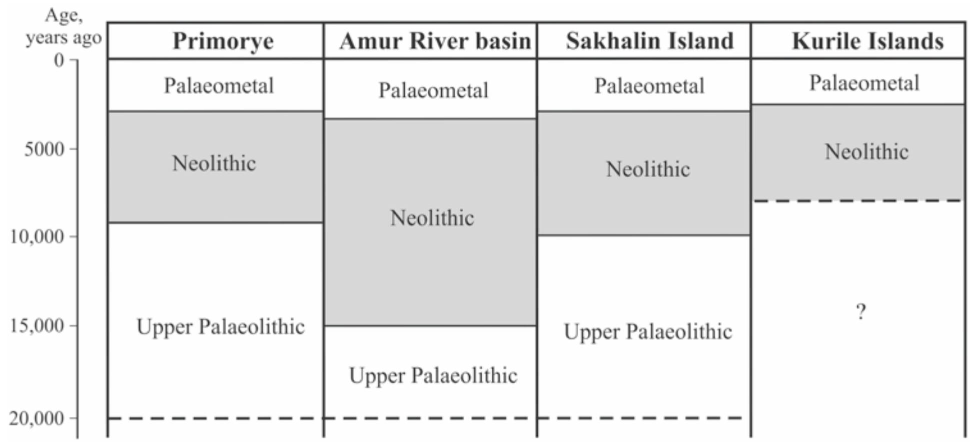

Fig. 3.1 Periodisation and chronology of prehistoric complexes in southern far eastern Russia

Kuzmin et al., 1998a, 2004; Keates et al., 2019). The Geographical Society Cave can be dated to ca. 39,000 years ago, although the association between ^{14}C-dated bones and artefacts is not very clear (Kuzmin et al., 2001), and this is the reason why it is not included in Fig. 3.1. The Upper Palaeolithic sites with wedge-shaped cores and microblades can be assigned to a time frame of ca. 23,500–12,000 years ago. At certain times, ca. 16,000–12,000 years ago, the final Upper Palaeolithic complexes in the Amur River basin coexisted with the Initial Neolithic settlements (Kuzmin & Jull, 1997; Kuzmin et al., 2003). On the Kurile Islands, Palaeolithic sites are still unknown (Fig. 3.1).

The Neolithic of the southern Russian Far East consists of several cultural complexes, distinguished mainly by using the typology of pottery and its design (e.g., Nelson et al., 2006: 101–166; Renfrew & Bahn, 2014: 852–863; Habu et al., 2018: 386–394; Shunkov, 2022: 304–336). The vast majority of pottery is flat-bottomed. The lithic assemblages include a variety of artefacts—heavy-duty tools (usually bifaces), knives, scrapers, skreblos, points, arrowheads, burins, borers, adzes, notched and denticulate tools, pestles, and anvils (Fig. 3.2b–c). Cores are represented mainly by the wedge-shaped type at the earliest sites, and the prismatic type at the later sites (Fig. 3.2c).

The Neolithic chronology of the southern Russian Far East is based on ^{14}C dating of key sites (Kuzmin, 2006a; Kuzmin & Shewkomud, 2003; Kuzmin et al., 1998a, 2004, 2012a; Shewkomud & Kuzmin, 2009). Particular attention was given to the timing of the origin of pottery in this region and other parts of Northeast Asia (Kuzmin, 2003b, 2014b, 2015a, 2017b, 2019; Kuzmin & Keally, 2001; Kuzmin et al., 1997). While the end of the Neolithic occurred almost simultaneously, at ca. 3500–3000 years ago, the emergence of pottery is first established in the lower part of the Amur River basin at ca. 15,000 years ago, followed by Primorye and Sakhalin Island at ca. 10,000–9500 years ago, and finally in the more remote southern Kurile Islands at ca. 8000 years ago (Fig. 3.1).

A few remains of shallow dwelling-like depressions are recorded at some Upper Palaeolithic sites of the southern Russian Far East. Pit dwellings are typical in the Neolithic complexes; a few village-like settlements with several dwellings were excavated. Numerous clay and stone figurines, and stone adornments are known in the Neolithic, especially in the Lower Amur region. At the Early Neolithic Chertovy Vorota site in Primorye, the earliest surviving textile in East Asia dated to ca. 9000 years ago was found (Kuzmin et al., 2012b). Burials are very rare due to acidic soil conditions, and only some human skeletons were discovered in shellmiddens and limestone caves (Jull et al., 1994; Popov et al., 1997; Kuzmin et al., 2012b).

In the Upper Palaeolithic of the southern Russian Far East, people were hunting terrestrial animals, although their bones are scarce at the excavated sites. The main branches of the Neolithic economy were hunting, fishing, and plant and marine mollusc gathering. A few Neolithic shellmiddens were excavated (e.g., Kuzmin & Rakov, 2011; Kuzmin, 1995, 1997, 2006b, 2015b; Shoda et al., 2020). As for agriculture, it first appeared in Primorye at ca. 5500 years ago as a result of migration from neighbouring Northeast China of populations which practiced the cultivation of millets (Kuzmin et al., 1998b; Kuzmin, 2013c). In some parts of the southern Russian Far East, such as Sakhalin Island and the Kurile Islands, agriculture was not practiced before the contact with Russians and Japanese in the eighteenth—nineteenth centuries AD.

Obsidian as a raw material in the southern Russian Far East in the Upper Palaeolithic and the Neolithic was used for making mainly microblades, blades, bifaces, scrapers, points, arrowheads, burins, drills, perforators, and notched/denticulate tools (Kuznetsov, 1996; Nelson et al., 2006; Kluyev & Sleptsov, 2007; Doelman et al., 2008, 2012). In the late Upper Palaeolithic, ca. 15,000–10,000 years ago, obsidian was more extensively procured for manufacturing microblades from wedge-shaped cores (Doelman, 2008).

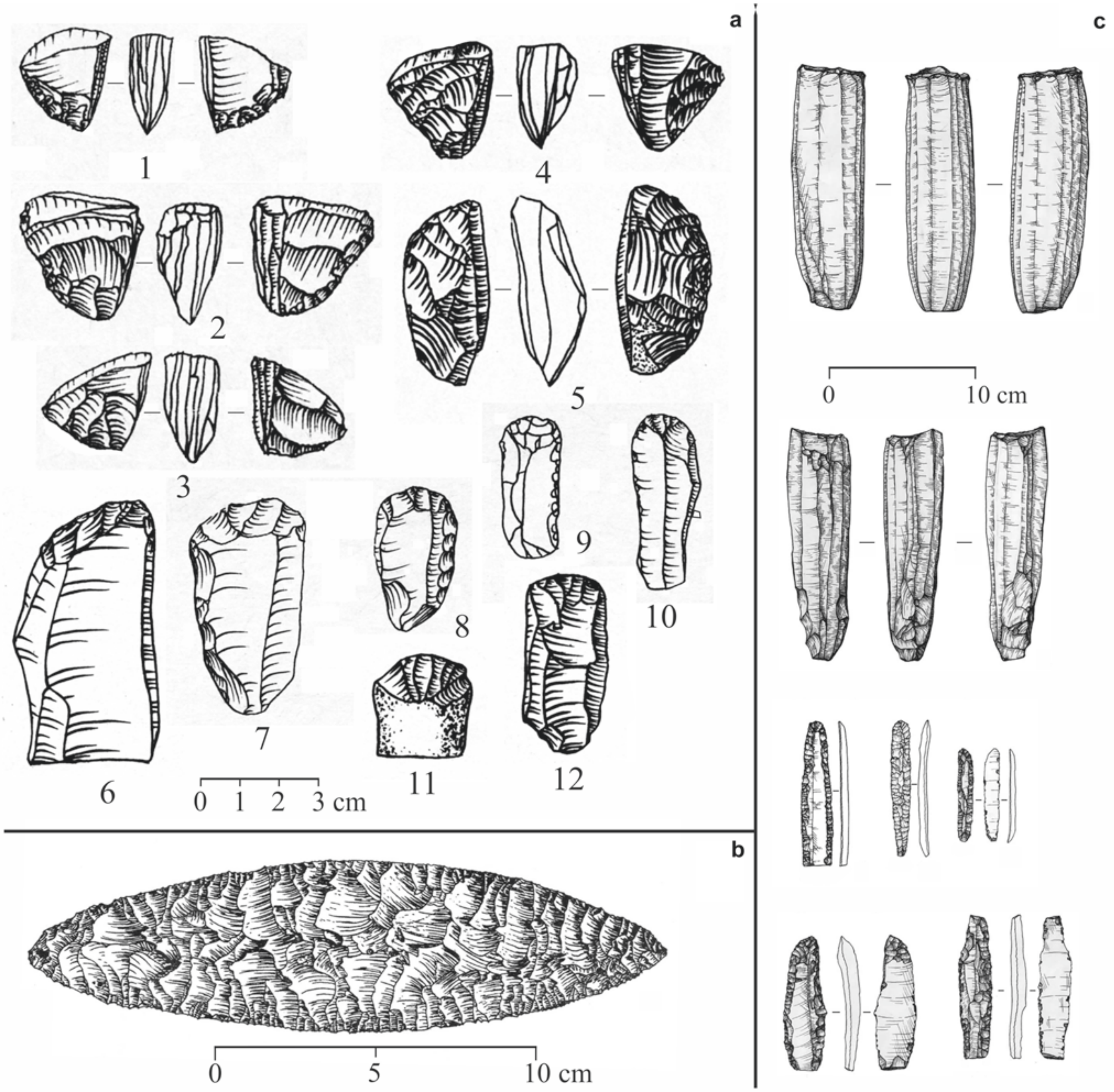

Fig. 3.2 Obsidian artefacts from the southern Russian Far East (after Kuznetsov 1992; Popov et al., 1997; Izuho et al., 2017; modified). **a** Ilistaya River basin, Primorye (Upper Palaeolithic): 1–4—wedge-shaped cores; 5—blank of wedge-shaped core; 6–12—scrapers. **b** Boisman 2 site, Primorye (Early Neolithic): biface. **c** Slavnaya 5 site, Sakhalin Island (Early Neolithic)

3.2 Northeastern Siberia

This vast part of Northeast Asia consists of the eastern part of Yakutia (basins of Kolyma and Indigirka rivers), the High Arctic (New Siberia Islands), Kamchatka Peninsula, and Chukotka region. The Stone Age complexes are sub-divided into Upper Palaeolithic, Mesolithic (or Final Palaeolithic), and the Neolithic (Fig. 3.3). The latter period does not always contain pottery as a typical feature, in contrast to the southern Russian Far East.

The Mesolithic of Northeastern Siberia is characterised by micro-prismatic pressure flaking, accompanied by stemmed points, and chipped and partly polished adzes. The difference between the Upper Palaeolithic and the Mesolithic is that in the latter complex there are prismatic (pencil-like) cores which are absent in the former

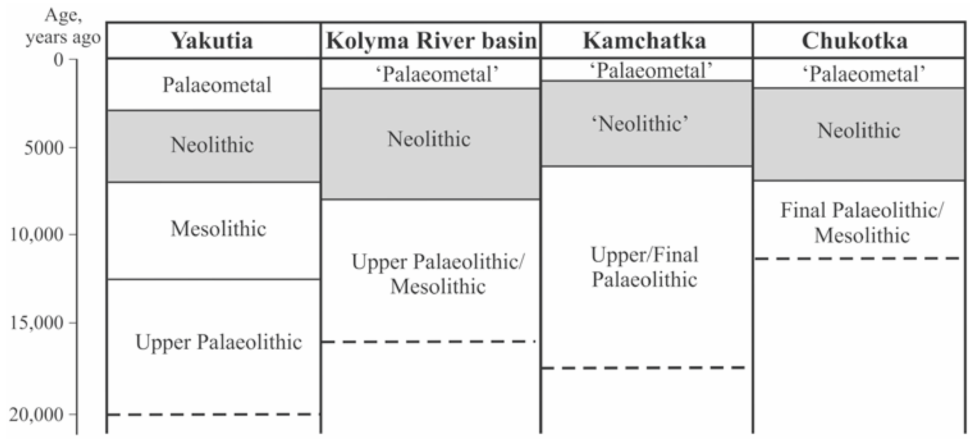

Fig. 3.3 Periodisation and chronology of prehistoric complexes in Northeastern Siberia

complex (Mochanov, 2009; Slobodin & Zelenskaya, 2023). Bifacial tools (spearheads and knives) are unknown in the Mesolithic (Mochanov, 2009).

The Upper Palaeolithic is poorly represented in the area under study; a few sites can be associated with it, mainly Berelekh (Indigirka River basin) (Mochanov, 2009; Pitulko et al., 2014), Ushki (Kamchatka) (Dikov, 2004), and localities in the Kolyma River basin (Slobodin et al., 2017). At the Ushki site, the lowest cultural layer 7 has sub-prismatic cores, knife-like blades, knives, points (including stemmed ones), arrowheads, scrapers, burins, and borers. Layer 6 contains wedge-shaped cores and microblades, ski spalls, leaf-shaped bifaces, knife-like blades, knives, skreblo-like tools, points, spearheads and arrowheads, scrapers, borers, and burins. Although the chronological framework is scanty (Kuzmin, 2000; Kuzmin & Dikova, 2014; Pitulko & Pavlova, 2016), the Upper Palaeolithic can in general be dated to ca. 17,500–12,500 years ago (Fig. 3.3).

More sites in Northeastern Siberia are associated with the Mesolithic period (Dikov, 2004; Kuzmin, 2023; Pitulko, 2013; Pitulko & Pavlova, 2016; Slobodin, 2014; Slobodin et al., 2017). It is characterised by prismatic and conical cores, wedge-shaped cores and microblades (at certain sites), knife-like blades, retouched insets, scrapers, crude skreblo-like tools, leaf-shaped points, arrowheads, burins, and axes (Fig. 3.4). The Mesolithic is dated to ca. 12,500–6000 years ago (Kuzmin, 2000, 2010c; Pitulko & Pavlova, 2016; Slobodin et al., 2017).

The Neolithic period in Northeastern Siberia is represented by several cultural complexes (e.g., Kuzmin, 2000, 2010c, 2023; Dikov, 2004; Pitulko & Pavlova, 2016; Shunkov, 2022). The most common lithic artefacts are prismatic and conical cores, insets, knife-like blades, bifacial knives, scrapers, skreblos, points, arrowheads, burins, borers, polished tools (like adzes and knives), and grinding stones (Fig. 3.4). In eastern Yakutia and the upper course of the Kolyma River, pottery appeared at ca. 8000–7000 years ago. In Chukotka, the oldest pottery is known at ca. 6000 years ago. The most common shape of vessels is round-bottomed. On Kamchatka, throughout the Neolithic period pottery is either unknown or found in the western part of the peninsula in very small quantities since ca. 1500 years ago, and it is associated with the so-called 'Palaeometal' complexes, although practically without any metal tools or their replicas. In central and southern Kamchatka, pottery in the Neolithic and 'Palaeometal' assemblages is absent (e.g., Dikov, 2003, 2004; Ponomarenko, 2005). The end of the Neolithic in Northeastern Siberia can be dated to ca. 3000 years ago in Yakutia, and ca. 1500–1400 years ago in Chukotka, Kamchatka, and the headwaters of the Kolyma River (Fig. 3.3).

Subterranean dwellings are known in the Stone Age of Kamchatka (Upper/Final Palaeolithic–Neolithic); in the Mesolithic–Neolithic of eastern Yakutia and Chukotka; and in the Mesolithic of the High Arctic. A cluster of dwellings was excavated at the Ushki site (Dikov, 2004). Burials are very rare in the Upper Palaeolithic and Mesolithic; at Ushki, their presence is to some extent controversial because of the poor preservation of presumably human bones. More burials are found in the Neolithic complexes of the Kolyma River basin and Chukotka. Adornments are known in the Upper/Final Palaeolithic of Kamchatka (pendants, labret-like items, and a stone figurine). In the Neolithic, labrets, stone pendants and beads, and stone figurines are known from Kamchatka, the Kolyma River basin, and Chukotka (Fig. 3.4b, 6, 8, 10–11) (Kiriyak, 2007).

The Stone Age economy of Northeastern Siberia was based on the procurement of wild natural resources, and agriculture was unknown until European contact and even later due to the harsh climatic conditions. In the Upper Palaeolithic and Mesolithic, the main branches of the economy were hunting (including polar bears in the High Arctic), fishing (including salmon on Kamchatka), and plant gathering. At the Mesolithic Zhokhov site in the High Arctic dated to ca. 9000 years ago (Pitulko &

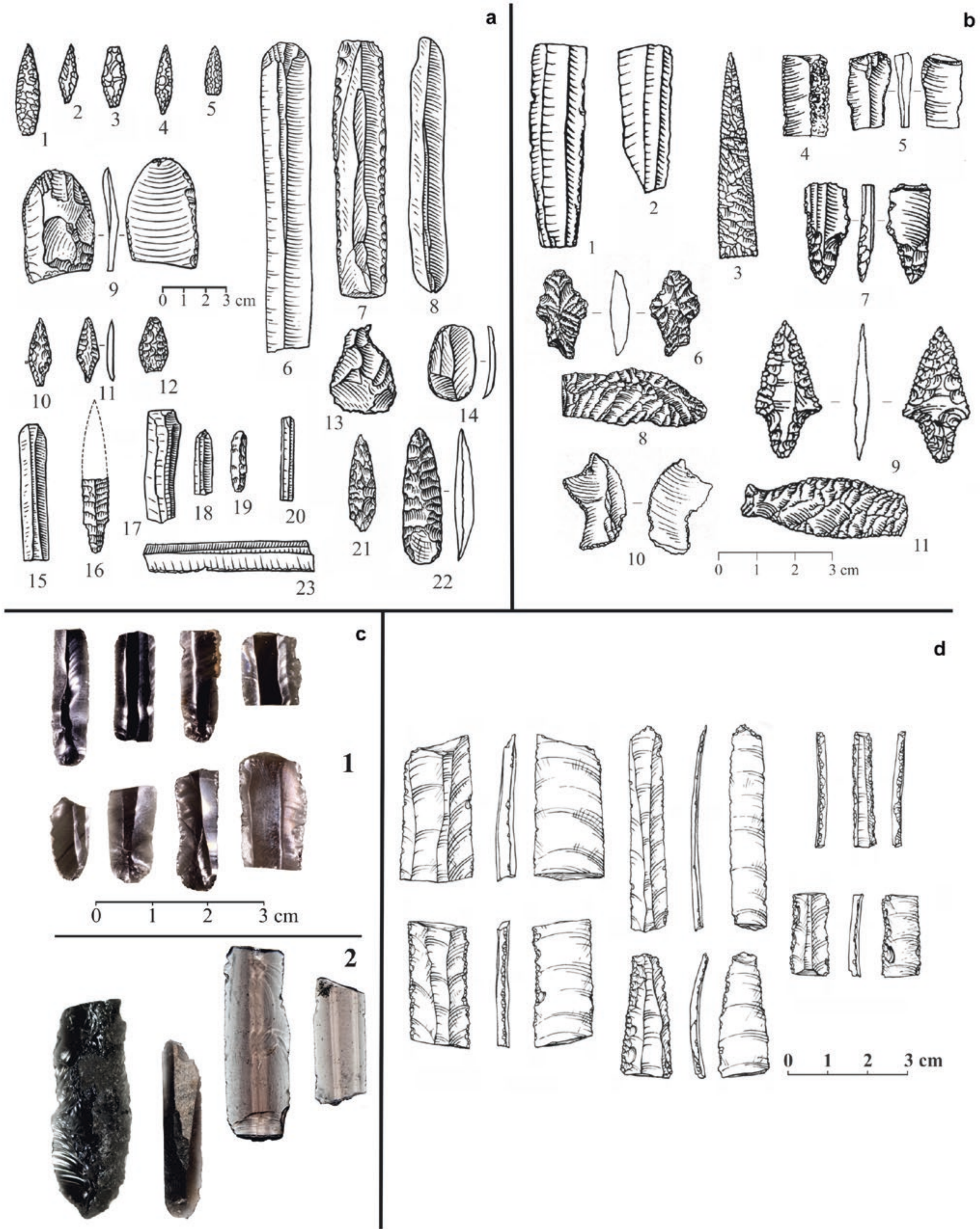

Fig. 3.4 Obsidian artefacts from Mesolithic–Neolithic complexes in Northeastern Siberia (after Dikov, 2003; Kiryak, 2010; Kuzmin et al., 2018; Pitulko et al., 2019; modified). **a** Kamchatka: 1–5, 22—points; 6–8—blades; 9, 14—scrapers; 10–12, 16, 21—arrowheads; 13—combined tool; 15, 17–20, 23—knife-like bladelets. **b** Chukotka: 1–2—knife-like bladelets; 3, 7, 9—points; 4—knife (?); 5—retouched knife-like bladelet; 6, 8, 10–11—small figurines. **c** Blades and scrapers, Zhokhov site (1) and Omolon River, Kolyma River basin (2). **d** Blades, Kolyma River

Pavlova, 2022), the remains of wooden sledge runners and other sledge component parts were excavated along with the skulls and bones of domesticated dogs (Pitulko, 2013; Pitulko & Kasparov, 2017; Pitulko et al., 2019). In the Neolithic and Palaeometal, the major activities were hunting, fishing, and gathering of plants in the interior regions and marine molluscs on seashores (Kuzmin, 2009; Pitulko, 2013; Pitulko et al., 2015).

The main kinds of obsidian artefacts in Northeastern Siberia are microblades, blades and knife-like blades, bifaces, knives, leaf-shaped points, arrowheads and spearheads, and scrapers and skreblos (Dikov, 1997, 2003; Kiryak, 2010; Kuzmin et al., 2018, 2020b, 2021; Pitulko et al., 2019) (Fig. 3.4). Obsidian tools are known in the Mesolithic–Neolithic of eastern Yakutia and the upper course of the Kolyma River; Upper/Final Palaeolithic, Neolithic, and Palaeometal (until Russian contact in the eighteenth-century AD) of Kamchatka; and Final Palaeolithic/Mesolithic, Neolithic, and Palaeometal of Chukotka.

3.3 Japanese Islands

Japan is the best-studied part of Northeast Asia in terms of archaeology (e.g., Aikens & Higuchi, 1982; Barnes, 2015; Habu et al., 2018; Ono et al., 1992). The Stone Age complexes belong to the Palaeolithic and Jomon (Neolithic) periods (Fig. 3.5). The existence of pre-Upper Palaeolithic sites is questionable (e.g., Ikawa-Smith, 2018, 2022; Nakazawa & Bae, 2018). The Upper Palaeolithic periodisation and chronology in Japan are well-established (e.g., Ono & Yamada, 2012; Ono et al., 2002), and can be used to understand the spatiotemporal features of obsidian exploitation, as well as changes in procurement patterns. The Upper (Late) Palaeolithic is sub-divided into three stages: knife-blade culture stage 1 (ca. 38,000–30,500 years ago); knife-blade culture stage 2 (ca. 29,300–18,400 years ago); and microlith culture stage 3 (ca. 17,100–14,000 years ago) (e.g., Ono et al., 1999; Morisaki et al., 2019a) (Fig. 3.5). Stages 1–2 are associated with the blade technology (e.g., Mizoguchi, 2002; Okamura, 1992). Stages 1 and 2 are

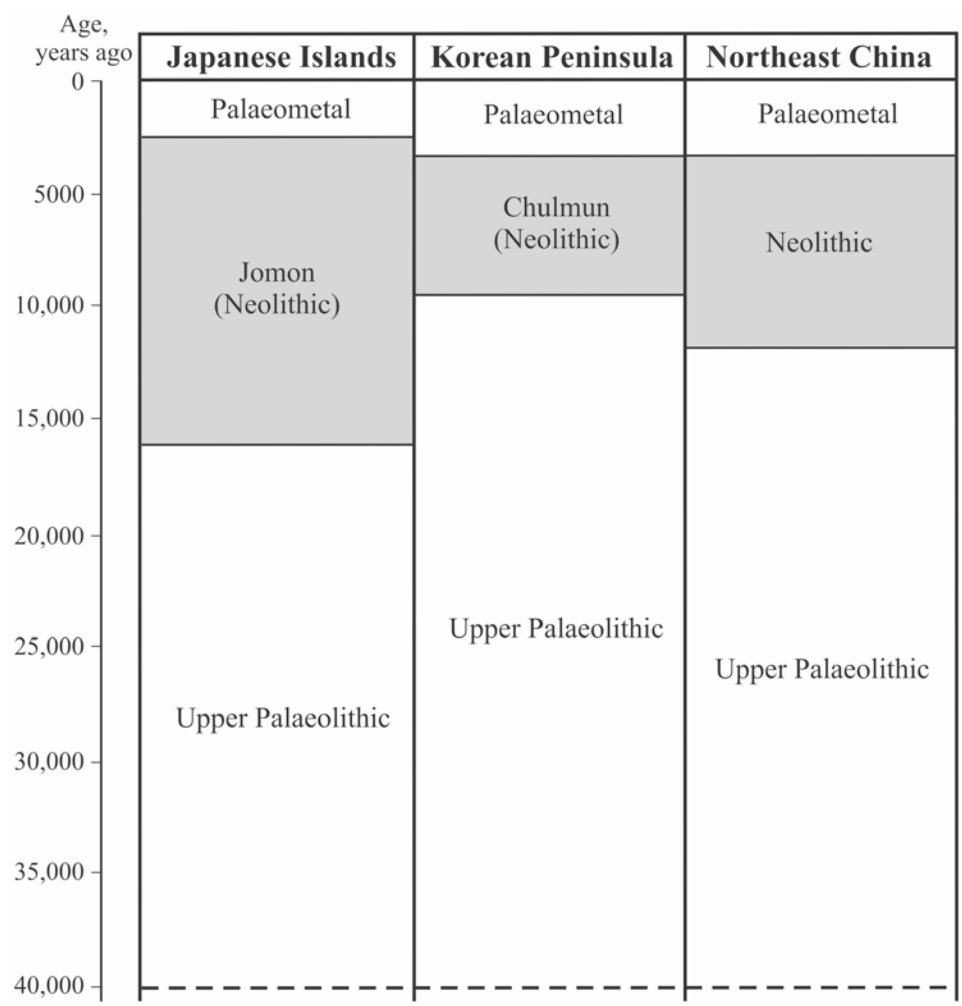

Fig. 3.5 Periodisation and chronology of prehistoric complexes in Japan, Korea, and Northeast China

separated stratigraphically by the AT (Aira–Tanzawa) tephra at the archaeological sites (e.g., Ono & Yamada, 2012) dated to ca. 30,000 years ago (e.g., Smith et al., 2013).

The most common artefacts in the Japanese Upper Palaeolithic were blade cores, wedge-shaped cores and microblades, trapezoids, backed blades and points, leaf-shaped and diamond-shaped bifaces (points), knives, chopping (axe-like) tools, end and side scrapers, stemmed points (at certain sites), spearheads and spear-tip points, burins, drills, awls, edge-ground axes and adzes, notches, denticulates, and whetstones (e.g., Akazawa et al., 1980; Aikens & Higuchi, 1982; Keally & Hayakawa, 1987; Ono et al., 1992; Ono et al., 1999; Okamura, 1992; Ono & Yamada, 2012; Morisaki, 2012; Morisaki et al., 2019a; Yamaoka et al., 2022) (Fig. 3.6a, b, d). The microblade technique (stage 3) with pressure flaking occurred first on Hokkaido Island at ca. 25,000 years ago, and it existed on Honshu, Shikoku, and Kyushu islands at ca. 18,000–14,000 years ago (e.g., Keates et al., 2019; Sato & Tsutsumi, 2007).

The Jomon of Japan is characterised by the appearance of pottery at ca. 16,300 years ago (e.g., Kaner & Taniguchi, 2018; Keally et al., 2003, 2004; Kuzmin, 2010d; Nakamura et al., 2001; Taniguchi, 1999, 2006). The variety of Jomon pottery is truly great; around 70 pottery styles are distinguished, with mainly round-bottomed vessels but also flat-bottomed ones (Kobayashi, 2004). Lithic artefacts are represented mainly by microblade cores and microblades (only at the earliest sites), cylindrical cores (at most sites),

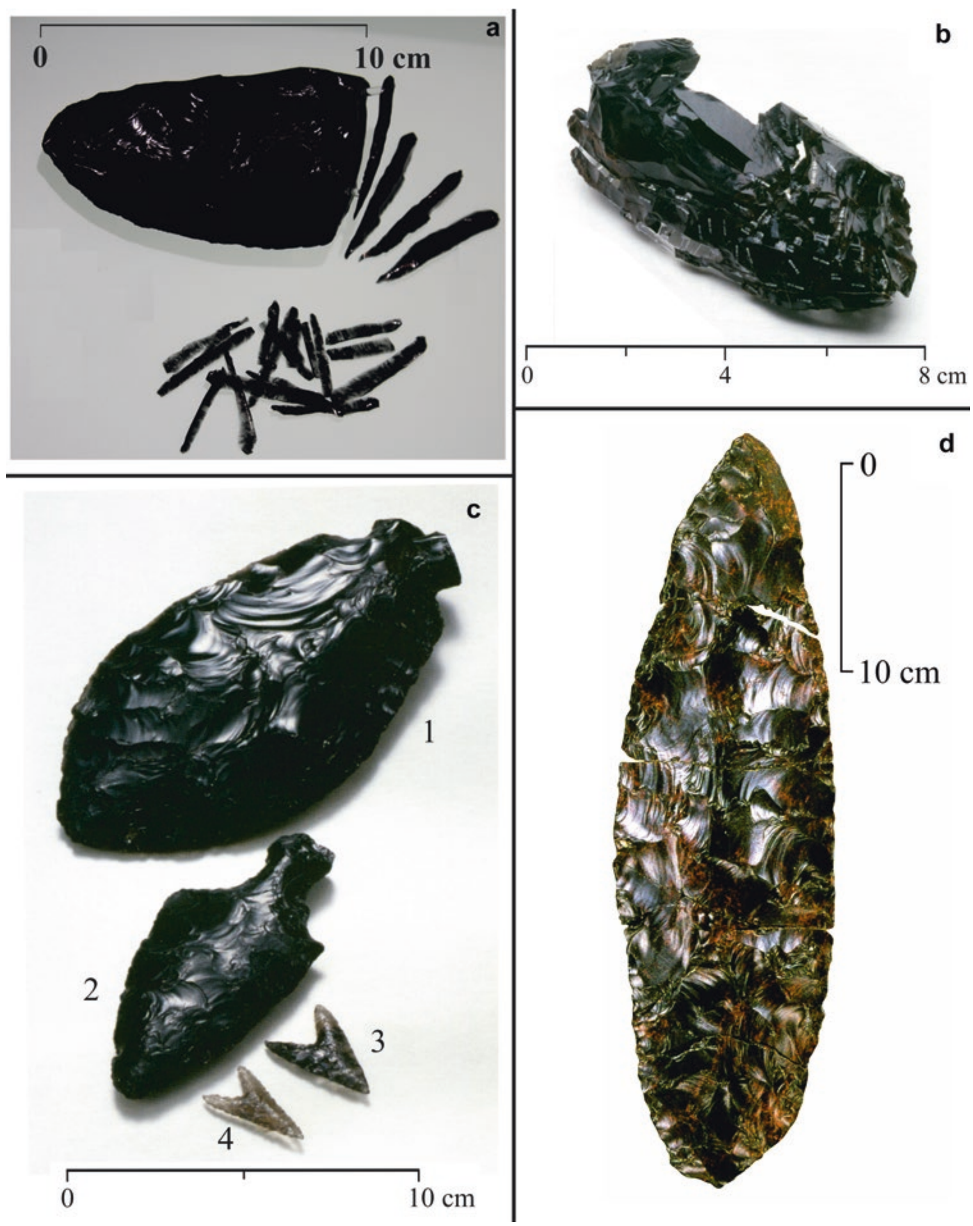

Fig. 3.6 Obsidian artefacts from the Stone Age complexes of Japan (after Steinhaus & Kaner, 2016; modified). **a** Obsidian wedge-shaped core and microblades, Shirataki sites (Upper Palaeolithic), Hokkaido; scale is approximate. **b** Refitted block of 25 obsidian flakes, Oki-Shirataki 1 site (Upper Palaeolithic), Hokkaido. **c** Artefacts from Sannai Maruyama site (Middle Jomon), Aomori Prefecture, Honshu. 1–2—tanged scrapers; 3–4—arrowheads. **d** Large biface (spearhead) from the Kami-Shirataki site (Upper Palaeolithic), Hokkaido

heavy bifaces, scrapers (including stemmed and tanged ones) (Fig. 3.6c), points (including projectile, stemmed, and tanged varieties), arrowheads, burins, perforators, drills, awls, chipped and polished axes and adzes, grinding stones and querns, mortars, anvils, and hammerstones (e.g., Aikens & Higuchi, 1982; Habu, 2004; Kaner & Taniguchi, 2018; Kobayashi, 2004; Steinhaus & Kaner, 2016) (Fig. 3.6c). The range of tool types increases in the Jomon compared to the Upper Palaeolithic. The chronology of Jomon cultural complexes in Japan is well-established (e.g., Habu, 2004; Kobayashi, 2004; Omoto et al., 2010). It consists of six stages: Incipient (ca. 16,000–12,000 years ago); Initial (ca. 12,000–7500 years ago); Early (ca. 7500–5500 years ago); Middle (ca. 5500–4500 years ago); Late (ca. 4500–3200 years ago); and Final (ca. 3200–2500 years ago).

Dwellings are rare in the Upper Palaeolithic of Japan (e.g., Mizoguchi, 2002), and they most probably were of the surface type without pits, like the tepee in ethnographic American Indian communities. For the Jomon period, a plethora of pit dwellings of different sizes were excavated (e.g., Habu, 2004; Kobayashi, 2004; Ono et al., 1992). Numerous village-like settlements with dozens of dwellings were found (e.g., Habu, 2004; Kobayashi, 2004; Mizoguchi, 2002). There are a few stone figurines in the Upper Palaeolithic (Iwato site, Oita Prefecture). Rich assemblages of adornments made of stone, clay, bone, and shell were excavated at Jomon sites, and they are represented mainly by figurines (including the famous *dogū* made of fired clay), tablets, bracelets, beads, earrings (including the elongated and curved *magatama* type), hairpins, and combs (e.g., Aikens & Higuchi, 1982; Habu, 2004: 142–159). Many of these adornments are associated with numerous Jomon burials of different shape and construction (e.g., Habu, 2004: 175). Lacquered artefacts and remains of textiles and basketry were found at some Early Jomon sites (e.g., Habu, 2004).

The Upper Palaeolithic economy of the Japanese Islands was generally of the hunting–gathering type, although only a few remains of animal bones and plants survived the acidic soil conditions. The Jomon people practiced a large variety of subsistence activities, and were truly 'affluent foragers' sensu Koyama and Thomas (1981). Jomon populations hunted terrestrial animals, marine mammals (including dolphins), and different kinds of birds; procured freshwater fish in rivers and marine fish in lagoons, bays, and the open sea; collected a wide spectrum of wild plants and their nuts and fruits; and gathered marine molluscs (e.g., Habu, 2004; Steinhaus & Kaner, 2016). Numerous shellmiddens left by mollusc collectors are the hallmark of coastal settlements. The issue of plant cultivation in the Jomon is still controversial (e.g., Crawford, 2011, 2016; Barnes, 2015: 111–113); one way or another, agriculture did not play an important economic role.

Kobayashi (2004: 94) created a seasonal calendar of Jomon subsistence, covering the whole year. According to Akazawa (1986), three regions with different economic activities can be distinguished for the main Japanese islands in the Jomon period: (1) Kyushu and Shikoku islands, western part of Honshu Island, and inland part and Sea of Japan coast of central Honshu—hunting terrestrial mammals, gathering of plants, and riverine fishing; (2) Pacific coast of central Honshu—fishing of marine species in sea bays and lagoons, and gathering of marine molluscs; and (3) northern Honshu and Hokkaido Island—hunting terrestrial and marine mammals, and gathering marine molluscs and salmon fishing on the coasts.

Artefacts made of obsidian from the Upper Palaeolithic and Jomon of Hokkaido include mainly microblades, points, trapezoids, and blades (Fukuda et al., 2022; Morisaki et al., 2018; Yakushige & Sato, 2014). The Upper Palaeolithic artefacts from Honshu Island made of obsidian are mainly microblades, trapezoids, blades, knives, scrapers, points (including bifacial ones), arrowheads, and ax-like tools (e.g., Keally & Hayakawa, 1987; Morisaki, 2012; Tsutsumi, 2010). During the Jomon period of Honshu Island, several kinds of obsidian artefacts were manufactured, especially knives, scrapers, arrowheads, drills and points, and other tools (Tsukahara, 2007; Yamamoto, 1990). In the Upper Palaeolithic of Kyushu islands, obsidian artefacts include mainly microblades, trapezoids, blades, knives, scrapers, tanged and plain points, and backed tools (Shiba, 2014). In the Ryukyu Islands, obsidian in Jomon times was used to manufacture various tools, including scrapers and arrowheads (Obata et al., 2004, 2010; Pearson, 2013).

3.4 Korean Peninsula

In Korea, the Upper Palaeolithic is sub-divided into two types of assemblages. Lithics from the early Upper Palaeolithic include prismatic cores, blades, bifaces, knives, scrapers, skreblo-like tools, tanged points, leaf-shaped points, rare arrowheads, burins, borers, drills, awls, notched and denticulate tools, anvils, and hammerstones (e.g., Bae, 2010; Chang, 2013; Lee, 2013; Seong, 2008, 2009, 2015). At some sites, chopper-like and handaxe-like tools were also found (Choi, 2004). In the late Upper Palaeolithic assemblages, two new artefact categories appeared: (1) wedge-shaped microblade cores and microblades detached by pressure flaking (Fig. 3.7); and (2) ground-polished axes and adzes (e.g., Lee, 2013).

The beginning of the Upper Palaeolithic in Korea is dated to ca. 40,000 years ago, and the boundary between the early and late stages can be estimated as ca. 29,600 years ago (e.g., Seong, 2009, 2011). Therefore,

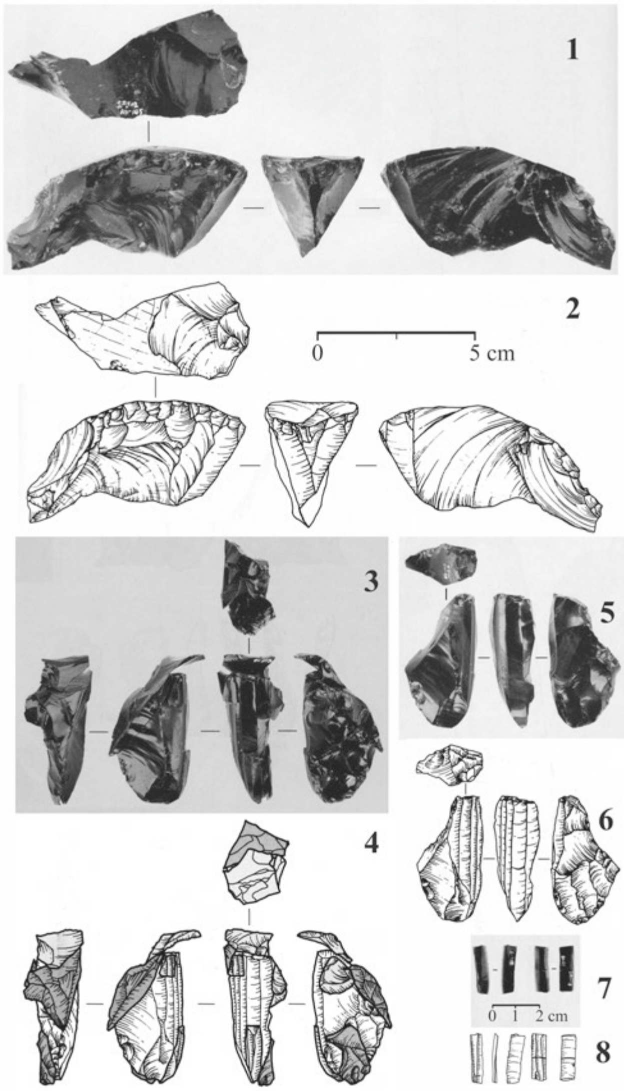

Fig. 3.7 Obsidian artefacts from the Hopyeong-dong site (Upper Palaeolithic), Gyeonggi Province (after Hong & Kim, 2008; modified). 1–6—wedge-shaped cores; 7–8—microblades. 1, 3, 5 and 7—photos; 2, 4, 6 and 8—drawings. The same scale for Nos. 1–6

microblade complexes appeared in the southern part of the Korean Peninsula at ca. 29,600–28,700 years ago at the Sinbuk and Jangheung-ri sites, respectively, earlier than in other parts of Northeast Asia (Kuzmin & Keates, 2021). The tanged points continued to exist in the late Upper Palaeolithic assemblages until ca. 19,500 years ago (e.g., Seong, 2009). The end of the Upper Palaeolithic in Korea can be dated to ca. 12,000–10,000 years ago (Fig. 3.5) (e.g., Seong, 2015).

The main criterion for the definition of the Neolithic (Chulmun) in Korea is the appearance of pottery (e.g., Barnes, 2015; Im, 2000; Nelson, 1993). The shape of vessels is mainly round-bottomed, although flat-bottomed pottery is known in the northern part of the Korean Peninsula. Lithics from the Neolithic cultural complexes include prismatic cores, insets, blades, chipped and polished tools (knives, scrapers, points, arrowheads, axes, and adzes), projectile spearheads, burins, borers, chisels, grinding stones, mortars and pestles, hoes, reaping knives, chopping tools, net sinkers, composite fishhooks, and hammerstones (Larichev, 1978; Lee, 2018; Nelson, 1993; Sample, 1974; Shin et al., 2012). Microblades are known only at the oldest site, Gosan-ri (e.g., Lee, 2018).

The earliest Neolithic site, Gosan-ri on Jeju Island, is now dated to ca. 9600 years ago (Kim et al., 2020). On the mainland of Korea, the first Neolithic complexes appeared at ca. 8000 years ago (e.g., Kim & Seong, 2022) (Fig. 3.5). The general upper boundary for the Neolithic and the beginning of the Bronze Age can be established at ca. 3500 years ago (e.g., Lee, 2018) (Fig. 3.5).

Pit dwellings of different shapes (rounded and elongated) are common in the Korean Neolithic. Several dwelling clusters, representing sedentary villages, were excavated (e.g., Lee, 2018). Adornments include pendants; shell bracelets and beads; jade ornaments like split earrings; and clay, bone, and stone figurines (e.g., Nelson, 1993). Currently, 15 burials are known in the Neolithic of Korea (Lee, 2018).

In the Upper Palaeolithic, the main economic activity was the hunting of land mammals; little is known about the gathering of wild plants. The Neolithic people subsisted on hunting terrestrial and marine mammals (including perhaps large-sized species like whales, dolphins, and porpoises), and different birds; catching marine fish in bays and the open sea; collecting wild plants; and cultivating millets (Lee, 2011, 2018). There are numerous shellmiddens left by the Neolithic inhabitants, mainly on the southern and eastern shores of Korea but also in the northern part of the peninsula (e.g., Henthorn, 1968; Komoto, 1997; Nelson, 1993). Agriculture based on the cultivation of millets emerged at ca. 5400–5300 years ago; the chronology is based on direct AMS ^{14}C dating of foxtail millet seeds (Lee, 2018). Rice eventually became the hallmark of subsistence by the middle Bronze Age (Mumun) after the end of the Neolithic period (Kwak, 2017), ca. 3200–3000 years ago (Ahn et al., 2015).

Obsidian artefacts in the Upper Palaeolithic and Neolithic of Korea include prismatic cores for blades, microblade cores and microblades, knife-like blades, knives, scrapers, spearheads, arrowheads, projectile points, burins, borers, and denticulate and cutting tools (e.g., Choi, 2001, 2004; Hong & Kim, 2008; Larichev, 1978; Nelson, 1993). Especially noteworthy is the wide use of obsidian in making microblades from wedge-shaped cores in the late Upper Palaeolithic (Fig. 3.7). At some Bronze Age (i.e., early Palaeometal) sites in the northern part of the Korean Peninsula, obsidian artefacts have been recorded (Larichev, 1978; Nelson, 1993: 159; see Table 5.1).

3.5 Northeast China

The later part of the Stone Age in this region consists of the Upper Palaeolithic and Neolithic periods (Fig. 3.5). The Upper Palaeolithic can be sub-divided into two complexes (e.g., Qu et al., 2013). The early Upper Palaeolithic is characterised by the blade technique, although the number of excavated sites is small (Ho & Jiang, 1993; Zhang et al., 2010; Qu et al., 2013; Chen & Yu, 2017). The lithic assemblages include blade cores (discoidal and prismatic), heavy-duty tools (such as bifaces), spheroids, chopping tools, scrapers, skreblos, points, burins, borers, notches, and denticulates. The late Upper Palaeolithic is represented by the typical Northeast Asian microblade complex (Fig. 3.8) (e.g., Keates et al., 2019). Pressure flaking was used to detach microblades from wedge-shaped cores (e.g., Yue et al., 2021). Lithics include mainly microblades, scrapers, bifacial points, burins, borers, axes and adzes, notches, and grinding stones (Yue et al., 2021) (Fig. 3.8). The early Upper Palaeolithic complexes existed from ca. 43,500 years ago (Zhang et al., 2010) to ca. 25,600 years ago, while the late Upper Palaeolithic sites can be assigned to the time period of ca. 25,600–13,500 years ago (Kuzmin & Keates, 2021; Qu et al., 2013).

The earliest Neolithic sites in Northeast China are currently Taoshan (Heilongjiang Province) and Houtaomuga (Jilin Province) (Wang & Sebillaud, 2019; Yang et al., 2017; Zou et al., 2018). The pots are flat-based; lithics are represented mainly by microblades, scrapers, arrowheads, borers, ground stone axes and adzes, and chisels (Wang & Sebillaud, 2019). In the later Neolithic, the pottery is mainly flat-based, although some sites also have tripod vessels. The main ceramic complexes in Northeast China emerged at ca. 8300–7800 years ago (e.g., Nelson, 1995; Underhill, 2013). Conical and pencil-like cores were used for making blanks—mostly microblades—by pressure flaking. The polishing technique was also widely employed. Stone artefacts at these sites are microblades (microliths sensu Nelson, 1995), knife-like blades and insets, knives, cutting tools (choppers), scrapers, projectile points, spearheads and arrowheads, burins, borers, drills, chipped and polished axes and adzes, chisels, mortars and pestles, querns and grinding stones, hoes, stone shovels, net weights and sinkers, hammerstones, and whetstones.

The oldest pottery in Northeast China can be dated to no later than ca. 11,200 years ago based on direct ^{14}C date of a human bone at the Houtaomuga site (Wang & Sebillaud, 2019: 77). Charcoal from the Toashan site is dated to ca. 14,900–14,400 years ago (Yang et al., 2017). Other pottery complexes are dated to ca. 8000–3900 years ago (e.g., Underhill, 2013; Wagner & Tarasov, 2014). The end of the Neolithic coincides with the beginning of the Bronze Age (i.e., early Palaeometal) (Fig. 3.5).

Villages with subterranean dwellings, arranged in geometric patterns, are typical for the Neolithic period in Northeast China (Wagner & Tarasov, 2014). After ca. 4500 years ago, walled settlements appeared; some enclosures are known even before that, at ca. 8000–7500 years ago (Shelach-Lavi, 2015: 72). Adornments in the Upper Palaeolithic are rare, and they are represented by pendants

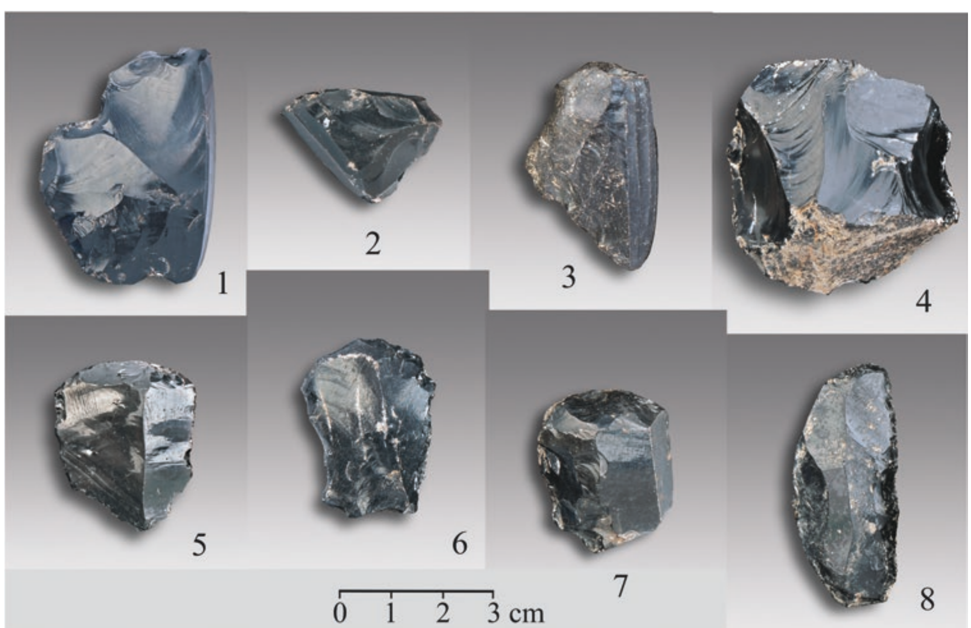

Fig. 3.8 Obsidian artefacts from the Dadong site (Upper Palaeolithic), Jilin Province (after Wan et al., 2017; modified). 1–3—wedge-shaped cores; 4—chunk with cortex; 5–8—scrapers

at the Xiaogushan site (Liaoning Province) (Qu et al., 2013). In the Neolithic, adornments made of jade are very common for the Hongshan complex dated to ca. 6700–201,775,000 years ago. Stone figurines, pendants, beads, rings, and clay figurines were found. The Niuhelang cult centre (Liaoning Province) belongs to the Hongshan complex. It consists of a temple, an altar, a stone quern and tombs, and individual graves (e.g., Nelson, 1995; Wagner & Tarasov, 2014). Numerous burials are known in other parts of the region (e.g., Wagner & Tarasov, 2014).

In the Upper Palaeolithic of Northeast China, the main kinds of economy were hunting large and medium-sized mammals, gathering of plants, and fishing. The latter activity is testified by a bone harpoon from the Xiaogushan Cave (early Upper Palaeolithic), with an age estimate of the harpoon-containing stratum of ca. 30,000–20,000 years ago (Zhang et al., 2010: 523). For the Neolithic, a wide diversity of economic activities is known. The hunting of terrestrial mammals, riverine fishing, and gathering of wild plants in the inland regions were common practices. As for the collecting of marine molluscs on the coast of the Yellow Sea, there is information about shellmiddens on the Liaodong Peninsula (e.g., Wa, 1992; Miyamoto, 2017: 161). At the same time, domestic plants and animals appeared. The earliest cultigens were millets from the Early Neolithic sites dated to ca. 7600 years ago (e.g., Zhao, 2011). These crops continued to dominate agriculture in Northeast China until the Bronze Age and even afterwards (e.g., Wagner & Tarasov, 2014). Dogs were domesticated most probably in the late Upper Palaeolithic, and were kept by humans during the Neolithic. Breeding of domestic pigs was also practiced since the Early Neolithic (e.g., Xiang et al., 2017, but see Price & Hongo, 2020: 596).

Obsidian in Northeast China was used as a raw material in the Upper Palaeolithic and the Neolithic for making wedge-shaped cores and microblades, and a variety of tools, including larger blades, bifaces, scrapers, points, spearheads, arrowheads, and burins (e.g., Doelman et al., 2014; Kato, 2017; Nelson, 1995; Wan et al., 2017; Zhao et al., 2016) (Fig. 3.8). Obsidian artefacts are often found in Jilin Province due to its proximity to the PNK1 source near the Chinese/North Korean border (see Chap. 5). At some sites, large quantities of obsidian were excavated. For example, at the Shirengou site (Jilin Province) ca. 18.5 kg of tools and flakes made of obsidian were found (Chen et al., 2006). In the Bronze Age, obsidian in Northeast China was still procured and used for making tools but in a very limited amount (Nelson, 1995: 219–221; see Table 5.1).

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In order to summarise the Stone Age economies of Northeast Asia, it is possible to use the concept of economic-cultural types (ECT) (Cheboksarov, 1981). It is based on the assumption that one can combine in the ECT prehistoric and ethnographic subsistences using peculiarities in the economy and culture that appeared during the development of human communities which are close to each other from the viewpoint of socioeconomic evolution, and which settled in similar landscapes.

It seems that hunting, gathering of plants, and riverine fishing existed in all of Northeast Asia since the Upper Palaeolithic, although direct evidence for some of these activities is often scarce. The appearance of the procurement of sea mammals and fish, and gathering of marine molluscs did not happen simultaneously. The first traces of these activities are found in the Japanese Islands at ca. 10,400–9400 years ago; salmon fishing was practiced even earlier, at ca. 15,700–15,400 years ago. During the height of the Holocene Climatic Optimum, ca. 7500–5800 years ago, the active exploitation of marine resources is known in the coastal areas of the southern Russian Far East, the Korean Peninsula, and Northeast China. In Northeastern Siberia, Sakhalin Island, and the Kurile Islands, hunting, fishing, and gathering of wild species existed throughout prehistory and early history, until the European/Japanese contact.

The earliest agriculture in Northeast Asia, based on different species of millet, emerged in Northeast China at ca. 7600 years ago. In neighbouring Korea and the southern Russian Far East, the first direct evidence of millet cultivation can be traced at ca. 5400 years ago. It seems that agriculture spread from a core region in North/Northeast China to other parts of Northeast Asia, beginning at ca. 5500 years ago. Animal husbandry based on pig rearing was probably practiced in Northeast China since ca. 7500 years ago. In other parts of Northeast Asia, domesticated animals are known only in the Bronze Age, since ca. 3700–3200 years ago, most probably due to the cultural influence from the core area in North/Northeast China.

Therefore, in the Upper Palaeolithic the uniform ECT of mobile hunter–fisher–gatherers was typical in all of Northeast Asia. In the Neolithic, two main types of ECT existed: (1) based on procurement of wild natural resources: (a) settled inland hunter–fisher–gatherers, and (b) settled coastal marine hunters, fishers, and mollusc gatherers; and (2) settled agriculturalists based on millets as the main crops, although hunting, fishing, and gathering of wild plants also continued to be practiced (Kuzmin, 2005; Kuzmin & Rakov, 2011).

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4 Obsidian Sourcing in the Southern Russian Far East

The Russian Far East belongs to the Pacific drainage basin (Fig. 4.1). It consists of Primorye Province, the Amur River basin within the borders of modern Russia, Sakhalin Island, the Kurile Islands, the northern coast of the Sea of Okhotsk, and Kamchatka Peninsula. Geographical and palaeoenvironmental data on the Russian Far East can be found in Ivanov (2002) and Kuzmin (2006); the geology is briefly described in Khain (1994: 283–307).

In the southern Russian Far East (consisting of Primorye, Amur River basin, Sakhalin Island, and the Kurile Islands), the following analytical methods were used for obsidian provenance studies: NAA (e.g., Glascock et al., 2011; Kuzmin & Glascock, 2007, 2014; Kuzmin et al., 2002a); XRF (e.g., Glascock et al., 2011; Kuzmin et al., 2002a; Tsurumaki et al., 2013); PIXE–PIGME (Doelman et al., 2008, 2012); LA–ICP–MS (Philipps, 2010); and K–Ar dating (Popov et al., 2010).

As for the amount of obsidian samples analysed for the Russian Far East and neighbouring Northeast Asia (Fig. 4.2; Table 4.1), the best-studied regions are Primorye, the Kurile Islands, the Korean Peninsula, and Northeast China. Sakhalin Island and especially the Amur River basin have been examined on a preliminary basis only. Nevertheless, this dataset is sufficient for the reconstruction of prehistoric exploitation and exchange of obsidian. Below, the characterisation of each region is presented in more detail.

4.1 Primorye Region

Primorye is the best-studied territory in the southern Russian Far East in terms of both archaeology and geology. The main source of archaeological volcanic glass, the Basaltic (Shkotovo) Plateau (size of ca. 1500 km^2), is situated in the southern part of Primorye, ca. 80 km northwest of the city of Vladivostok. It should be mentioned that here high-quality volcanic glass originates from basic rocks—basalts and basaltic andesites, with a content of $SiO_2 = 55.6\%$ wt (Popov & Shackley, 1997; Tsurumaki et al., 2013), unlike the majority of obsidian localities worldwide related to silicic rocks (rhyolites). Therefore, the volcanic glass from the Basaltic Plateau is not an obsidian sensu stricto; nevertheless, for the sake of uniformity this rock is also sometimes called obsidian (e.g., Lajčáková & Kraus, 1993). High-quality basaltic volcanic glass from mainland Northeast Asia—known from both the Basaltic and Obluchie plateaux (Fig. 4.1)—is a rare occurrence of this rock in the matrix of basic composition.

The main outcrops of volcanic glass are located in the northwestern part of the Basaltic Plateau in the basins of the Pravaya Ilistaya and Levaya Ilistaya rivers, tributaries of the larger Ilistaya River; smaller sources are situated in the basin of the Poperechnaya River, a tributary of the Arsenyevka River (Fig. 4.3). Basaltic glass is included in the hyaloclastites. Because of lava contact with water, the fast cooling creates the aphyric glass without any (or with a very small content of) cristallites; this feature is quite unique for the Basaltic Plateau (Tsurumaki et al., 2013).

Horizons of hyaloclastites are generally related to the bottom of basalt flows, and are associated with pillow lavas (Fig. 4.4). The hyaloclastites and pillow lavas are overlapped with massive and porous basaltic andesite lava flows of different thicknesses (from 1 to 7 m). The blocks of pure glass, mainly black in colour, are a quenching crust located around the rinds of pillows, measuring up to 15–20 cm, practically without phenocrysts (Popov et al., 2009, 2010; Doelman et al., 2012, 2014; Tsurumaki et al., 2013). More rarely, volcanic glass occurs at the bottom of lava flows as a quenching crust, created due to contact of hot lava with the cold earth surface, and rapid cooling. This kind of glass is dark blue and grey in colour (size of blocks is up to 10 cm), with numerous cristallites, and it is less suitable for toolmaking compared to the glass from pillow lavas. The K–Ar age of volcanic glass from the Basaltic Plateau is ca. 13.8–12.7 Ma (Doelman et al., 2012; Popov et al., 2010), which places it in the Late Miocene.

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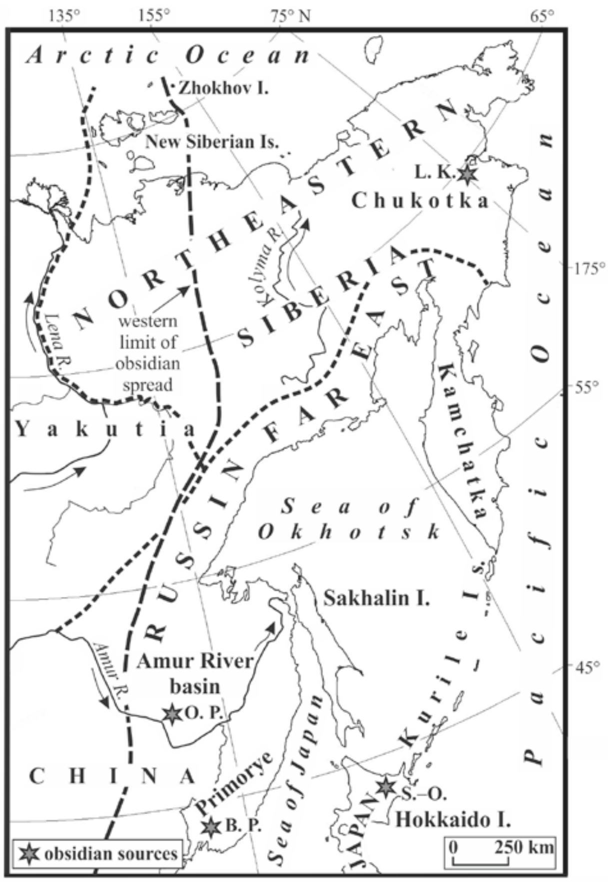

Fig. 4.1 The main regions of the Russian Far East and neighbouring Northeast Asia, and of Northeastern Siberia. Abbreviations for obsidian sources: B. P.—Basaltic Plateau; O. P.—Obluchie Plateau; S. O.—Shirataki and Oketo; and L. K.—Lake Krasnoe. Sources in Kamchatka and other locales on Hokkaido are not shown

The most representative outcrop of the Basaltic Plateau is Ilistaya 1, with the highest quality glass located in the central cores of pillow lavas. The outcrop is ca. 120 m long and 8 m high, and consists of pillow lavas and hyaloclastites (Figs. 4.4, 4.5). Volcanic glass is concentrated inside the pillow cores, with the thickness of fragments up to ca. 20 cm. Overall, ca. 20% of the rock volume at the Ilistaya 1 outcrop is represented by glass (Popov et al., 2010).

Because of the outcrops' erosion, blocks of glass were transported downslope to the valleys of the Ilistaya and Arsenyevka rivers that drain the Basaltic Plateau (Fig. 4.4). The size of glass fragments in colluvial deposits on the slopes is up to 15–25 cm. Finally, volcanic glass appears in the river channel. The size of rounded debris near the outcrops is ca. 15–20 cm, and ca. 20 km away from the source it is ca. 5–8 cm; at a distance of more than 35 km the pebbles are usually no larger than ca. 2–4 cm (Doelman et al., 2012), and are not suitable for tool-making. Sometimes pebbles up to 7 cm long can be found at a distance of ca. 45 km from the primary outcrops, near the modern village of Ivanovka (Popov et al., 2010) (Fig. 4.3). This raw material without any cracks is the best quality volcanic glass for the manufacture of lithic tools. The use of cobbles and pebbles in river channels around the Basaltic Plateau as a raw material is well-documented (Doelman et al., 2008, 2012; Pantukhina, 2007).

The exploitation of volcanic glass from the Basaltic Plateau in the prehistory of Primorye and neighbouring regions is well-established (e.g., Kuzmin, 2010, 2014; Kuzmin & Popov, 2000; Kuzmin & Glascock, 2014; Kuzmin et al., 2002a; Doelman, 2008; Doelman et al., 2008, 2012, 2014; Jia et al., 2010, 2013) (Table 4.2). The procurement of raw material at the Basaltic Plateau source and nearby was studied at the Tigrovy site cluster (Klyuev & Sleptsov, 2007; Doelman et al., 2009). For sites located away from the source, data are summarised by Doelman et al. (2008, 2012, 2014), Kuzmin (2010, 2014), Kuzmin et al. (2002a), and Jia et al. (2010, 2013). The overall intensity of obsidian use as a raw material in the southern Russian Far East is presented in Table 4.2.

Fig. 4.2 Statistics of analysed obsidian samples in the Russian Far East and neighbouring Northeast Asia (see Table 4.1)

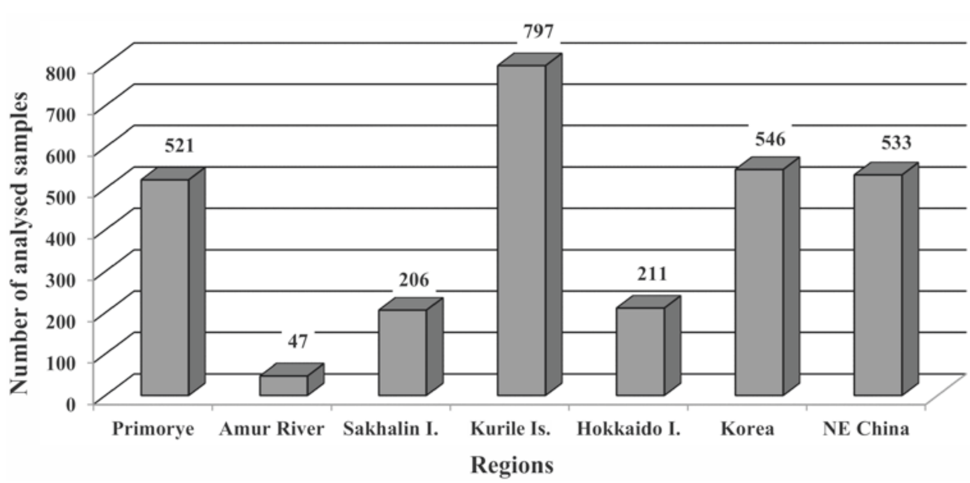

Table 4.1 Number of obsidian samples analysed for far eastern Russia and neighbouring Northeast Asia

Regions	Number of samples analysed	Geological samples	Archaeological samples	References[a]
Primorye	521	161	360	1–4
Amur River basin	47	12	35	1, 5
Sakhalin Island	206	–	206	1, 6
Kurile Islands	797	–	797	7–8
Hokkaido Island[b]	211	211	–	9–13
Korean Peninsula	546	71	475	14–22
Northeast China	533	–	533	23–24
Total (%)	2861 (100.0)	455 (15.9)	2406 (84.1)	

[a] 1. Kuzmin (2014); 2. Doelman et al. (2008); 3. Yoshitani et al. (2003); 4. Tsurumaki et al. (2013); 5. Glascock et al. (2011); 6. Izuho et al. (2017); 7. Phillips (2010); 8. Kuzmin et al. (2023); 9. Hall and Kimura (2002); 10. Kuzmin et al. (2013); 11. Wada et al. (2014); 12. Ferguson et al. (2014); 13. Suda et al. (2018a); 14. Kuzmin et al. (2002a); 15. Popov et al. (2005); 16. Kim et al. (2007); 17. Kim (2014); 18. Lee and Kim (2015); 19. Yi and Jwa (2016); 20. Chang and Kim (2018); 21. Popov et al. (2019); 22. Kim and Chang (2021); 23. Jia et al. (2010); 24. Jia et al. (2013)

[b] Only data for Shirataki and Oketo sources ('geological' obsidian) are included

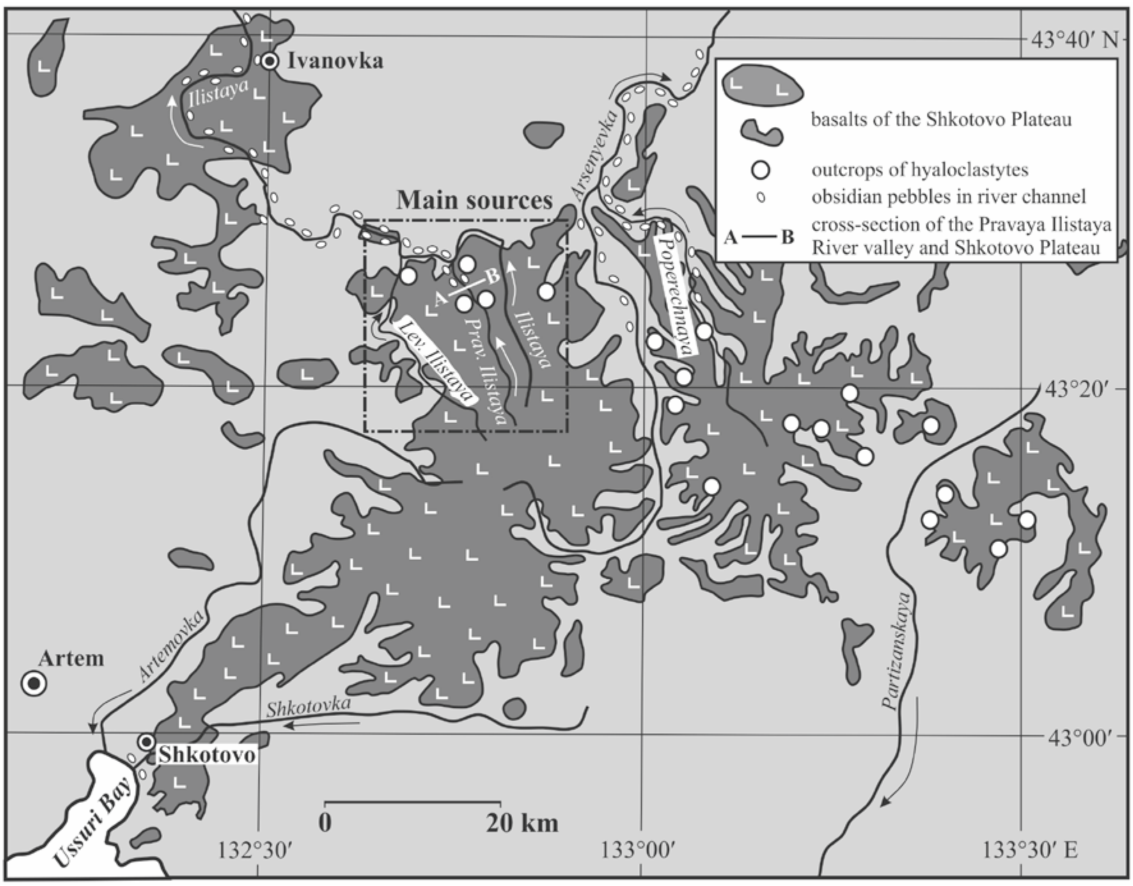

Fig. 4.3 The Basaltic Plateau in Primorye, with the main outcrops of high-quality volcanic glass (after Popov et al., 2010; modified)

Volcanic glass from the Basaltic Plateau source is widely distributed in Primorye and neighbouring Northeast China, and in smaller amounts in the Amur River basin (Fig. 4.6). It is spread throughout all of Primorye (49 sites), with distances from source to utilisation sites from a few dozen metres (the Tigrovy site cluster) to ca. 20–250 km (as the crow flies). It was also brought to the lower course of the Amur River (two sites; ca. 570 km away) and Northeast China (eight sites; ca. 320 km from the source).

Other kinds of volcanic glass of basic composition were identified at some sites in Primorye and the Amur River basin. Based on the available geological and geochemical

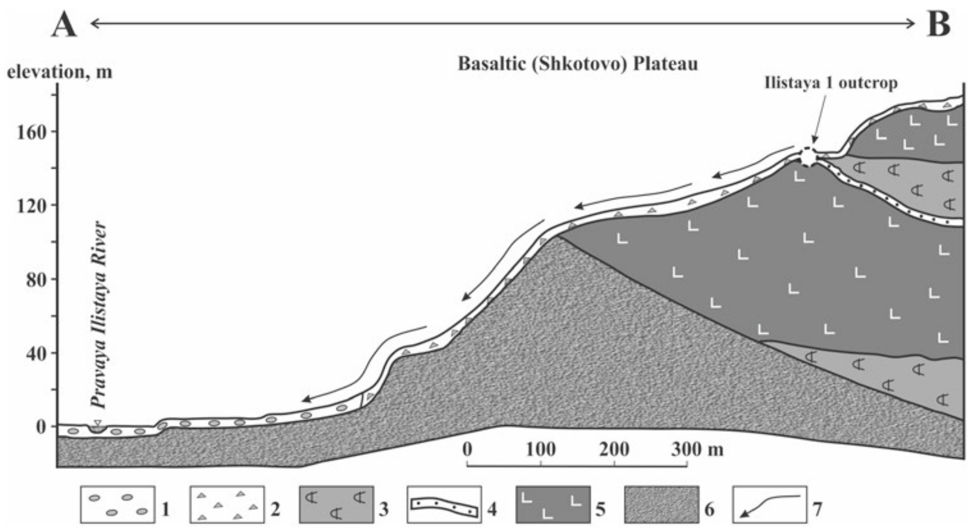

Fig. 4.4 Cross-section of the Basaltic Plateau (see position of profile in Fig. 4.3) (after Popov et al., 2010; modified). 1—alluvial deposits; 2—colluvial deposits; 3—pillow lavas and hyaloclastites; 4—layers of hyaloclastites with high-quality volcanic glass; 5—basalts and basaltic andesites; 6—Palaeozoic bedrock; 7—movement of volcanic glass from plateau to the river channel

Fig. 4.5 The Ilistaya 1 outcrop of hyaloclastites on the Basaltic Plateau, with Profs. A. Ono (left) and S. Sugihara (right); some cores of pillow lava are indicated by arrows (photo by V. K. Popov, 2011)

data (Chashchin et al., 2007), its most probable source is located in the Samarga River basin in northern Primorye where the Nelma Plateau is known to consist of Cenozoic basalts (although no detailed studies were conducted on its age, geology, and geochemistry). The distance from this presumed source called “Samarga” (Kuzmin, 2014; Glascock et al., 2011; Kuzmin et al., 2002a) to utilisation sites, belonging to the Neolithic (three sites) and Palaeometal (three sites), is up to ca. 260–470 km (Figs. 4.6, 4.7).

An important source of rhyolithic obsidian was identified in modern North Korea, not far from Primorye. It is called PNK1 (see Chap. 5), although there are still doubts about its exact location (Popov et al., 2019). It was initially identified in the late 1990s (Kuzmin & Popov, 2000; Kuzmin et al., 2002a), and confirmed later on (Popov et al., 2005, 2019). In Primorye, 34 sites belonging to the Upper Palaeolithic, Neolithic, and Palaeometal periods (Kuzmin, 2014), contain obsidian from this source.

In the southernmost part of Primorye, next to Northeast China and North Korea, a small source of rhyolithic volcanic glass was identified in the Gladkaya River basin (Doelman et al., 2008, 2014; Kuzmin & Popov, 2000; Kuzmin et al., 2002a). It is represented by dykes near the Vinogradnaya River; the obsidian of this source called “Gladkaya” (Fig. 4.6) is mainly of green colour, with some black and dark grey varieties (Doelman et al., 2014). It was identified at seven archaeological sites in Primorye (Kuzmin, 2014), predominantly of the Neolithic period;

Table 4.2 The use of obsidian in the prehistoric southern Russian Far East

Regions	Upper Palaeolithic		Neolithic		Palaeometal		Total no. of sites[a]
	Intensity	No. of sites (%)	Intensity	No. of sites (%)	Intensity	No. of sites (%)	
Primorye	++	25 (35)	++	27 (37)	+	20 (28)	71
Amur River basin	—	—	++	17 (94)	+	1 (6)	18
Sakhalin Island	++	10 (13)	+++	28 (38)	+++	37 (49)	75
Kurile Islands	—	—	++	3 (16)	+++	17 (84)	19

+++—very intensive; ++—intensive; +—occasional
[a]The total number may not be the sum of all sites if there are two or more cultural components at one site (Kuzmin 2014; Kuzmin et al., 2023)

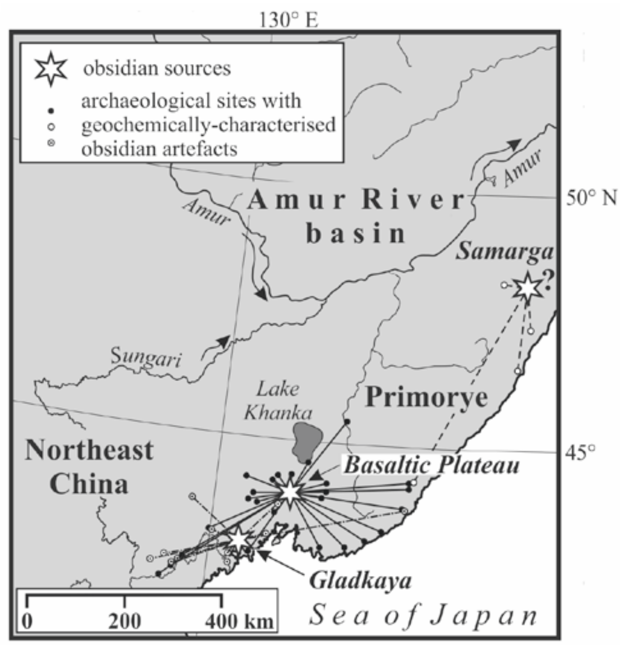

Fig. 4.6 Distribution of obsidian from the sources in Primorye

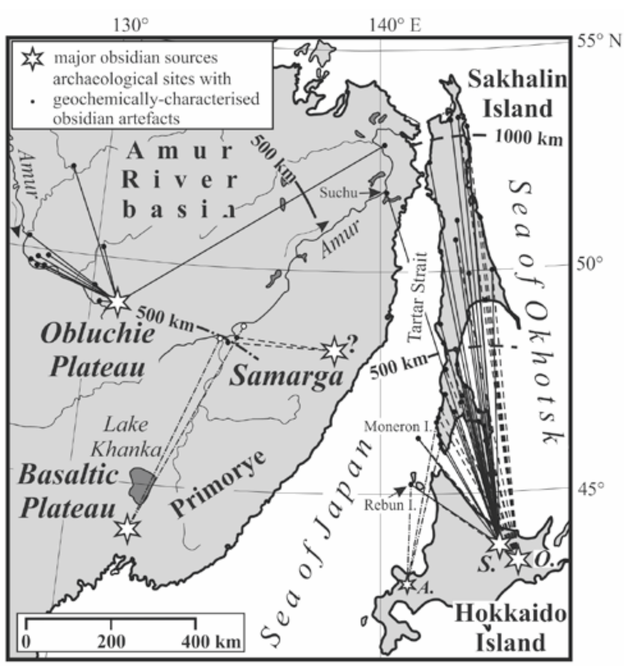

Fig. 4.7 Distribution of obsidian from different sources in the Amur River basin and Sakhalin Island. Abbreviations: S.—Shirataki; O.—Oketo; A. —Akaigawa

and at seven sites in Northeast China (Jia et al., 2010, 2013) belonging mainly to the Upper Palaeolithic. The distances from the Gladkaya source to utilisation sites are up to 160–350 km in a straight line.

Overall, two sources—Basaltic Plateau and PNK1—were the main suppliers of obsidian in Primorye. From the view of technology (Doelman et al., 2008, 2012, 2014), obsidian was used for the manufacture of microblades from wedge-shaped cores, and also larger blades. Most of the microblades are made of PNK1 raw material. Retouch is observed mainly on obsidian from the PNK1 source; some kinds of tools (like scrapers and bifaces) were made predominantly from the Basaltic Plateau raw material. As for the latter, pebbles from secondary contexts were widely used. Microblades made of PNK1 material are often broken, supposedly for use in composite tools, while microblades of Basaltic Plateau obsidian are usually complete. Therefore, it seems that the strategy of obsidian processing was aimed to maximise the use of material from a remote source (PNK1), in contrast to the frequent abandonment of preforms made of local raw material (Basaltic Plateau).

Petrographic analysis of artefacts in the Russian Far East is still at the infancy stage. For sites in Primorye, the most complete data are provided by Pantukhina (2007). At two Upper Palaeolithic sites north of the Basaltic Plateau, the ratios of obsidian artefacts from both Basaltic Plateau and PNK1 sources are 13–17% by weight, and 34–39% by count.

4.2 Amur River Basin

This vast area in the southern Russian Far East on the left bank of the Amur River is the least studied part of this region in terms of obsidian provenance (Tables 4.1, 4.2; Fig. 4.2). This is partly due to the small amount of obsidian that has been found at archaeological sites. The main primary source of high-quality volcanic glass is located in the middle course of the Amur River at the basaltic Obluchie Plateau (area of ca. 1500 km^2), north of the town of Obluchie (Fig. 4.1). Outcrops of pillow lavas are known here in the basins of the Khingan and Kundurka rivers. The K–Ar age of basalts and basaltic andesites of the Obluchie Plateau is ca. 22.6–18.6 Ma (Glascock et al., 2011).

Volcanic glass at this source is associated with pillow lavas, similar to the Basaltic Plateau in Primorye. In the most visible outcrop, volcanic glass is part of a mixture of pillow lavas and hyaloclastites. It occurs as numerous fragments in a hyaloclastic matrix re-deposited from pillow lavas and in the hardened crust of pillow lavas. The glass is mostly black in colour, more rarely dark grey, with a size of ca. 0.5–5 cm; it constitutes about 15–20% of the matrix by volume. Besides these outcrops, pebbles of volcanic glass were found in the channel of the Khingan River, with a size up to 7–8 cm.

Geochemical analysis of obsidian artefacts has allowed us to establish the main sources used by prehistoric people in the Amur River basin. At 19 archaeological sites, belonging to the Neolithic (18 sites) and Palaeometal (one site), obsidian from four primary sources was identified: Obluchie Plateau in the Amur River basin (14 sites, 24 samples), Shirataki-A on Hokkaido Island (one site, five samples), Samarga east of the Amur River (two sites, three samples), and the Basaltic Plateau in neighbouring Primorye (two sites, three samples). The Obluchie Plateau was the main supplier of obsidian; the distance from source to utilisation sites vary mainly from ca. 50 km to ca. 350 km, and in rare cases—up to ca. 750 km (Fig. 4.7). The distance from the Samarga source (with unknown exact location) to sites is ca. 260 km.

Glascock et al. (2011) securely established for the first time the presence of obsidian from the remote insular source of Shirataki-A (Kuzmin et al., 2013) in the mainland of Northeast Asia (Fig. 4.7); this was suggested previously by Kimura (1998) based on a very limited amount of data. Five artefacts from the Suchu site in the lower course of the Amur River derive from this source. The distance between site and primary source is ca. 850 km as the crow flies; if we consider that the obsidian was brought from Hokkaido Island across the La Pérouse (Soya) Strait to Sakhalin Island, and from there across the Tartar Strait to the lower Amur River basin, the real distance could be up to ca. 900–1000 km. This is a remarkable example of long-distance obsidian transport in the Russian Far East.

4.3 Sakhalin Island

Sakhalin is the largest island in the southern Russian Far East, with a length of ca. 950 km (Fig. 4.1). Its geology and environment are sumarised in Kuzmin and Glascock (2007) and Pietsch et al. (2012). The geochemistry of obsidian artefacts from Upper Palaeolithic, Neolithic, and Palaeometal sites was studied in the 2000s (Kuzmin & Popov, 2000; Kuzmin et al., 2002b; Kuzmin & Glascock, 2007; Keiko-Ekkususen, 2009: 39–41), and at a smaller scale in the 2010s (Izuho et al., 2017), summarised in Kuzmin (2014).

According to our data, there are no sources of obsidian on Sakhalin (Kuzmin & Glascock, 2007: 101–103); thus, it must have been brought from outside of the island. The closest primary locations of obsidian are known on the neighbouring Hokkaido Island (e.g., Kuzmin et al., 2013; Wada et al., 2014). Geochemical data allowed the identification of three major sources—Shirataki-A (Akaishiyama outcrop), Shirataki-B (Hachigozawa and Ajisaitaki outcrops), and Oketo-A (Tokoroyama outcrop); there is also the minor source of Akaigawa (Fig. 4.7). Vasil'evskiy (1998a: 288–290) and Kimura (1998) mention earlier attempts to analyse obsidian from some Upper Palaeolithic sites on Sakhalin; however, the results were not conclusive and required further studies which were conducted later on (Kuzmin & Glascock, 2007; Kuzmin et al., 2002b).

Obsidian is widely distributed in the prehistoric cultural complexes of Sakhalin Island (Table 4.2). In our dataset (Kuzmin, 2014; Kuzmin & Glascock, 2007), there are ten Upper Palaeolithic, 28 Neolithic, and 37 Palaeometal sites; in total, 206 artefacts from 75 sites were examined (Table 4.1). The sites are situated mainly in the southern part of the island (Kuzmin & Glascock, 2007: 104) because it is the best-studied area in terms of prehistoric archaeology; the central and northern parts of Sakhalin have been investigated in preliminary fashion (Kuzmin, 2006; Kuzmin et al., 2004; Vasilevski et al., 2010). The distribution network of Hokkaido obsidian covered the whole of Sakhalin, from sites on the coast of the La Pérouse Strait in the south to the extreme north (Fig. 4.7). Obsidian is an important raw material in southern Sakhalin, while further north its amount in prehistoric assemblages rapidly decreases, and the majority of lithics are made of jasper-like rocks (Vasilevski & Grishchenko, 2011).

Throughout prehistoric times, the Shirataki source cluster (Shirataki-A and Shirataki-B groups) was the main supplier of obsidian on Sakhalin; ca. 81% of sites contain its raw material. Another source, Oketo-A, was also widely used (ca. 35% of sites). The importance of the Akaigawa source is relatively minor (ca. 2.7% of sites). At 13 sites (ca. 17%), obsidian from both the Shirataki and Oketo-A sources was identified (Izuho et al., 2017; Kuzmin & Glascock, 2007).

In the Upper Palaeolithic, the Shirataki obsidian is the most frequently procured one (93%); in the Neolithic, its share is 85%, and in the Palaeometal it drops to 60%. The Oketo-A obsidian was important in the Palaeometal period (38%), and relatively minor in the Neolithic (12%) and Upper Palaeolithic (7%). The role of Akaigawa obsidian was very small in the Neolithic and Palaeometal (3% and 2%, respectively). While obsidian in southern Sakhalin was an important—but not the most common—raw material in the Upper Palaeolithic, it was dominant in Neolithic and Palaeometal times (Table 4.2).

The distances from primary sources to utilisation sites are from ca. 290 km (southern part of Sakhalin) to ca. 1000 km (northern part) as the crow flies. This is another example of long-distance movement of valuable raw material in the prehistory of the southern Russian Far East, along with the Amur River basin (Figs. 4.6, 4.7). Because Hokkaido and Sakhalin have been separated by the sea strait since ca. 12,000 years ago, it was necessary to use seagoing transport to bring obsidian from the sources to the sites beginning in the late Upper Palaeolithic (see Chap. 9).

4.4 Kurile Islands

The Kurile Islands region is an archipelago that stretches for ca. 1150 km from southeast to northwest, between Hokkaido Island and the Kamchatka Peninsula (Figs. 1.2 and 4.1). Its geology and natural environment are summarised in Pietsch et al. (2003) and Belousov et al. (2009). No obsidian sources are known in the Kuriles, and possible primary localities of rhyolithic volcanic glass are situated at both ends of the region—Hokkaido Island of Japan (e.g., Wada et al., 2014) and Kamchatka Peninsula of the northern Russian Far East (Grebennikov et al., 2010).

The Kurile chain can be divided into three parts—southern (Kunashir and Iturup islands, and Lesser Kuriles), central (from Urup Island to Onekotan Island), and northern (from Paramushir Island to Shumshu Island) (Fig. 4.8). From the view of prehistoric archaeology, the oldest assemblages belong to the Early Jomon (Kuzmin et al., 2012). According to current knowledge, this cultural complex is found only in the southern Kuriles, and the rest of the archipelago has only sites associated with the Palaeometal period represented by Epi-Jomon and Okhotsk complexes (Fitzhugh et al., 2016; Gjesfjeld, 2018; Gjesfjeld et al., 2019).

Although the amount of obsidian artefacts studied in terms of provenance from the Kurile Islands is relatively large (797 specimens; see Table 4.1, Fig. 4.2), only 18 sites (with 19 cultural components) have been examined (Kuzmin et al., 2023; Phillips, 2010). The number of sites with one to ten artefacts analysed is 53%; with 11 to 60 artefacts—21%; and with more than 60 artefacts—26%. Three sites (16% of the total) are associated with the

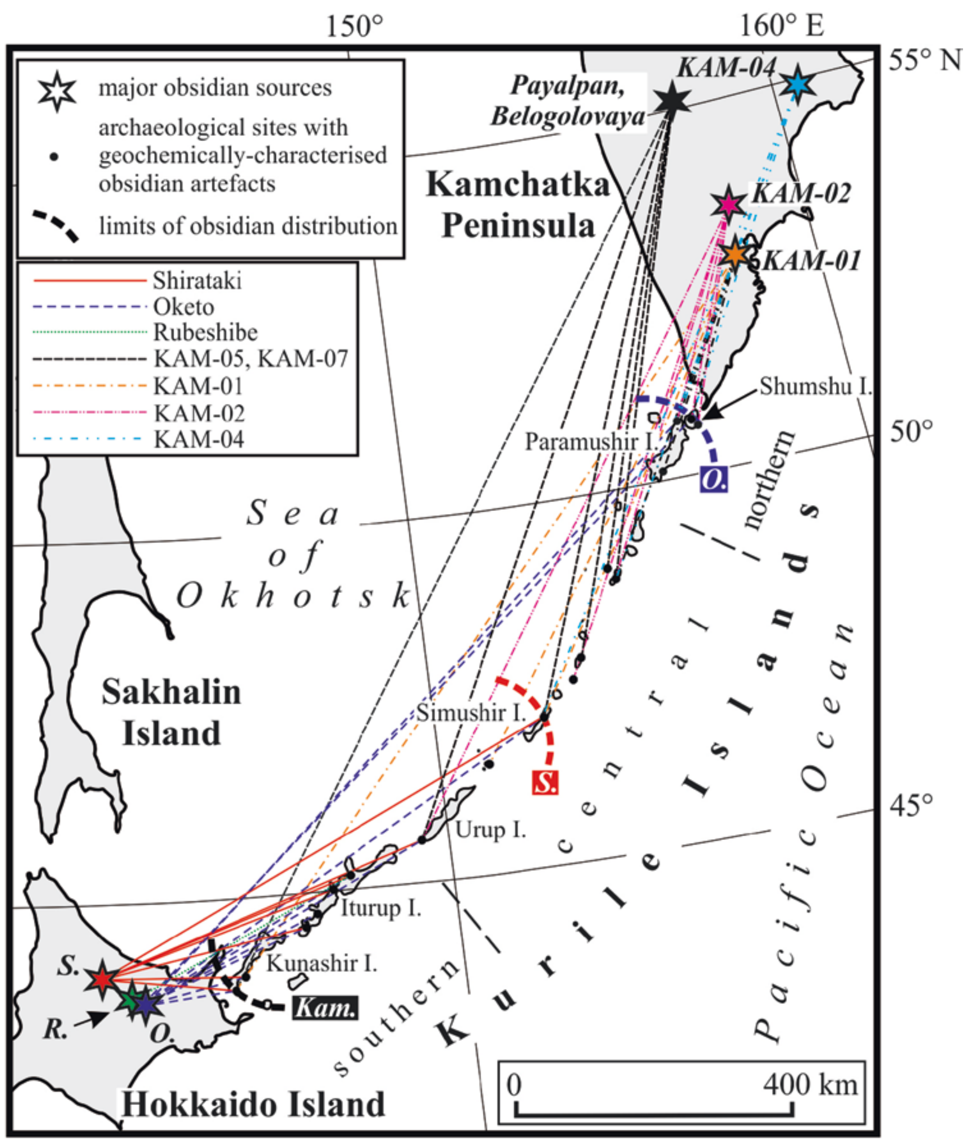

Fig. 4.8 Distribution of obsidian from different sources in the Kurile Islands. Abbreviations: S.—Shirataki; O.—Oketo; R.—Rubeshibe; Kam.—Kamchatka

Jomon, and the majority of them (15 sites, 84%) belong to the Palaeometal period (Table 4.2).

Geochemical analysis of 23 artefacts from the Epi-Jomon complex of the Yankito 2 site (Iturup Island) by the XRF method (Kuzmin et al., 2023) made it possible to identify three obsidian sources, all from Hokkaido Island: Oketo-A (52%), Shirataki cluster (27%), and Rubeshibe (4%). Four artefacts (17%) were unassigned to any sources known to us.

The analysis of 774 artefacts from 18 sites applying the LA–ICP–MS technique (Phillips, 2010) resulted in the establishment of 11 obsidian sources, located on both Hokkaido Island and Kamchatka. They represent the Oketo cluster (Oketo-A and Oketo-B groups) (34.0%) and the Shirataki cluster (24.5%) from Hokkaido; and KAM-01 (14.1%), KAM-02 (11.2%), KAM-04 (5.6%), KAM-05 (a.k.a. Palaypan) (3.6%), and KAM-07 (a.k.a. Belogolovaya River) (2.1%) from Kamchatka. Two sources, Group-A (0.6%) and Group-B (2.0%), cannot be associated with any known primary localities (Grebennikov et al., 2010), but are probably situated on Kamchatka (Phillips, 2010: 127).

Nineteen artefacts (2.4%) are unassigned to any sources. Overall, in Phillips' (2010) dataset, 58.5% of artefacts originate from the Hokkaido sources, and 36.5% from Kamchatkan ones. However, at the Ainu Creek 1 site in southern Urup Island, 337 obsidian artefacts—98.8% of the total assemblage geochemically analysed by Phillips (2010)—derive from the Hokkaido sources, and further north the raw material from these localities is quite rare (Fig. 4.8). Therefore, the role of Hokkaido obsidian beyond the southern Kuriles was not important.

The distribution of obsidian artefacts and their assignment to primary sources in the Kuriles demonstrate complex patterns of human movement (Fig. 4.8). It is clear that from the beginning of colonisation of the archipelago at ca. 7900 years ago people used seagoing transport to move between Hokkaido, Kamchatka, and the Kurile Islands (Kuzmin, 2016; Kuzmin et al., 2012, 2023) (see Chap. 9). In total, obsidian from at least eight primary locations was used by prehistoric people. The Hokkaido sources supplied mainly the southern part of the island chain, with some of the sites in the central part (Ainu Creek 1 site, Urup Island; and Vodopadnaya 2 site, Simushir Island). Only a small amount of Hokkaido obsidian—three artefacts from the Savushkina 1 and Baikova 1 sites on Paramushir and Shumshu islands, respectively—was identified in the northern Kuriles. The obsidian from Kamchatkan sources was widely used by people in the northern and central Kuriles, while in the southern islands only one site, Rikorda 1 (Kunashir Island), has 17 artefacts from KAM-01 and KAM-05 (Payalpan) sources (Fig. 4.8).

The distances for transportation of Hokkaido obsidian reach ca. 750 km (Shirataki cluster; see Fig. 4.8, curve 'S.') and ca. 1200 km (Oketo cluster; curve 'O.') in a straight line. Kamchatkan obsidian was moved up to ca. 1100 km to the central part of the Kuriles, and ca. 1300–1400 km to the southern part as the crow flies (curve 'Kam.'). The appearance of obsidian from remote sources at both the northern and southern ends of the archipelago is an excellent example of long-distance exchange/trade of valuable raw material in the prehistory of the Russian Far East and, by extension, of Hokkaido.

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5 Obsidian Sourcing in Korea and Northeast China

The Korean Peninsula and Northeast China (a.k.a. Manchuria) are located south of the Primorye and Amur River regions of far eastern Russia (Fig. 1.2). Prehistoric artefact assemblages are to some extent similar to those of Primorye and the Amur River basin (Nelson, 1993, 1995; Nelson et al., 2006). The following analytical methods were used in Korea and Northeast China for obsidian provenance studies: NAA (Popov et al., 2005, 2019); LA–ICP–MS (Chang & Kim, 2018; Kim & Chang, 2021; Lee & Kim, 2015; Yi & Jwa, 2016); XRF (Jia et al., 2010, 2013); PIXE (Kim et al., 2007); PGAA (Jwa et al., 2018); and K–Ar dating (Popov et al., 2019).

A particular problem with obsidian source(s) in Korea is that since the end of the nineteenth century (see Anert, 1904) it was accepted that obsidian was found on the Korean side of Mt. Paektu (it is divided between China and Korea). Much later it became clear that this assumption is erroneous (see below), and the exact location of the source(s) is to some extent an enigma. The problem is also related to the political situation in the Democratic People's Republic of Korea (DPRK), a.k.a. North Korea, with strict control of access to the country for foreigners, especially to border regions like Mt. Paektu. Only a few teams were able to travel and research there in the 1960s–2010s (Denisov & Ten, 1966; Chichagov et al., 1991; Horn & Schminke, 2000; Kyong-Song et al., 2016; Oppenheimer et al., 2017).

5.1 Korean Peninsula

According to current knowledge of the geology of the Korean Peninsula (Kim, 1998; Popov et al., 2019; Paek et al., 1993), the principal obsidian source is thought to be located in North Korea. This is a region of Cenozoic volcanism that includes the iconic Mt. Paektu (as it is known in DPRK) and Changbaishan (as it is called in China) (Fig. 5.1). Hereafter, the obsidian source is referred to as 'PNK1' (Paektusan North Korea 1 geochemical group; see Popov et al., 2005). Mt. Paektu is an intraplate volcano, composed mainly of basalts (and some trachyte–comendites), dated from the Pliocene to the Holocene (e.g., Liu et al., 2015; Ri, 1993; Zhang et al., 2015). It was the site of the so-called 'Millennium Eruption', one of the largest of the Common Era, in AD 946 (Oppenheimer et al., 2017). Mt. Paektu has three neighbouring volcanoes, Xiaobaishan, Baotaishan (Namphothe), and Huangfeng (Hwangbong), situated in North Korea (Taniguchi et al., 2010; Wei et al., 2021). The wider region of Cenozoic volcanism forms the Gaima Plateau (e.g., Taniguchi et al., 2010).

The precise position of the obsidian source in the northern part of the Korean Peninsula remains uncertain. Following Anert (1904), Asano (1947), and Denisov & Ten (1966), the prevailing view has been that the source is near the rim of Mt. Paektu's caldera (e.g., Ri, 1993; Sakhno, 2007). This, however, has not been corroborated by observations on the ground, conducted in the 2000s and 2010s by Russian and South Korean researchers, and by North Korean, British, and U.S. scholars (Kim, 2014; Kyong-Song et al., 2016; Popov et al., 2005, 2019). Only perlites were found near the rim of Mt. Paektu, and it emerged that the so-called 'obsidian' (Anert, 1904: 275), 'obsidian trachyte' (Denisov & Ten, 1966), and 'trachytic obsidian or tuff' (Ri, 1993: 334) refer to a perlite-like volcanic glass not well suited for making stone tools. Therefore, information about the presence of "… comenditic lava (rhyolite and obsidian) …" (Zhang et al., 2018: 24) on the Chinese side of Mt. Paektu, associated with the Qixiangzhan Formation dated to 25,000–10,000 years ago (Wei et al., 2013; Zhang et al., 2018), is most probably incorrect because no pure obsidian exists in the vicinity of Mt. Paektu.

It was also difficult to obtain obsidian source samples from North Korea. Research in the 1990s was based on four flakes given to Soviet archaeologists by North Korean colleagues in 1974 (Kuzmin et al., 2002: 513). Much later, obsidian raw material was acquired in 2010—although indirectly, via Japanese archaeologists—by Mi-Young Hong who

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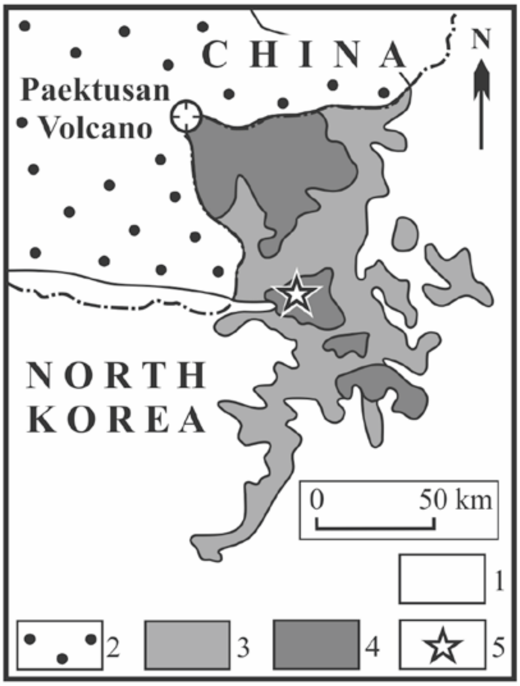

Fig. 5.1 Scheme of Cenozoic volcanic rocks in the Mt. Paektu region (after Fan et al., 2007; Popov et al., 2019; Zhang et al., 2018; modified). 1—Precambrian to Mesozoic rocks in China and North Korea; 2—Cenozoic basalts and other rocks in China; 3—Pliocene–Quaternary basalts in North Korea; 4—Quaternary trachytes, and alkali and subalkali rhyolites in North Korea; 5—possible location of PNK1 obsidian source

named it the 'Chongjin' specimen (Kim, 2014). It turned out that its geochemical composition is identical to the PNK1 group (see Appendix, Table A1 and Figure A1), common among artefacts from the Russian Far East analysed over a period exceeding 20 years (Kuzmin & Glascock, 2014). According to geochemical data, the PNK1 source is a peralkaline rhyolite, dated by the K–Ar method to ca. 1.34 Ma (Popov et al., 2019). Its SiO_2 content is 72.6–72.9% wt (Popov et al., 2005). The name 'Chongjin' derives from the seaport in North Korea from where obsidian was shipped to Japan, and has nothing to do with the position of the primary source. It is possible that the same source of obsidian as 'Chongjin' is represented in a sample obtained by Yi and Jwa (2016) from a mineral dealer in China (S. Yi, personal communication 2016). Finally, another sample of PNK1 obsidian from North Korea was obtained in 2018 (unpublished data of M.-Y. Hong, Y. V. Kuzmin, M. D. Glascock, J.-C. Kim, S. Y. Budnitsky, and A. V. Grebennikov), this time via a mineral dealer from China who asserted it came from North Korea. According to unconfirmed information, the obsidian extraction enterprise that was still active in 2017 is located in one of the so-called Bocheon mines.

All this suggests that the source is located in the wider Mt. Paektu region, and not to be found on the volcano itself. In Kim (1998), there is an indication that at Mt. Paektu obsidian is found in the Bukseollyeong (Puksollyong in Ri, 1993: 333) Formation. Also, Kim (1998: 310, Fig. 6–1) mentions an obsidian outcrop around the Nureunbong and Seollyeong ring structures. Most likely, the primary source is situated SSE of Mt. Paektu, in Bocheon (Poch'ŏn) County, Yanggang (Ryanggang) Province of North Korea (Fig. 5.1). Here trachytes, comendites, and pantellerites associated with a significant phase of silicic volcanism are found, and they can contain obsidian (Liu et al., 2015; Zhao et al., 2018; Wei et al., 2021). Hopefully, continued international collaboration in the region (see Stone, 2013; Witze, 2016) will bring to light the precise location of the PNK1 outcrop in the field.

Other geochemical groups of volcanic glass from the Mt. Paektu region are recognised. The PNK2 group was first identified by Popov et al. (2005), and found at some archaeological sites (e.g., Kim, 2014). This glass is of relatively poor quality, with numerous phenocrysts, and it was rarely used in prehistory (Kim & Chang, 2021). The primary source of PNK2 is most probably close to Mt. Paektu. The volcanic glass of the PNK3 group (Kim, 2014; Popov et al., 2005) was not found among artefact collections, possibly due to its poor quality. Two new groups, PNK1v and PNK4, have been identified by Kim and Chang (2021) among Neolithic (and possibly Palaeolithic) artefacts, found at North Korean sites and archived in South Korean museums. The obsidian of these groups was exploited by ancient populations in small quantities. As its designation suggests, PNK1v is most probably a sub-group of the PNK1 obsidian.

Until today, ca. 550 obsidian specimens from Korea have been geochemically analysed; 71 items (13%) are of geological association, and 475 pieces (87%) are artefacts (Table 4.1). To date, PNK1 has been identified at 30 sites in Korea (both South and North), 34 sites in Primorye, and 33 sites in Northeast China (Fig. 5.2). The distances from the source to utilisation sites vary from ca. 40–50 km to ca. 290 km for Northeast China, ca. 670 km for Primorye, and ca. 790 km for the most distant sites on the Korean Peninsula. Obata (2003) suggests that this obsidian may have spread even further, toward the Hulun Nur Lake in the Chen Barag area (Inner Mongolia Autonomous Region) of Northeast China, and Buyr Nuur Lake in easternmost Mongolia, ca. 1000 km away as the crow flies (see Kuzmin, 2010: 141). In the latter area, obsidian artefacts are present in minor quantities at the Mesolithic–Neolithic site of Tamsagbulag (Sériadès, 2004) but they have not been analysed geochemically. It is clear, nevertheless, that obsidian from the Mt. Paektu region was exported widely to sites in Northeast Asia.

Besides the Mt. Paektu region as a main supplier of obsidian for the Korean Peninsula, the major Koshidake source and minor Yodohime locale (both on Kyushu Island)

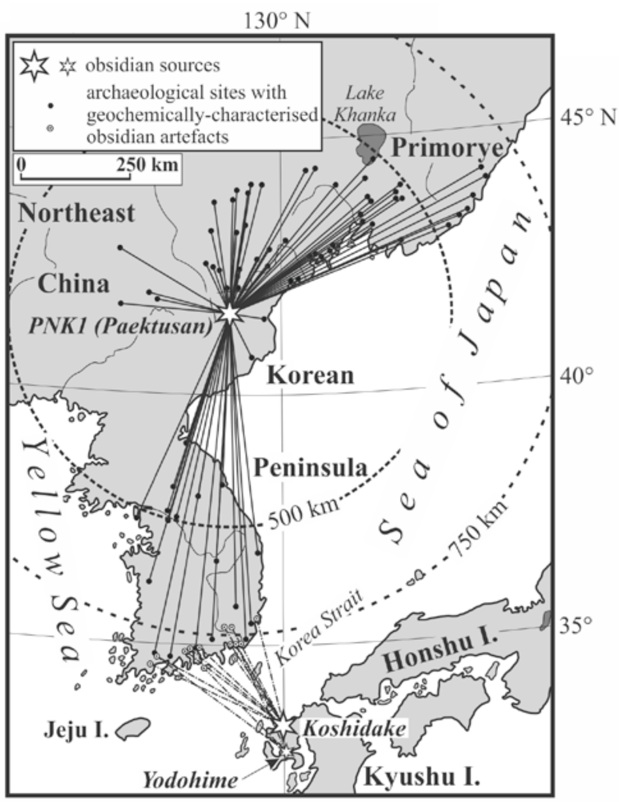

Fig. 5.2 Distribution of obsidian on the Korean Peninsula and neighbouring regions from different sources

Fig. 5.3 Obsidian artefacts from the Sinbuk site (after Lee & Kim, 2015; modified). Sources of obsidian: P—PNK1; Y—Yodohime; K—Koshidake; Unass.—unassigned

were also exploited (Kim, 2014; Kim & Chang, 2021; Kim et al., 2007) (Fig. 5.2). The Sinbuk site in South Jeolla Province and the Sinhwari site near the city of Ulsan (both in South Korea) are the only Upper Palaeolithic sites with obsidian from the Koshidake and Yodohime sources (Kim & Chang, 2021; Lee & Kim, 2015) (Fig. 5.3). Obsidian from these sources has also been identified at several Neolithic sites in the southernmost part of the peninsula (Fig. 5.2). The separation of all these sites from Kyushu Island by the Korea (Tsushima) Strait implies maritime transport of the obsidian (see Chap . 9).

The use of obsidian as a raw material in Korea is recognised as far back as the beginning of the Upper Palaeolithic (e.g., Kim et al., 2007; Lee & Kim, 2015; Popov et al., 2005; Yi et al., 2022) (Table 5.1). The most frequent procurement is evident in the central and southwestern parts of Korea, where it represents up to 26.5% of lithic assemblages (Hong, 2012, 2016). The latest summary (Hou et al., 2022) provides more details. Obsidian is present at 18 Upper Palaeolithic sites, though it usually represents a relatively small fraction of the total raw materials, ca. 0.2–8.7%. The average amount of obsidian at Upper Palaeolithic sites in South Korea is ca. 8%, due to the long distance (up to 800 km) from the PNK1 source. Only at three sites—Jangheung-ri, Hopyeong-dong, and Hahwagae-ri; all in Gyeonggi Province—located near the border with North Korea, is its amount much higher (Hong, 2016; Hong & Kim, 2008). Around half of the artefacts are represented by debitage, and blades and microblades (average of ca. 43.3%). Only one site (Youngsujaeyul, Gyeonggi Province) contains 91.1% of blades and microblades in the obsidian assemblage, with much smaller amounts of microblade cores (0.8%), retouched tools (5.1%), and debitage (3.0%). The lack of cortex (e.g., Hong & Kim, 2008) can testify that obsidian was transported from the source area as cores or other semi-prepared pieces.

As for the Neolithic period, the majority of sites with obsidian are located on the southern coast of Korea (Fig. 5.2). The PNK1 source remained in use, represented at 12 Neolithic sites in North Korea (Kim & Chang, 2021). In South Korea, most of the Neolithic sites (except for Cheoyong-ri near Ulsan) contain obsidian from the Koshidake and Yodohime sources (Fig. 5.2). Obsidian use declined in the Palaeometal period once metallurgy had emerged (Table 5.1).

Table 5.1 The use of obsidian in the prehistoric Korean Peninsula and Northeast China (+++—very intensive; ++—intensive; +—occasional)

Regions	Upper Palaeolithic		Neolithic		Palaeometal		Total no. of sites
	Intensity	No. of sites (%)	Intensity	No. of sites (%)	Intensity	No. of sites (%)	
Korea	+++	19 (40)	++	26 (54)	+	3 (6)	48
Northeast China	++	18 (49)	++	18 (49)	+	1 (2)	37

5.2 Northeast China

For this region of Northeast Asia, ca. 530 obsidian artefacts have been geochemically analysed (Table 4.1), but the number of sites is still relatively small (Table 5.1). No sources of good quality volcanic glass have been identified in Northeast China to date, though Jia et al. (2013) suggested that some primary locales of volcanic glass may exist, and they identified a few artefacts from two sources, Jingpohu and Wudalianchi/Laoheishan (Heilongjiang Province). Even though basaltic glass from these areas was exploited, it is not the dominant kind of archaeological volcanic glass in Northeast China. According to the latest summaries, both the Jingpohu and Wudalianchi volcanic fields do not contain any acidic rocks, and consist of different kinds of basalts without pure volcanic glass (e.g., Bai et al., 2021; Chen et al., 2021). Therefore, they have no geological potential to represent important sources of obsidian. Among the artefacts analysed by Jia et al. (2013), basaltic volcanic glass from the Jingpohu and Wudalianchi/Laoheishan sources constitutes only 5.4% of the artefact assemblages.

According to Doelman et al. (2014), the obsidian found in Northeast China derives from two main sources, PNK1 (Fig. 5.2) and the Basaltic Plateau (Fig. 4.6), with ca. 90% from the former locale, and ca. 4% from the latter one. The use of the Gladkaya source (6% of total obsidian analysed) is also established. In the latest summary (Hou et al., 2022), 24 Upper Palaeolithic sites are mentioned. The ratio of obsidian in the assemblages is significant, reaching up to more than 90%. Obsidian artefacts are represented mainly by debitage (ca. 48–82%; average of ca. 74%). It appears that obsidian was brought to sites as either chunks or semi-prepared cores due to the rare occurrence of cortex (e.g., Wan et al., 2017).

Distances from sources to utilisation sites for PNK1 are from ca. 90 km to ca. 290 km; for the Basaltic Plateau, from ca. 70 km to ca. 320 km; and for Gladkaya River, from ca. 50 km to ca. 200 km. Beyond the ca. 300 km radius with the centre at the PNK1 source, obsidian in Northeast China is practically absent (e.g., Kato, 2007; Yue et al., 2020). Hou et al. (2022) report a distance of ca. 150–200 km for the distribution of the PNK1 obsidian, with a few exceptions. Limited quantities of volcanic glass (1% of the total amount) were acquired from two basaltic fields in Northeast China, Jingpohu (ca. 170 km distant from sites) and Wudalianchi (ca. 670 km distant).

The use of obsidian as a raw material is first documented at the Upper Palaeolithic site of Shoushan-Xianrendong Cave (Jilin Province) dated to ca. 39,100 years ago (Chen et al., 2007; Kato, 2021). From ca. 27,000–30,000 years ago, obsidian was common in the Upper Palaeolithic such as the Dadong site dated to ca. 25,500 years ago (see Xu, 2023; Luo et al., 2023), and in Neolithic complexes (Lian et al., 2023; Nelson, 1995; Shen et al., 2023). By the time when bronze and metallurgy were introduced to the region, the role of obsidian was greatly diminished (Table 5.1).

There are rare cases of finds of obsidian artefacts from the Upper Palaeolithic complexes in North China (outside of the northeastern provinces of Jilin, Heilongjiang, and Liaoning) (Kato, 2023). They are documented at three sites in Hebei Province: Shuiliandong Cave dated to ca. 36,500–34,500 years ago; Jijitan site dated to ca. 16,000–14,000 years ago (Guan et al., 2021); and Hutouliang site dated to ca. 13,000 years ago (Zhu & Gao, 2006). There is some information about the presence of obsidian even further northwest, in the northern part of Inner Mongolia Autonomous Region of China (Obata, 2003: 70), and at the Tamsagbulag site (Dornod Province, Mongolia) (Séfériadès, 2004: 142–144) (see also Kuzmin, 2010: 141–148). However, due to the absence of geochemical analyses it is currently not possible to identify the primary source(s) for these artefacts.

Recently, data on the presence of obsidian at the Early Upper Palaeolithic site of Shiyu in the Nihewan Basin (northern China, Shanxi Province) was published (Yang et al., 2024). Two primary sources for four artefacts were identified based on pXRF analysis—Gladkaya in southern Primorye Province (Russian Far East) and PNK1. If correct, this is the earliest—ca. 45,000 years ago—example of a very long-distance transport/exchange of obsidian in the entire region of Northeast Asia, because the straight distances to sources are ca. 1500 km (Gladkaya) and ca. 1300 km (PNK1). However, the data for the composition of artefacts provided by Yang et al., (2024, Supplementary Information, pp. 65–67) does not correspond to any known geochemical signatures of obsidian sources in Northeast Asia (Kuzmin & Glascock, 2014; Kuzmin et al., 2002; Jia et al., 2010, 2013; see also Appendix, Table A1). There is a slim possibility that only one of four artefacts can be matched to the Gladkaya source because it is to some extent similar to the geochemistry of this primary locality (M. D. Glascock, personal communication 2024). In addition, Yang et al. (2024) provide no details about the calibration of the pXRF apparatus and the standard samples used. Therefore, it is impossible to accept the identification of obsidian sources for Shiyu site at face value; additional analysis in an independent laboratory is still needed to get secure information.

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6 Obsidian Sourcing in the Japanese Islands

The Japanese Islands are the best-studied region of Northeast Asia in terms of obsidian provenance. Obsidian as a raw material is known in many areas throughout Japan (Fig. 6.1). It is called *kokuyo-seki* (Kanji writing—黒曜石; *koku* [黒] is "black", and seki [石] is "stone"). Research with a focus on the sources of archaeological obsidian in Japan began in the late 1960s (e.g., Watanabe & Suzuki, 1969), with the first summaries published in the early-to-mid 1970s (Ono, 1976; Suzuki, 1973a, 1973b). The number of analysed obsidian samples for Japan until now is perhaps several hundred thousand.

Japan is one of the most dynamic volcanic regions on the Pacific Rim, and the world in general. Around 200 Pleistocene volcanoes are known here, of which 80 are currently active (Ogawa et al., 1997). This reflects the unique position of the Japanese Islands on the junction of three large tectonic plates—Eurasian (No. 1), Pacific (No. 2), and Philippine Sea (No. 3)—separated by four island arcs (e.g., Reading, 2000; Searle, 2000; Taira et al., 2016) (Fig. 6.1). Summaries on the geology of Japan can be found in volumes edited by Hashimoto (1991) and Moreno et al. (2016).

All volcanoes in Japan are associated with subduction zones of the Pacific and Philippine Sea plates. The main phase of volcanic activity occurred in the Neogene (Miocene; ca. 23–5.3 Ma; and Pliocene, ca. 5.3–2.6 Ma), and in the Pleistocene (from ca. 2.6 Ma). The largest concentration of volcanoes (including obsidian-bearing formations) is known on Hokkaido Island; on the northern part of Honshu Island (called Tohoku region); on the central part of Honshu Island (called Chubu and Kanto regions); on and Kyushu Island (Ogawa et al., 1997). This is related to the position of volcanic fronts (e.g., Matsuda & Uyeda, 1971) (Fig. 6.1). The active front is the area where volcanism occurred at a certain time. Fronts may move over time (on the order of millions of years), changing their distance from the island arc.

The total number of obsidian sources in Japan varies, depending on the author, from 50 to 100 (Geochemistry Laboratory, 2020; Kannari et al., 2014; Tsutsumi, 2010) and even more (Shimada, 2014). Obsidian from geological sources and archaeological sites in Japan is analysed by a variety of methods (see brief review: Ambrose et al., 2003: 203–205), primarily by XRF (e.g., Ikeya, 2014, 2015; Kannari et al., 2014; Wada et al., 2014), NAA (e.g., Osawa et al., 1977; Watanabe & Suzuki, 2009; Kuzmin & Glascock, 2014; Kuzmin et al., 2002, 2013; Ferguson et al., 2014), and K–Ar dating (Wada et al., 2014); and to a lesser extent by LA–ICP–MS (Suda et al., 2021a) and EPMA (Wada et al., 2014). Fission-Track dating was employed in the 1960s and 1970s (Suzuki, 1969, 1970, 1973a, 1973b; Watanabe & Suzuki, 1969), and thereafter only occasionally (Sugihara et al., 2009).

Obsidian was widely procured and used as a raw material in different parts of Japan in the Palaeolithic and Jomon, mainly on Hokkaido Island, the central part of Honshu Island (regions of Kanto and Chubu, and parts of the Tokai and Chugoku regions), Kyushu Island, and the Ryukyu Islands (Ono et al., 1992: 35, 79).

6.1 Hokkaido Island

In the north of the Japanese Archipelago, Hokkaido Island is located at the junction of Northeast Japan and Kurile island arcs (Izuho & Hirose, 2010; Izuho & Sato, 2007). Volcanic formations, including obsidian-bearing ones, are related to the subduction-type back-arc volcanism, which was the most active in the Late Miocene, Pliocene, and Pleistocene. The major obsidian sources are situated in the eastern and central parts of Hokkaido, with the highest concentration within the Monbetsu-Kamishihoro graben (Hirose & Nakagawa, 1999; Wada et al., 2014) (Fig. 6.2). Here the main phase of volcanism occurred after ca. 9 Ma. It began in the Middle Miocene as Kitami rhyolite (Takagi et al., 1999), and continued afterwards. The SiO_2 content in obsidian is ca. 75.6–77.4% wt, and its age is ca.

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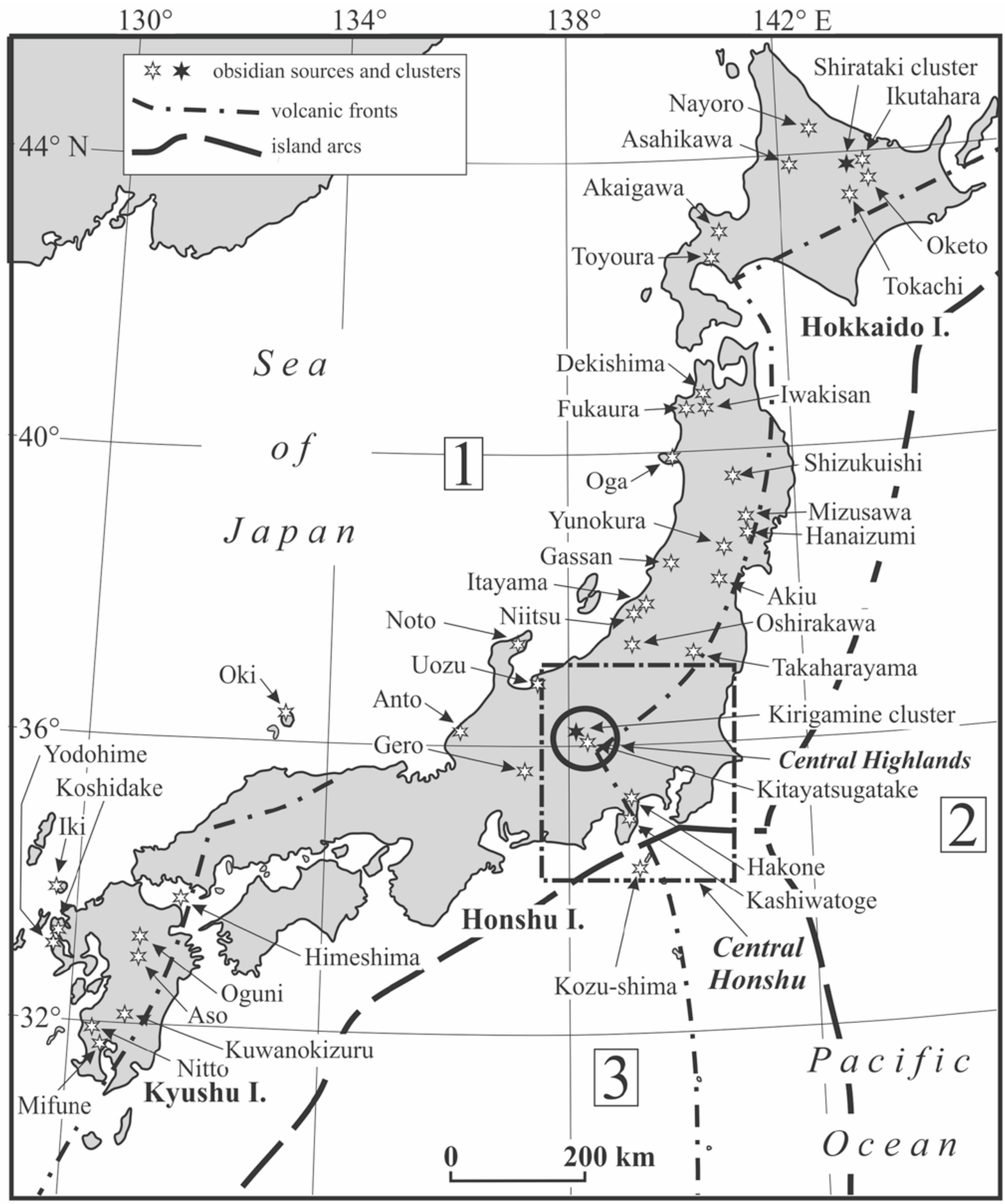

Fig. 6.1 Main obsidian sources in the Japanese Islands (after Kannari et al., 2014; Sugihara, 2011; modified). Numbers in frames represent tectonic plates

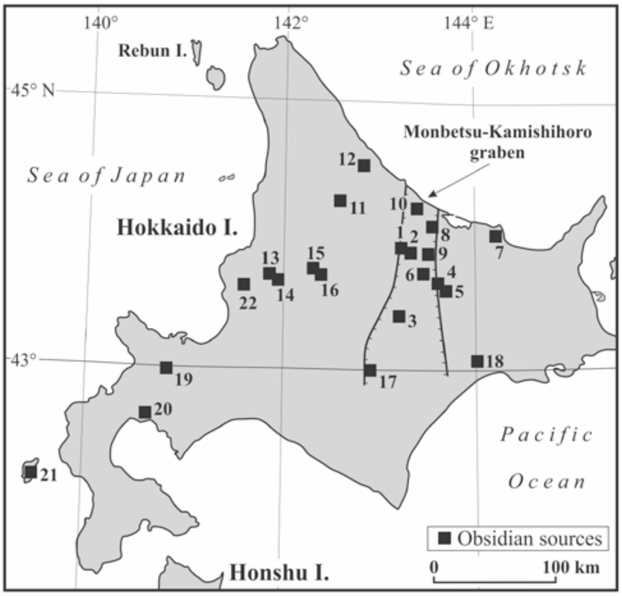

Fig. 6.2 Obsidian sources of Hokkaido Island (after Ferguson et al., 2014; Izuho & Sato, 2007; Wada et al., 2014 modified). 1—Shirataki-A (Akaishiyama); 2—Shirataki-B (Tokachi-Ishizawa); 3—Tokachi; 4—Oketo-A (Oketoyama); 5—Oketo-B (Tokoroyama); 6—Keshomappu and Rubeshibe; 7—Abashiri; 8—Engaru; 9—Ikutahara; 10—Monbetsu; 11—Nayoro; 12—Oumu (secondary source); 13—Hokuryu; 14—Chippubetsu; 15—Chikabumidai; 16—Ubundai; 17—Shikaribetsu (secondary source); 18—Kushiro (secondary source); 19—Akaigawa; 20—Toyoura; 21—Okushiri; 22—Takikawa (secondary source)

7.3–0.75 Ma (Wada et al., 2014). The sources most widely used by prehistoric people—Shirataki and Oketo—are dated to the Pliocene—Early Pleistocene, ca. 4.5–2.1 Ma ago. They are represented by rhyolithic lavas and felsic pyroclastic flows (Izuho & Hirose, 2010). In the western part of Hokkaido, the number of obsidian sources is smaller (Hirose et al., 2000; Wada et al., 2014); the most important ones, Akaigawa and Okushiri, were formed from ca. 3.1 Ma to ca. 0.7–0.2 Ma. Of more than 20 obsidian sources on Hokkaido, only a handful was actively exploited by ancient people (Izuho & Sato, 2007; Izuho & Hirose, 2010; Kuzmin et al., 2002, 2013; Wada et al., 2014).

The most important source of Hokkaido is the Shirataki cluster, consisting of several outcrops (Fig. 6.3) and accumulations of obsidian pebbles in river channels. In the Shirataki obsidian–rhyolite field there are lavas, erupted ca. 2.2 Ma ago, which formed a monogenetic volcano composed of ten obsidian flow units (Sano & Wada, 2023; Wada et al., 2014; Sano et al., 2015; Suda, 2023). Obsidians are divided into two types. The first one has a jet-black lustre and consists almost entirely of glass, with trace amounts of tiny magnetite crystals (smaller than 70 microns). The second type has a rough surface and is formed almost entirely of glass, with trace amounts of plagioclase crystals (size of 20–200 microns), and with very small magnetite microlites.

The Oketo obsidian derives from two rhyolitic lavas, Tokoroyama and Oketoyama (e.g., Kuzmin et al., 2013). The Tokoroyama lava can be further sub-divided into two lavas, Tokoroyama and Kita-Tokoroyama. These three lavas are distributed along a NE–SW trending direction, and each was formed independently. The age of obsidian from the Tokoroyama is ca. 3.8 Ma, and from Oketoyama—ca. 4.5 Ma (Wada et al., 2014; Suda, 2023).

The Tokachi (a.k.a. Tokachi-Mitsumata) obsidian is represented by gravel deposits of the Tokachi Plain. The primary source, of which the exact position is still unknown, is probably situated in the headwaters of the Jyusannosawa River, a branch of the Otofuke River, in the Tokachi-Mitsumata Caldera. The K–Ar date of two obsidian samples is 2.1 Ma, showing the same age as the Shirataki source (Wada et al., 2014; Suda, 2023).

The Akaigawa obsidian occurs as fragments in talus deposits on the northwest flank of an unnamed summit along the Dobokugawa and Magarigawa rivers, south of the Akaigawa Caldera. The probable primary source is rhyolitic lava on the plateau around the Akaigawa summit. The age of obsidian was determined as ca. 3.1 Ma; most of it contains small laminar spherulites, but some of the pieces are jet-black in colour and without spherulites, thus of high quality (Wada et al., 2014).

Attempts to establish the geochemical signatures of the main obsidian sources from Hokkaido were undertaken in the 1970s and early 1980s (Osawa et al., 1977; Koshimizu, 1981), with more work done in the 2000s (Hall & Kimura, 2002; Kuzmin et al., 2002; Watanabe & Suzuki, 2009). Based on our research (e.g., Kuzmin et al., 2002, 2013), the Shirataki obsidians are divided geochemically into two groups, Shirataki-A and Shirataki-B. Two groups are established for the Oketo source cluster—Oketo-A and Oketo-B. These results are confirmed by the latest studies (Ferguson et al., 2014; Izuho & Hirose, 2010; Wada et al., 2014). The geochemical composition of other obsidian sources on Hokkaido has also been securely identified (e.g., Ferguson et al., 2014; Wada et al., 2014).

According to the inventory of Palaeolithic sites (Japanese Palaeolithic Research Association, 2010), there are ca. 600 Upper Palaeolithic locales on Hokkaido with ca. 860 cultural components. Obsidian is widely distributed in the central and eastern parts of Hokkaido, with a ratio of more than 85% of the total raw material (Kimura, 1995, 1998; Kimura & Girya, 2016; see also Morisaki et al., 2015). Only in the extreme southwest of Hokkaido, the amount of obsidian is ca. 0.1–11% of total lithics (Kimura, 1995). Throughout the Stone Age (both Upper Palaeolithic and Jomon), beginning at ca. 34,500 years ago (Izuho et al., 2012), obsidian was widely used as a raw material on Hokkaido.

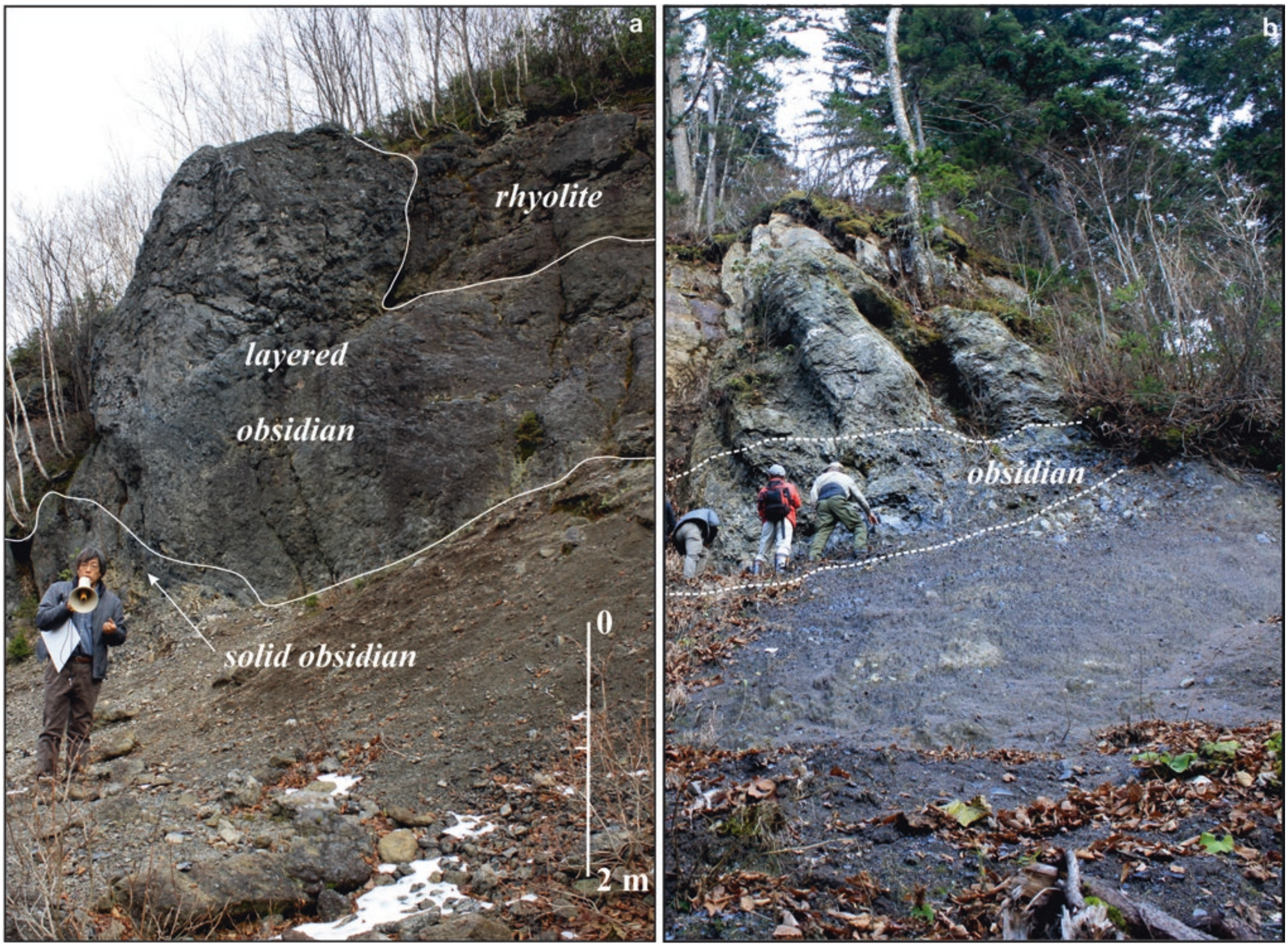

Fig. 6.3 Outcrops of the Shirataki source cluster (photos by Y. V. Kuzmin, 2011). **a**—Hachigozawa; **b**—Ajisaitaki

Analyses of the exploitation of obsidian sources on Hokkaido in the Upper Palaeolithic were conducted by Sato and Yakushige (2014) and Yakushige and Sato (2014) who summarised data for 80 sites consisting of 178 cultural components (Figs. 6.4 and 6.5) (see also Yamada, 2023). They established that the largest amounts of this raw material originated from the Shirataki cluster (58%) and Oketo cluster (23%). Other important sources of obsidian were Tokachi (11%) and Akaigawa (5%). The share of the minor Hokkaido sources (Keshomappu, Chikabumidai, Nayoro, and Toyoizumi) of the analysed obsidian artefacts is ca. 3%.

The Shirataki cluster was the main source of obsidian for Hokkaido and neighbouring parts of Northeast Asia (Fig. 6.4). Kimura (1995, 1998, 2006) established that in the early Upper Palaeolithic only pebbles from the Yubetsu River were used as raw material. Since ca. 22,000 years ago, the obsidian outcrops on the summit of the Shirataki area—Akaishiyama, Hachigozawa, and Ajisaitaki—began to be exploited. Tools manufactured from Shirataki obsidian spread throughout not only Hokkaido but also Sakhalin Island, the southern Kurile Islands, and the northern and central parts of Honshu Island (see Chap. 8), with distances often more than 500 km from the source in the Upper Palaeolithic and the following Jomon and Epi-Jomon periods (e.g., Kuzmin et al., 2002, 2013; Yakushige & Sato, 2014; Lynch et al., 2018; Natsuki, 2022). The longest distance for the transport of Shirataki obsidian—ca. 1200 km as the crow flies—was detected in the central part of Honshu Island, at the Early Jomon Shidaka site (Kyoto Prefecture) (Uemine, 2018: 184–189) (see Chap. 8). The single occurrence of Shirataki obsidian in mainland Northeast Asia was identified in the southern Russian Far East, at the Suchu site (Khabarovsk Province) in the lower course of the Amur River (Fig. 4.7). The distances from the Shirataki source to utilisation sites are from a few kilometres to more than 900 km in a straight line.

The Oketo source cluster is the second major primary locale of archaeological obsidian on Hokkaido (Fig. 6.4). Raw material was collected from both talus deposits at the sources and the channel of the Tokoro River (Izuho & Hirose, 2010; Izuho & Sato, 2007). The Oketo obsidian was widely used in central and eastern Hokkaido, with

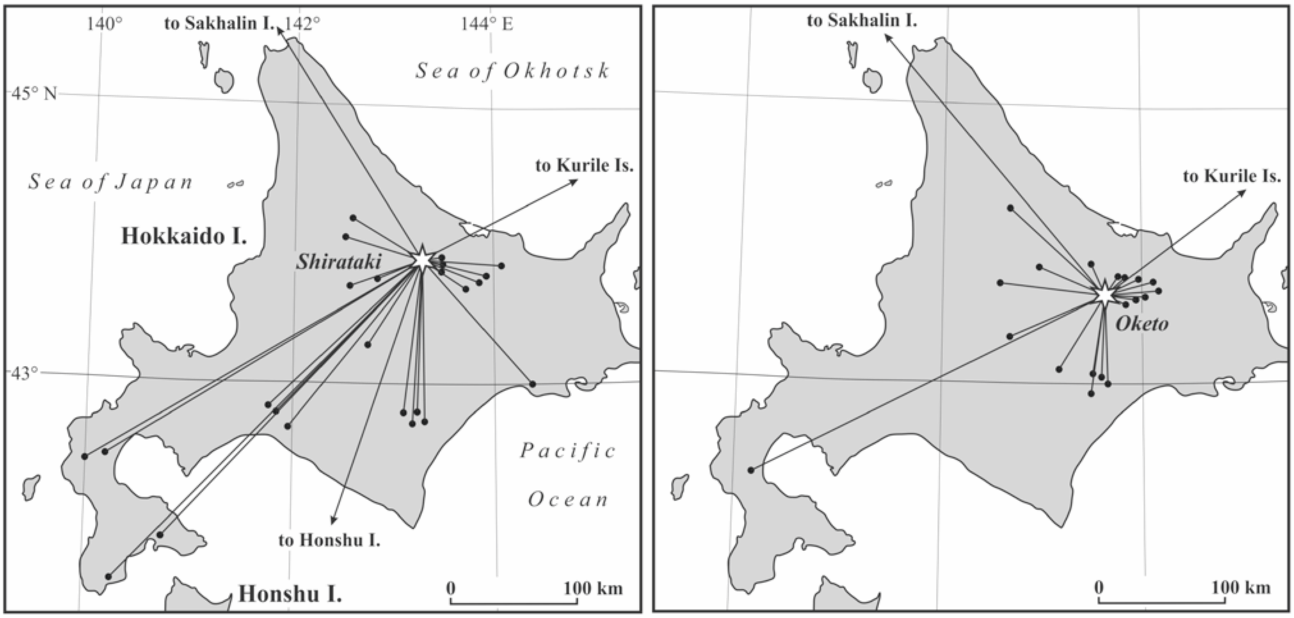

Fig. 6.4 Spread of obsidian from two major source clusters on Hokkaido Island in the Upper Palaeolithic (after Sato & Yakushige, 2014; modified)

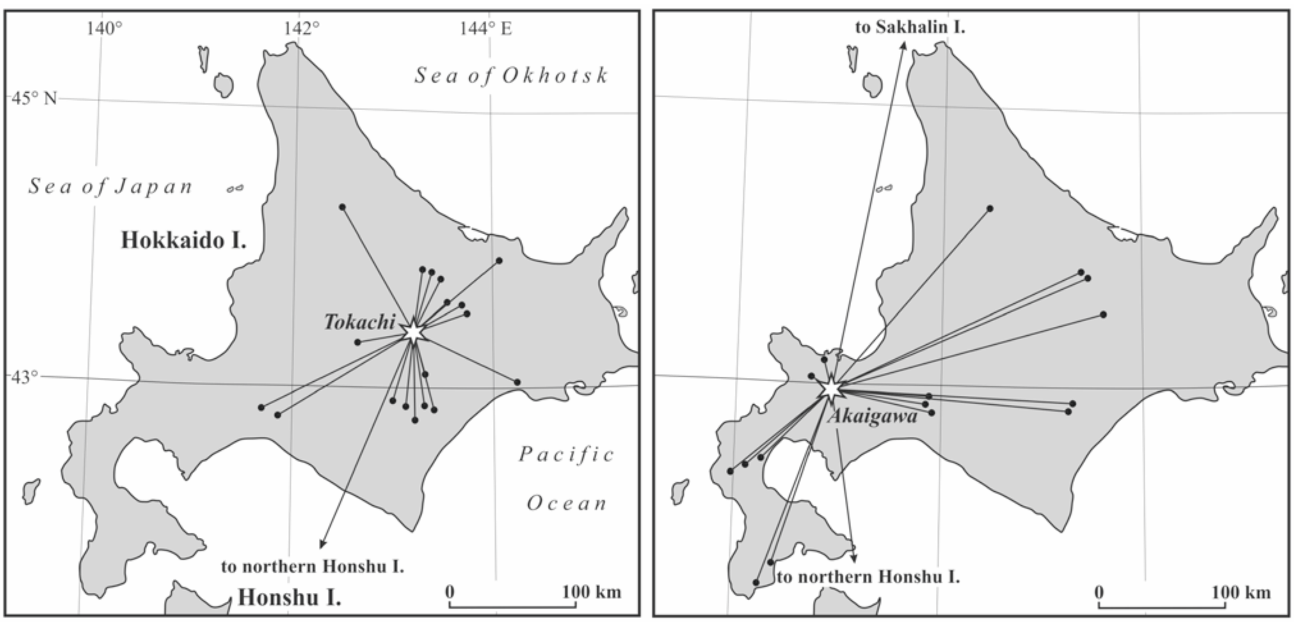

Fig. 6.5 Spread of obsidian from two other sources on Hokkaido Island in the Upper Palaeolithic (after Sato & Yakushige, 2014; modified)

occasional occurrences in the southwestern part of the island. The long-distance transportation of Oketo obsidian is established for Sakhalin Island and the Kurile Islands, up to ca. 1200 km from the source in a straight line (see Chap. 4).

Two other sources, Tokachi and Akaigawa (Fig. 6.5), were also actively used by prehistoric people. In the Upper Palaeolithic, obsidian from the Tokachi source was identified at archaeological sites in central and eastern Hokkaido, while tools made of the Akaigawa obsidian are abundant in the southern part, with occasional occurrences in the centre of the island. The distances from sources to sites are up to ca. 150–200 km as the crow flies. In Initial Jomon times (ca. 9500–7200 years ago), obsidian from the Hokkaido sources (Akaigawa, Tokachi, and Toyoura) was transported across the Tsugaru Strait to the Tohoku region (northern Honshu) (Kanomata et al., 2022; Negishi et al., 2020, 2022). The distances between sources and sites are ca. 200–350 km in a straight line.

The results of obsidian provenance for Hokkaido show that simultaneous acquisition of this raw material from several sources by the same Upper Palaeolithic populations of Hokkaido was quite common (Sato & Yakushige, 2014). For example, at the Ogachi-Kato 2 site in the eastern part of the island obsidian from four sources was exploited (Ferguson et al., 2014).

As for the possibility of transportation of Hokkaido obsidian to mainland Northeast Asia (see reviews: Sato, 2004, 2011), the only securely established case is the presence of Shirataki obsidian in the lower Amur River basin in the Early Neolithic, ca. 9500–8100 yearsago, at the Suchu site (Glascock et al., 2011) (Fig. 4.7). All other claims—beginning with a preliminary suggestion by Suzuki (1990) which later turned out to be unreliable (see Kuzmin & Popov, 2000; Izuho & Sato, 2007: 119; Kuzmin, 2010: 148–149)—have not been substantiated.

6.2 Honshu Island

On Honshu, the largest island in the Japanese Archipelago, numerous obsidian sources are known (Fig. 6.1). The degree to which they have been investigated differs, and the central part of Honshu is the best-studied region. The largest amount of work on obsidian source identification in archaeological assemblages was carried out here (e.g., Ikeya, 2014; Kannari et al., 2014; Ono & Yamada, 2012; Ono et al., 1992; Shimada, 2014; Shimada et al., 2017; Tsutsumi, 2010; Yamaoka et al., 2022). The obsidian sources of Honshu are usually related to rhyolite rocks, mainly in the form of dykes and other extrusions, small lava flows and domes, or pieces embedded in pyroclastic flows and talus deposits (e.g., Makino et al., 2015; Nishiki et al., 2011). A short description of the major sources is presented below.

The Kirigamine cluster of obsidian sources (a.k.a. Wada–Suwa; Tsutsumi, 2010) is located in the so-called Central Highlands (a.k.a. Shinshu region) (Fig. 6.1). It consists of several individual obsidian locales, and has been studied in detail since the 1970s (Yamazaki et al., 1976). Obsidian is a part of the Enrei Formation (Nishiki et al., 2011; Oikawa & Nishiki, 2005; Takahashi & Nishiki, 2006), dated in general to ca. 1.6–0.7 Ma or ca. 1.3–0.6 Ma (Suda, 2023), and more narrowly to ca. 1.0–0.9 Ma. The Kitayatsugatake (a.k.a. Tateshina) source forms part of the Kirigamine cluster. Recent geochemical studies of this area have allowed researchers to determine several source groups within an area of ca. 10 km^2 (Sugihara et al., 2009; Kannari et al., 2014; Ikeya, 2014; Suda, 2014; Suda et al., 2018b, 2021a). This data constitutes a solid basis for obsidian provenance research in central Honshu.

Unfortunately, not much information about the other important obsidian sources in central Honshu is available in non-Japanese languages. Several locales on Honshu—such as Kizukuri (Dekishima), Fukaura, and Oga—are secondary in origin, without exact knowledge about the position of the primary obsidian-bearing rocks (Tsutsumi, 2010). The quality of obsidian from these sources in northern Honshu (Tohoku region) is not very high compared to those in central Honshu (e.g., Yamamoto, 1990).

The Takaharayama source is located northeast of the Kirigamine cluster (Fig. 6.1), in a mountain range with an elevation of 1300–1400 m above sea level (a.s.l.) (Tsutsumi, 2010). This is a small stratovolcano with lava domes. This basaltic-to-dacitic volcano lies within the Shiobara Caldera that was formed in the Middle Pleistocene, ca. 0.4–0.2 Ma ago (Suda, 2023).

Two sources—Hakone and Amagi (consisting of two sub-sources, Kashiwa-toge and Kawago-daira)—are situated on the Izu Peninsula (Fig. 6.1). They are part of the Fuji volcanic zone (Oki et al., 1978). Both sources are associated with andesitic–dacitic lava flows. According to Suzuki (1970, 1973a), the Fission-Track date of the Hakone obsidian is ca. 0.12 Ma; and of Amagi obsidian, ca. 15,000 years. The latter age is at odds with the distribution of Amagi obsidian among the early Upper Palaeolithic sites in the Kanto region, dated to ca. 38,000–30,000 years ago (e.g., Shimada, 2014). Koyama (2015: 78) and Suda (2023) establish the age for the Amagi volcanic activity as ca. 0.8–0.2 Ma. It should be noted that the quality of obsidian from the Hakone and Amagi sources is inferior to that of the Central Highlands and the Kozu-shima locales, and this is why it was not widely procured in prehistory (Tsutsumi, 2007, 2010).

The Kozu-shima (a.k.a. Kozujima) sources are located on a small group of the Izu Islands, ca. 170 km southwest of central Tokyo City and ca. 50 km off the coast of the Izu Peninsula (e.g., Ono, 2014) (Fig. 6.1). These localities belong to the northern part of the Fuji volcanic zone (Taniguchi, 1977). Two sources were exploited in prehistory: Sanukazakai (a.k.a. Sanukazaki; Ono & Yamada, 2012) on Kozu Island; and Onbase on the islet of the same name 4 km off the main island (e.g., Ono, 2014; Ono & Yamada, 2012) (see Chap. 9). Obsidian is included in rhyolitic rocks here, and represents a separate lithofacies (Furukawa et al., 2019). At the Sanukayama lava exposure in the western part of Kozu Island, the obsidian zone is ca. 10–20 m thick. The superior quality of the Kozu-shima obsidian (Fig. 6.6) was perhaps the main reason why it was procured by prehistoric humans. The age of the Sanukayama lava containing obsidian, according to different studies, is from ca. 80,000 years to ca. 51,000 years

Fig. 6.6 Obsidian from the Onbase-jima source (photo by Y. V. Kuzmin, 2015)

(Yokoyama et al., 2004), or ca. 0.2–0.1 Ma (Suda, 2023). At the Onbase Islet, the obsidian source called Onbase-jima is now hidden under water (Ono, 2014: 160, Fig. 5), and diving was necessary to obtain samples from it (N. Ikeya, personal communication, August 2015).

In the western part of Honshu, obsidian sources are rare, and the best-known one is located in the Oki Islands, on the island of Dogo (Fig. 6.1). Obsidian here is part of alkaline and sub-alkaline rhyolites and trachytes, dated to ca. 4.5–3.9 Ma ago, and is associated with lava and pyroclastic flows, and dykes (Suda, 2023; Suda et al., 2021b).

There are ca. 4570 Upper Palaeolithic sites (with ca. 8180 cultural components) in central Honshu (Japanese Palaeolithic Research Association, 2010). Obsidian from ca. 520 sites (in total, ca. 85,520 artefacts) was analysed (Shimada et al., 2017), and the distribution of obsidian at prehistoric sites in central Honshu is now well-studied (e.g., Shimada et al., 2017; Shimada, 2012a, 2012b, 2014; Tsutsumi, 2010).

The main sources that constitute the Kirigamine (Wada–Suwa) cluster—sometimes called the Shinshu source group (e.g., Tsutsumi, 2010)—are located in the Central Highlands (Fig. 6.7). Obsidian from this region was widely used for tool production by Upper Palaeolithic populations in the Kanto region, the Lake Nojiri area (Nagano Prefecture), and the coast of Suruga Bay such as the foothills of Mount Ashitaka (Shizuoka Prefecture). This raw material was also brought to other parts of central Honshu northeast of the sources. According to Shimada (2012a), the share of Shinshu obsidian for central Honshu is ca. 81%. The maximum distance from the Shinshu sources to utilisation sites is ca. 250–300 km. In the Jomon period, obsidian from the Wada–Suwa cluster was brought to northern Honshu (Sannai Maruyama site, Aomori Prefecture) and southern Hokkaido (Tatezaki site) (Archaeological Raw Material, 2017; Warashina, 2005), with a distance between source and utilisation sites of ca. 650 km in a straight line (see Chap. 8). Obsidian from the Takaharayama source was transported mainly to sites in the Kanto region, and in all other directions from the primary locale (Fig. 6.7). The overall amount of this obsidian among the sources of central Honshu is small, 2.2% (Shimada, 2012a). The distances between source and sites are up to ca. 150 km in a straight line.

A detailed study of obsidian procurement around the Hiroppara bog (Nagano Prefecture) in the Central Highlands has allowed researchers to establish the particular patterns of human use (Ono et al., 2016; Shimada et al., 2017; Yoshida et al., 2016). In the Upper Palaeolithic, just before and during the Last Glacial Maximum, since ca. 30,000 years ago, people actively exploited high elevations due to the lack of vegetation cover, but the harsh climate prevented them to stay at the obsidian sources for a long time. On the other hand, the open nature of the landscape was a favourable factor for easy collection of obsidian. At ca. 20,000–17,000 years ago, climatic amelioration began, and the tree line went up. Nevertheless, there was no increase in the use of obsidian from sources in the Central Highlands, and the spread of microblade technology was responsible for the increasing importance of the remote Kozu-shima obsidian source (Fig. 6.8). A clear reorganisation of mobile human groups into northern and southern areas of central Honshu took place; the former populations exploited the obsidian from sources in the Central Highlands, while the latter ones focused on the Kozu-shima one. The appearance of vegetation since ca. 17,000 years ago made it more difficult to acquire pieces of obsidian, and perhaps this is why Jomon populations at ca. 13,000–12,000 years ago developed the mining of obsidian from shallow shafts and pits (Fig. 6.9).

Besides the major sources in central Honshu, obsidian from three other locales was used in prehistory (Fig. 6.8). The Hakone and Amagi sources supplied the neighbouring regions, the Kanto Plain and the coast of Suruga Bay, with distances of up to ca. 100 km. Their respective shares for central Honshu are 7.9% and 3.8% (Shimada, 2012a). Obsidian from the insular Kozu-shima source was identified

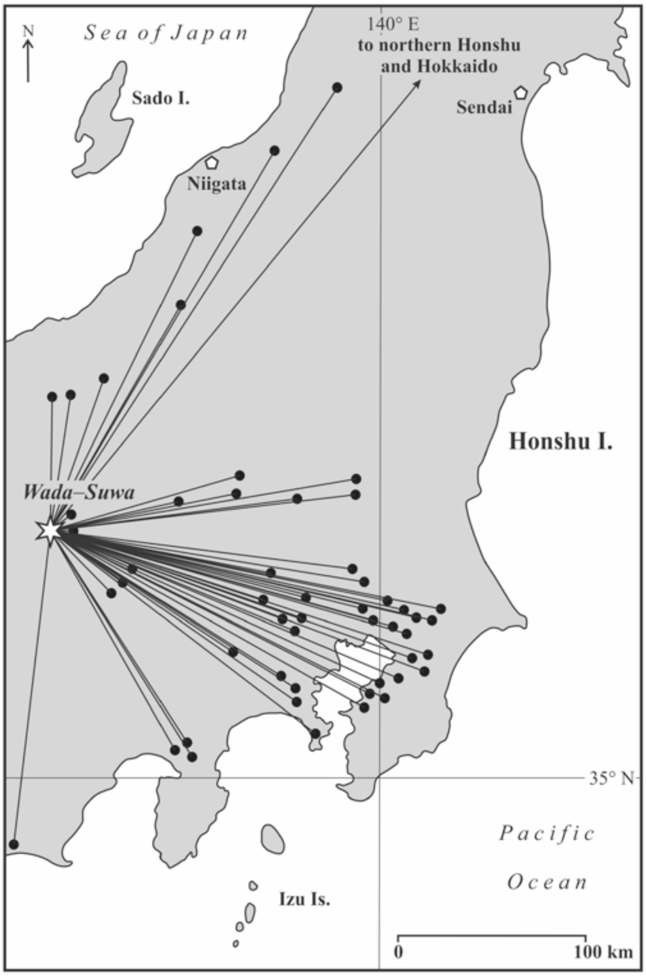

Fig. 6.7 Spread of obsidian from two major sources in central Honshu Island (after Tsutsumi, 2010; modified)

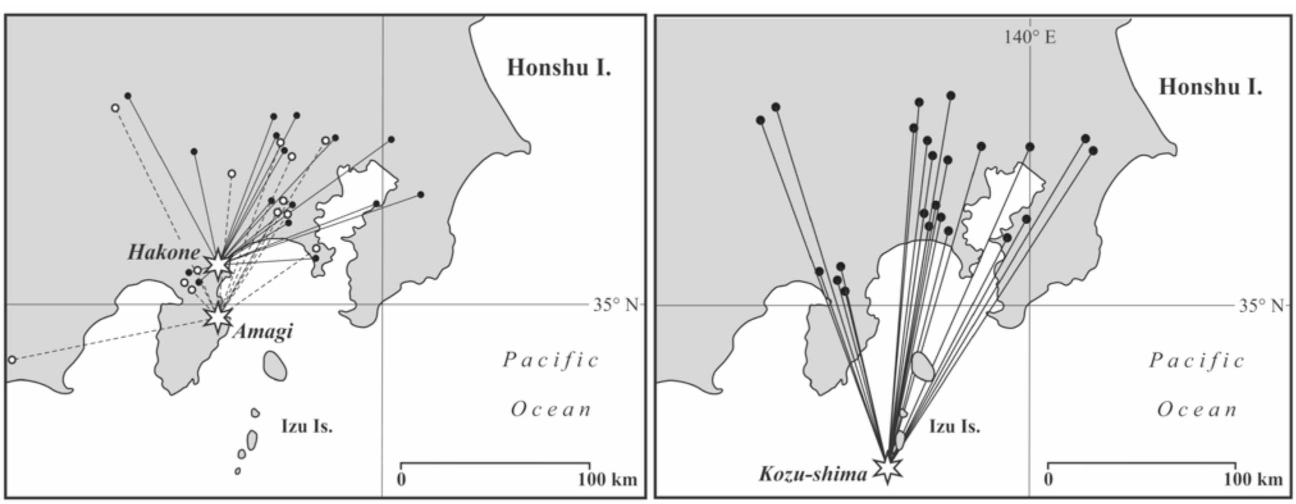

Fig. 6.8 Spread of obsidian from three other sources in central Honshu Island (after Tsutsumi, 2010; modified)

Fig. 6.9 A Jomon obsidian pit, Hoshikuso Pass, Nagano Prefecture (photo by Y. V. Kuzmin, 2011)

at several sites in the Kanto region, the Mount Ashitaka area, and in rare cases in the Central Highlands (Yadegawa site, Nagano Prefecture) (Tsutsumi, 2010). The spread of Kozu-shima obsidian is up to ca. 200 km in a straight line. The ratio of this obsidian in central Honshu is 5.2% (Shimada, 2012a).

As for the intensity of obsidian exploitation in different periods of the Upper Palaeolithic, the first evidence of its use is known at ca. 37,500 years ago (Ikeya, 2014, 2015; Shimada, 2014). In the beginning of the early Upper Palaeolithic (ca. 37,500–35,000 years ago), the amount of obsidian in total raw material composition is less than 10% (Shimada, 2012a, 2012b, 2014). In the developed early Upper Palaeolithic (ca. 35,000–30,000 years ago), it increased significantly, up to ca. 38–99% (Shimada, 2014). In the late Upper Palaeolithic, since ca. 18,000–17,000 years ago, obsidian from the Kozu-shima source was actively procured for making microblades due to its excellent quality along with sources in the Central Highlands (Tsutsumi, 2007). It is worthwhile noting that all the main obsidian sources in central Honshu were known to people in the early Upper Palaeolithic, before ca. 30,000 years ago, and obsidian procurement at that time did not depend on a single source (Shimada, 2014; Tsutsumi, 2012). At some early Upper Palaeolithic sites in central Honshu, obsidian from up to eight sources was identified (Tsutsumi, 2012). The dynamics of exploitation of the main obsidian sources in the Kanto and Chubu regions in central Honshu is examined in detail by Shimada et al. (2017).

Concerning the use of other obsidian sources on Honshu Island, relatively little information has been published. Tsutsumi (2010) refers to the transportation of obsidian from three sources in the Tohoku region—Dekishima, Fukaura, and Oga—to the central part of the island (Fig. 6.1). The distances between these primary locales and sites are from ca. 400 km to ca. 600 km in a straight line. The source at Dogo Island (Oki Islands) supplied western Honshu (Fig. 6.1) (Ono et al., 1992; Suda et al., 2021a; Tsutsumi, 2010), with sites located up to ca. 250–300 km away.

Obsidian was actively acquired as a raw material in the Jomon period of Honshu. In contrast to Upper Palaeolithic people who only collected obsidian, Jomon populations practiced mining and digging it from relatively loose pyroclastic deposits and colluvial sediments, especially around Lake Suwa (Nagano Prefecture) in the Central Highlands (Shimada, 2012a; Tsutsumi, 2010). It was studied in detail at the Hoshikuso Pass (Otake, 2022) (Fig. 6.9). In this region, Tsutsumi (2010) reconstructed the patterns of obsidian use during the Jomon. In the Early Jomon, the share of obsidian of all raw materials is less than 10%; toward the end of the Early Jomon and in the Middle Jomon, it increases from 10–20% to 30–50%. In the Kanto region, obsidian from all primary sources located in central Honshu was exploited; the Central Highlands and Kozu-shima were the main suppliers (Fig. 6.10). Obsidian was the dominant raw material for Middle Jomon artefacts (Yamamoto, 1990). The range of obsidian transportation in Jomon times for central Honshu is up to ca. 200 km (Tsutsumi, 2010).

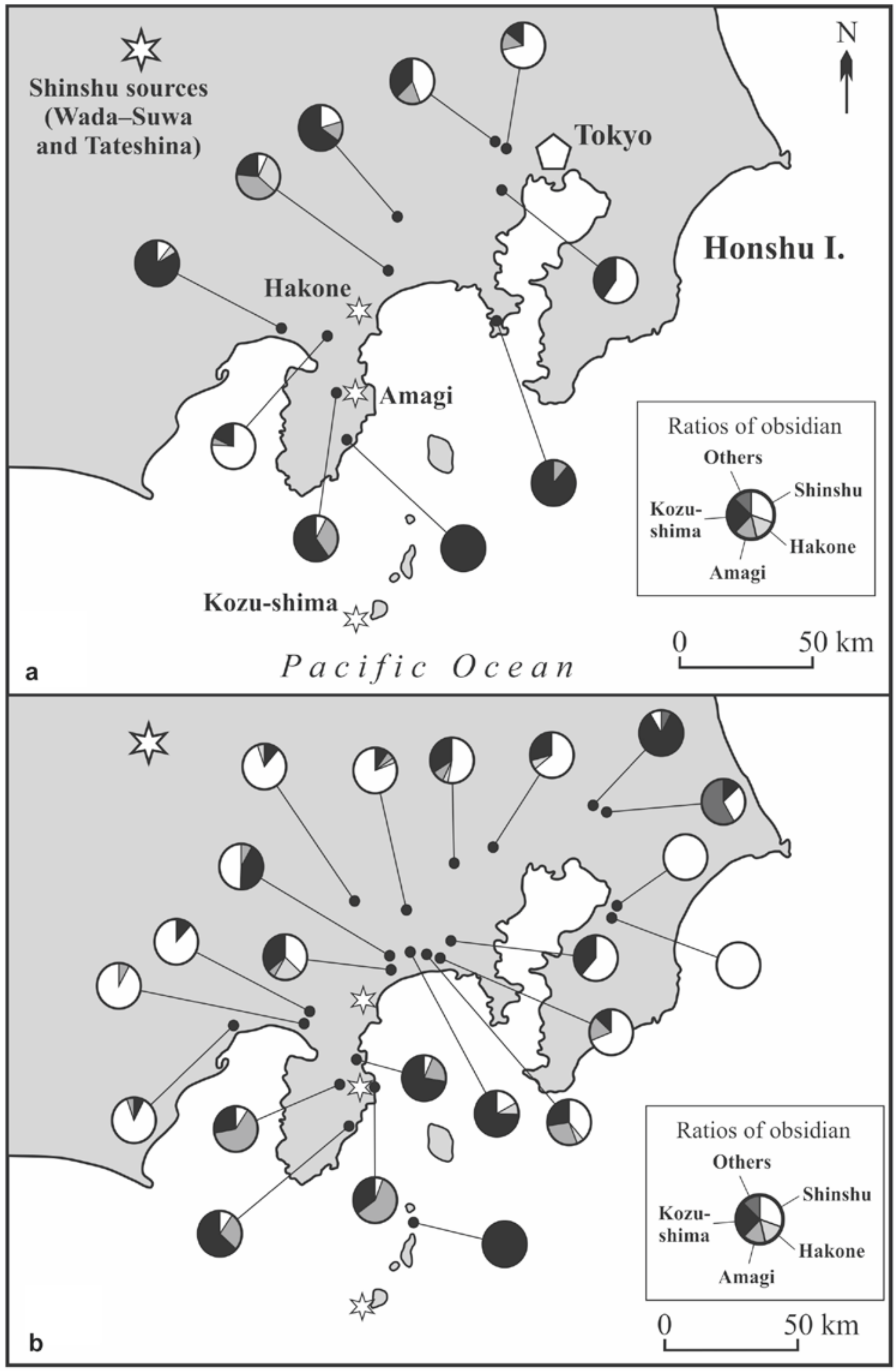

Fig. 6.10 Ratios of obsidian sources in Jomon lithic assemblages of the Kanto region and the Izu Peninsula (after Ikeya, 2006; Tsutsumi, 2010; modified). **a** Early Jomon; **b** Middle and Late Jomon

Some patterns of the dynamics for the use of different obsidian sources in the Jomon of the Kanto region have been established by Tsutsumi (2010). In the Early Jomon, obsidian from Kozu-shima (Onbase-jima locale) dominated (Fig. 6.10a); in the Middle Jomon, the quantity of obsidian from the Central Highlands increased (Fig. 6.10b). In the coastal areas, the role of Kozu-shima obsidian was always important. It is of interest to note that obsidian from the second obsidian source of Kozu-shima, called Sanukazaki (Furukawa et al., 2019), was procured only in the Final Jomon, ca. 3000 years ago (Ono & Yamada, 2012), while the Onbase-jima source was exploited since the early Upper Palaeolithic.

In the recent summary on obsidian exploitation for the Jomon sites in the Kanto Plain (central Honshu Island), based on ca. 21,000 geochemically-analysed samples from ca. 270 sites, the patterns of transport and exchange are established (Sakahira & Tsumura, 2023). Sites are subdivided into five periods: (1) Period 1, Incipient Jomon—Initial Jomon (ca. 16,000–7000 years ago); (2) Period 2, Early Jomon (ca. 7000–5500 years ago); (3) Period 3, Middle Jomon (ca. 5500–4500 years ago); (4) Period 4, Late Jomon (ca. 4500–3200 years ago); and (5) Period 5, Final Jomon (ca. 3200–2400 years ago). During the periods 1 and 2, the main suppliers of obsidian were the Shinshu group (Wada-toge, Suwa, Omegura and Tateshina sources located in the Central Highlands) and Kozu-shima sources. In Period 3, the Takaharayama source became the third important primary locale; this continued into Period 4. The Period 3 (Middle Jomon) was the time of the most active obsidian procurement and transport in central Honshu. In periods 4–5, the ratio of obsidian from the nearby sources increased. Obsidian from the insular source of Kozu-shima, accessible only by watercraft (see Chap. 9), was widely used in Period 3; before that it was restricted to coastal areas of the Kanto Plain. In Period 5, the role of the Kozu-shima source decreased significantly.

Therefore, in periods 1–2 (Incipient to Early Jomon, ca. 16,000–5500 years ago), small regional exchange networks existed in the Kanto Plain. In Period 3 (Middle Jomon, ca. 5500–4500 years ago), the size of networks significantly increased; they cover the entire region, with co-occurrence of obsidian from two major sources—Shinshu and Kozu-shima. Afterwards, in periods 4–5 (Late to Final Jomon, ca. 4500–2400 years ago) the exploitation of obsidian was to some extent limited to the local networks.

6.3 Kyushu Island and Ryukyu Islands

The number of publications accessible to non-Japanese scholars on obsidian procurement and use for the southernmost parts of the Japanese Archipelago—Kyushu Island and the Ryukyu Islands—is very limited (Obata et al., 2010; Shiba, 2014). In this section, a brief description of the main primary obsidian localities on Kyushu Island and spread of its obsidians in Northeast Asia is presented.

In northwestern Kyushu, two main obsidian sources, Koshidake and Yodohime, are situated (Fig. 6.1). Koshidake is the most important obsidian locale. It is associated with the Arita rhyolite extrusion originating from the Koshidake Mount near the city of Imari, Saga Prefecture (Fig. 6.11). The SiO_2 content is ca. 73% wt (Hayashida, 1964); the obsidian has been dated to ca. 3.0–2.8 Ma ago (Kamei et al., 2016; Suda, 2023). While there are no outcrops, today one can collect pieces of volcanic glass on the slopes of the hill from the surface of colluvial deposits (personal observation, 2003). The quality of this obsidian is very high. The Yodohime source is part of the Hario cluster (Shiba, 2014), and is derived from secondary deposits (breccia) originating from rhyolite rocks. As at Koshidake, this obsidian is of high quality.

Several other obsidian locales are known in central and southern Kyushu Island (Fig. 6.12). The Himeshima source, dated to ca. 0.3–0.1 Ma ago (Furukawa et al., 2021; Suda, 2023), is situated on a small island off northeastern Kyushu, and is associated with rhyolites of the Shiroyama Volcano. A layer of massive obsidian forms part of the rhyolite Shiroyama lava, with a SiO_2 content of ca. 74–75% wt. The water content in obsidian is ca. 0.3%. The origin of this obsidian is related to the shallow conduit from which magma was effused as a dense obsidian lava (Furukawa et al., 2021).

The Oguni secondary source (pebbles in river channels, and angular pieces in colluvial sediments) originated from the Yamanokogawa rhyolite; this raw material contains many phenocrysts. The Zogahana source is related to pyroclastic deposits in the northeastern part of the Aso Caldera; it is sometimes also called “Aso obsidian” (Shiba, 2014). The Nitto secondary source is located in the Yamano area. The Kuwanokizuru source is also represented by nodules (up to fist size) in river channels; the quality of this obsidian is high. The Kamiushibana and Mifune sources belong to rhyolites. The former raw material has less impurities than the latter one.

On Kyushu Island, there are ca. 2030 Upper Palaeolithic sites with ca. 2500 cultural components (Japanese Palaeolithic Research Association, 2010). The number of localities analysed for obsidian provenance is perhaps less than 100. Shiba’s (2014) analysis of obsidian exploitation in the Upper Palaeolithic of Kyushu Island established that the Koshidake and Yodohime sources were the most widely exploited at this time, at distances of up to 230 km as the crow flies (Fig. 6.12). The raw material from the Koshidake source was commonly used for manufacturing microblades due to its high quality. Obsidian from the Koshidake source was also transported across the Korea Strait to the Korean Peninsula in the Upper Palaeolithic, ca. 31,000 years ago (Lee & Kim, 2015; Chang & Kim, 2021), with straight distances of ca. 230–310 km (see Chap. 9). The traffic of Koshidake and Yodohime obsidians across the Korea Strait continued in the Neolithic, up to 3200 years ago (Chang & Kim, 2021). Other Kyushu sources were procured at a smaller scale, and obsidian in the form of pebbles (and sometimes angular fragments) is usually found not very far from the primary locales. The largest distances (ca. 80–130 km) can be determined for the Nitto and Kuwanokizuru sources (Fig. 6.12). The use of several kinds of obsidian at a single site is common; for example, at the Nitaonaka A & B sites (Kagoshima Prefecture), dated from ca. 26,000 to ca. 13,000 years ago, raw material from three to four sources was detected (Shiba, 2014: 217, 221).

Fig. 6.11 View of the Koshidake Mount (photo from open source)

Obata et al. (2010) analysed ca. 150 obsidian artefacts from 39 Jomon sites in the Ryukyu Archipelago. Obsidian from the Kyushu sources was transported to several islands (Fig. 6.12). It was found that the Koshidake locale was the most intensively procured, followed by Yodohime. The ratios of obsidian from these sources is 94% and 2.6%, respectively. Three other sources, Himeshima, Ryugamizu, and Kuwanokizuru, also supplied sites in the Ryukyu Islands, albeit in smaller quantities.

The spread of obsidian from the Koshidake source to the Ryukyus in Jomon times is an excellent example of the wide geographic expanse of high quality raw material transport. The distances from Koshidake to utilisation sites in the Ryukyu Islands vary from ca. 300 km (to Tanegashima Island) to ca. 620–830 km (to Tokunoshima and Okinawa islands) (Fig. 6.12). It is clear that maritime transportation of obsidian was necessary to convey it (see Chap. 9). The first appearance of Kyushu obsidian in the Ryukyu Archipelago is known at ca. 8800–6800 years ago at the neighbouring Tanegashima and Yakushima islands. Since the end of the Middle Jomon (ca. 4500 years ago), the Koshidake and Yodohime obsidians reached the Amami O-shima Island. In the Late Jomon (after ca. 4000 years ago), the exploitation of Kyushu sources increased dramatically, and obsidian arrived on Okinawa Island for the first time (Obata et al., 2010; Takamiya & Shizato, 2024). Volcanic glass from other sources was brought only to the Tanegashima and Yakushima islands (Kamiushibana and Himeshima locales), and to Amami O-shima Island (Kuwanokizuru and Ryugamizu sources) (Fig. 6.12). It is worth mentioning that the use of obsidian from different primary locales on the same island was quite common, such as on Tanegashima and Amami O-shima.

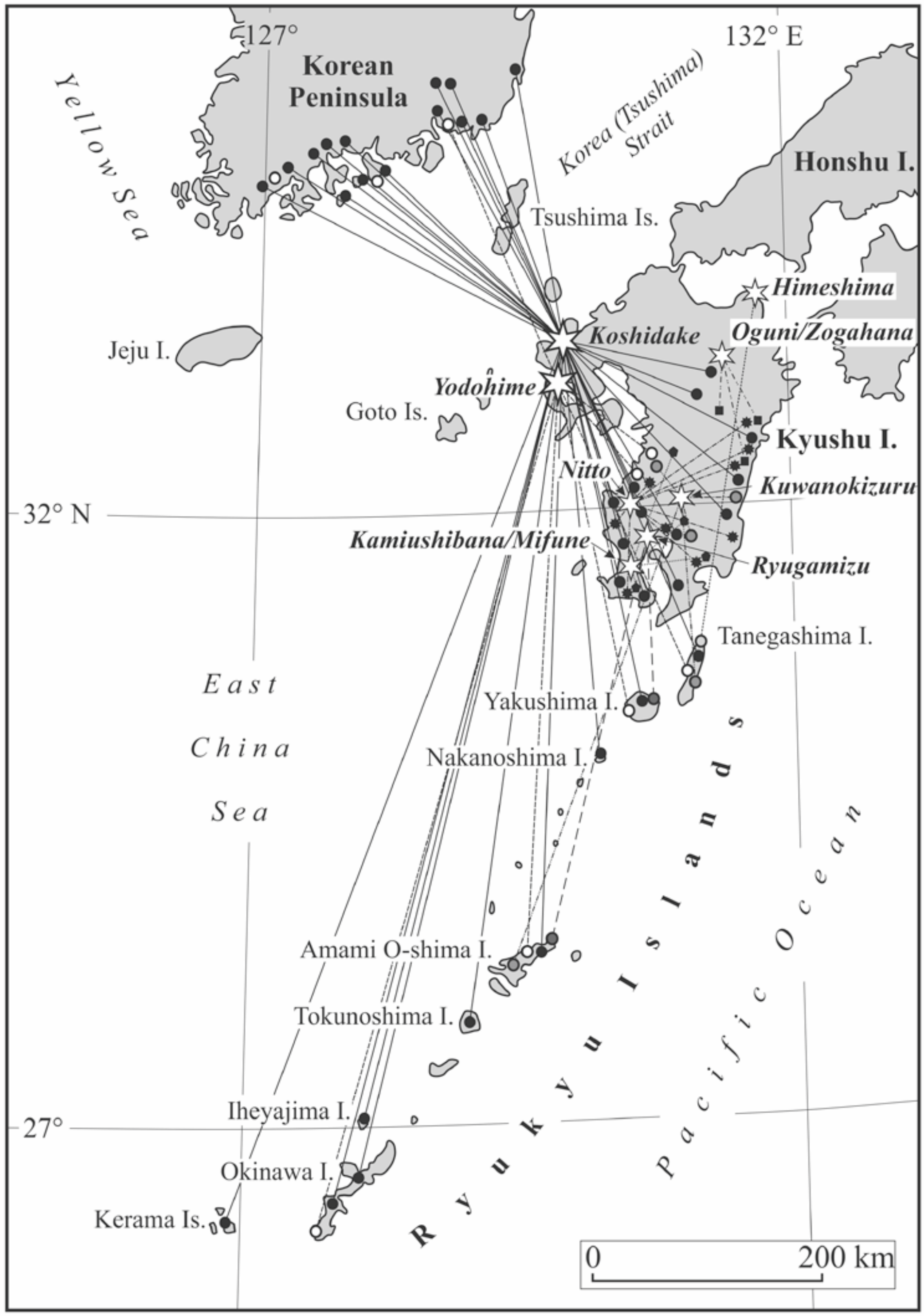

Fig. 6.12 Spread of obsidian from sources on Kyushu Island (after Obata et al., 2010; Shiba, 2014; modified)

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7 Obsidian Sourcing in Kamchatka and Northeastern Siberia

These regions constitute vast swathes of land in Northeast Asia, including its most northern region, the High Arctic. Although Kamchatka Peninsula—as part of the Pacific Ocean drainage basin—belongs to the Russian Far East, according to Soviet/Russian geographers (Ivanov, 2002; Suslov, 1961), it is combined here with Northeastern Siberia which constitutes part of the Arctic Ocean drainage basin (Figs. 1.2 and 4.1). The main geographic features for these territories can be found in Shahgedanova et al. (2002), Ivanov (2002), and Jones and Solomina (2015). The Kamchatka Peninsula is the region with one of the largest amounts of obsidian sources in the world. The geology of Kamchatka and Northeastern Siberia is briefly described in Khain (1994) and Khain & Nikishin (1997).

Since the early 2000s, a relatively large amount of obsidian was analysed by our informal team for Kamchatka and Northeastern Siberia (Table 7.1; Fig. 7.1). Kamchatka is the best-studied area, followed by the Kolyma and Chukotka regions. The scarcity of obsidian in the archaeological assemblages of the Indigirka River basin and High Arctic, at the western limit of its occurrence in Northeast Asia (Fig. 4.1), makes the number of samples very small. For obsidian provenance, the following analytical methods were used: NAA (Grebennikov et al., 2010, 2018; Kuzmin et al., 2008); XRF (Kuzmin et al., 2018, 2020, 2021; Pitulko et al., 2019); and K–Ar dating (Grebennikov & Kuzmin, 2017; Grebennikov et al., 2018).

7.1 Kamchatka Peninsula

The Kamchatka Peninsula in the Northwestern Pacific stretches approximately 1200 km in SSW–NNE direction, and is flanked by the Bering Sea in the east, the Sea of Okhotsk in the west, and the open Pacific Ocean in the south. The main geomorphic features of the region are two mountain ranges, Central and Eastern, with a sedimentary basin between them occupied by the Kamchatka River (Central Valley) (Fig. 7.2, A). From a tectonic point of view, Kamchatka sits on the boundary between the Pacific and Eurasian plates. This is one of the most active volcanic arcs in the world, and at least 28 modern volcanoes are known in the region (Fedotov & Masurenkov, 1991). Most of the Kamchatkan terrain consists of Cenozoic volcanic rocks, with some sedimentary and volcanic-sedimentary formations (Khain, 1994). General petrological information about the volcanic rocks of Kamchatka is readily available (Avdeiko et al., 2006, 2007; Bindeman et al., 2010; Dorendorf et al., 2000; Ishikawa et al., 2001; Pevzner et al., 2019; Popolitov & Volynets, 1982; Volynets et al., 1990).

Volcanic glasses (obsidians and perlites) are widely distributed in Kamchatka. They occur as extrusive domes, lava and pyroclastic flows, and in the pyroclastic products (tephras and pumice tuffa). According to their chemical composition, volcanic glasses correspond to dacites and rhyolites. The acidic volcanic glasses on Kamchatka belong to metaluminous and peraluminous rhyodacites and rhyolites of calc–alcali and subalcali types. The SiO_2 content in Kamchatkan volcanic glasses ranges from 72.65% to 76.84% wt.

Currently, more than 30 sources of high and medium quality volcanic glasses are known in Kamchatka (Grebennikov et al., 2010) (Fig. 7.2b). In the Central Kamchatkan Volcanic Belt, corresponding to the Central Range, obsidian-bearing formations belong to the Oligocene–Neogene (ca. 34–3 Ma ago). In the Eastern Kamchatkan Volcanic Belt, occupied by the Eastern Range, obsidian is known mainly among Pleistocene rocks dated to the last 2.6 Ma. In southern Kamchatka, obsidian-containing formations are dated to the Pliocene–Pleistocene (ca. 5–0.03 Ma ago). Direct dating of Kamchatkan obsidian sources is still rare (see Grebennikov et al., 2014).

Volcanic glasses of Kamchatka have been systematically studied by our group since 2003, and an extensive database containing information on the geochemical composition of about 510 obsidian samples was created (Grebennikov

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Table 7.1 Number of obsidian samples analysed for Kamchatka and Northeastern Siberia

Regions	Number of samples analysed	Geological samples	Archaeological samples	References[a]
Kamchatka	507	63	444	1–2
Chukotka	167	37	130	3–4
Kolyma River basin	219	—	219	4–6
Indigirka River basin	7	—	7	7
High Arctic (Zhokhov)	14	—	14	8
Total (%)	914 (100.0)	100 (10.9)	814 (89.1)	

[a]1—Grebennikov et al. (2010); 2—Kuzmin et al. (2008); 3—Grebennikov et al. (2018); 4—Yoshitani et al. (2013); 5—Kuzmin et al. (2018); 6—Kuzmin et al. (2021); 7—Kuzmin et al. (2020); 8—Pitulko et al. (2019)

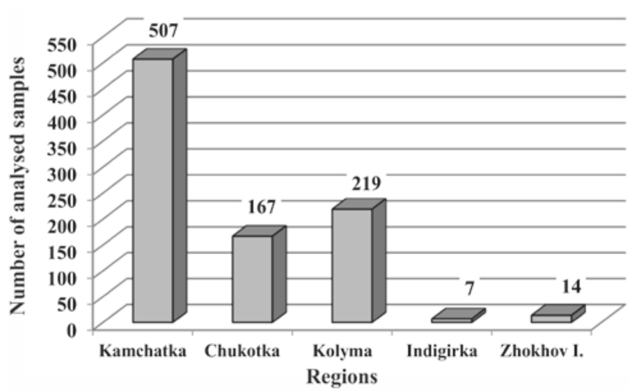

Fig. 7.1 Statistics of analysed obsidian samples in the northern Russian Far East and Northeastern Siberia (see Table 7.1)

et al., 2010, 2018; Kuzmin et al., 2021). Based on the results obtained, Kamchatkan obsidians can be divided into 16 geochemical groups (see Appendix, Table A2) following the approach developed by Glascock et al. (1998). Seven of them include both geological and archaeological samples, and correspond to the main obsidian sources used by prehistoric people. The other seven groups consist of 'archaeological' obsidian (i.e., artefacts) only, and the primary sources for these groups are so far unknown (Grebennikov & Kuzmin, 2017; Grebennikov et al., 2014). Two groups are represented solely by geological source samples that were not procured by ancient people, as far as we know.

The Itkavayam source (group KAM-03) is located near the headwaters of the Itkavayam River drainage basin on the western slope of the Central Range. Volcanic glass constitutes the cone of the small Obsidianovy Volcano which is probably not older than ca. 150,000 years. Obsidian is part of the lava flow, and occurs in layers of massive and striped volcanic glass of black and white colours about 0.4–15 m thick. Obsidians are black coloured, transparent in thin sections, and sometimes banded due to light and dark streaks, with a strong glassy lustre and shell-like fracture with sharp edges. Red and mahogany coloured varieties, due to the presence of dusty and flaky hematite, were also observed. There are at least three more sub-sources of obsidian in the vicinity (Grebennikov et al., 2010).

The Ichinsky Massif as a cluster of obsidian sources is situated in the middle sector of the Central Range (Fig. 7.2b). This is the largest concentration of volcanic glass locales in Kamchatka, with a territory of ca. 700 km^2. In the vicinity of the Ichinsky Volcano, there are at least 11 distinct sources (Grebennikov et al., 2014: 100). Obsidians from three of them—Payalpan (group KAM-05), Belogolovaya (a.k.a. Belogolovaya Vtoraya) River (KAM-07), and Nosichan (KAM-16)—have been identified in archaeological collections.

Payalpan is one of the major obsidian sources in Kamchatka, and it is famous because of a rare decorative blue variety. It is located 25 km NE of the Ichinsky Volcano, on the western slope of the Maly Payalpan Volcano. Obsidian is associated mainly with the Upper Pliocene sub-volcanic rhyolitic domes and effusive formations like sheets and covers of lavas, tuffs, tuff breccias, and ignimbrites. The obsidian layers are generally not thick, at 1–2 m on average. Obsidian occurs mainly as individual strata, and also as sets of extended, squeezed, and contiguous lenses in rhyolites; small flows are also known. The richest in obsidians are colluvial deposits on the banks of the Obsidianovy Creek, with a diameter of pieces from 3–5 to 50 cm. Obsidians vary in colour and texture: there are dark-grey, black, and greenish massive varieties; and finely fragmented reddish-brown and bluish-banded ones.

The Belogolovaya River source is a set of lenses and layers of obsidian embedded in effusive and pyroclastic rocks. Obsidian lenses are found in the upper part of the dacitic lava flow outcrop of Middle Pleistocene age, as scatters of colluvium on steep slopes of the Tynya Summit. Volcanic glass is mostly black, with cracks, and contains plagioclase phenocrysts. Other varieties are represented by brownish and mahogany coloured obsidians with black inclusions.

The Nosichan source is situated on the right bank of the Nosichan River, in the vicinity of the Polyarnaya Summit. Here there are small obsidian scatters and rare primary outcrops in the form of lenticular beds and dikes of Pliocene

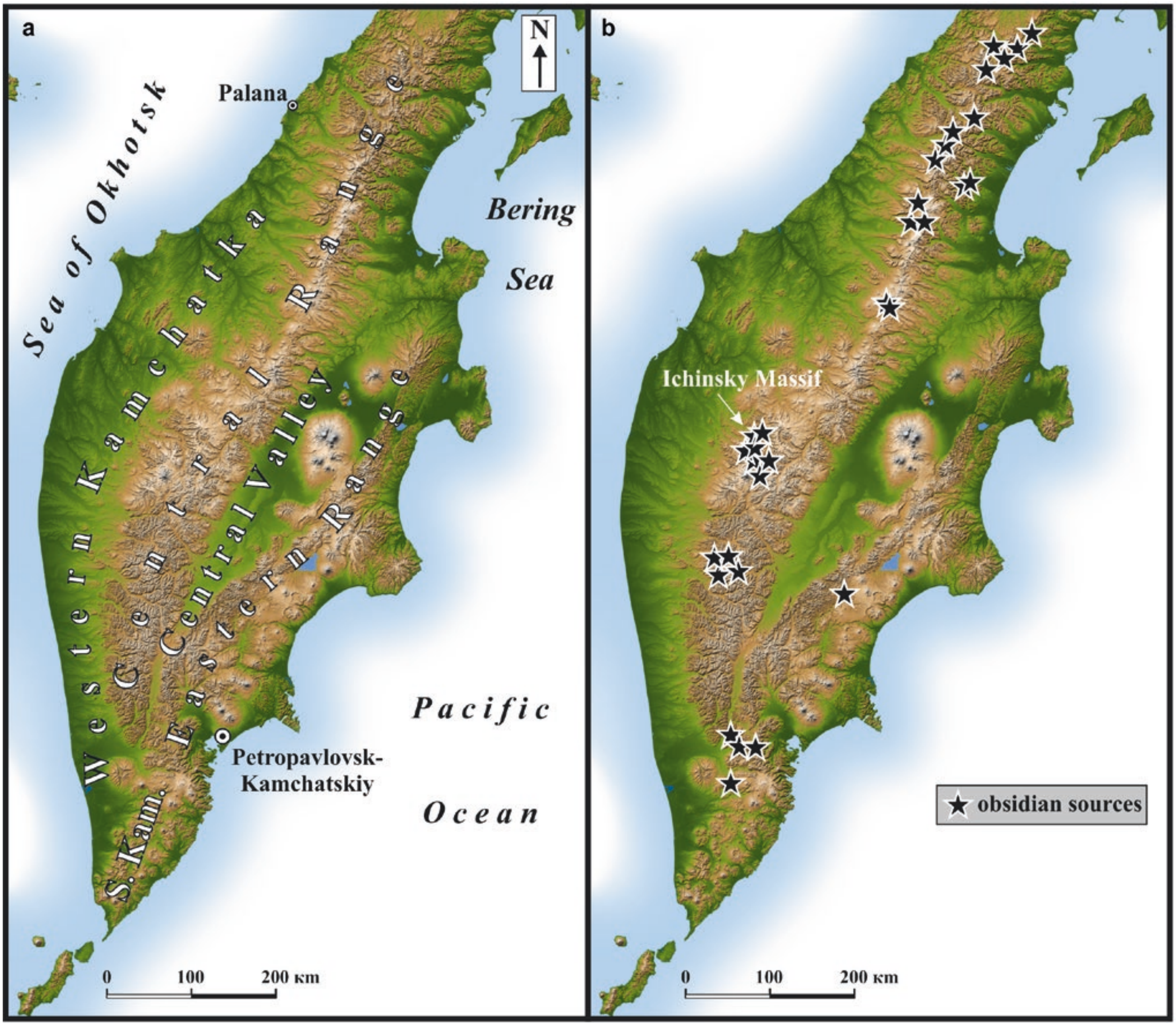

Fig. 7.2 **a** Main geographical regions of Kamchatka Peninsula (S. Kam.—southern Kamchatka); **b** Location of major obsidian sources in Kamchatka (after Grebennikov et al., 2010; modified)

age, from 4–5 to 8 m thick (at bulges), and up to 270 m long. This obsidian is genetically related to rhyolitic extrusions, and is represented by multicoloured varieties: mostly black (both transparent and smoky), and more rarely amber, brown, and lilac ones.

In the Eastern Range, there are some obsidian sources for which geochemical information exists. They are known in the central part of the range, and are correlated to the Pleistocene phase of the acidic ignimbrite volcanism. The best-known source is the Karymsky Volcanic Centre (group KAM-09) (Fig. 7.2b); however, prehistoric people rarely used it (Grebennikov et al., 2010). Here pure obsidians are embedded in the pumice tuffa of the Odnoboky Volcano, dated to ca. 100,000 years ago. The younger pyroclastic pumices of the Akademii Nauk Caldera, dated to ca. 40,000–28,000 years ago, also contain obsidian fragments. The texture is massive, with a transparent thin edge, and black in colour.

Two obsidian sources are known in southern Kamchatka, but they were rarely used in antiquity (Grebennikov et al., 2010). The best-known one is the Nachiki source of perlites and pure obsidians (group KAM-06), as a part of the extrusive dome of the Shapochka Volcano dated to the Pliocene (Fig. 7.2b). A distinct feature of the Nachiki source is the presence of plagioclase and pyroxene phenocrysts in the black glass matrix. Natural outcrops of obsidian are visible at the top of the Nachiki Summit as a sheet of volcanic glasses representing the selvedge of chilled extrusive rhyolites. The obsidian and perlite deposits have a complex structure. The obsidian is black, whereas the perlites have a lighter colour (greyish-black), and are weakly transparent and gently banded. Perlite from the Nachiki source is commercially mined for making insulation materials.

The second source, Chasha Maar (group KAM-11), is located to the west of the Gorelaya Sopka Volcano in the Tolmachev Dol River valley (Fig. 7.2b). It originated from the slaggy lava cone of the Chasha Maar dated to the mid-Holocene, ca. 5300 years ago (Dirksen et al., 2002). Among the fragments of volcanic tephra, large (up to 30 cm long) pieces of obsidian of light grey colour were found.

Based on geochemical matching of primary sources and artefacts in Kamchatka, the spatial distribution of obsidian from the major sources can be reconstructed. The main suppliers for Kamchatkan prehistoric populations were Payalpan and Itkavayam; the distribution of raw material originating from the Belogolovaya River source is very similar to the former locale (Grebennikov et al., 2010: 101). Distances from primary locale to utilisation sites (as the crow flies) for the Payalpan source are from ca. 100 km to ca. 900 km; for the Itkavayam—from ca. 130 km to ca. 700 km (and sometimes more than ca. 1000 km); and for the KAM-3 group—ca. 270–900 km (values are tentative because the exact position of this source is still unknown) (Fig. 7.3). Obsidian was widely used in the Upper Palaeolithic (ca. 17,400–12,000 years ago), Neolithic (ca. 6000–1500 years ago), and Palaeometal (1500–300 years ago).

The issue of unknown obsidian sources for Kamchatka is highly relevant to the main subject of this chapter. In total, seven geochemical groups of archaeological samples do not have matches with known primary sources. Currently, we have 281 obsidian artefacts from 44 sites in Kamchatka and the adjacent areas that belong to these groups (Table 7.2), and they cannot be assigned to any of the nine primary Kamchatkan sources with an exactly known position.

Artefacts of the KAM-08 group are known from northernmost Kamchatka (Grebennikov et al., 2010: 113, Fig. 6.18), the Koryak Upland and the adjacent Bering Sea coast (Grebennikov et al., 2018), and the Omolon River basin (Kuzmin et al., 2021). This distribution of sites to some extent is similar to that of the Payalpan and Itkavayam sources in central Kamchatka (Fig. 7.3). According to geological data (Grebennikov & Kuzmin, 2017: 97–98), the KAM-08 group belongs to the Central Range. The K–Ar age of obsidian from the Pakhachi site is ca. 6.9–6.3 Ma. Obsidian from the Lake Palana source in northern Kamchatka is ca. 6.6 Ma old, and this locale could be a possible candidate for the primary source of the KAM-08 group. Judging from the spatial distribution of artefacts of the KAM-08 group only in northern Kamchatka and adjacent regions, it is therefore plausible to suggest that the source is situated somewhere northeast of the town of Palana (Fig. 7.3).

The best possible suggestions about the position of other unknown sources can be made for the KAM-01 and KAM-10 groups with known absolute ages (Fig. 7.4). Less information is available for other artefact groups: KAM-02, KAM-04, KAM-14 and KAM-15 (Grebennikov & Kuzmin, 2017). According to geochemical zoning, the KAM-02, KAM-04, and KAM-14 groups belong to the Eastern Range, and the KAM-15 group to the Central Range.

Artefacts of the KAM-01 group are distributed all over Kamchatka, mainly in its southern part (Fig. 7.4a). The K–Ar age of obsidian from the Avacha site is ca. 1.94 Ma (Grebennikov et al., 2014). This geochemical group belongs to the Eastern Range. In this part of Kamchatka, powerful ignimbrite eruptions at ca. 1.8 Ma ago at the Karymshyna Caldera occurred in the southernmost part of the Eastern Range (Bindeman et al., 2010; Grebennikov et al., 2014: 105, Table 7.1).

Artefacts of the KAM-10 group are known from the central part of the peninsula, the Kamchatka River basin (Fig. 7.4b). The K–Ar age of obsidian from the Anavgai 2 archaeological site is ca. 3.3 Ma (Grebennikov et al., 2014). According to geochemical zoning, this group belongs to the Eastern Range, similar to the Karymsky Centre (KAM-09 group). Judging from the available geological information (Bindeman et al., 2010), the Stol Summit is the most probable candidate for the primary source of the KAM-10 obsidian. Here the ignimbrites are dated to ca. 3.7 Ma.

Due to its large size and remoteness, obsidian provenance research in Kamchatka is still at the infancy stage. More work is clearly needed in terms of analysis of both sources and artefacts, including the K–Ar dating of obsidian groups with unknown primary localities.

7.2 Chukotka Region

The only primary source of high-quality volcanic glass in Chukotka and adjacent regions of Northeastern Siberia (outside of Kamchatka) is known from the eastern shore of Lake Krasnoe (*Red* Lake). It is located 120 km W of the town of Anadyr (Fig. 7.5). Obsidian from this source was known to geologists and archaeologists for decades (e.g., Cook, 1995), but a real study was not undertaken until 2009 when our team investigated it (Grebennikov et al., 2018; Popov et al., 2017).

The general geological features of the Lake Krasnoe area are described as follows. The lake is surrounded on the west by the Chikaevo Mountains (heights of 280–390 m a.s.l.), and on the east by the Rarytkin Ridge (350–420 m a.s.l.); both mountainous systems consist of Paleogene (Late Eocene–Oligocene) effusives that belong to the West Koryak Volcanic Belt (Fig. 7.5). It is characterised by the widespread occurrence of acidic volcanic rocks (lavas and

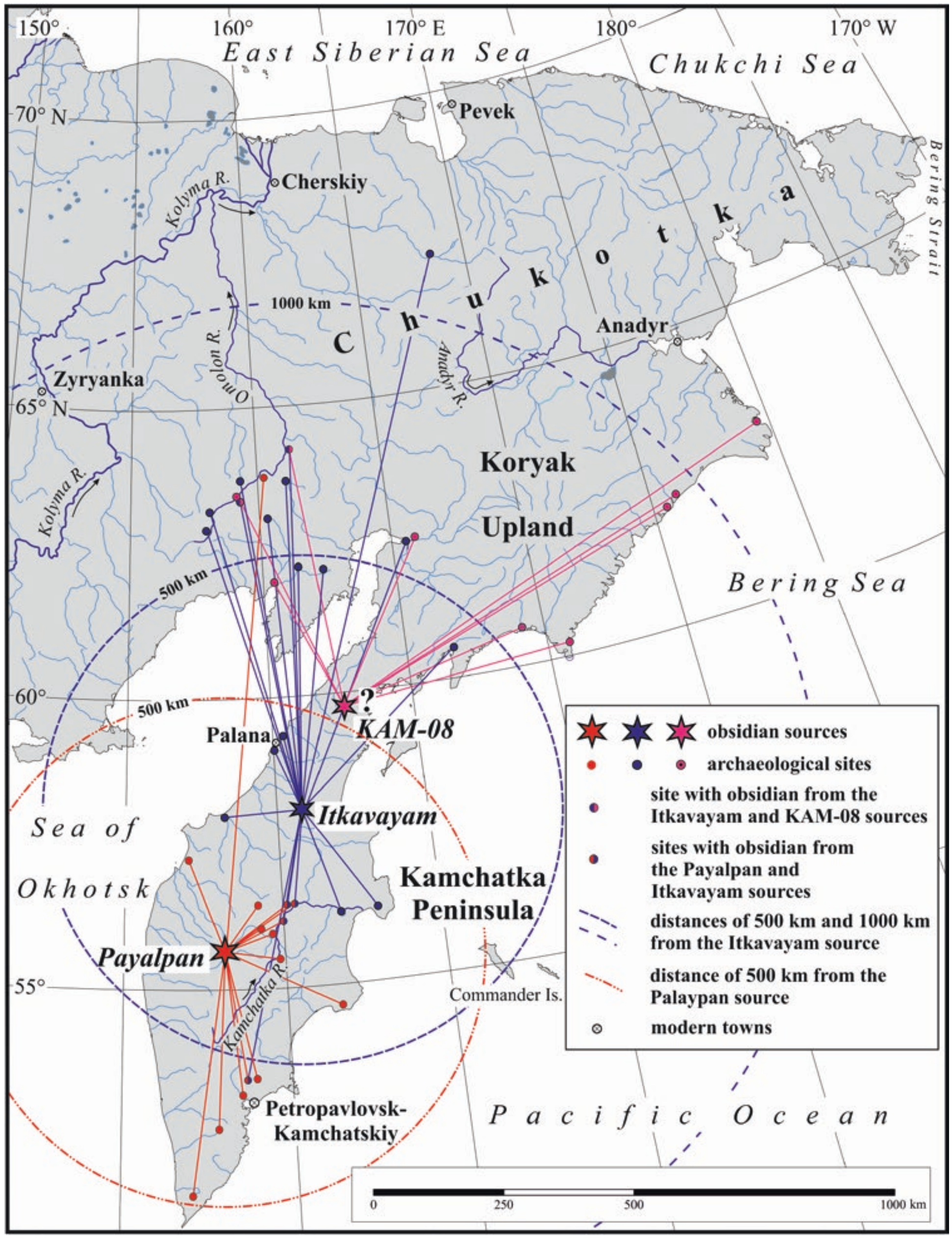

Fig. 7.3 Distribution of obsidian artefacts from two known Kamchatkan sources, Payalpan (KAM-05) and Itkavayam (KAM-03), and from the unknown KAM-08 source

ignimbrites; and tuffs of rhyolites, rhyodacites, dacites, and, less commonly, andesites) and basalts, up to 270 m thick.

On the eastern lakeshore, the bottom part of outcrops consists of intensively metasomatised rhyolitic tuff strata. Above them, thick layers of ignimbrite flows of rhyolitic and rhyodacitic composition exist, which in some places are intruded by felsites and mafites. No obsidian nodules are observed in these rocks, *contra* descriptions made by some scholars who had not visited Lake Krasnoe, and thus had no familiarity with the area concerned (e.g., Nasedkin, 1983). However, beach deposits—especially at the Cape Medvezhy (Cape *Bear*) (Fig. 7.5)—contain numerous rounded obsidian pieces. The size of them varies from small pebbles (1–2 cm in diameter) to relatively large boulders (up to 30 cm in diameter, and sometimes even larger).

Two kinds of obsidian are known from the Lake Krasnoe shore: black and dull. The first type is the most common, with its highest concentrations at the Cape Medvezhy, Mysovoi (*Cape*) Creek, and Cape Rybachy (*Fisher*) (Fig. 7.5). The colour is black (morion-like), with a strong lustre; its surface is covered with conchoidal micro-cracks and has impact traces of glass shards. There are also rare examples of motley-layered obsidian, and its colour is due to red-brown oxidation. In thin slides, the glass matrix has very small particles of ore minerals and inclusions as thin stripes that reflect the flow of the melt. In some samples,

Table 7.2 Geochemical groups for unknown sources of archaeological obsidian in Kamchatka and neighbouring regions (after Grebennikov & Kuzmin, 2017; Grebennikov et al., 2018; Kuzmin et al., 2021)

Source group	Number of sites	Number of artefacts	Suggested primary source
KAM-01	20	113	Karymshyna Caldera
KAM-02	16	45	Bakening Volcano
KAM-04	11	28	Uzon Caldera
KAM-08	10	35	Northern part of Central Range[b]
KAM-10	9	49	Stol Summit[c]
KAM-14	2	2	Karymsky Volcanic Centre
KAM-15	1	9	Ichinsky Volcano
Total	44[a]	281	

[a]At 20 sites, obsidian from two or more unknown sources was identified
[b]See Fig. 7.2 for the distribution of sites with obsidian from this source
[c]Situated in the vicinity of the Karymsky Volcanic Centre

there are small (up to 0.2 mm in diameter) crystal-like inclusions of sanidine, zircon, and amphibole. The dull variety of obsidian is very rare, and it has a cryptocrystallic texture. The SiO_2 content in obsidian from Lake Krasnoe is 73.5–77.1% wt; the K–Ar age is ca. 33–31.3 Ma (Grebennikov et al., 2018).

As for the origin of the Lake Krasnoe obsidian, initially it was suggested to be the result of erosion of tuff strata but without actual observation. During our 2009 fieldwork, we did not detect any obsidian pieces, even small ones, in the lakeshore outcrops. The western coast of the lake has no obsidian at all. On the eastern shore, obsidian is plentiful in the beach deposits only; small rivers flowing from the watershed do not carry any obsidian pebbles (Fig. 7.5). Therefore, the suggestion about the primary source of obsidian being located in the rocks of coastal cliffs near Cape Rybachy (Nasedkin, 1983: 39–40) seems to be incorrect. Based on the chemical compositions of obsidian pebbles and volcanic glasses from the groundmass of felsites (Grebennikov et al., 2018), it is plausible to suggest that the accumulation of obsidian may be related to the erosion of extrusive domes (dikes). Most probably, these dikes are now hidden under the lake's water, and only pebbles can be found on the beaches of the eastern shore.

According to the geochemical data, there are three groups of obsidian (see Appendix, Table A3). The Cape Medvezhy group (KRASN-1) is the most numerous, and the majority of artefacts from Chukotka (ca. 82%) belong to this group. A few artefacts (ca. 3%) belong to the Cape Rybachy group (KRASN-2); the proportion of specimens associated with the Vakarevo group (the exact source is still unknown) is ca. 4%. Prehistoric people transported some artefacts (ca. 11%) to Chukotka from Kamchatkan sources (Grebennikov et al., 2018).

Obsidian is widely distributed in the prehistoric Chukotkan sites (Dikov, 1997, 2003; Kiryak, 2010). We have in our database the results of geochemical analysis of 130 samples from 41 sites (Table 7.1; Fig. 7.6). The assemblages are associated with the Upper Palaeolithic (ca. 15,000–10,000 years ago), Neolithic (ca. 6500–2500 years ago), and Palaeometal (ca. 2500–500 years ago) periods (Kuzmin, 2000). Most of the sites with obsidian artefacts (56% of the total) belong to the Neolithic period. The distances from the Lake Krasnoe source to utilisation sites in Chukotka vary from a few kilometres to ca. 500–700 km in a straight line (Fig. 7.6). There are cases of long-distance transportation of Chukotkan obsidian, with the distance exceeding 1000 km, such as Zhokhov Island and Alaska (Fig. 7.6; see also Chap. 9).

As for the distribution of obsidian from the Lake Krasnoe source in the immediate vicinity of the Chukotka region, a few artefacts were identified in the Koryak Upland, and none in northern Kamchatka (Fig. 7.6). This to some extent can be explained by the insufficient degree of archaeological survey of these regions. Many more obsidian items made by ancient people, originating from Lake Krasnoe, were detected in the assemblages of the neighbouring Omolon and Gizhiga rivers that are better explored by archaeologists (Kuzmin et al., 2021).

Recently, some obsidian artefacts from Kamchatkan sources were securely identified in central Chukotka and the Koryak Upland (Fig. 7.3). The distances from source to sites are ca. 500–1100 km in a straight line. Previously, the transport of Kamchatkan obsidian to Chukotka was suggested based on a few samples only (Grebennikov et al., 2018), and has now been confirmed by additional data (Kuzmin et al., 2021).

7.3 Basins of Kolyma and Indigirka Rivers

In Northeastern Siberia, Kolyma is the largest river (Figs. 1.2 and 4.1). It is ca. 1800 km long, and its drainage basin occupies an area of ca. 643,000 km^2. Most of this region is not well-surveyed by archaeologists, and only a few dozen sites have been excavated to date (e.g., Dikov, 2003, 2004; Kashin, 2013; Slobodin, 2014, 2015). In the middle and lower courses of Kolyma, significant work was done in the 1990s—early 2000s (Kuzmin et al., 2018). Obsidian provenance study was carried out at 15 sites, and 107 artefacts were matched with the Lake Krasnoe source. The sites associated with the three main Neolithic cultural complexes of the region—Syalakh, Belkachi, and

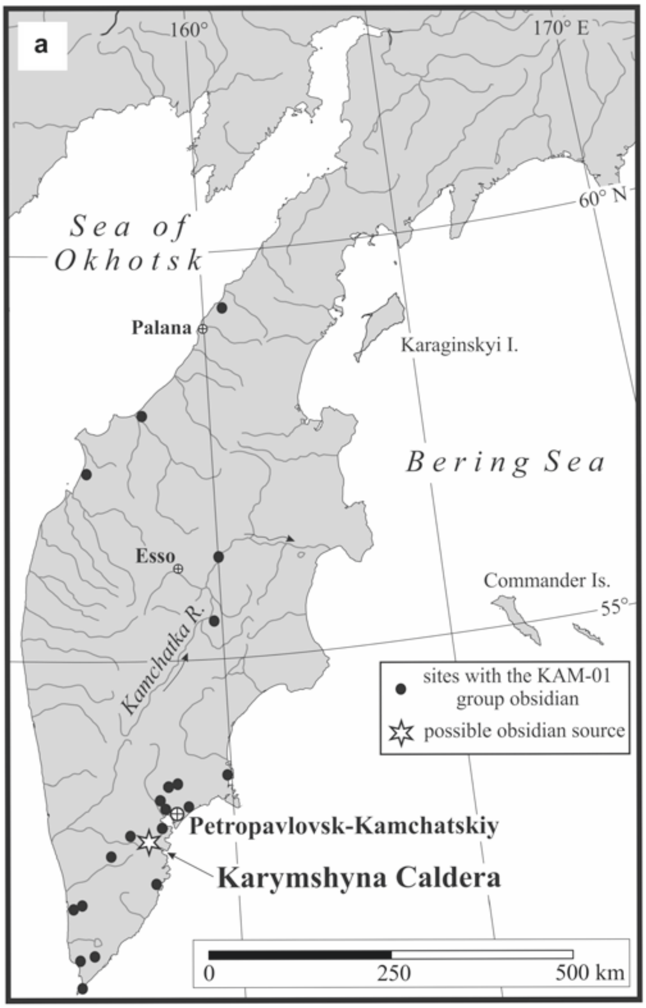

Fig. 7.4 Distribution of obsidian artefacts belonging to the KAM-01 group (**a**) and the KAM-10 group (**b**), and suggested locations of the sources

Ymyyakhtakh—are dated to ca. 6900–3000 years ago. Distances between the Chukotkan source and sites in the Kolyma River are very big, ca. 800–1100 km as the crow flies (Fig. 7.6).

Another part of the Kolyma River region is the basin of its largest tributary, the Omolon River (Fig. 7.6). It is ca. 1150 km long, and the drainage basin covers ca. 113,000 km^2. An obsidian provenance study in this area was recently conducted by Kuzmin et al. (2021) in the upper course of the river. Fifty samples from 22 sites were geochemically analysed and assigned to the Lake Krasnoe source. Also, 57 obsidian artefacts from 13 sites belong to three Kamchatkan sources (Fig. 7.3). Sites are associated with the final Upper Palaeolithic (ca. 13,000–10,800 years ago), Mesolithic (ca. 10,100–7800 years ago), and Neolithic (ca. 6800–2900 years ago). The majority of sites (17, or 57% of the total) belong to the Neolithic, and nine sites (30%) can be assigned to a general Mesolithic–Neolithic category (Kuzmin et al., 2021). The distances between the primary locality of Lake Krasnoe and consumer sites are ca. 650–850 km in a straight line (Fig. 7.6), and for the Kamchatkan sources—ca. 500–700 km and even up to ca. 900 km (Fig. 7.3).

Some obsidian provenance work was also done in the lower course of the Indigirka River (Kuzmin et al., 2020). This is the region with the westernmost finds of obsidian artefacts in northern Asia (Fig. 4.1), and they are very rare here; a handful of obsidian items has been recorded (Fedoseeva, 1980: 150). Seven artefacts from the Buolumuna-Taasa site are assigned to the Lake Krasnoe source. This Neolithic site can be dated to a broad interval of ca. 7000–3000 years ago. The straight distance between the primary source and the site is ca. 1300 km (Fig. 7.6), and this is one of the longest cases of raw material transportation in the entire region of Northeast Asia.

In general, the Lake Krasnoe source in Chukotka was the main supplier of obsidian for the vast swathes

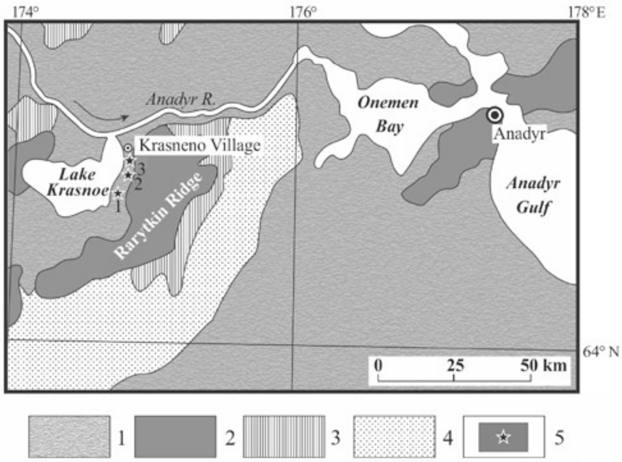

Fig. 7.5 Schematic geological map of Lake Krasnoe (after Popov et al., 2017; modified). 1—Quaternary deposits; 2—Late Eocene–Oligocene rocks of the West Koryak volcanic belt; 3—Palaeocene–Middle Eocene basalts; 4—rocks of the Mesozoic basement; 5—obsidian sampling sites on the Lake Krasnoe shore: Cape Medvezhy (1); Cape Rybachy (2), and Mysovoi Creek (3)

of Northeastern Siberia (Fig. 7.6). Kamchatkan obsidian was transported to some areas in the Koryak Upland and Omolon River basin, and occasionally to central Chukotka (Fig. 7.3). The absence of Chukotkan obsidian in Kamchatka is noteworthy, most probably because of the dominance of Kamchatkan sources in the latter region.

7.4 Insular Northeast Siberian Arctic (Zhokhov Island)

The Zhokhov site at 76° N is the northernmost Mesolithic settlement in the world. It is located on a small island of the same name, and on the western limit of obsidian distribution in the Siberian Arctic (Fig. 4.1). According to lithic typology, the Zhokhov site can be associated with the Sumnagin cultural complex, which was widely dispersed across northern Siberia (e.g., Pitulko, 2001). The site is dated to ca. 9200–8600 years ago (Pitulko & Pavlova, 2022). The amount of obsidian artefacts is small, at 0.54% of the total lithics (Pitulko et al., 2019).

Analysis of the faunal remains from the Zhokhov site demonstrates a quite unusual adaptation based on the procurement of reindeer and polar bear. The site functioned as a year-round base camp; in the winter, people hunted polar bears; in the spring and autumn, the pursuit of reindeer was the main activity, involving movements around the present-day New Siberian Islands (Pitulko et al., 2015). It is remarkable that inhabitants of the Zhokhov site kept domesticated dogs for hunting and as draught animals for sledges (Pitulko & Kasparov, 2017).

Of 79 obsidian artifacts found at the site, 14 were randomly selected for provenance analysis. After comparison of the results obtained from all major sources in Kamchatka and Chukotka, it was found that the geochemistry of the Zhokhov artefacts is in good agreement with a 90% confidence ellipse for the Cape Medvezhy group (KRASN-1), at Lake Krasnoe in the Chukotka region (Pitulko et al., 2019). This result indicates extremely long-distance movement of obsidian from the source to the utilisation site, ca. 1500 km as the crow flies (Fig. 7.6).

The presence of wooden remains of sledge runners, other sledge equipment, and domesticated dogs allows the suggestion that sledge transport was used for extensive travel by the inhabitants of the Zhokhov site. When the settlement existed, it was located on the shore of the Arctic Ocean; this is confirmed by the presence of the large amount of driftwood found at the site and the general palaeogeographic situation (Pitulko et al., 2019). Due to the Holocene transgression and inundation of the continental shelf, the area of today's Zhokhov Island after the site was abandoned became disconnected from the mainland of Northeast Asia at ca. 8600 years ago. At ca. 8800 years ago, the last evidence of a land connection between the northern New Siberian Islands (De Long group) and mainland Northeast Asia—with reference to a horse bone retrieved from Vilkitskyi Island—is known (Pitulko et al., 2019). After ca. 8800 years ago, horses could not reach the De Long island group by crossing the wide cold water space.

There are only a few localities where obsidian artefacts are known elsewhere in the northeastern Siberian Arctic, between the Chukotkan source area and the Zhokhov site. These are poorly dated surface and in situ contexts of Holocene age, namely Belaya Gora and Buolumuna-Taasa in the Indigirka River basin; Starye Petushki, Konzaboi, Pomazkino, Rodinka, Kamenka, Kigilyakh, and Labuya in the middle and lower courses of the Kolyma River; and the Lake Tytyl cluster of sites in western Chukotka. It is therefore plausible to suggest that transportation of obsidian from the Lake Krasnoe source to the Zhokhov site was conducted via several prehistoric 'hubs' where exchange took place (Pitulko et al., 2019).

Fig. 7.6 Distribution of archaeological obsidian from the Lake Krasnoe source in Northeastern Siberia

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8 Patterns of Human Movements and Migrations in Prehistoric Northeast Asia Based on Obsidian Provenance

8.1 Obsidian Distribution Networks in the Stone Age of Northeast Asia

Throughout the Upper Palaeolithic and Neolithic of Northeast Asia, several large-scale obsidian exchange networks existed. In the southern part of the region (Russian Far East, Japan, Korea, and Northeast China), the main sources of high quality lithic raw material were the Basaltic Plateau, PNK1, Shirataki, Oketo, Wada–Suwa, Takaharayama, Kozu-shima, and Koshidake. Other primary obsidian locales, such as Oki, Akaigawa, Fukaura, and Iwakisan, were also exploited (Fig. 8.1).

According to the latest summaries, the earliest exploitation of obsidian as raw materials in Northeast Asia can be assigned to the first part of the Upper Palaeolithic: in Japan—at ca. 37,500 years ago (sites of Idemaruyama and Doteue, Shizuoka Prefecture) (Ono, 2014; Ikeya, 2015; Yamaoka et al., 2022); in Korea—at ca. 29,600–28,700 years ago (sites of Sinbuk, South Jeolla Province; Janghung-ri, Gangwon Province; and Samgeo-ri, Gyeonggi Province) (Choi, 2001; Lee & Kim, 2015; Baekdu Institute …, 2019; Kim & Seong, 2022); in Northeast China—at ca. 39,100 years ago (Shoushan-Xianrendong Cave, Jilin Province) (Chen et al., 2007; Kato, 2021); in the southern Russian Far East—at ca. 23,400 years ago (Ogonki 5 site, Sakhalin Island) (Kuzmin, 2014; Kuzmin & Glascock, 2007); and in Northeastern Siberia—at ca. 17,500 years ago (Ushki site cluster, Kamchatka) (Kuzmin et al., 2008).

The beginning of obsidian transport in the insular part of Northeast Asia can be dated to the early Upper Palaeolithic, ca. 37,500 years ago on Honshu Island, when the Kozu-shima obsidian was brought across the sea straits. Obsidian was widely circulated in Japan and on Sakhalin Island in the Upper Palaeolithic, at ca. 31,000–14,000 years ago. In the mainland areas of southern Northeast Asia, the earliest evidence of obsidian transport is known for Korea, ca. 30,000 years ago. The procurement of obsidian continued in Korea, the Russian Far East, and Northeast China throughout the Upper Palaeolithic, ca. 40,000–14,000 years ago.

In the Holocene, the inhabitants of southern Northeast Asia (Fig. 8.1) extensively used obsidian. In Japan, it was circulated on Hokkaido, Honshu, and Kyushu islands in the Jomon period, ca. 9000–3000 years ago. The Koshidake source on Kyushu Island supplied the raw material for the southern coast of Korea at ca. 7000–3000 years ago, and for the northern and central Ryukyu Islands at ca. 8800–4500 years ago. In Korea, the exploitation of obsidian from the PNK1 source in the Neolithic is still not well-documented, but it was found at some sites in both the northern and southern parts of the Korean Peninsula, dated to approximately 7000–4000 years ago. In the mainland southern Russian Far East (Primorye and Amur River basin), obsidian from three major sources—Basaltic Plateau, PNK1, and Obluchie Plateau—was widely used at ca. 12,000–3000 years ago (Fig. 8.2).

The active colonisation of the Kurile Islands in Epi-Jomon times, ca. 2500–1500 years ago (Gjesfjeld et al., 2019; Phillips, 2010), reflects a more general pattern of goods exchange in later prehistoric and early historic times between Hokkaido and the neighbouring territories (Hudson, 2004, 2014; see also Tezuka, 1998). This is documented, for example, by the presence of imported items of Chinese origin in the Ainu culture, and by the spread of Ainu trade from Hokkaido to Sakhalin Island, Kurile Islands and Kamchatka (Sasaki, 1999).

The phenomenon of long-distance exchange and/or transport of obsidian in southern Northeast Asia is well-known (Fig. 8.1). According to the most widely accepted viewpoints, when the space between the source and utilisation site exceeds ca. 300 km in a straight line, the exchange via a chain of middlemen was the most likely mechanism of obsidian acquisition. In the region under consideration, there are several cases when this range is ca. 500–700 km and even more. For example, in mainland Northeast Asia sites with obsidian are up to ca. 700–800 km distant as the

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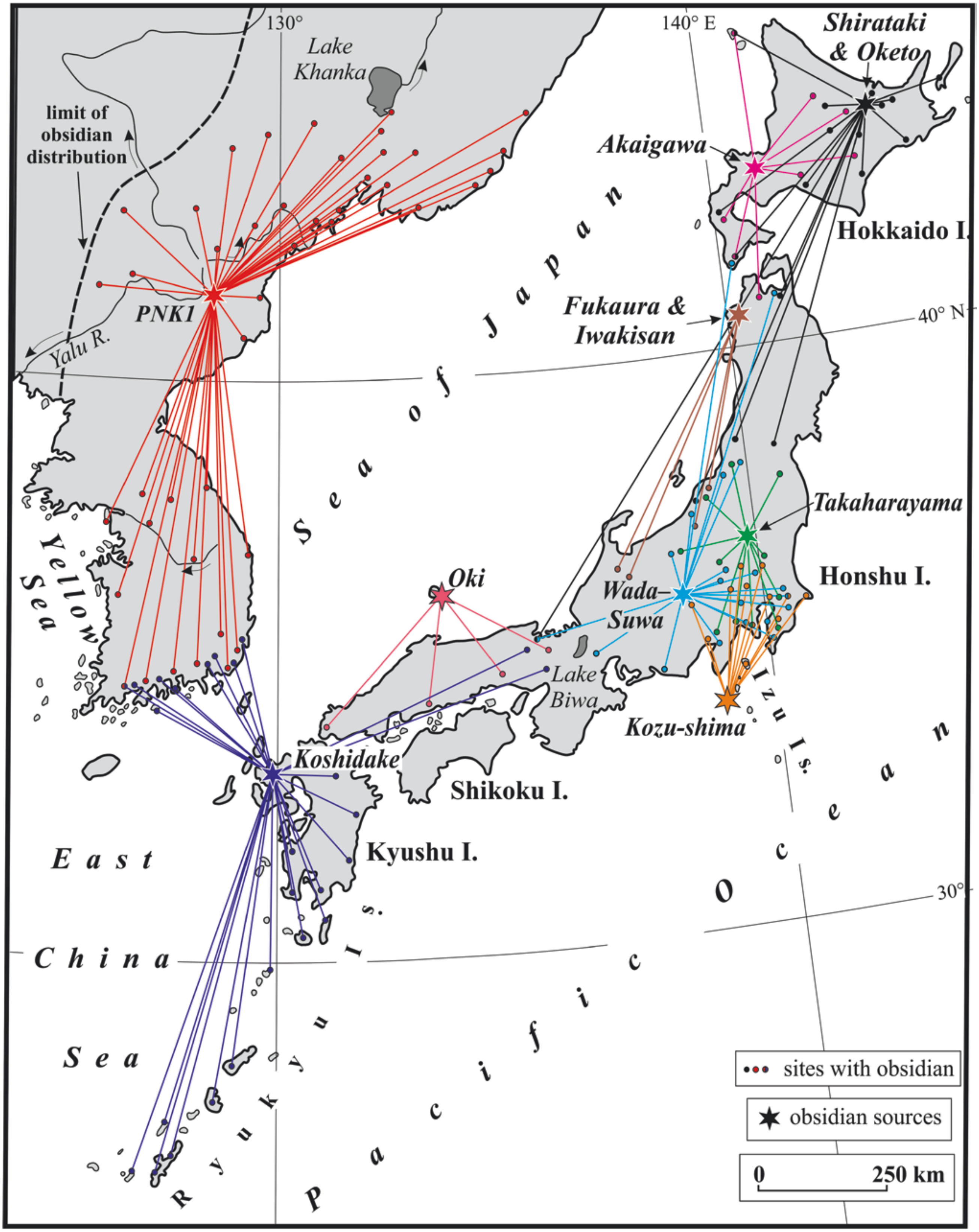

Fig. 8.1 Obsidian distribution networks in the southern part of Northeast Asia

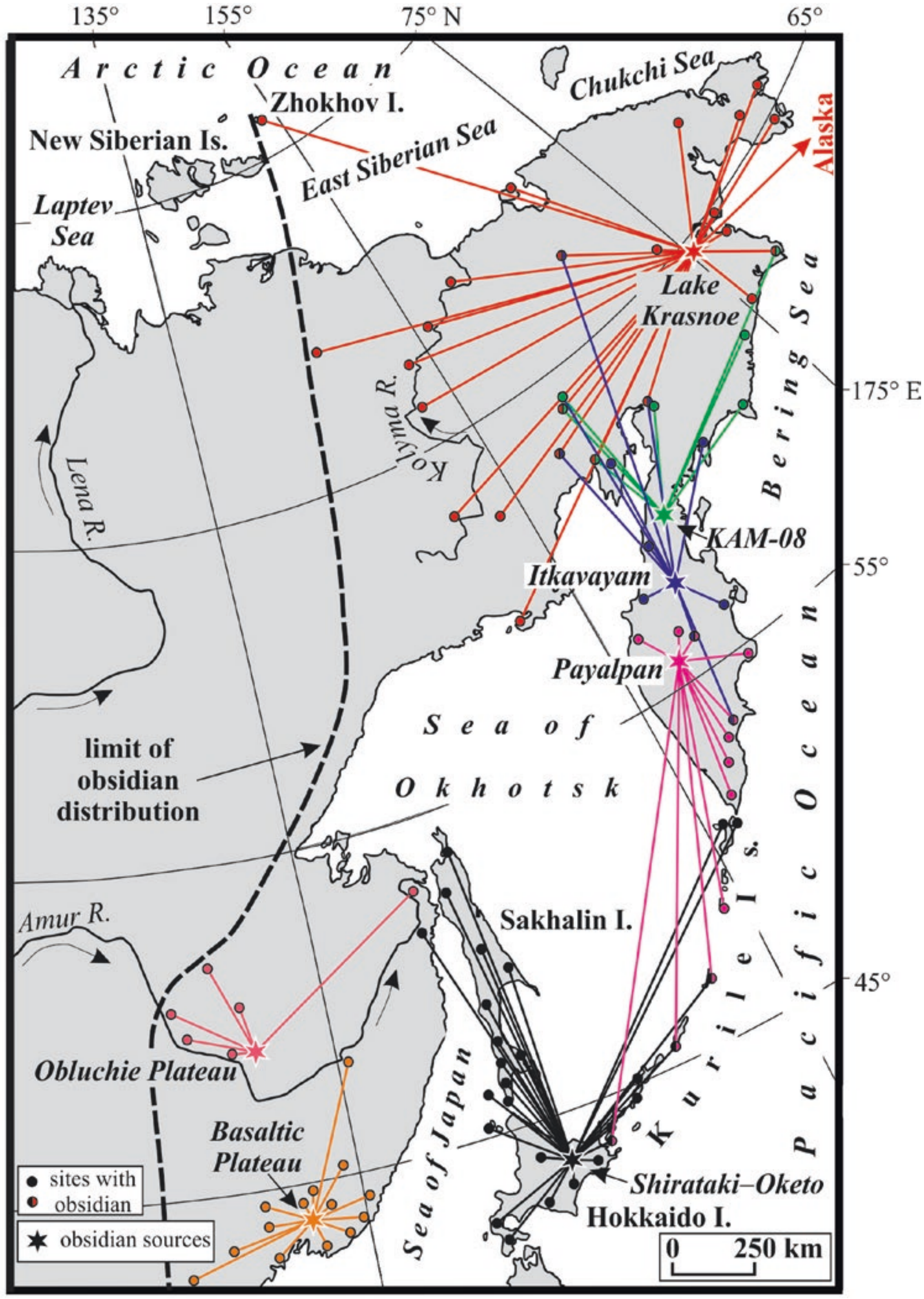

Fig. 8.2 Obsidian distribution networks in the northern part of Northeast Asia

crow flies from the PNK1 source. The sites on Okinawa Island and Kerama Islands are located ca. 700–800 km from the Koshidake source. Two primary locales on Hokkaido Island—Shirataki and Oketo—supplied the vast swathes of land, from central Honshu Island (Kosegasawa and Kamihara E sites, Niigata Prefecture; and Shidaka site, Kyoto Prefecture) to northern Sakhalin Island and the lower course of the Amur River (Suchu site), and to the northern part of the Kurile Islands (Baikova 1 site, Shumshu Island). The scale of the spread of obsidian from the Shirataki and Oketo sources to the south is ca. 700–1200 km, and to the north and northwest—ca. 1200 km (Figs. 8.1 and 8.2).

In the northern part of Northeast Asia, two main obsidian distribution centres in prehistory were the Kamchatka Peninsula and Lake Krasnoe in Chukotka (Fig. 8.2). There is a limited amount of data available for the Upper Palaeolithic sites in these regions in terms of obsidian exploitation. One can place the initial use of obsidian on Kamchatka at ca. 17,500 years ago, and in Chukotka at ca. 13,000 years ago. In the former region, it was procured until European contact in the early eighteenth century AD (Vasil'evskiy, 1998; Dikov, 2003, 2004). The Mesolithic site of Zhokhov, now located on a remote island in the High Arctic, preserves evidence of obsidian procurement dated to ca. 9200–8600 years ago. The most intensive exploitation of obsidian in Northeastern Siberia is known in the Neolithic and Palaeometal, ca. 6000–600 years ago (Kuzmin, 2000).

As for the scale of the distribution of both Kamchatkan and Chukotkan obsidians, it is truly enormous, especially by prehistoric standards, in the absence of draught animals such as dogs (except for the Zhokhov site), reindeer, and horses. In several cases, the distances between obsidian sources and utilisation sites exceeds 1000 km in a straight line. The longest examples are known for the transport of obsidian from Kamchatka to the southern Kurile Islands (ca. 1300–1400 km), and from the Chukotkan source of Lake Krasnoe to the Zhokhov site (ca. 1500 km) (Figs. 8.2. and 7.6). In many instances, spans of ca. 500–700 km are known.

In terms of the scale of obsidian exchange networks, Choi et al. (2021) suggested a territorial extent for the Korean Peninsula and Northeast China of ca. 190,000–500,000 km^2. The Zhokhov site in the Siberian High Arctic is a remarkable example of a sophisticated and large-scale communication network. Obsidian from the remote Lake Krasnoe source, located at a distance of ca. 1500 km as the crow flies, was delivered here at ca. 9000 years ago, most probably through a chain of middlemen (Pitulko et al., 2019). The estimate for the size of this exchange network, based on archaeological and ethnographic evidence, could be ca. 4,000,000 km^2 in the Early Holocene (Fig. 8.3).

Today, at least 16 primary obsidian locales have been identified on Kamchatka, and four of them—Payalpan, Belogolovaya River, Itkavayam, and KAM-08—supplied the entire Kamchatkan territory and the neighbouring Kolyma River basin, Chukotka, and the Kurile Islands (Fig. 8.2). It is noteworthy that Chukotkan obsidian never entered Kamchatka, while the raw material from the latter region is known from archaeological sites in Chukotka and along the Omolon River, part of the Kolyma River basin.

As for the diachronic aspect of obsidian exploitation in Northeast Asia, the Ushki site cluster on Kamchatka is perhaps one of the best examples because of several well-dated cultural components with obsidian artefacts (Kuzmin et al., 2008) (Fig. 8.4, Table 8.1). Here obsidian from eight sources located in the Central Range, Eastern Range, and southern Kamchatka, was procured beginning in the Upper Palaeolithic, ca. 17,500 years ago, almost until European contact about 300 years ago. Three sources—Payalpan, Belogolovaya River, and KAM-15—are situated in the Ichinsky volcanic centre. The Itkavayam source belongs to the Central Range. Four other primary obsidian locales (with unknown exact position; Grebennikov & Kuzmin, 2017) are situated in the Eastern Range (KAM-04, KAM-10, and KAM-14), while the KAM-01 source is most probably associated with southern Kamchatka (Fig. 8.4).

In the oldest Cultural Layer 7 (dated to ca. 17,500–12,700 years ago), the simultaneous use of raw material from six sources has been established. In younger cultural components, the number of sources is from one (Layer 2) to six (Layer 4). The distances from sources to the Ushki sites across the rough terrain are ca. 140–260 km in a straight line (confirmed) and ca. 150–400 km (suggested). The minimum size of the interaction sphere is ca. 70,000 km^2 (Kuzmin et al., 2008). Because the quality of obsidian is the same for all sources, this strategy in acquiring valuable raw material can be explained by the diversity of human behaviour and by the existence of well-developed exchange networks on Kamchatka since the Upper Palaeolithic.

The simultaneous use of several obsidian sources in the Stone Age of Northeast Asia is a common pattern (e.g., Tsutsumi, 2012). This is established for archaeological sites in Primorye, the Amur River basin, Sakhalin Island, the Kurile Islands, and Kamchatka (Russian Far East); Chukotka (Northeastern Siberia); Northeast China; and the Japanese Islands. The overlap of obsidian exchange networks for the Upper Palaeolithic and Neolithic of Northeast Asia is now evident. This testifies in favour of the active exchange/trade of obsidian in antiquity, and intensive contacts between different populations.

8.2 Main Prehistoric Human Migrations in Northeast Asia

Investigations in the field of ancient human migrations and subsequent movements in Northeast Asia are based on several lines of evidence, including archaeology (e.g., Kuzmin, 2015), ancient DNA (Mao et al., 2021; Sikora et al., 2019; Wang et al., 2023), and linguistics (Bellwood 2015). Obsidian provenance can also significantly contribute to this issue, as it was demonstrated by Williams-Thorpe (1995) for the Mediterranean and Near East.

In the Upper Palaeolithic of Northeast Asia (ca. 40,000–12,000 years ago), four main vectors of human migrations can now be reconstructed (Fig. 8.5a). People from modern Taiwan travelled to the southern Ryukyu Islands (Vector 1). Humans from modern Northern China moved first to the Korean Peninsula and continued to the Japanese Islands (Kyushu, Shikoku, Honshu, and Hokkaido, and to the northern Ryukyus); and to the Russian Far East and Northeastern Siberia (Vector 2). From Hokkaido Island, some populations went further north, to Sakhalin Island. From the southern part of Eastern Siberia people at ca. 32,000 years ago penetrated into the Arctic (Sikora et al., 2019) (Vector 3). Since ca. 25,000–20,000 years

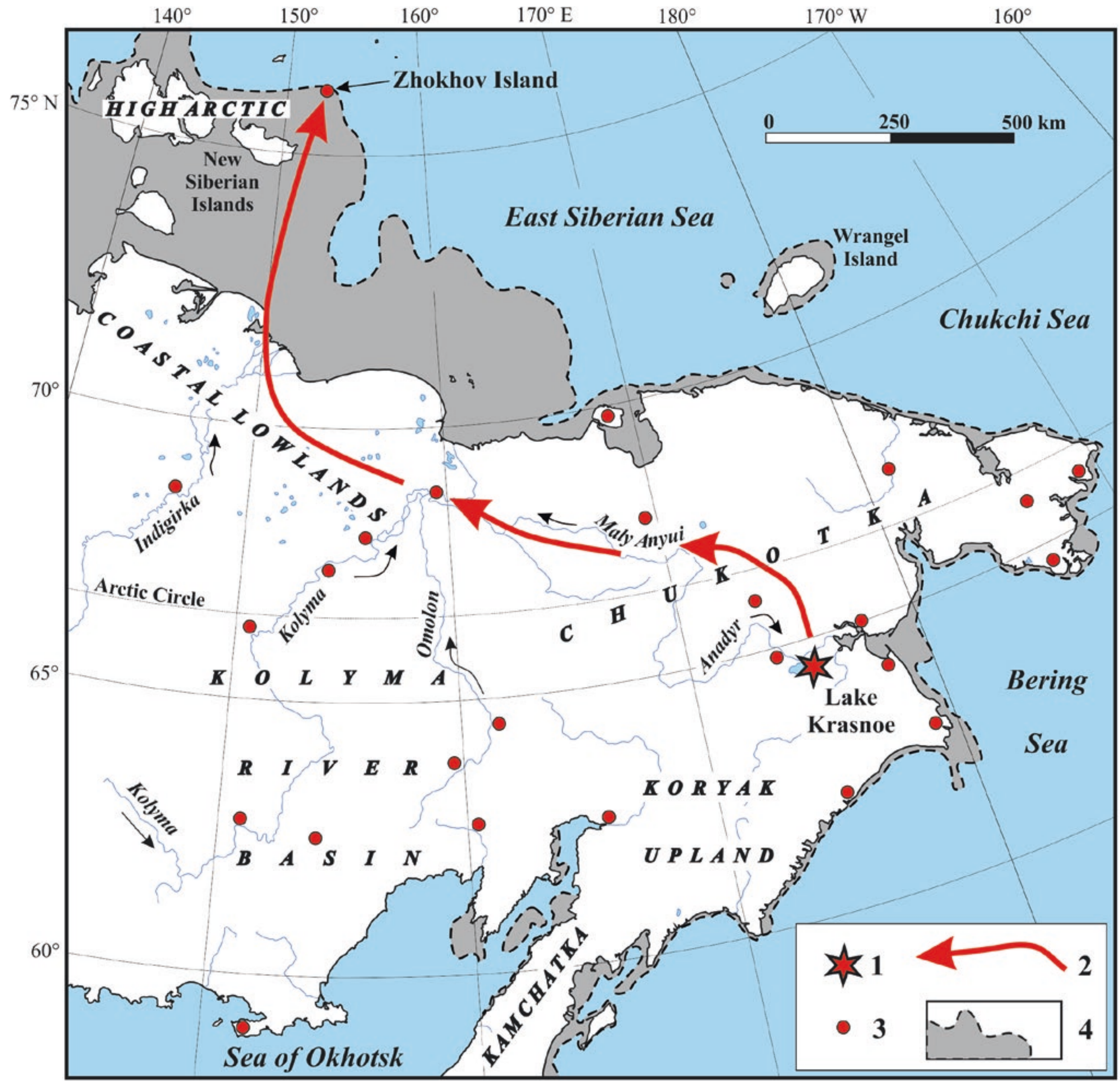

Fig. 8.3 The possible route for obsidian exchange of the Zhokhov site (after Pitulko et al., 2019; modified). 1—obsidian source; 2—suggested route; 3—selected sites with obsidian from the Lake Krasnoe source; 4—exposed continental shelf at ca. 9000 years ago

ago, human movement occurred from the northern part of Eastern Siberia (basins of Lena and Kolyma rivers) to the east, toward Chukotka and Kamchatka, and further to North America (Vector 4) (e.g., Hoffecker & Elias, 2007). Several migrations involved crossing open water by means of sea-going transport (see Chap. 9).

Holocene migrations and movements of people in Northeast Asia (ca. 12,000–3000 years ago) are much better documented than for the Upper Palaeolithic (Fig. 8.5b) (e.g., Kuzmin, 2015; Hudson, 2015). Populations from the Korean Peninsula first went across the Korea Strait to the Japanese Islands, and the movement was further split in two directions: from Kyushu Island toward Honshu, Shikoku, and Hokkaido islands; and from Kyushu Island to the northern and central Ryukyu Islands (Vector 1). From Hokkaido Island, humans continued to move to Sakhalin Island, and also started to settle the Kurile Islands (Vector 1). Some populations of Northeast China and the northern Korean Peninsula travelled toward the southern Russian Far East (Vector 1). People from the Yenisei River basin in Eastern Siberia migrated to the east, toward the Lena River basin, and from there to the High Arctic, reaching the extreme

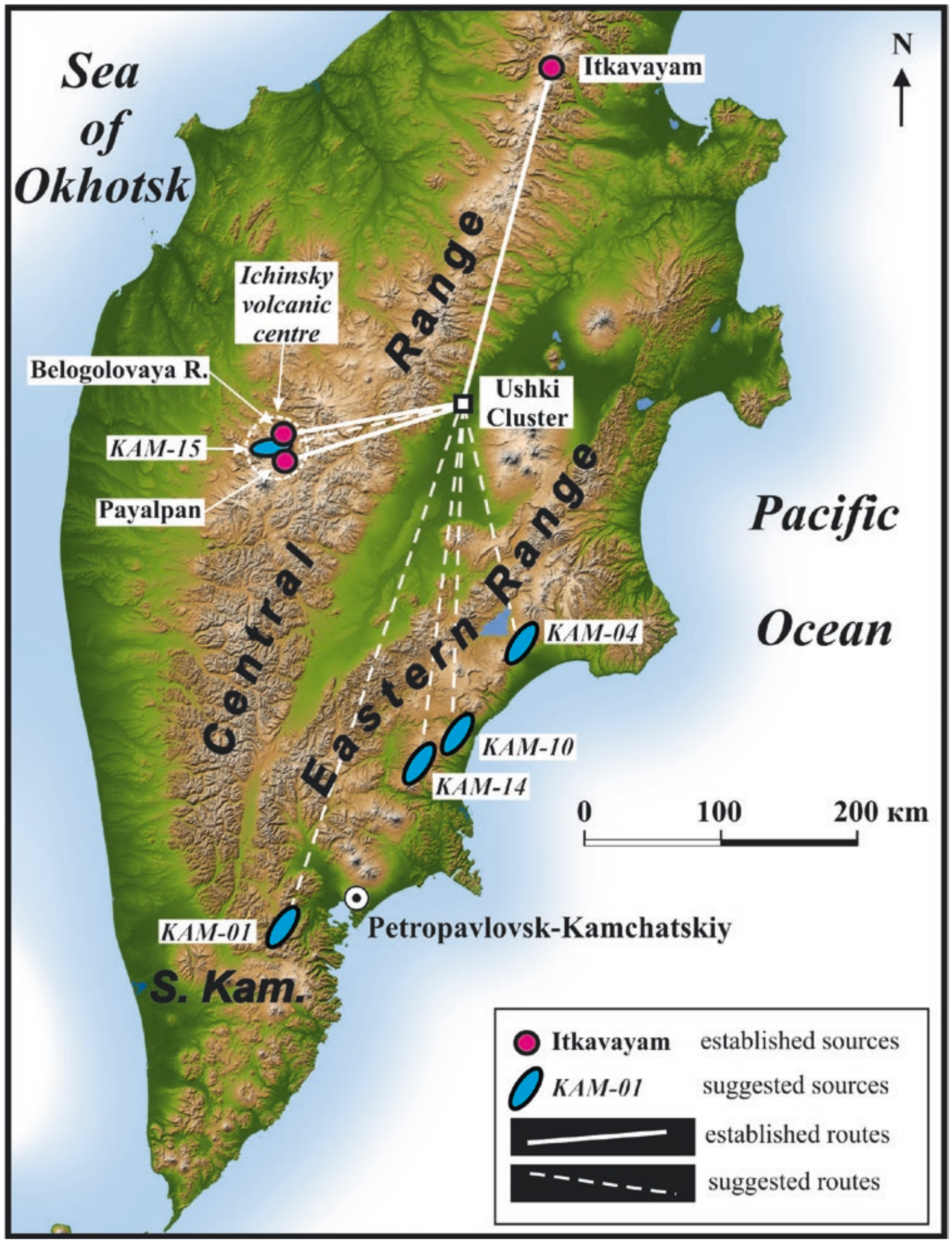

Fig. 8.4 Obsidian sources of the Ushki cluster, Kamchatka (after Kuzmin et al., 2008; Grebennikov & Kuzmin, 2017; modified). S. Kam.—southern Kamchatka

Table 8.1 Sources for obsidian artefacts from the Ushki site cluster, Kamchatka (+ presence)

Layer (No. of sources)	KAM-01	Itkava-yam	KAM-04	Payalpan	Belogolovaya River	KAM-10	KAM-14	KAM-15
Layer 1 (4)	–	+	–	+	+	+	–	–
Layer 2 (1)	–	–	–	–	–	+	–	–
Layer 3 (2)	–	+	–	–	–	+	–	–
Layer 4 (6)	–	–	+	+	+	+	+	+
Layer 5 (3)	–	–	–	+	+	+	–	–
Layer 6 (4)	–	–	–	+	+	+	–	+
Layer 7 (6)	+	+	–	+	+	+	–	+

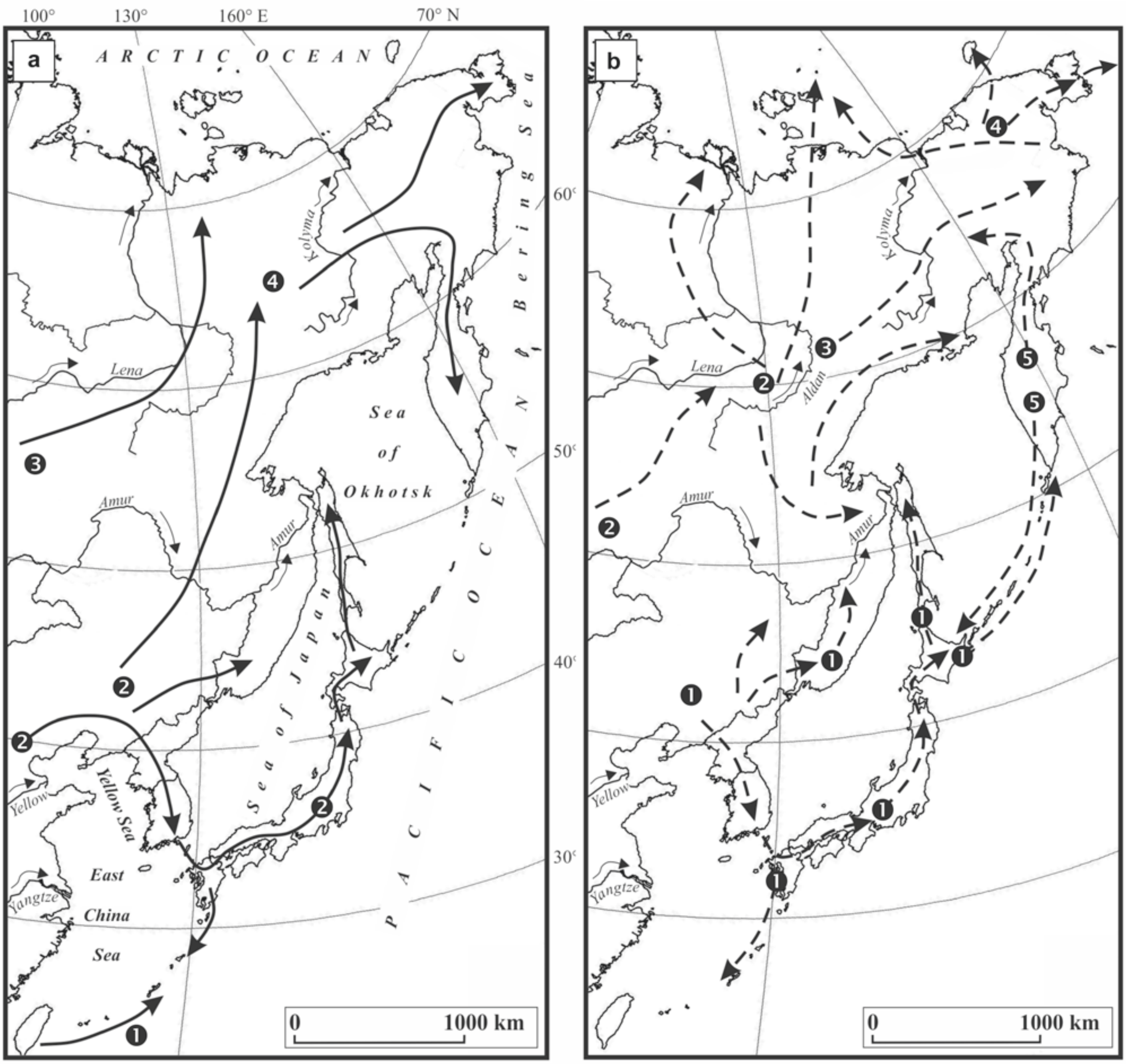

Fig. 8.5 Main prehistoric migrations in Northeast Asia: **a**—Upper Palaeolithic (Nos. 1–4—main vectors, see text); **b**—Neolithic (Nos. 1–5—main vectors, see text)

northern region of the New Siberian Islands, ca. 76 °N, at ca. 9000 years ago (Vector 2). At the same time, a connection with Chukotka existed (Vector 3).

From the secondary core area in the Aldan River valley, people moved to the east and settled the Kolyma River basin and Chukotka in the Neolithic (e.g., Kuzmin, 2015) (Vector 3). Active movements in Northeastern Siberia occurred at ca. 7500–4000 years ago, especially between Chukotka and the Kolyma River basin (vectors 3–4). From Kamchatka, Neolithic people migrated to the north (Chukotka and the Omolon River basin), and to the south (Kurile Islands) (Vector 5). In the Late Neolithic, some populations crossed the Bering Strait from Chukotka to Alaska (Vector 4) (Raghavan et al., 2014), most probably by boat (see Chap. 9).

Therefore, some of the main patterns for human migration in Northeast Asia are now established, and obsidian provenance as an independent proxy is important to support archaeological and palaeoanthropological (i.e., ancient DNA) data. It securely demonstrates the existence in prehistory—since the Upper Palaeolithic, and especially in the Neolithic—of large interaction zones, stretching for hundreds of kilometres and covering areas often in excess of ca. 1,000,000 km^2.

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9 Prehistoric Seafaring in Northeast Asia: Current State-of-the-Art

The archaeology of seafaring and underwater sites actually started in the 1970s—early 1990s by focusing on coastal regions (e.g., Masters & Fleming, 1983). In the 2000s, it became a separate branch of maritime-related archaeology (e.g., Erlandson, 2001; Erlandson & Fitzpatrick, 2006; Anderson et al., 2010; Bailey et al., 2020). It is now a dynamic field of research, with a better understanding of prehistoric adaptation to marine ecosystems compared to the 1970s.

The modelling of crossing the open water between Africa, Asia, and Mediterranean Europe shows that only active rafting (using paddles to accelerate the movement of seagoing transport) enabled people to arrive on the opposite shore of relatively wide sea straits in case of strong currents (Hölzchen et al., 2021, 2022). This kind of activity is usually associated with modern humans (Gaffney, 2021; Leppard, 2015).

According to the general knowledge of world sea levels in the second part of the Late Pleistocene (Lambeck et al., 2014; Murray-Wallace & Woodroffe, 2014: 275–281), they were at ca. -50–60 m (i.e., 50–60 m below the current level) about 50,000 years ago. During the Last Glacial Maximum (LGM), dated to ca. 26,500–19,000 years ago (Clark et al., 2009), sea levels were as low as ca. -120–135 m. At that time, several land bridges existed in the Western Pacific region (e.g., Voris, 2000), and this made it easier for prehistoric humans to travel and access previously isolated islands.

In the greater Western Pacific, part of which is Northeast Asia, the issue of the initial peopling of Australia—or the Sahul landmass, comprising Australia, New Guinea, and Tasmania (e.g., Mulvaney & Kamminga, 1999)—is closely related to early seafaring because Sahul was never connected to Southeast Asia (e.g., Bird et al., 2018, 2019; O'Connell et al., 2010; O'Connor, 2010). A conservative estimate for the appearance of modern humans in Sahul is ca. 55,000–50,000 years ago (O'Connell et al., 2018). At that time, people were able to conduct repeated voyages across wide water spaces; this can give us an idea about the antiquity of seafaring in the Western Pacific. Based on numerous studies, two routes have been suggested for crossing the sea straits between Island Southeast Asia and Sahul at ca. 60,000–40,000 years ago (e.g., O'Connor et al., 2017; Kealy et al., 2017; Bird et al., 2018, 2019).

Within the main topic of this volume, it is important to emphasise that obsidian provenance can be used as a proxy for identifying prehistoric seafaring. Even though this is still indirect evidence, it shows the existence of movements and contacts between people separated by wide water spaces. Reliable examples are now known for Japan, Korea, Sakhalin Island and the Kurile Islands in Northeast Asia; and for Oceania (see below).

9.1 Crossing of Sea Straits in Pre-LGM Times, ca. 44,000–26,500 Years Ago

In order to present a full picture of seafaring, it is necessary to examine the whole set of evidence for insular Northeast Asia at pre-LGM times, ca. 44,000–26,500 years ago. Some islands of the Japanese Archipelago—Honshu, Kyushu and Shikoku—were settled no later than ca. 44,000 years ago, followed by Hokkaido at ca. 36,000 years ago (Morisaki et al., 2019a; Ono et al., 2002). According to archaeological data (e.g., Nakazawa & Bae, 2018), the increase of contacts between Japan and the continent is evident since ca. 40,000–30,000 years ago.

The most reliable age estimate for the oldest Palaeolithic artefacts in Japan comes from Lake Nojiri in central Honshu Island (Nagano Prefecture), where the Middle Nojiri-ko Member I stratum with human-modified animal bones and a bone tool is dated to ca. 44,400–40,600 years ago (Ono et al., 2002). This early age of human occupation is confirmed by Kondo et al. (2018) who dated the Tategahana Sand Member T4 stratum (with unequivocal bone tools) to ca. 43,800 years ago. Human presence in

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Japan at that time indicates that people were able to cross the open water of the Korea Strait by some means of seagoing transport. Another candidate for the earliest archaeological site in Japan is Kanedori (Iwate Prefecture) on Honshu Island, with a suggested age of ca. 50,000–35,000 years (Matsufuji, 2010; Nakazawa, 2017). Earlier Palaeolithic sites in Japan (e.g., Ikawa-Smith, 2022: 60–61) are not widely accepted.

Because of the very limited number of Pleistocene human fossils in Japan and Korea (e.g., Kaifu & Fujita, 2012; Keates, 2010), it is uncertain who the first settlers of the Japanese Islands—modern humans or Neanderthals—were. The majority of scholars (e.g., Fujita, 2021; Tsutsumi, 2012) accept the view that the Upper Palaeolithic is associated only with modern humans. The oldest early Upper Palaeolithic sites in Japan are dated to ca. 38,000 years ago (Morisaki et al., 2019a). The most probable route to the Japanese Islands was via the Korean Peninsula (e.g., Nakazawa, 2017). The best age estimate for modern human fossils in Korea is known for the Gunang Cave (North Gyeongsang Province) where they are indirectly dated by presumably associated animal bones to ca. 43,000 years ago (Park et al., 2019).

In the Ryukyu Islands (Fig. 9.1), the earliest unequivocal artefacts are from Okinawa Island, now dated to ca. 36,500 years ago (Fujita et al., 2016). Several early modern human fossils are known from the Ryukyus (e.g., Matsu'ura, 1999; Ono et al., 1999), and a few of them are directly dated (Keates, 2010; Keates et al., 2012; Kuzmin & Keates, 2014). At the Shiraho-Saonetabaru Cave, located on Ishigaki Island (Sakishima island group of the Ryukyu Archipelago), the age of human bones is ca. 28,800–22,700 years (Kuzmin & Keates, 2014; Shinoda & Adachi, 2017). According to mitochondrial DNA data, these people are closely related to the modern populations of Southeast Asia (Shinoda & Adachi, 2017). At the Minatogawa site (Okinawa Island), one cranium was dated to ca. 19,200 years ago (Matsu'ura, 1999: 185; Keates et al., 2012).

Crossing of open waters in the early Upper Palaeolithic has been established by determining the provenance of obsidian at sites in central Honshu Island; their source is located on the Onbase-jima islet near Kozu-shima Island (Fig. 9.1, No. 1). While today the distance between Kozu-shima and mainland Honshu is ca. 50 km in a straight line, it was still ca. 30–40 km even during the LGM (Fig. 9.2). The earliest evidence of the transportation of Kozu-shima obsidian to Honshu Island is dated at the Idemaruyama site to ca. 37,500 years ago, and at the Doteue site to ca. 35,400 years ago (both sites are in Shizuoka Prefecture) (Ikeya, 2014, 2015; Tsutsumi, 2010). This information became available in the late 1970s (see Oda, 1990), but only after additional excavations and provenance studies was it confirmed (Ikeya, 2014, 2015; Ono, 2014). Around

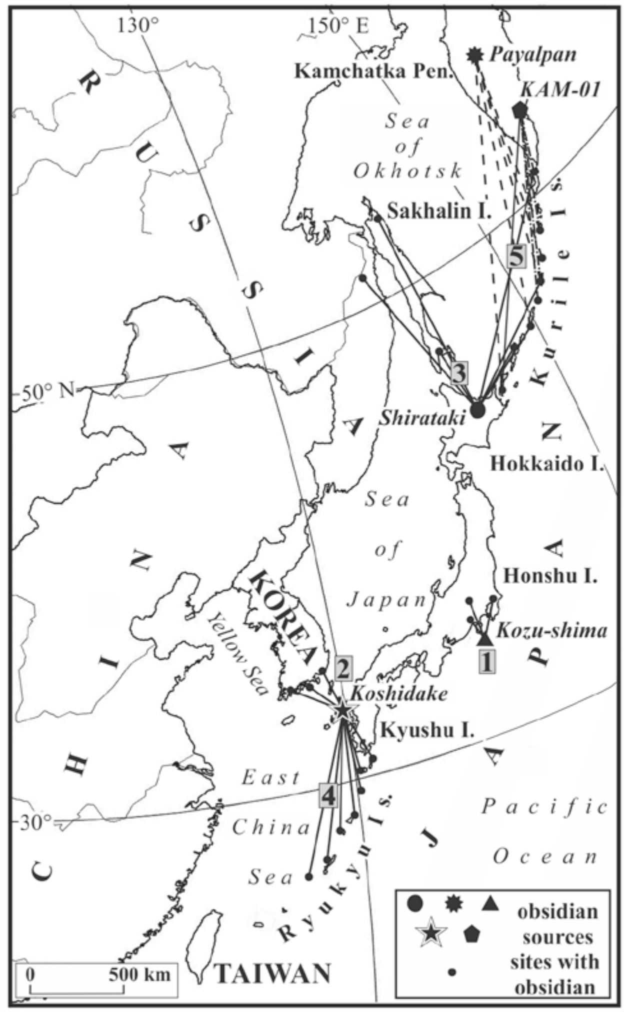

Fig. 9.1 The insular parts of Northeast Asia with evidence of early seafaring supported by obsidian provenance: 1—Honshu Island; 2—Korea Strait; 3—La Pérouse Strait; 4—Ryukyu Islands; 5—Kurile Islands

the Kozu-shima source, there is a high sea completely open to the elements. If one were to suggest s that people travelled by an alternative route from one island to another in the Izu Archipelago toward mainland Honshu, wide-open water spaces still needed to be crossed (Fig. 9.2). One can assume that Upper Palaeolithic people of Honshu Island had very efficient seagoing transport—perhaps, log boats or leather-clad canoes (Ikeya, 2015). It is therefore possible to conclude that the earliest traces of seafaring in Northeast Asia, although indirect, now date back to ca. 44,000–36,500 years ago.

The earliest excavated boat remains in Japan and Korea are represented by the dugout canoes (Habu, 2004, 2010). In order to produce them, it was necessary to use heavy woodworking tools. The edge-ground adze-like tools are known in Japan in the Early Upper Palaeolithic

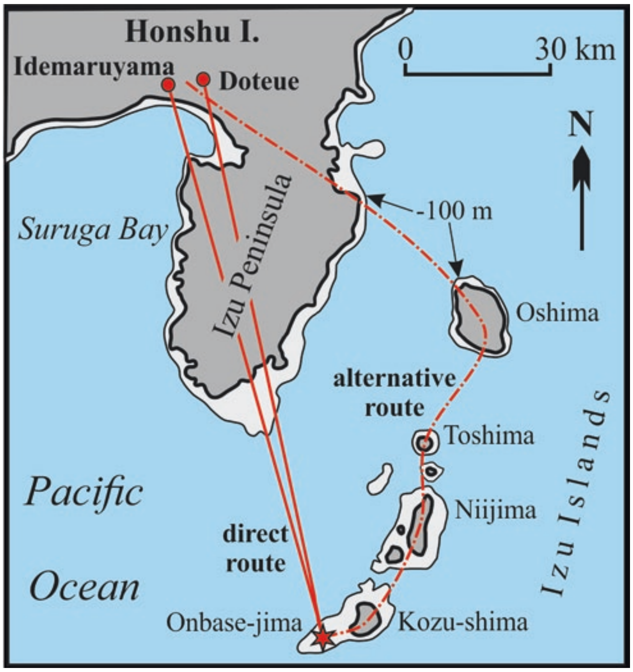

Fig. 9.2 The earliest cases of obsidian transport from the Onbase-jima source (after Ikeya, 2015; modified)

since ca. 38,000–35,000 years ago (e.g., Oda & Keally, 1992; Tsutsumi, 2012). It was therefore possible for inhabitants of the Kanto Plain (Honshu Island) to make a dugout boat from a tree trunk, and travel by the open sea to the Kozu-shima obsidian source at ca. 37,500 years ago. Alternatively, skin (leather) boats could have been used; they are known for natives of ethnographic times (eighteenth–nineteenth centuries AD) in Northeast Asia (e.g., Luukkanen & Fitzhugh, 2020).

Recent progress in experimental crossings of the sea between Taiwan and the westernmost islands of the Ryukyu Archipelago (Kaifu, 2022; Kaifu et al., 2019, 2022) generated new data about the possible kind of transport that was used at around 35,000–30,000 years ago for the initial colonisation of this island chain. Building and testing of three types of watercraft—reed boat, bamboo raft, and dugout canoe—convinced scholars that only people with dugout boats were able to navigate ocean currents like the Kuroshio to safely cross ca. 200 km of open water (Servick, 2019).

Information about obsidian exchange across the Korea Strait, beginning at ca. 31,000 years ago, is now available (Kim & Chang, 2021; Lee & Kim, 2015) (Fig. 9.1, No. 2). Obsidian from the Koshidake source was identified at the Upper Palaeolithic sites of Sinbuk (a.k.a. Shinbuk) and Sinhwari in the southernmost part of the Korean Peninsula (Fig. 9.3a). This is the oldest direct evidence of contacts between humans of Korea and Japan, although archaeological data (e.g., Chang, 2013; Morisaki et al., 2022; Nakazawa, 2017) suggests that people could have moved between these regions even before that.

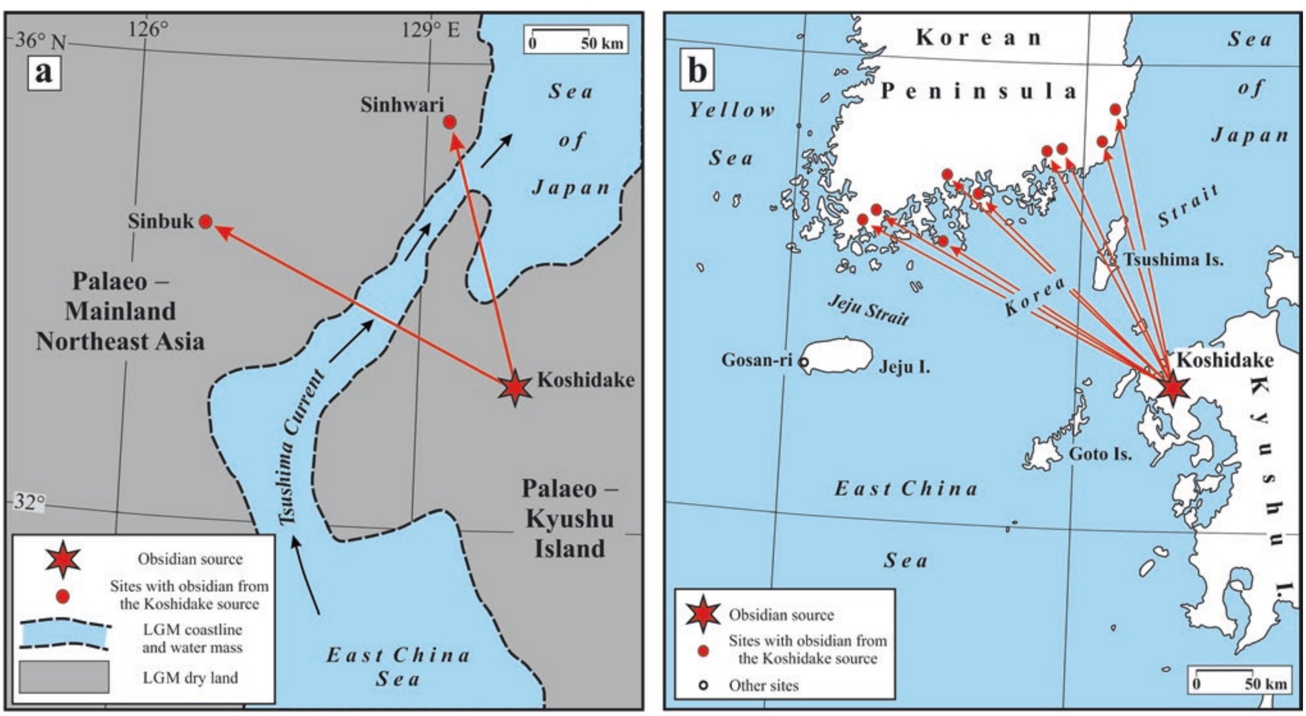

Fig. 9.3 The Korea Strait: **a** At the LGM, and obsidian exchange across it at ca. 22,300–31,000 years ago; **b** In the Holocene (since ca. 12,000 years ago), and obsidian exchange across it

9.2 Seafaring at the LGM and in the Late Glacial, ca. 26,500–12,000 Years Ago

The LGM was the period of the lowest level of water in the oceans and seas for the last 130,000 years. The water level of the Sea of Japan in the second part of the Late Pleistocene started dropping from ca. 35,000 years ago toward the peak of the LGM, and reached the minimum at ca. 24,000–21,800 years ago (Korotkii, 1985) (Fig. 9.4). Palaeoeceanographic studies (Dong et al., 2021; Gorbarenko et al., 2014; Lee et al., 2008) show that the inflow of the Tsushima Current (a branch of the Kuroshio Current) to the Sea of Japan through the Korea Strait had gradually weakened since ca. 30,000 years ago due to a drop in sea level and shrinking of this strait (Fig. 9.3a). Nevertheless, the connection between the Sea of Japan and the Pacific Ocean existed throughout the second part of the Late Pleistocene, and the Korean Peninsula and Kyushu Island were always separated by water.

The LGM period was more favourable for human movements in insular Northeast Asia than earlier times because the sea straits were not as wide as before. Several early modern human remains with direct dates of ca. 28,800–19,200 years ago are known from the Ishigaki and Okinawa islands of the Ryukyu Archipelago. According to the latest archaeological studies, people continued to live on Okinawa Island throughout the LGM until the end of the Late Glacial, at ca. 16,000–13,000 years ago (Fujita et al., 2016).

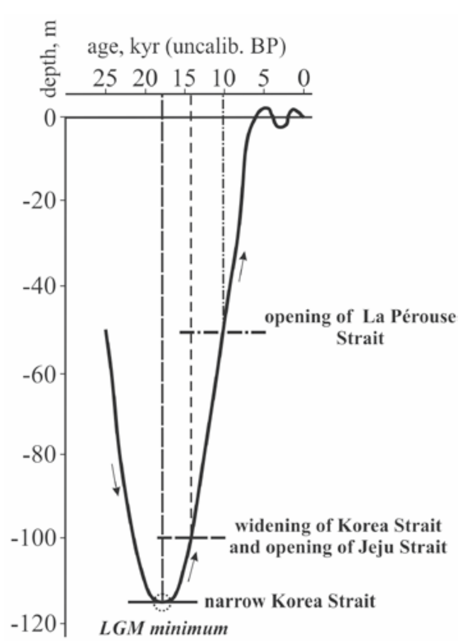

Fig. 9.4 Changes in the Sea of Japan level since ca. 25,000 BP (ca. 30,000 years ago) (after Korotkii, 1985; modified)

Data from the Ruykyu Islands clearly demonstrate the human ability of seafaring at the LGM. Today, the straight distance between Taiwan (as the closest large landmass) and Ishigaki Island—where the LGM-associated Shiraho-Saonetabaru Cave site is located (e.g., Kaifu, 2022)—is ca. 230 km. In order to cross it, one has to negotiate the strong Kuroshio Current. A recent attempt to do so resulted in the successful crossing with a wooden dugout boat from Taiwan to Yonaguni Island in 2019, a distance of ca. 225 km (Kaifu et al., 2019, 2022).

The Korea Strait at the height of the LGM (ca. 26,500–19,000 years ago) was quite narrow, restricted to a ca. 20–25 km wide channel west of the Tsushima Islands (Fig. 9.3a). Since ca. 19,000 years ago, the Korea Strait became wider, with the water exchange between the Sea of Japan and the Pacific Ocean increasing (e.g., Gorbarenko et al., 2014). Obsidian exchange between the Koshidake source and the Sinbuk site most probably continued until ca. 22,300 years ago when the Korea Strait was still narrow.

It is to some extent intriguing that during the LGM obsidian from the Kozu-shima source has not been identified at Upper Palaeolithic sites in central Honshu near Mount Ashitaka where an earlier presence of obsidian from this source is known (Ikeya, 2015). In the late Upper Palaeolithic, after ca. 17,000 years ago, people of Honshu Island again exploited obsidian from this source. One-third of microblade cores at the Yadegawa site in the Central Highlands of Honshu, located about 200 km from the coast and dated to ca. 15,500 years ago, are made of Kozu-shima obsidian (Ikeya, 2015; Tsutsumi, 2007).

Due to the low sea level, some straits in Northeast Asia did not exist at the LGM. For example, the modern La Pérouse Strait between Hokkaido and Sakhalin islands (Fig. 9.1, No. 3) was dry land, and at ca. 23,400–21,700 years ago people carried obsidian from the Shirataki source on Hokkaido to Sakhalin as testified by data from the Ogonki 5 and Sokol sites in the southern part of Sakhalin (Kuzmin & Glascock, 2007) (Fig. 9.5a). While the water level of the Sea of Japan was rising from ca. 19,000 years ago (Fig. 9.4), the land bridge between Hokkaido and Sakhalin existed until the beginning of the Holocene, ca. 12,000 years ago. At this time, obsidian from the Shirataki source was transported to southern and central Sakhalin (sites of Olimpiya 1 and Ostantsevaya Cave) by land (Fig. 9.5b).

9.3 Seafaring and Maritime Adaptation in the Holocene, Since ca. 12,000 Years Ago

From ca. 12,000 years ago onwards, the ability of humans to navigate the open water dramatically increased (see Leppard et al., 2022), as a plethora of data for the

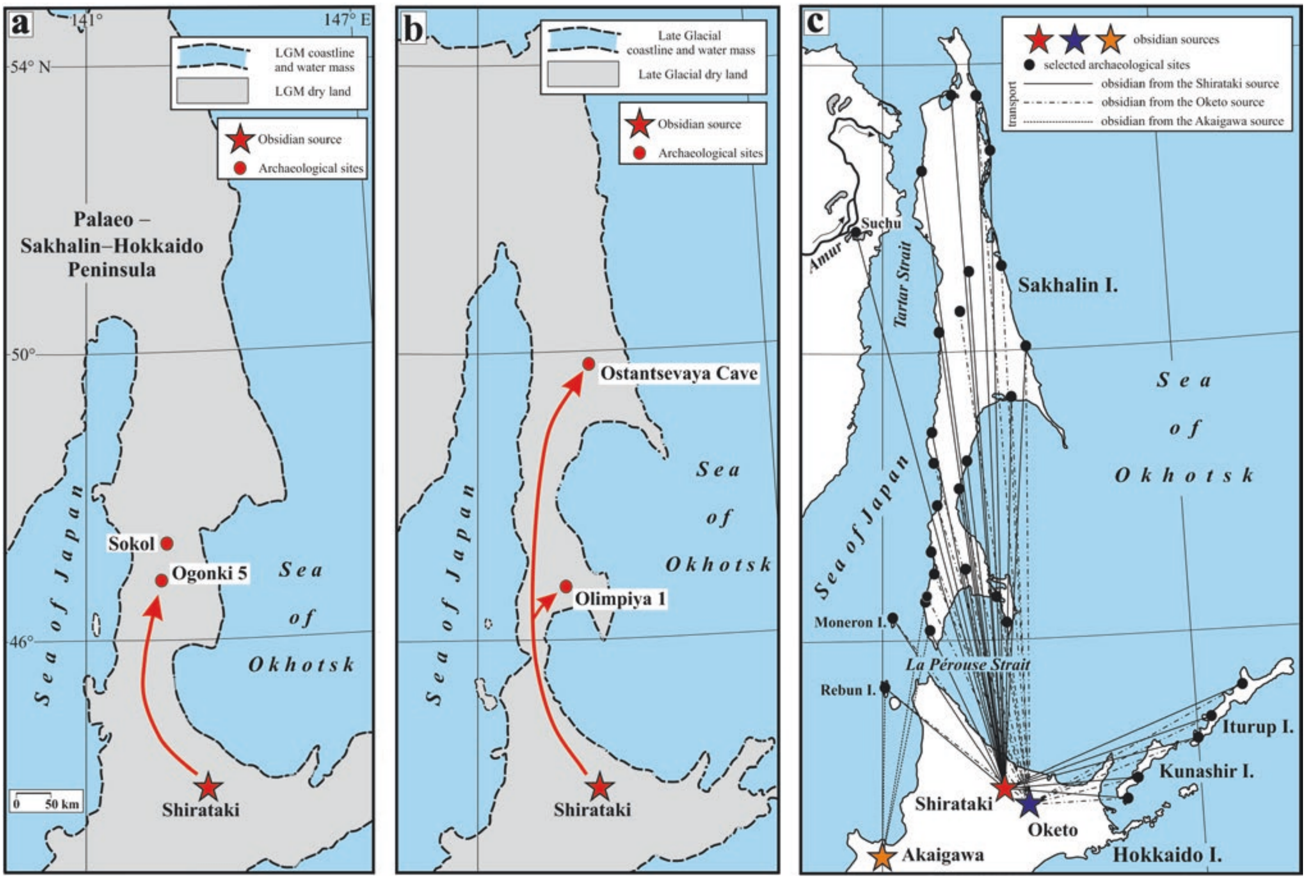

Fig. 9.5 Obsidian exchange between Hokkaido and the neighbouring insular and mainland regions in the Late Pleistocene–Holocene: **a**—the LGM, ca. 21,700–23,400 years ago; **b**—the Late Glacial, ca. 13,000 years ago; **c**—the Holocene, since ca. 12,000 years ago

Mediterranean region shows (e.g., Broodbank, 2013; Freund & Batist, 2014). The information on seafaring in the Holocene of Northeast Asia is the most prolific compared to previous times, including archaeological sites on remote islands and obsidian exchange across the wide sea straits. In the southern part of the Japanese Archipelago, obsidian from the Koshidake source on Kyushu Island was brought to Okinawa and Amami-O-shima islands in the Ryukyus since ca. 4500 years ago (Obata et al., 2010) (Fig. 9.1, No. 4). The distances from source to sites are ca. 550–800 km in a straight line, and this is good evidence of well-developed seagoing transport at that time corresponding to the Late Jomon (Takamiya et al., 2019; Takamiya & Shinzato, 2024) (Fig. 9.6).

The exchange of obsidian between the Koshidake source and the southern coast of the Korean Peninsula was quite active in the Neolithic/Chulmun, beginning at ca. 6800 years ago (Kim, 2014) (Fig. 9.3b). Also, the Gosan-ri (a.k.a. Kosan-ri) site, the earliest settlement on Jeju Island separated since ca. 18,000 years ago from the mainland because the depth of the Jeju Strait is ca. 100 m (Fig. 9.4), is dated to ca. 9600 years ago (Kim et al., 2020). It is clear that seafaring was active in the Korea Strait area since the Early Holocene. Additional evidence comes from the oldest actual remains of log boats in Japan and Korea directly dated to ca. 7900–7600 years ago, such as Kamo (Chiba Prefecture) and Torihama (Fukui Prefecture) in Japan, and Bibong-ri (South Gyeongsang Province) in Korea (Habu, 2004, 2010; Park et al., 2010) (Fig. 9.7). For example, in coastal South Korea people were sailing in the palaeo-bay near the Bibong-ri site at ca. 7700 years ago (Lim et al., 2022) using the wooden dugout canoe found in the shellmidden (e.g., Shin et al., 2012).

In the insular parts of the Russian Far East—Sakhalin Island and the Kurile Islands—obsidian exchange patterns revealed active seafaring in the Holocene. The opening of the La Pérouse Strait at ca. 12,000 years ago did not prevent the traffic of obsidian from Hokkaido to Sakhalin. At ca. 9900–7800 years ago, obsidian exchange networks covered essentially all of Sakhalin Island (Kuzmin & Glascock,

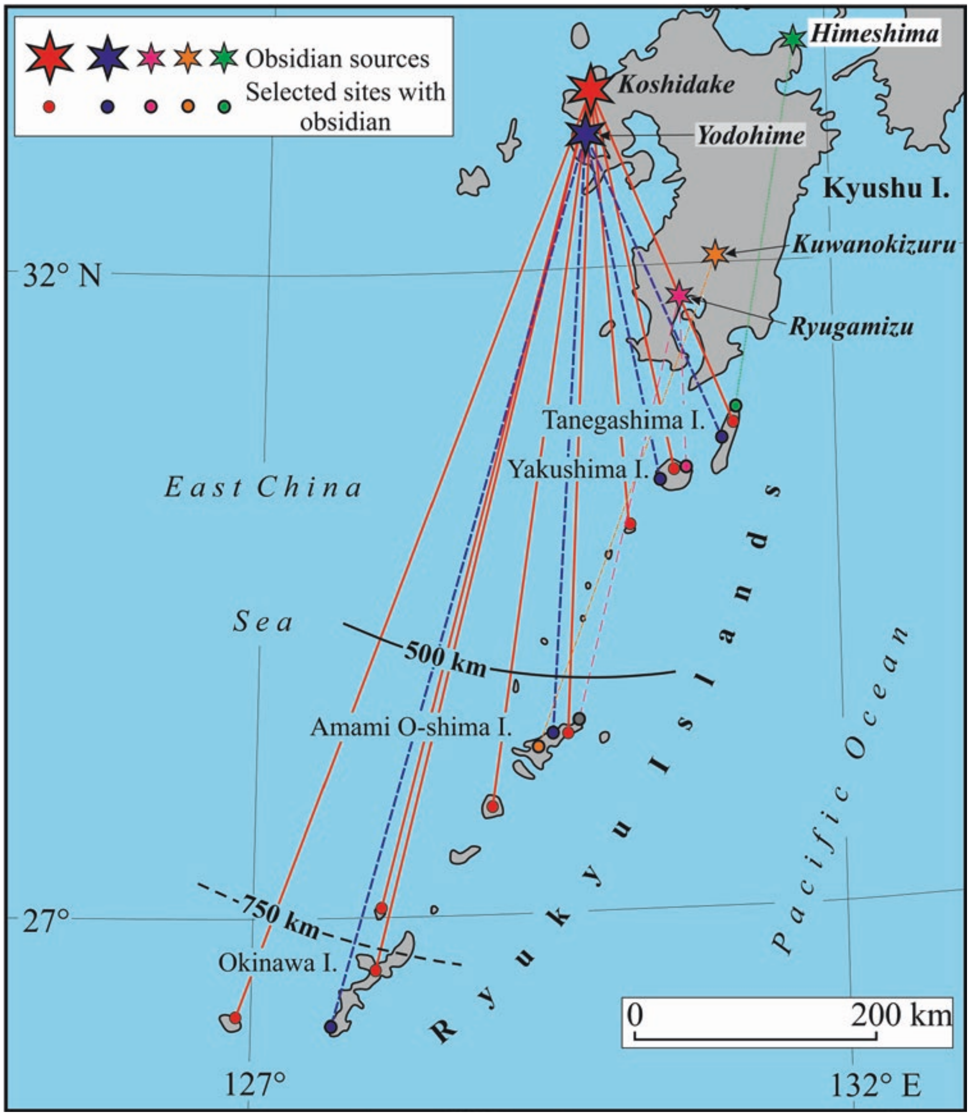

Fig. 9.6 Exchange of obsidian between the sources of Kyushu Island and the Ryukyu Archipelago (distances are from the Koshidake source)

2007) (Fig. 9.5c). At ca. 9600–8100 years ago, obsidian from the Shirataki source on Hokkaido Island was transported to the mainland, as it was identified at the Suchu site (Khabarovsk Province, Russia) (Glascock et al., 2011). The distance between the source and site is ca. 800 km as the crow flies. The movement of obsidian across the ca. 50 km wide La Pérouse Strait continued until late in prehistory, ca. 1300–700 years ago (Kuzmin & Glascock, 2007). Some smaller islands—Moneron and Rebun—were also a part of these exchange networks (Kuzmin & Glascock, 2007; Lynch et al., 2018) (Fig. 9.5c).

Since the initial human occupation of the Kurile Islands (Fig. 9.1, No. 5) at ca. 8100–7800 years ago (Kuzmin, 2016; Kuzmin et al., 2012a), obsidian from two major sources on Hokkaido Island—Shirataki and Oketo—was transported to the Kunashir and Iturup islands of the southern Kuriles (Kuzmin et al., 2023). At ca. 2500 years ago, the Epi-Jomon complex (i.e., early Palaeometal) was widespread in all of the Kurile Islands. Obsidian from regions at both ends of the Kuriles—Hokkaido Island and Kamchatka Peninsula—was moved throughout the island chain, beginning at ca. 2500–2300 years ago (Fig. 9.8). It is noteworthy

Fig. 9.7 The Middle Jomon dugout canoe from the Nakazato site, Tokyo; the scale is approximate (after Habu, 2004; Steinhaus & Kaner, 2016; modified)

that at several sites obsidian from multiple sources was identified (Kuzmin et al., 2023; Phillips, 2010). This testifies that the traffic of obsidian in the Kuriles was very active at that time. The distances from Hokkaido to the northern Kuriles and from Kamchatka to the southern Kuriles are extremely long, ca. 1200–1400 km in a straight line.

As for the type of seagoing transport used by the Holocene populations of Northeast Asia, the most probable kind was the dugout canoe (Habu, 2010) as it was recently confirmed by experiments (Kaifu, 2022). Actual remains of these boats were found in Japan and Korea (e.g., Habu, 2010). The increase in the number of vessels from the beginning of the Early Jomon, ca. 8100 years ago, testifies to their systematic production, and this allowed Jomon people to move between the large and small islands of the Japanese Archipelago since the Early Holocene.

The colonisation of small islands, devoid of large and medium-sized mammals as a food source, made it necessary to use marine resources (e.g., Erlandson, 2001). In Northeast Asia, the earliest traces of maritime adaptation go back to the Early Holocene. In Japan, the oldest shellmiddens in the Kanto region of central Honshu and on the Sea of Japan coast are dated to ca. 10,600–9400 years ago (e.g., Habu, 2004; Habu et al., 2011; Kobayashi, 2004). The procurement of salmonids as anadromous fish began at ca. 15,700–15,400 years ago, was discovered at the Maedakochi (a.k.a. Maeda Kochi) site (Tokyo Metropolitan Prefecture) (Keally & Miyazaki, 1986; see also Morisaki et al., 2019b). This is supported by data derived from lipids in the oldest pottery of Japan, the Amur River basin (far eastern Russia), and Korea where the markers of marine organisms are detected (Craig et al., 2013; Lucquin et al., 2016; Shoda et al., 2017, 2020). In Korea, the southern Russian Far East, and China the active exploitation of marine food resources is known since ca. 8000–7800 years ago (Kuzmin, 2009, 2015c; Kim & Seong, 2022; Kwak et al., 2022; He et al., 2023).

In the extreme northeastern part of the region under study, traffic of obsidian across the Bering Strait to Alaska is known (Fig. 9.9). Cook (1995) identified obsidian from the Chukotkan source of Lake Krasnoe at the Aqulaak 3–3 site, belonging to the Denbigh complex which is generally dated to ca. 4500–3500 years ago (Tremayne & Rasic, 2016); and at the Hillside site, St. Lawrence Island, associated with the Old Bering Sea complex dated to ca. 2000–1200 years ago (Mason, 2016). Other sites in coastal Alaska with obsidian from Chukotka are: Iyatayet directly ^{14}C-dated to ca. 4200–3500 years ago, and Cape Espenberg directly ^{14}C-dated to ca. 4300 years ago (both sites belong to the Denbigh complex) (Tremayne et al., 2018); and the Deering site (Reuther and (2009)) associated with the Ipiutak complex dated to ca. 1400–1200 years ago (Moss & Bowers, 2007; Prentiss et al., 2022). The distances between the obsidian source and utilisation sites are up to 1000 km as the crow flies (Fig. 9.9). Even though actual boat remains of this age are unknown in the Arctic, the movement of obsidian across a strait that today is ca. 80 km wide in the narrowest part implies the use of watercraft, beginning at ca. 4500 years ago. This again highlights the importance of obsidian provenance studies for understanding early seafaring.

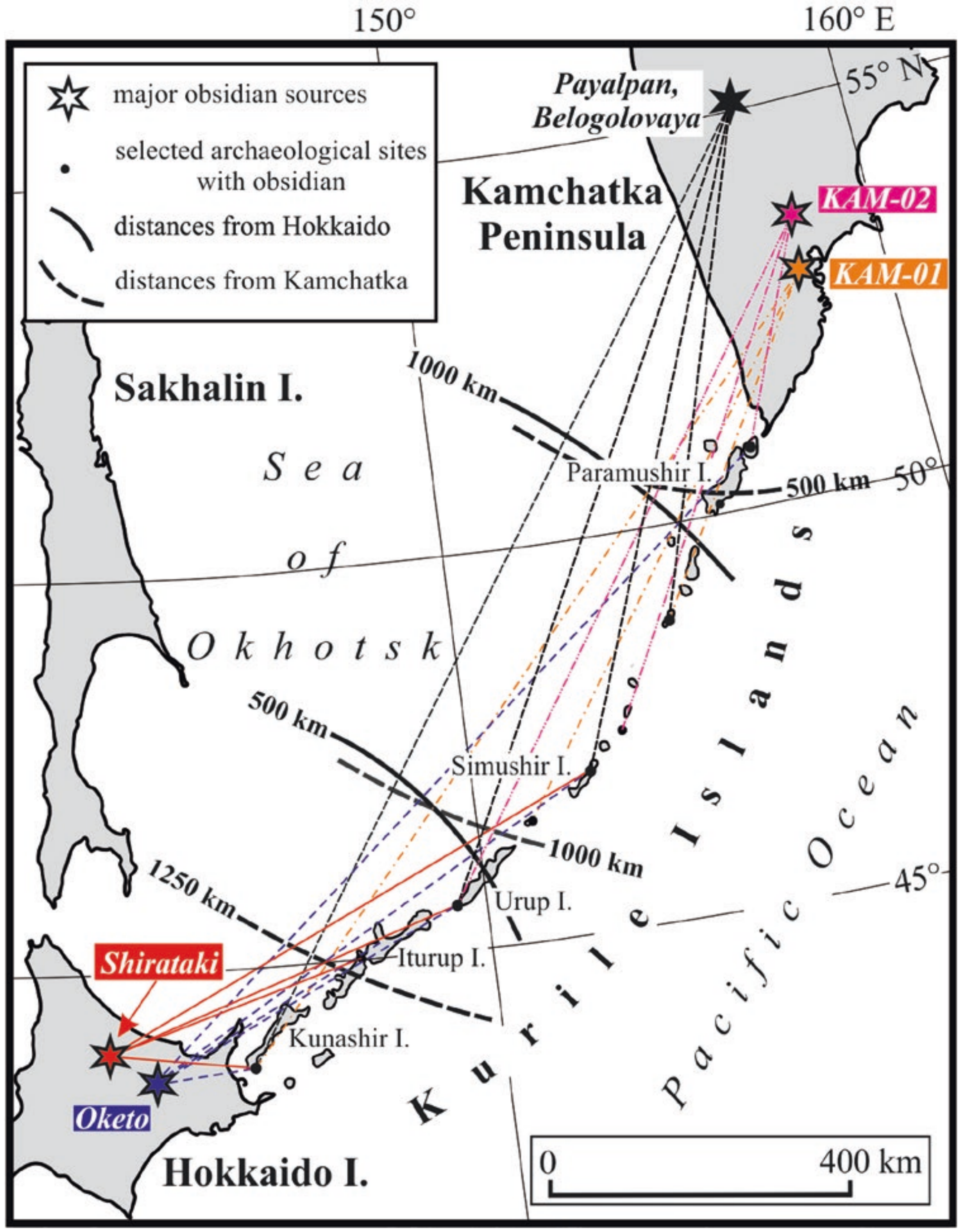

Fig. 9.8 Obsidian exchange in the Kurile Islands region across the sea straits

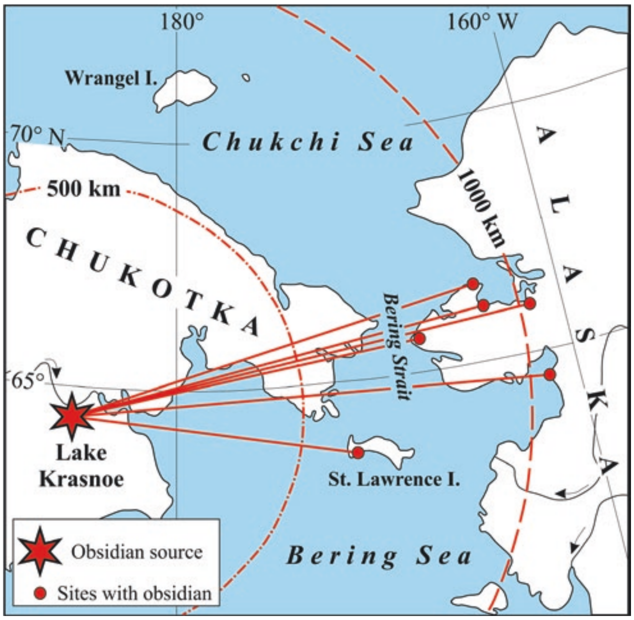

Fig. 9.9 Obsidian transportation from Chukotka to Alaska across the Bering Strait in the Late Holocene (after Rasic, 2016; Tremayne et al., 2018; Kuzmin, 2019; modified)

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10 Toward an Understanding of Prehistoric Exchange and Contacts in the North Pacific Rim

This conclusion to the book is based on 30+years of my own research in eastern Russia, and on summarising the existing knowledge related to obsidian provenance in Northeast Asia and its implications. This also puts the region under investigation into the wider context of the North Pacific Rim, as one of our edited volumes is called (Kuzmin & Glascock, 2010).

Obsidian is one of the rare kinds of rock which has a unique geochemical signature for each primary source. It was repeatedly demonstrated, beginning with the groundbreaking work by Cann and Renfrew (1964) and confirmed afterwards (e.g., Glascock et al., 1998). This circumstance is a great advantage for scholars who work in the field of provenance for archaeological obsidian compared to those who examine the sources of other kinds of lithic raw materials like flint/chert (e.g., Malyk-Selivanova et al., 1998; but see Craddock & Cowell, 2009 and Boulanger et al., 2015).

Obsidian is an abundant raw material in the Pacific Rim region, East Africa, the Near East, the Americas, and the Mediterranean. Since the early 1960s, it is used as a proxy for the reconstruction of prehistoric exchange and migrations (e.g., Williams-Thorpe, 1995). The most common occurrence of obsidian at archaeological sites worldwide is known for the Stone Age complexes (Palaeolithic and Neolithic periods). Obsidian was also recorded in some Palaeometal (Bronze Age and Early Iron Age) assemblages, and even in the later prehistory/early history of remote parts of the globe like Kamchatka and Chukotka.

In Northeast Asia, obsidian provenance research was initiated in the late 1960s, and really took off in the 1970s in Japan. Later on, geochemical analysis of geological and archaeological obsidians was conducted in the southern part of far eastern Russia and Korea since the early 1990s, and in Northeastern Siberia and Northeast China since the 2000s. Despite the relatively short history of these studies (except for Japan), a great deal of work has been achieved in the last two to three decades, and now the main patterns of obsidian acquisition, transportation, and use in prehistoric Northeast Asia can be established.

Of the several analytical methods currently ~~are~~ employed for the geochemical analysis of obsidian, the most common ones are NAA and XRF. The rapid development of portable XRF equipment in the last decade made it possible to examine quickly and at a very low cost hundreds of artefacts (e.g., Frahm, 2014; Frahm et al., 2014; Liritzis & Zacharias, 2011). This, however, raised the issue of calibration and cross-analysis. Only when it is performed on a regular basis (e.g., Suda et al., 2018a), is the determination of obsidian sources by pXRF analysis secure.

The study of the processes of obsidian procurement, transport, and utilisation is now a dynamic field. It begins with the works by Renfrew et al., (1966, 1968; see also Renfrew, 1975, 1977; Renfrew & Dixon, 1976) who introduced the down-the-line mechanism and related ways (free-lance, prestige-chain, and redistribution) of obsidian acquisition and exchange. Later on, this subject was developed further by other scholars (e.g., Ericson, 1977; Findlow & Bolognese, 1982; Chataigner & Gratuze, 2014; Ortega et al., 2014; Ibáñes et al., 2015, 2016; Golitko & Feinman, 2015; Barge et al., 2018; Campbell & Healey, 2018). Today, the application of different approaches such as factor analysis, least-cost path, indices (Chao 1, Shannon, and Simpson), agent-based modelling, and network analysis, allows researchers to reveal patterns of obsidian exchange/trade in greater detail compared to what was possible in the 1960s and 1970s.

In Northeast Asia, the obsidian-containing cultural complexes are associated with the Upper Palaeolithic, Neolithic (with pottery as a hallmark), and sometimes the Palaeometal. Obsidian artefacts are known in the Upper Palaeolithic and Neolithic of Japan, the Russian Far East, Korea, Northeast China, and Northeastern Siberia. In Korea, the Russian Far East, and Northeast China the use of obsidian as a raw material continued in the

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early Palaeometal (Bronze Age). In Northeastern Siberia (Kamchatka and Chukotka), obsidian was exploited for even longer—until the eighteenth-century AD, the time of contact with Russian and Japanese explorers. The palaeoeconomy of these Northeast Asian complexes was based primarily on hunting, fishing, and gathering. Agriculture in the form of millet cultivation and pig breeding originated in North China in the Early Neolithic, and spread to Northeast China, Korea, and the southern Russian Far East in the Middle–Late Neolithic.

Because the southern Russian Far East and Northeastern Siberia are my primary regions of research, obsidian procurement and use for these territories are described in more detail in this volume compared to the neighbouring parts of Northeast Asia such as Japan, Korea, and Northeast China. Currently, the amount of data for the southern Russian Far East is sufficient to understand the main patterns of obsidian exchange. In Northeastern Siberia, due to logistical difficulties, not all primary obsidian sources have been adequately studied, especially on Kamchatka. Nevertheless, the main trends in obsidian exploitation can now be established.

Obsidian can be used as a commodity for investigation of ~~the~~ early seafaring that in Northeast Asia started in the early Upper Palaeolithic in Japan (e.g., Ikeya, 2014, 2015). In the absence of actual boat remains this is one of the most reliable ways to establish the crossing of wide water spaces by ancient humans who had seagoing transport. Another important issue is the wide use of obsidian in Northeast Asia for making microblades—by applying pressure flaking—in the Upper Palaeolithic and Neolithic (e.g., Keates et al., 2019).

Significant progress was achieved in the last 15–20 years in Korea in terms of obsidian provenance (Chang & Kim, 2018; Kim, 2014; Kim & Chang, 2021; Kim et al., 2007; Lee & Kim, 2015; Popov et al., 2005), and the degree of study of the Upper Palaeolithic complexes in Korea is now quite advanced. As in the neighbouring regions of Northeast Asia, obsidian was extensively used for the manufacture of microblades as the most suitable kind of raw material, perhaps because the entire Korean Peninsula does not have other high-quality rocks like flint/chert. For the Neolithic, more work is still needed in the northern and central parts of Korea (Kim & Chang, 2021). For Northeast China, additional research could advance our knowledge on obsidian procurement and use in the Upper Palaeolithic, Neolithic, and Bronze Age complexes.

Japan is a very important region in Northeast Asia for obsidian provenance due to two circumstances: (1) the large number of primary sources (no less than ca. 50–70); and (2) the high degree of investigation of both geological and archaeological obsidians. Also, the Stone Age complexes (Upper Palaeolithic and Jomon) are well-studied compared to other parts of Northeast Asia. The mining of obsidian in central Honshu Island in the Jomon period is a unique phenomenon for strategies of acquiring this valuable raw material. The common use in Japan of exhaustive analysis sensu Tsutsumi (2010) allowed the identification of primary sources that were rarely used by prehistoric people. This gives us a better understanding of obsidian exchange because a larger number of locales with deposits of this raw material can be detected.

As a result of the identification of obsidian sources in prehistoric lithic assemblages, the exchange networks in Northeast Asia were reconstructed. One of the most remarkable examples is the very long-distance ('super-long-distance' sensu Pitulko et al., 2019: 35) of obsidian transport across the rough terrain between the Siberian Arctic and the Lake Krasnoe source. The distances between the primary locales containing high quality obsidian and archaeological sites in Northeastern Siberia, where this raw material was utilised, sometimes are ca. 1200–1500 km long in a straight line (Pitulko et al., 2019; Kuzmin et al., 2018, 2020). According to a preliminary estimate, the real path of delivery to Zhokhov site in the High Arctic could be even bigger, up to 2000 km (e.g., Pitulko et al., 2019). This is one of the longest distances for obsidian exchange in the entire mainland of Eurasia, as far as I know.

Another interesting pattern is the simultaneous use of obsidian from different sources at the same site and in the same cultural complex. In Northeast Asia, such cases are common in Japan (e.g., Ferguson et al., 2014; Ikeya, 2006; Obata et al., 2010; Sato & Yakushige, 2014; Shiba, 2014; Tsutsumi, 2010), far eastern Russia (e.g., Kuzmin, 2014; Kuzmin & Glascock, 2007), and Northeastern Siberia (e.g., Kuzmin et al., 2021). An excellent example of complex human behaviour and sophisticated exchange activity is the Ushki site on Kamchatka where obsidian from eight sources was procured for a long time (Kuzmin et al., 2008).

Obsidian exchange networks operated in Northeast Asia since the Upper Palaeolithic, ca. 38,000 years ago in Japan and ca. 31,000 years ago in Korea. The maximal length of obsidian transport was of ca. 800 km in a straight line, as it is demonstrated for the Korean Peninsula. The movement of obsidian intensified in the Mesolithic and Neolithic/Jomon times, since ca. 12,000 years ago, and the distances of obsidian transportation became longer, up to ca. 1500 km as the crow flies, for Northeastern Siberia (Zhokhov Island) and the Ryukyu Islands. The ranges of interaction spheres for the Mesolithic–Neolithic humans in the former region were on an enormous scale even by today's standards, ca. 1,000,000 km^2 and even more (e.g., Pitulko et al., 2019).

Because obsidian is a proxy for human movements across the sea straits, it is now possible to establish the earliest cases of seafaring in Northeast Asia. The relatively short (ca. 40–50 km) travel by boat across a rough sea is known for the early Upper Palaeolithic of Honshu Island, where obsidian from the insular Onbase-jima source was brought to ~~the~~ sites in mainland Honshu at ca. 38,000 years ago (e.g., Ikeya, 2015). Another short trip across the Korea Strait—between Kyushu Island and the southern coast of the Korean Peninsula—took place at ca. 31,000 years ago, as testified by the discovery of obsidian from the Koshidake primary locale at two Upper Palaeolithic sites in Korea (e.g., Kim & Chang, 2021; Lee & Kim, 2015). In the Neolithic/Jomon and Palaeometal (Epi-Jomon) periods, seafaring was significantly developed because of the manufacture of dugout canoes, and obsidian was distributed from the mainland and insular sources to remote regions like the Ryukyu Archipelago and the Kurile Islands.

One of the urgent tasks for the near future in the field of obsidian provenance in Northeast Asia is the search for the unknown but existing sources on Kamchatka (at least seven locales) and Primorye ("Samarga"). It is also necessary to pinpoint the exact position of the PNK1 source near the Chinese/North Korean border, although the consequences of the COVID-19 pandemic, as well as other difficulties related to work in North Korea, has slowed down this process.

Another region where obsidian provenance studies are still at the infancy stage is the northern Okhotsk Sea coast. The obsidian of the few artefacts analysed so far derived from the Lake Krasnoe source in Chukotka, with a distance of ca. 1350 km in a straight line. There is also a claim that obsidian from Hokkaido sources was brought to the Okhotsk Sea coast (Speakman et al., 2016), although no details are given in the short abstract published. This, if true—although what follows from Carl Sagan's standard, "extraordinary claims require extraordinary evidence"—could increase the transportation distance even more, up to ca. 2300 km as the crow flies, considering the terrestrial route without the use of seagoing vessels. In my opinion, it is hard to imagine that in prehistory people could cross the Okhotsk Sea directly from Hokkaido to the northern coast, because it was a quite difficult part of the Northwest Pacific to navigate even by sailing vessels in the seventeenth–nineteenth centuries (e.g., Findlay, 1851: 586–623; Snow, 1897; Gibson, 1969: 34–45).

The intriguing issue in obsidian provenance of Northeast Asia is the possible connection between its extreme northeastern part, namely the Chukotka region, and Alaska. Unfortunately, currently neither Chukotkan obsidian is known from the Palaeoindian sites of Alaska nor has obsidian from Alaska been detected at any sites in Chukotka. At a few Alaskan sites belonging to later prehistory—Denbigh, Old Bering Sea, and Ipiutak cultural complexes—obsidian from the Lake Krasnoe source in Chukotka was identified (e.g., Cook, 1995; Tremayne et al., 2018). Surprisingly enough, there is still little information published on the provenance of obsidian artefacts from Alaska, Aleutian Islands, and the Yukon River basin and neighbouring regions of western Canada (Alberta Province) (e.g., Cook, 1995; Speakman et al., 2007; Goebel et al., 2008; Reuther et al., 2011; West et al., 2012: 211–237; Rasic et al., 2017; Kristensen et al., 2019, 2023; Schmuck et al., 2022; see also Gómez Coutouly, 2017). Based on preliminary estimates, up to 60 geochemical groups of archaeological obsidian have been identified, and they could potentially represent primary sources that exist in Alaska and the Yukon Territory (e.g., Rasic et al., 2017). Nevertheless, no numerical data have so far been fully presented, which makes it impossible to use the results obtained for comparison with Chukotka and Kamchatka; hopefully, this information will be available in the near future.

The application of ancient DNA analysis to the remains of prehistoric people from Northeastern Siberia and the North American Arctic (e.g., Flegontov et al., 2019; Raghavan et al., 2014; Sikora et al., 2019) allowed researchers to obtain secure evidence of human migrations across the Bering Strait since at least ca. 5000 years ago, and most probably much earlier, up to ca. 15,000 years ago (e.g., Sikora et al., 2019: 185). It is of interest that not only movements from Siberia to North America are detected, but also in the opposite direction, from Arctic North America to Northeastern Siberia (e.g., Wang et al., 2023). This is in accord with initial data on obsidian traffic between Chukotka and Alaska, and gives us hope that one day more Chukotkan obsidian will be found in Alaska, and obsidian from Alaskan source(s) will be identified in Chukotka.

Finally, my own 30 + years of research in the field of obsidian provenance in Northeast Asia has born some fruit. The data presented in this book should be considered as an advanced and extended background for in-depth analysis of obsidian procurement, transport, and use in this vast region. While definite progress is currently achieved for Japan, far eastern Russia, and Korea, a relatively small amount of primary data has been accumulated for Northeast China and Northeastern Siberia. The connection between Chukotka and Alaska needs to be explored in more detail. Nonetheless, the 'critical mass' of information necessary for the application of obsidian as a commodity to investigate prehistoric migrations and exchange in Northeast Asia is already created. *Feci quod potui faciant meliora potentes* (I have done what I could; let those who can do better).

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Appendix

Table A.1 Concentration of elements (in ppm, unless indicated) measured by NAA in obsidian from far eastern Russia, Paektusan (PNK), and Hokkaido Island

Source	Basaltic plateau	Obluchie plateau	PNK1	PNK2	PNK3	Chongjin sample*	Shirataki-A	Shirataki-B	Oketo-A	Oketo-B
Element	(n = 40)	(n = 26)	(n = 38)	(n = 7)	(n = 3)	(n = 1)	(n = 59)	(n = 37)	(n = 26)	(n = 2)
Na (%)	2.36 ± 0.1	3.00 ± 0.13	3.07 ± 0.09	3.80 ± 0.23	4.17 ± 0.11	3.00	2.87 ± 0.05	2.94 ± 0.06	2.78 ± 0.06	3.25 ± 0.04
Al (%)	7.90 ± 0.39	8.04 ± 0.29	6.76 ± 0.48	5.78 ± 0.58	8.19 ± 0.25	6.86	6.86 ± 0.31	6.88 ± 0.3	6.72 ± 0.32	6.94 ± 0.18
Cl	91 ± 38	81 ± 24	703 ± 87	1435 ± 671	429 ± 53	706	561 ± 118	517 ± 88	464 ± 81	449 ± 130
K (%)	0.41 ± 0.14	0.96 ± 0.16	4.19 ± 0.28	3.89 ± 0.31	4.51 ± 0.08	4.78	3.79 ± 0.24	3.81 ± 0.18	3.40 ± 0.19	3.05 ± 0.18
Sc	17.9 ± 0.9	12.3 ± 0.6	1.1 ± 0.1	1.31 ± 0.59	4.7 ± 0.7	1.15	2.7 ± 0.1	2.9 ± 0.1	3.3 ± 0.1	3.3 ± 0.1
Mn	1107 ± 47	960 ± 22	310 ± 7	864 ± 219	1036 ± 32	308	379 ± 6	447 ± 11	319 ± 6	385 ± 3
Fe (%)	7.22 ± 0.24	6.54 ± 0.17	1.08 ± 0.02	2.96 ± 0.1	3.70 ± 0.06	1.04	0.79 ± 0.01	0.74 ± 0.01	0.73 ± 0.01	0.89 ± 0.03
Co	37.6 ± 1.3	31.8 ± 1.1	0.3 ± 0.1	0.21 ± 0.13	1.2 ± 0.3	0.40	0.2 ± 0.2	0.1 ± 0.1	0.5 ± 0.1	0.5 ± 0.1
Zn	126 ± 21	132 ± 8	111 ± 138	245 ± 9	139 ± 15	85	44 ± 40	39 ± 15	30 ± 4	37 ± 1
Rb	11.6 ± 2.9	25.4 ± 3.6	236 ± 9	302 ± 28	132 ± 5	220	150 ± 2	174 ± 2	134 ± 2	99 ± 3
Sr	390 ± 93	658 ± 153	28 ± 6	< 5	n.d	30	28 ± 8	n.d	73 ± 23	79 ± 37
Zr	96 ± 20	129 ± 17	251 ± 12	1430 ± 313	506 ± 19	249	91 ± 9	87 ± 16	119 ± 9	128 ± 2
Sb	n.d.*	0.03 ± 0.01	0.37 ± 0.03	0.32 ± 0.09	0.15 ± 0.01	0.33	0.29 ± 0.04	0.35 ± 0.04	0.26 ± 0.06	0.40 ± 0.02
Cs	0.24 ± 0.07	0.29 ± 0.08	3.90 ± 0.16	4.36 ± 0.62	1.40 ± 0.03	3.62	9.54 ± 0.11	11.8 ± 0.2	6.77 ± 0.09	5.34 ± 0.07
Ba	121 ± 29	375 ± 50	102 ± 36	50 ± 20	61 ± 26	117	850 ± 17	192 ± 18	989 ± 16	722 ± 10
La	6.35 ± 1.07	16.3 ± 1.6	67.7 ± 1.6	164 ± 6	80.4 ± 4.5	64	20.0 ± 0.3	13.3 ± 0.3	22.2 ± 0.4	21.0 ± 0.4
Ce	14.3 ± 2.0	33.6 ± 2.6	137 ± 4	322 ± 13	155 ± 7	129	42.5 ± 0.7	31.34 ± 0.7	43.6 ± 0.6	41.8 ± 1.2
Nd	9.0 ± 2.0	18.5 ± 0.8	49 ± 5	125 ± 19	65 ± 2	53	15.7 ± 1.8	12.2 ± 1.1	15.0 ± 1.6	15.5 ± 0.4
Sm	3.71 ± 0.29	5.11 ± 0.17	10.9 ± 0.5	23.6 ± 1.9	11.9 ± 0.3	10.4	3.99 ± 0.06	3.83 ± 0.08	3.39 ± 0.07	3.24 ± 0.06
Eu	1.47 ± 0.07	1.66 ± 0.08	0.27 ± 0.06	0.33 ± 0.03	0.51 ± 0.12	0.33	0.28 ± 0.01	0.13 ± 0.01	0.37 ± 0.01	0.54 ± 0.01
Tb	0.85 ± 0.27	0.66 ± 0.05	1.62 ± 0.12	3.16 ± 0.44	1.48 ± 0.01	1.44	0.65 ± 0.03	0.73 ± 0.03	0.51 ± 0.02	0.50 ± 0.04
Dy	3.86 ± 0.4	3.39 ± 0.45	10.3 ± 0.8	19.9 ± 2.3	8.07 ± 0.39	10.3	4.39 ± 0.32	5.08 ± 0.42	3.49 ± 0.4	3.35 ± 0.18
Yb	1.34 ± 0.1	1.15 ± 0.06	4.55 ± 0.34	9.02 ± 0.78	4.05 ± 0.48	4.12	2.98 ± 0.16	3.55 ± 0.14	2.61 ± 0.16	2.64 ± 0.1
Lu	0.26 ± 0.05	0.17 ± 0.02	0.72 ± 0.06	1.34 ± 0.18	0.56 ± 0.03	0.57	0.45 ± 0.01	0.53 ± 0.01	0.42 ± 0.01	0.39 ± 0.01
Hf	2.28 ± 0.17	3.44 ± 0.26	10.0 ± 0.3	40.3 ± 9.0	14.6 ± 0.3	9.4	2.78 ± 0.09	2.69 ± 0.08	3.18 ± 0.05	3.66 ± 0.13
Ta	0.29 ± 0.08	0.67 ± 0.11	6.77 ± 0.42	10.5 ± 2.7	4.28 ± 0.1	6.05	0.54 ± 0.01	0.66 ± 0.01	0.57 ± 0.01	0.52 ± 0.01
Th	0.77 ± 0.19	1.44 ± 0.17	27.5 ± 0.8	33.8 ± 7.8	12.7 ± 0.4	25.6	11.1 ± 0.1	9.7 ± 0.2	11.9 ± 0.2	9.3 ± 0.2
U	n.d	0.46 ± 0.21	7.1 ± 3.0	11.4 ± 3.9	5.19 ± 0.46	8.6	3.19 ± 0.25	3.72 ± 0.31	3.40 ± 0.24	2.57 ± 0.28

[*] This specimen most probably belongs to the PNK1 group (Popov et al., 2019) (see Fig. A.1)

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Table A.2 Concentration of elements (in ppm, unless indicated) measured by NAA in obsidian from Kamchatka Peninsula*

Source	KAM-01	KAM-02	KAM-03 Itkavayam	KAM-04	KAM-05 Payalpan	KAM-06 Nachiki	KAM-07 Belogolvaya River	KAM-08
Element	(n = 12)	(n = 8)	(n = 15)	(n = 8)	(n = 9)	(n = 8)	(n = 24)	(n = 9)
Na (%)	3.09 ± 0.1	3.23 ± 0.04	3.21 ± 0.04	2.95 ± 0.07	2.81 ± 0.08	3.09 ± 0.03	3.19 ± 0.07	3.04 ± 0.07
Al (%)	7.08 ± 0.24	7.16 ± 0.27	7.1 ± 0.29	6.76 ± 0.4	6.67 ± 0.26	6.97 ± 0.28	7.59 ± 0.2	7.54 ± 0.22
Cl	376 ± 73	686 ± 105	112 ± 23	356 ± 24	239 ± 42	409 ± 29	238 ± 79	37 ± 20
K (%)	2.62 ± 0.32	4.19 ± 0.21	3.2 ± 0.17	2.75 ± 0.15	3.94 ± 0.16	3.76 ± 0.2	3.25 ± 0.2	3.17 ± 0.04
Sc	3.03 ± 0.52	7.48 ± 0.11	1.99 ± 0.04	3.26 ± 0.14	1.72 ± 0.04	2.02 ± 0.03	1.82 ± 0.05	3.26 ± 0.07
Mn	486 ± 11	587 ± 5	542 ± 10	391 ± 18	377 ± 5	755 ± 32	558 ± 8	339 ± 12
Fe (%)	1.08 ± 0.04	1.35 ± 0.02	0.58 ± 0.02	0.96 ± 0.04	0.41 ± 0.01	0.53 ± 0.01	0.85 ± 0.04	0.93 ± 0.08
Co	1.29 ± 0.12	0.59 ± 0.02	0.35 ± 0.01	1.03 ± 0.08	0.16 ± 0.03	0.22 ± 0.02	0.95 ± 0.11	0.91 ± 0.16
Zn	34.8 ± 2.4	65.4 ± 3.1	34.1 ± 2.1	35.1 ± 2.7	24.5 ± 3.7	32.3 ± 1	34.3 ± 4.4	44.1 ± 5.6
Rb	60.0 ± 2.2	104.8 ± 1.3	74.2 ± 1.5	66.6 ± 1.4	92.2 ± 1.5	99.8 ± 1.6	70.8 ± 1.4	114.0 ± 3.8
Sr	206 ± 20	84 ± 41	111 ± 17	157 ± 7	53 ± 6	77 ± 10	354 ± 54	153 ± 18
Zr	131 ± 9	282 ± 10	126 ± 6	145 ± 8	97 ± 5	114 ± 6	133 ± 10	106 ± 16
Sb	1.28 ± 0.13	1.01 ± 0.1	0.41 ± 0.03	1.73 ± 0.22	0.41 ± 0.02	0.5 ± 0.05	0.12 ± 0.01	0.24 ± 0.02
Cs	3.54 ± 0.09	4.74 ± 0.07	3.23 ± 0.08	4.4 ± 0.15	2.26 ± 0.05	4.58 ± 0.07	1.26 ± 0.02	10.39 ± 0.81
Ba	773 ± 24	945 ± 10	890 ± 19	867 ± 21	289 ± 18	700 ± 17	1093 ± 28	645 ± 216
La	11.5 ± 0.2	27.0 ± 0.4	16.8 ± 0.4	12.9 ± 0.2	24.2 ± 0.5	22.8 ± 0.3	18.7 ± 0.4	15.9 ± 2.5
Ce	23.4 ± 0.7	61.6 ± 1.2	34.1 ± 0.9	26.9 ± 0.6	44.0 ± 1.5	45.4 ± 0.9	34.0 ± 0.8	33.8 ± 4.9
Nd	9.5 ± 1.2	30.9 ± 1.5	14.9 ± 0.5	11.6 ± 1.2	14.2 ± 0.7	17.8 ± 1.5	12.6 ± 1.2	14.1 ± 2.3
Sm	2.24 ± 0.4	7.5 ± 0.08	2.78 ± 0.1	2.78 ± 0.56	2.48 ± 0.05	3.57 ± 0.72	2.16 ± 0.08	3.2 ± 0.23
Eu	0.473 ± 0.044	1.006 ± 0.015	0.455 ± 0.017	0.491 ± 0.011	0.296 ± 0.007	0.499 ± 0.01	0.513 ± 0.011	0.502 ± 0.041
Tb	0.31 ± 0.03	1.23 ± 0.03	0.37 ± 0.01	0.39 ± 0.01	0.29 ± 0.01	0.39 ± 0.01	0.22 ± 0.01	0.47 ± 0.03
Dy	1.84 ± 0.38	7.78 ± 0.47	2.24 ± 0.28	2.71 ± 0.22	1.64 ± 0.16	2.25 ± 0.21	1.09 ± 0.26	2.68 ± 0.35
Yb	1.77 ± 0.14	5.18 ± 0.14	1.8 ± 0.11	2.11 ± 0.07	1.35 ± 0.03	1.85 ± 0.12	1.09 ± 0.06	1.51 ± 0.09
Lu	0.29 ± 0.016	0.778 ± 0.006	0.32 ± 0.026	0.341 ± 0.007	0.265 ± 0.03	0.294 ± 0.005	0.194 ± 0.018	0.277 ± 0.017
Hf	4.06 ± 0.11	8.66 ± 0.14	3.5 ± 0.08	4.41 ± 0.09	2.95 ± 0.08	3.39 ± 0.11	3.44 ± 0.08	3.01 ± 0.36
Ta	0.2 ± 0.01	0.53 ± 0.01	1.15 ± 0.02	0.22 ± 0.01	1.56 ± 0.04	0.56 ± 0.01	0.74 ± 0.02	0.87 ± 0.05
Th	3.98 ± 0.14	7.43 ± 0.11	7.62 ± 0.17	4.71 ± 0.13	9.27 ± 0.05	7.14 ± 0.13	4.65 ± 0.11	5.72 ± 0.79
U	1.52 ± 0.35	2.95 ± 0.18	4.1 ± 0.28	1.72 ± 0.52	4.47 ± 0.31	2.77 ± 0.11	2.54 ± 0.22	3.05 ± 0.29

*Sources without names do not have exactly determined positions (see Chap. 7)

Source	KAM-09 Karimsky	KAM-10	KAM-11 Maar chasha	KAM-12	KAM-13	KAM-14	KAM-15	KAM-16 Nosichan
Element	(n = 18)	(n = 11)	(n = 34)	(n = 2)	(n = 2)	(n = 2)	(n = 7)	(n = 3)
Source	KAM-09 Karimsky	KAM-10	KAM-11 Maar chasha	KAM-12	KAM-13	KAM-14	KAM-15	KAM-16 Nosichan
Element	(n = 18)	(n = 11)	(n = 34)	(n = 2)	(n = 2)	(n = 2)	(n = 7)	(n = 3)
Na (%)	3.29 ± 0.06	2.93 ± 0.19	2.95 ± 0.04	3.64 ± 0.03	2.97 ± 0.01	2.79 ± 0.01	3.04 ± 0.07	2.98 ± 0.18
Al (%)	6.93 ± 0.28	7.08 ± 0.41	7.03 ± 0.25	7.44 ± 0.29	6.66 ± 0.03	6.68 ± 0.14	7.46 ± 0.44	7.26 ± 0.35
Cl	756 ± 136	253 ± 33	355 ± 74	363 ± 9	533 ± 31	215 ± 18	254 ± 20	254 ± 20
K (%)	2.81 ± 0.18	3.14 ± 0.15	3.07 ± 0.21	2.83 ± 0.07	3.99 ± 0.05	2.98 ± 0.01	3.31 ± 0.15	3.82 ± 0.29
Sc	3.1 ± 0.12	2.11 ± 0.11	1.52 ± 0.1	1.55 ± 0.03	2.38 ± 0.01	1.72 ± 0.01	1.49 ± 0.04	1.71 ± 0.04
Mn	481 ± 10	610 ± 22	599 ± 10	657 ± 4	554 ± 6	539 ± 3	534 ± 12	395 ± 19
Fe (%)	0.94 ± 0.03	0.78 ± 0.03	0.54 ± 0.03	0.74 ± 0.03	0.53 ± 0.01	0.55 ± 0.01	0.64 ± 0.02	0.41 ± 0.01
Co	0.724 ± 0.15	0.563 ± 0.101	0.264 ± 0.098	0.235 ± 0.004	0.197 ± 0.038	0.336 ± 0.036	0.361 ± 0.029	0.171 ± 0.034
Zn	35.3 ± 2.6	37.6 ± 3.0	34.0 ± 3.2	45.4 ± 1.9	34.8 ± 0.4	28.9 ± 1.3	31.1 ± 2.0	20.7 ± 0.2
Rb	50.4 ± 0.8	63.1 ± 2.9	76.9 ± 1.4	71.3 ± 0.0	127.0 ± 0.0	56.5 ± 0.3	78.9 ± 1.4	88.7 ± 0.8
Sr	119 ± 20	282 ± 21	216 ± 24	205 ± 4	39 ± 0	219 ± 25	276 ± 25	47 ± 5
Zr	145 ± 11	134 ± 12	89 ± 5	151 ± 7	141 ± 5	107 ± 15	120 ± 6	98 ± 4

(continued)

Table A.2 (continued)

Source	KAM-09 Karimsky	KAM-10	KAM-11 Maar chasha	KAM-12	KAM-13	KAM-14	KAM-15	KAM-16 Nosichan
Element	(n = 18)	(n = 11)	(n = 34)	(n = 2)	(n = 2)	(n = 2)	(n = 7)	(n = 3)
Sb	0.39 ± 0.05	0.41 ± 0.11	0.36 ± 0.02	0.24 ± 0.0	0.71 ± 0.01	2.16 ± 0.02	0.14 ± 0.01	0.36 ± 0.02
Cs	1.74 ± 0.03	1.68 ± 0.13	2.66 ± 0.06	1.69 ± 0.0	5.67 ± 0.03	2.8 ± 0.01	1.44 ± 0.02	2.2 ± 0.0
Ba	650 ± 16	1391 ± 100	1024 ± 24	767 ± 11	639 ± 10	1439 ± 12	1167 ± 48	279 ± 13
La	15.3 ± 0.2	19.2 ± 3.5	18.4 ± 0.3	20.6 ± 0.1	23.3 ± 0.2	13.8 ± 0.2	20.3 ± 0.5	24.2 ± 0.1
Ce	34.5 ± 1.0	37.1 ± 3.3	33.9 ± 0.9	41.1 ± 0.1	48.7 ± 0.4	27.4 ± 0.1	37.0 ± 1.1	42.0 ± 0.3
Nd	16.5 ± 1.2	16.4 ± 3.4	12.8 ± 1.8	17.1 ± 0.2	20.5 ± 0.3	12.0 ± 2.8	13.7 ± 0.9	13.3 ± 0.1
Sm	3.69 ± 0.1	3.1 ± 0.48	2.29 ± 0.21	3.01 ± 0.02	3.82 ± 0.0	2.11 ± 0.04	2.33 ± 0.11	2.45 ± 0.02
Eu	0.594 ± 0.013	0.611 ± 0.037	0.458 ± 0.012	0.661 ± 0.008	0.46 ± 0.001	0.4 ± 0.002	0.498 ± 0.011	0.294 ± 0.004
Tb	0.6 ± 0.02	0.37 ± 0.04	0.26 ± 0.01	0.36 ± 0.01	0.46 ± 0.0	0.22 ± 0.02	0.24 ± 0.01	0.28 ± 0.01
Dy	3.89 ± 0.39	2.11 ± 0.46	1.49 ± 0.28	1.78 ± 0.42	2.83 ± 0.11	1.09 ± 0.08	1.37 ± 0.33	1.73 ± 0.26
Yb	2.89 ± 0.04	1.75 ± 0.16	1.26 ± 0.07	1.77 ± 0.04	2.37 ± 0.03	1.12 ± 0.03	1.16 ± 0.14	1.38 ± 0.03
Lu	0.432 ± 0.018	0.292 ± 0.034	0.214 ± 0.012	0.271 ± 0.005	0.357 ± 0.003	0.222 ± 0.021	0.234 ± 0.025	0.297 ± 0.026
Hf	4.63 ± 0.07	3.68 ± 0.22	2.53 ± 0.06	4.19 ± 0.08	4.24 ± 0.1	259 ± 0.3	3.28 ± 0.12	2.9 ± 0.06
Ta	0.33 ± 0.01	0.4 ± 0.11	0.49 ± 0.01	0.94 ± 0.02	0.61 ± 0.01	0.27 ± 0.01	0.81 ± 0.02	1.51 ± 0.01
Th	3.43 ± 0.07	4.01 ± 0.25	5.6 ± 0.1	4.69 ± 0.02	8.97 ± 0.02	4.24 ± 0.04	5.41 ± 0.18	9.08 ± 0.02
U	1.99 ± 0.22	2.26 ± 0.52	2.46 ± 0.15	2.95 ± 0.29	3.4 ± 0.21	2.93 ± 0.27	2.72 ± 0.16	4.46 ± 0.03

Table A.3 Concentration of elements (in ppm, unless indicated) measured by NAA in samples from the Lake Krasnoe area

Source	Cape Medvezhy (KRASN-1)	Cape Rybachy (KRASN-2)	Cape Mysovoi (KRASN-3)
Element	(n = 29)	(n = 8)	(n = 1)
Na (%)	2.91 ± 0.05	3.17 ± 0.06	3.61
Al (%)	6.24 ± 0.29	6.01 ± 0.39	6.82
Cl	66 ± 18	128 ± 24	< 50
K (%)	3.92 ± 0.11	3.8 ± 0.16	3.34
Sc	2.37 ± 0.02	0.79 ± 0.01	7.17
Mn	78 ± 2	113 ± 5	379
Fe (%)	0.598 ± 0.005	1.034 ± 0.011	1.78
Co	0.14 ± 0.02	0.06 ± 0.03	0.45
Zn	57 ± 2	106 ± 2	88
Rb	197 ± 2	142 ± 1	132
Sr	< 20	< 20	33
Zr	155 ± 7	399 ± 17	429
Sb	0.88 ± 0.08	0.99 ± 0.12	2.27
Cs	13.2 ± 0.1	7.34 ± 0.04	8.72
Ba	37 ± 9	33 ± 6	619
La	21.2 ± 0.4	37.4 ± 0.5	31.4
Ce	55.4 ± 0.8	90.2 ± 0.9	73.0
Nd	27.7 ± 1.4	45.0 ± 1.6	35.3
Sm	8.18 ± 0.15	11.2 ± 0.3	8.91
Eu	0.036 ± 0.003	0.177 ± 0.006	0.931
Tb	1.54 ± 0.02	2.19 ± 0.03	1.58
Dy	10.7 ± 0.6	15.2 ± 0.8	9.7
Yb	5.86 ± 0.07	8.19 ± 0.17	6.22
Lu	0.84 ± 0.01	1.12 ± 0.01	0.90
Hf	6.00 ± 0.15	13.6 ± 0.2	12.2
Ta	0.85 ± 0.01	0.92 ± 0.01	0.78
Th	15.3 ± 0.1	12.2 ± 0.1	10.3
U	6.3 ± 0.3	4.2 ± 0.3	3.74

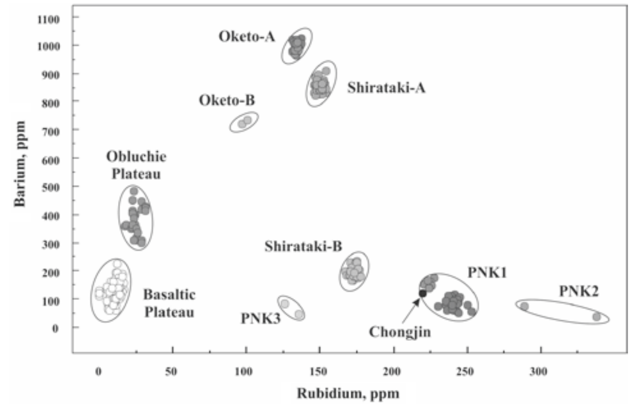

Fig. A.1 Bivariate plot of obsidian sources in the southern Russian Far East and the neighbouring regions of Northeast Asia (see Table A.1)

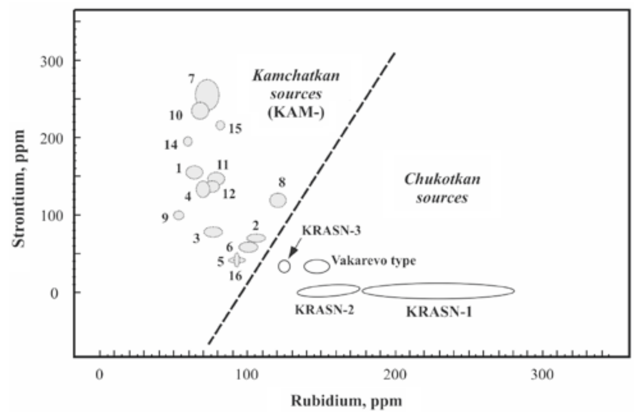

Fig. A.2 Bivariate plot of obsidian sources in the Northeastern Siberia (see Tables A.2, A.3)

See Fig. A.2.

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