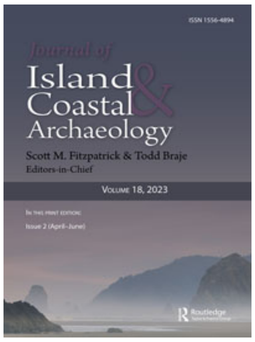

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Provenance and distribution networks of the earliest bronze in the Maritime Territory (Primorye), Russian Far East

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ABSTRACT
Metal artifacts from the Paleometal Epoch (ca. 1100 BC–400 AD) of the Primorye (Russian Far East) have shed new light on the introduction of the earliest bronzes into the Pacific coastal areas of prehistoric Eurasia. However, little is known about raw material circulation and the role of metal in the context of inter-regional exchange. This paper investigates 12 copper artifacts from major Paleometal settlements using alloy composition, trace elements, and lead isotopes to explore the metal sources and distribution networks. The results suggest that most objects are made of a copper-tin alloy, but some have arsenic as a significant minor element . Geologically, copper is unlikely to have come from local ore sources, but rather from the Liaoxi corridor and Liaodong Peninsula in Northeast China. This may indicate an inland route of metal trade across Northeast China or alternately, a coastal route via the northern Korean Peninsula. Archaeologically, the combined study of artifact typology and chemistry indicates two possible origins for the metal: the Upper Xiajiadian culture in Northeast China and Slab Grave culture in Mongolia/Transbaikal. Remarkably, the connection with Upper Xiajiadian communities parallels the transport route along which millet agriculture spread from Northeast China to the Primorye during the Neolithic.

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KEYWORDS
Paleometal Epoch; bronze metallurgy; chemical and lead isotope analysis; provenance; Northeast Asia

Introduction

The rise and spread of early metal use and associated technologies has been a major focus of research on the archaeology of the Eurasian steppe (Chernykh 2008). Most studies have focused on the evolution of early metallurgy in regions where metal

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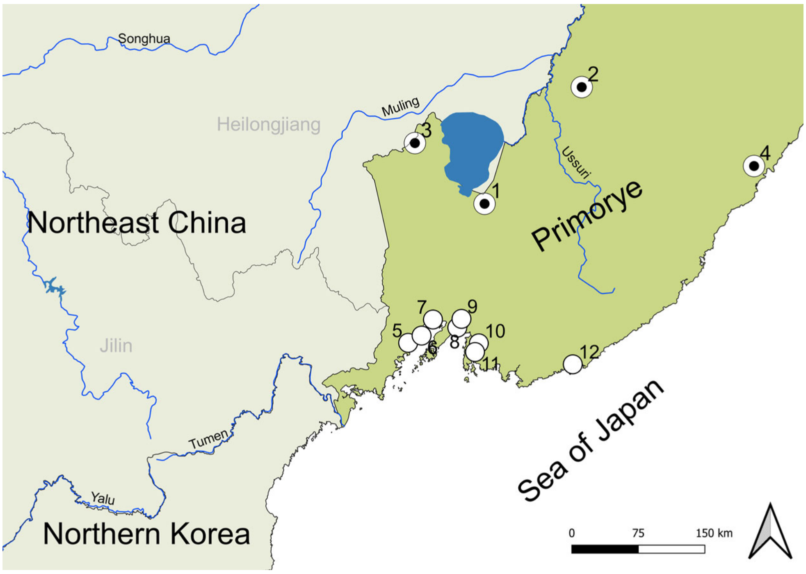

Figure 1. Map of research area and archaeological sites of Paleometal period. Study sites: (1) Siny Gai A; (2) – Elizavetovka-1; (3) Dvoryanka-1; (4) Vetrodui. Sites with bronze or iron artifacts; (5) Barabash-3; (6) Peschanny; (7) Chapaevo; (8) Cherepakha-7; (9) Oleny (Maihe) – 1; (10) Malaya Podushechka; (11) Solontsovy-2; (12) Kievka; (13) Krounovka-1; (14) Korsakovskoe-2.

production was concentrated, such as the southern Urals (Hanks and Doonan 2009; Sharapov 2017), Kazakhstan (Stöllner et al. 2013), the Minusinsk Basin (Legrand 2004), and northern China (Youshimitsu 2001). By contrast, comparably little attention has been paid to the development of metallurgy among early societies on the peripheries of these influential production centers. This article addresses the beginnings of copper metallurgy in one such peripheral area: the Primorye of the Russian Far East. It thus presents the first comprehensive archaeometallurgical study of early copper in the easternmost part of the Eurasian continent (Figure 1). Due to the close proximity to Manchuria and the Korean Peninsula, the archaeology of Primorye exhibits a high degree of cultural dynamism and long-distance interaction from the Late Neolithic period (ca. 5000–3300 cal BP) as evidenced by the diverse ceramics, textile production, subsistence strategies (particularly millet agriculture), and exotic artifacts, such as ornaments made from a jade-like mineral and stone replicas of metal daggers and spearheads (Nelson et al. 2020; Popov, Zhushchikhovskaya, and Nikitin 2019; Tao et al. 2020; Zhushchikhovskaya 2018).

The earliest copper-based artifacts in the Russian Far East are found in settlements of the western Primorye dated to the late second millennium BC (Brodyansky 2013; Kon'kova 1989, 32–36; Nikitin 2012). This signifies the beginning of the Paleometal Epoch (ca. 1100 BC–400 AD), which is a transitional period characterized by the sporadic use of metal alongside stone tools before the widespread adoption of metal in the Iron Age (ca. fourth to seventh centuries AD) (Aikens, Zhushchikhovskaya, and Rhee 2009). A specific feature of early Primorye metallurgy is the rapid arrival of bronze and iron throughout the region, separated by a short chronological gap, allowing “Early Bronze” and “Early Iron” stages to be identified within the Paleometal period. The first bronze appeared between 1100 and 800 BC and the first iron between 700 and 500 BC, which has been taken as evidence for metallurgy having been transmitted to the region as a package rather than being invented locally (Popov, Zhushchikhovskaya, and Nikitin 2019). The idea that the first copper was introduced by new groups of people is supported by the simultaneous appearance of pottery tempered with crushed shell. Use of shell temper was not found in the Late Neolithic pottery of the Primorye, but it was practiced widely in parts of western and southern Siberia, Central Asia, and Northeast China from the Neolithic onward, meaning these groups potentially took the technique to the Primorye (Zhushchikhovskaya 1996, 2005, 128–133).

In addition, the coastal region of southern Primorye during the Paleometal period shows likely cultural contacts with the northern part of the Korean Peninsula. There are some similarities between the shapes and ornamentation of pottery assemblages from the sites of the Yankovskaya culture of the Primorye dated to around 9000–3000 BC and those at Yalu and Tumen river basins dated to the Mumun period of prehistoric Korea, ca. 1500–300 BC (Nelson 1993, 121–123). Furthermore, the Yankovskaya sites and middle and late Mumun sites contain a similar package of prestige goods, namely red-polished pottery, greenstone ornaments, and polished stone replicas of bronze daggers (Zhushchikhovskaya 2018). It is also important to note that in southern Primorye, a few examples of Korean-type bronze daggers and mirrors dated to the final Mumun period have been discovered (Kon'kova 1989, 44).

Overall, the Paleometal period in the Primorye is marked by distinctive archaeological communities, who were supposedly of different cultural backgrounds (Popov, Zhushchikhovskaya, and Nikitin 2019). The apparent cultural diversity represents a marked departure from the situation during the Neolithic. Rather than being the result of gradual local developments, the cultural and technological change seen at Paleometal sites likely testifies to external stimuli, probably involving the migration of people. The emergence of early copper in Primorye at this time may be positioned within the context of these cultural and demographic processes.

Previous studies

Initial evidence for the earliest metallurgy in the Primorye and neighboring areas was discovered in the 1960s (D'yakov 1989; Kon'kova 1989, 5–6; Okladnikov 1966). These were mostly single, occasional finds from non-stratified cultural layers that could not be reliably dated or associated with any particular archaeological context. The one exception was an assemblage of 21 copper-based artifacts that was reportedly unearthed from controlled excavation at the settlement of Siny Gai A and dated to the twelfth to ninth centuries BC (Brodyansky 1972).

An attempt to trace the origin of this assemblage was made in the late 1970s and 1980s by Lyudmila V. Kon'kova as a part of a general investigation of Far Eastern bronzes in prehistory (Kon'kova 1989). Based on artifact typology, chemical composition, and metallographic structure, she concluded that the morphological, functional, and chemical features of Primorye bronzes resembled the well-known Karasuk metallurgy of the Minusinsk Basin, which was spread widely across eastern Eurasia in the late second millennium BC. Early metals in Primorye are made of either copper-tin or copper-arsenic alloys, of which raw materials potentially originated from Siberia, specifically the Transbaikal (Zabaykal'ye) area. She suggested that initial bronzes and, probably, associated metal technology, were brought to the easternmost part of the Eurasian continent by new populations from the west, where large metal production centers had existed from the second millennium BC (Kon'kova 1989, 32–41 and 84). Later, Kon'kova employed lead isotopic analysis to pinpoint the geological ore sources for Primorye bronzes (Kon'kova, Fefelov, and Zarudneva 1990). The results pointed to the southern edge of the Siberian Platform, which encompasses the Altai-Sayan mountains, Kuznetsk Alatau range, the region of Krasnoyarsk, and the western part of the Transbaikal region. The bronze artifacts from Palaeometal sites in the Primorye were, therefore, likely rooted in the "Siberian tradition" of metal production (Kon'kova 1996, 2016, 2019).

From the 1990s onward, several settlements were excavated and yielded more evidence for the use of metals during the Paleometal Epoch (Nikitin 2012; Sidorenko 2007; Yanshina and Kluyev 2005). The majority of copper-based objects are concentrated in the settlements of the western and northwestern Primorye, all dated between the twelfth and eighth centuries BC. In contrast, sites in the central and eastern Primorye region produce single finds of metal from a later period: around 500 BC to 400 AD. The settlements associated with early metals do not show much cultural unity, as morphological and technological features of local pottery remain distinct (Nikitin 2012; Zhushchikhovskaya 2005, 128–133;). This may indicate that the process of early metal adoption in the Primorye was dictated by regional networks that were organized by several distinct communities rather than a single centralized production center.

Despite Kon'kova's (1989, 1996) scientific investigation, the Siberian origin of metallurgy in the Primorye was mainly based on limited archaeological and geological data. Over the past few decades, metal working remains have been excavated from numerous sites in Northeast China, which are not only contemporary with those in the Primorye, but also demonstrate cultural links to the region (Girchenko 2018; Nelson 1995, 147–250). Meanwhile, increasing numbers of lead isotope analyses on Russian and Chinese ore deposits have provided a large body of reference data that can be used to trace the geological sources of the ore used for the Primorye metals (Hsu and Sabatini 2019). The present study therefore represents a new phase in a scientific program that aims to analyze archaeological metals in relation to a comprehensive chemical and isotopic database of ores and relevant metal assemblages. In comparing the Primorye copper with this database, we characterize the origin, movement, and production of copper and its alloys in the Pacific region of Eurasia, which lies on routes that were crucial in the spread of domesticated crops and languages in prehistory (Nelson et al. 2020; Tao et al. 2020).

Materials and methods

A total of 12 copper-based artifacts were obtained from the Paleometal settlements of Siny Gai A ($n = 7$), Elizavetovka-1 ($n = 3$), Dvoryanka-1 ($n = 1$), and Vetrodui ($n = 1$) for the investigation of their chemical compositions and lead isotopic ratios (Figure 2). Siny Gai A, Elizavetovka-1, and Dvoryanka-1 are spatially and temporally close to

Figure 2. Metal artifacts examined in this research.

each other along the western part of the Primorye and date to ca. 1100–800 BC (Figures 1 and 3). These sites represent the earliest stage of the Paleometal Epoch. In contrast, Vetrodui in the eastern Primorye is relatively late, dating to the early first millennium AD, which represents the end of the period. A summary of archaeological information on the sites is presented in the online supplementary material (S1). It is important to note that those early sites in western Primorye represent the existence of various material cultures, as reflected by their distinctive pottery assemblages (Figure 2S).

The most typical metal artifact from the four study sites is a type of single-edged, perforated knife with a trailing point and semi-spherical buttons. These metal items were common among various groups located in Siberia, the Transbaikal, Central Asia, Northeast China, and the Korean Peninsula at the turn of the first millennium BC (Kon'kova 1989; Nelson 1993, 132–163, 1995, 147–250). A particularly distinctive item is a comma-shaped pendant from Vetrodui, which strongly resembles greenstone

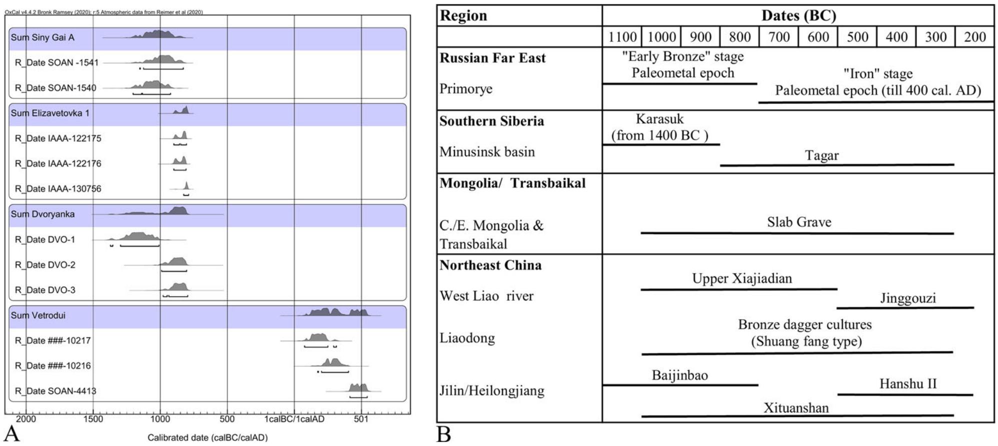

Figure 3. (A) The average calibrated dates ("sum") for each Paleometal site (OxCal v.4.4.2 [Bronk Ramsey 2009], calibration curve IntCal20 [Reimer et al. 2020]); and (B) chronology of main archaeological cultures discussed in this paper according to Svyatko et al. (2009), Taylor et al. (2019), Popov, Zhushchikhovskaya, and Nikitin (2019), and Zhu (1998).

ornaments widely distributed over the Korean Peninsula, Japanese Archipelago, and other Paleometal sites in the early first millennium BC (Aikens and Higuchi 1982, 165, 173; Bale and Ko 2006; ; D'yakov 1989, 171; Nelson 1995, 132; Zhushchikhovskaya 2018). In addition to the artifacts mentioned above, there are some small items, including a fishhook and a ring-like item, which could have been manufactured locally.

In preparation for analysis, the samples were cut with a fine jeweler's saw grade 6/0 blade (70 teeth per inch), then polished with 300-grit abrasive paper to remove remaining patina. To gauge the bulk composition, the specimens were dissolved in a 1:1 mixture of 7 N HNO_3 and 6 N HCL, dried, and diluted with ultrapure water to a concentration of ca. 1000 mg/L. The diluted solutions were injected into a high resolution inductively coupled plasma mass spectrometer (HR-ICP-MS, Thermo Scientific Element XR^{TM}) at the Research Laboratory of the Deutsches Bergbau-Museum Bochum. Quantification was performed with external calibration. The solutions were diluted in 5% HNO_3 to 1:100 for both main and minor elements then 1:10 for trace elements. The analyses were carried out with a SC-FAST automated sample introduction system ST5532 PFA μ-FLOW nebulizer, Peltier-cooled PFA spray chamber, and 1.8 mm sapphire injector in triple detector mode at all three mass resolutions ($m/\Delta m$) depending on the element of interest.

Measurements were controlled with compatible standards for the pure copper and copper-tin alloy, including BAM-376 (Bundesanstalt für Materialforschung und -prüfung) and BRONZE C (British Chemical Standards). Relative standard deviation for trace elements varied between 0.5 and 4.5%, and between 0.6 and 2% for main elements. As one ICP-MS analysis (SG5) yielded an erroneous analytical total (65%), the major elements of this sample were re-assessed using a Carl Zeiss SUPRA^{TM} 40 field emission scanning electron microscope (FE-SEM) based on the procedures described by Hsu et al. (2020).

Table 1. The lead isotopic results of the Primorye metal objects.

ID	Site	Object	$^{206}Pb/^{204}Pb$	2σ	$^{207}Pb/^{204}Pb$	2σ	$^{208}Pb/^{204}Pb$	2σ
EL1	ELIZAVETOVKA	knife	18.263	0.168	15.61	0.144	38.14	0.354
EL2	ELIZAVETOVKA	knife	18.215	0.01	15.599	0.008	38.378	0.021
EL3	ELIZAVETOVKA	knife	18.211	0.011	15.606	0.01	38.1	0.026
DVO1	DVORYANKA	button	18.005	0.011	15.555	0.01	37.861	0.025
VET1	VETRODUI	pendant	18.522	0.012	15.617	0.009	38.621	0.023
SG1	SINY GAI	knife	17.733	0.01	15.571	0.01	38.01	0.026
SG2	SINY GAI	knife	17.749	0.012	15.580	0.012	38.031	0.033
SG3	SINY GAI	knife	17.664	0.009	15.553	0.009	37.928	0.024
SG4	SINY GAI	hook	17.97	0.011	15.582	0.01	38.028	0.025
SG5	SINY GAI	fragment	18.036	0.011	15.608	0.009	38.382	0.025
SG6	SINY GAI	ring	17.1	0.009	15.397	0.008	37.258	0.022
SG7	SINY GAI	button	17.798	0.01	15.551	0.009	37.877	0.022

The analysis of Pb isotopes started with the acid digestion and chromatographic separation as reported by Hsu et al. (2020). The sample solutions were spiked with Tl isotopic standard NIST SRM 997 (National Institute of Science and Technology) and were measured with a Thermo Scientific NEPTUNE^{TM} multi-collector inductively coupled plasma mass spectrometer (MC-ICP-MS) at Frankfurt Isotope and Element Research Center (FIERCE) of Goethe University Frankfurt. Except for the sample EP1, which had a higher experimental error (~1% 2σ), the precision of the Pb isotope measurements was mostly less than 0.065%. Further details of the method can be found in Klein et al. (2009) and Westner et al. (2020). All results are reported in Tables 1 and 2.

Results and discussion

Characterization of the Primorye metals

The Primorye assemblage is mainly characterized by copper containing tin with two variants: tin-bronze and tin-bronze with arsenic as a significant minor element (Figure 4A). The first group contains less than 0.5% arsenic and comprises the objects from Siny Gai A and Dvoryanka-1 exclusively. The second group, with higher arsenic content, comprises the whole Elizavetovka-1 assemblage and two Siny Gai A objects. Copper-tin artifacts feature variable quantities of tin, typically ranging from ca. 1 to 12%. One exceptional item, a semi-spherical button found at Dvoryanka-1, comprises up to 41% tin. Conversely, lead content in the Primorye objects is normally present as an impurity below 1%, except for SG6, which has 1.4% lead. Previous optical emission spectroscopy (OES) analyses of Siny Gai A metals reported by Kon'kova (1989) are consistent with the results of the present study, as both data sets show a similar spread of tin and arsenic. Unfortunately, the legacy data does not specify the archaeological context of each artifact, which precludes direct comparison of the new and old analyses.

The trace element patterns allow the raw materials used at each site to be specified to an extent. The Elizavetovka-1 objects have elevated arsenic contents, which may be an impurity derived from the copper ore, while the Dvoryanka-1 button is rich in nickel (Figure 4B). Comparing these analyses with the old measurements reveals a discrepancy, as the OES data for Siny Gai A generally presents smaller quantities of antimony, silver, and nickel. This raises the issue of how legacy data should be treated in the discussion of metal provenance. A well-established problem with OES is that it suffers from poor

Table 2. The chemical composition of the Primorye metal objects.

ID	Cu%	Sn%	Pb%	As%	Sb%	Ag%	Ni%	Bi%	Fe%
EL1	80	13.637	0.2	3.201	0.607	0.162	0.022	0.064	0.316
EL2	93	3.026	0.185	1.017	0.093	0.1	0.046	0.03	0.005
EL3	91	5.751	0.319	1.738	0.154	0.115	0.068	0.035	0.037
DVO1	56	41.03	0.104	0.723	0.201	0.074	0.174	0.069	0.033
VET1	96	0.473	0.053	0.199	0.343	0.336	0.013	0.018	0.001
SG1	91	1.08	0.03	0.025	0.073	0.057	0.018	0.005	0.01
SG2	85	2.82	0.036	0.1	0.17	0.051	0.038	0.008	0.006
SG3	87	5.18	0.17	0.23	0.14	0.036	0.027	0.014	0.041
SG4	91	1.57	0.049	0.249	0.309	0.062	0.058	0.01	0.254
SG5*	93	3.3	0.4	1.5	0.8				0.6
SG6	72	3.43	1.4	2.95	0.19	0.69	0.037	0.53	0.62
SG7	89	11.302	0.332	0.35	0.037	0.377	0.058	0.269	0.085

*Measured by scanning electron microscopy coupled energy-dispersive x-ray spectroscopy.

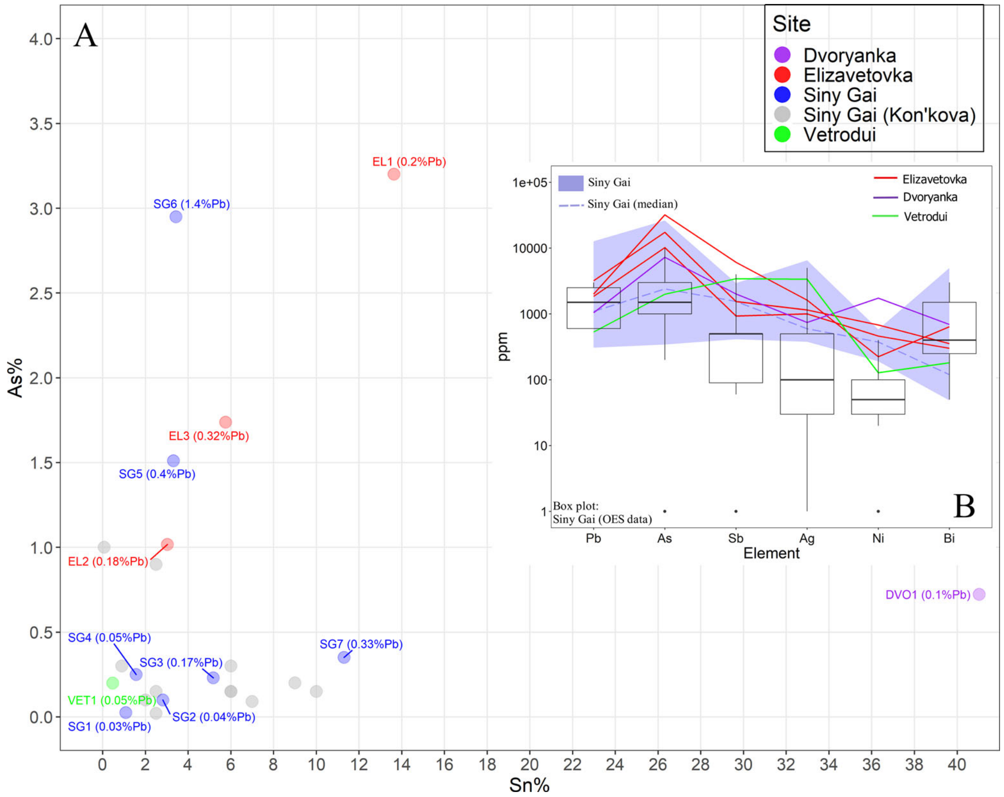

Figure 4. (A) The tin and arsenic concentrations of the Primorye objects; and (B) trace element patterning of the Primorye objects. The shaded area represents 95% confidence level. The boxplot displays the legacy OES data from Kon'kova (1989).

precision and measurement repeatability due to unstable excitation conditions and development of the photographic plates (Pollard, Batt, and Young 2007, 48). Therefore, OES results tend to be less precise than those of recently developed analytical techniques. Due to these issues, this study does not consider trace elements from legacy data.

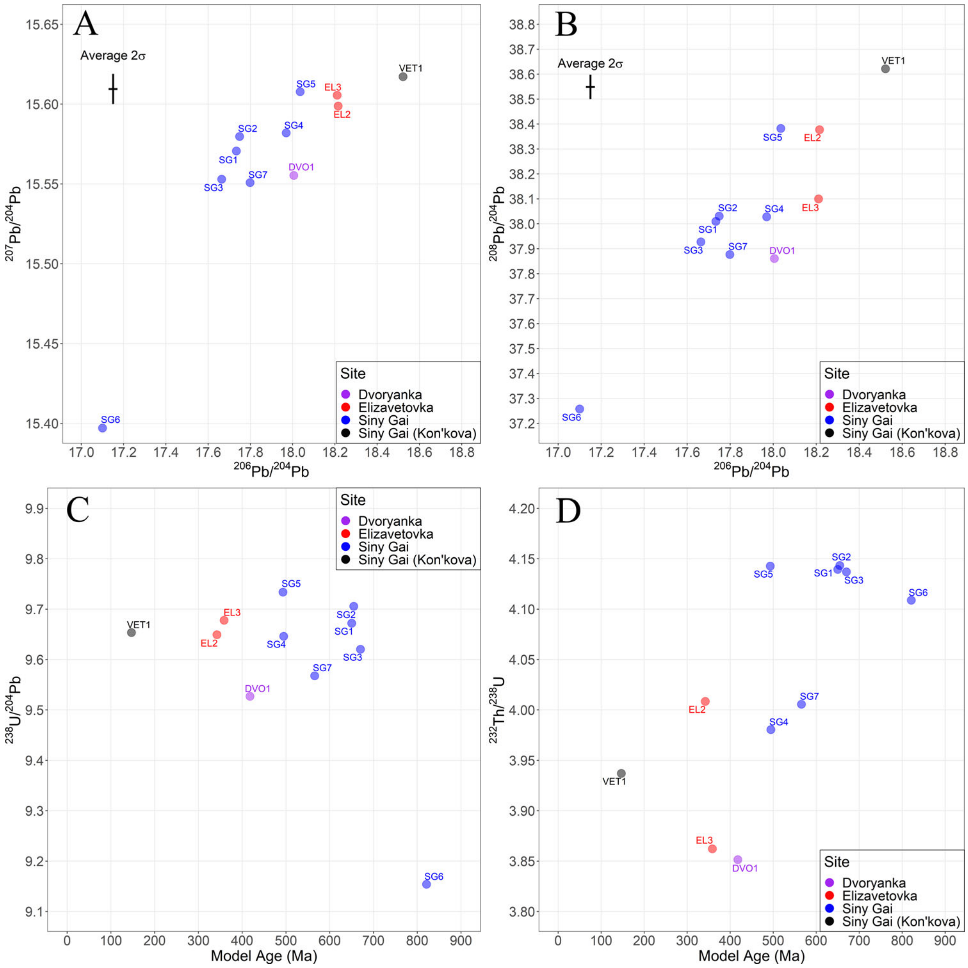

Figure 5. (A) Conventional plot of $^{206}Pb/^{204}Pb$ versus $^{207}Pb/^{204}Pb$ for the data from the present study and Kon'kova, Fefelov, and Zarudneva (1990); (B) conventional plot of $^{206}Pb/^{204}Pb$ versus $^{208}Pb/^{204}Pb$; (C) plot of the model age versus $^{238}U/^{204}Pb$; and (D) plot of the model age versus $^{232}Th/^{238}U$.

Although certain trace elements (e.g., arsenic, antimony, silver, bismuth, and nickel) could in principle indicate specific ore bodies that produced the copper used in certain artifacts (Pernicka 2014, 253), variation in element quantities is dependent on several parameters, such as the heterogeneity of the ores, smelting conditions, and whether metal has been recycled. Hence, lead isotopes can provide complementary evidence to determine provenance. Lead commonly occurs as a trace constituent in copper minerals and its isotopic composition is mostly unaffected by either geological weathering or pyrometallurgical processes, meaning that it is a good indicator for the source of raw material (Gale and Stos-Gale 1982).

Lead isotope ratios and their geological parameters (model age, $^{238}U/^{204}Pb$, and $^{232}Th/^{238}U$) for the Primorye objects are displayed in Figure 5, in addition to the legacy data from Kon'kova, Fefelov, and Zarudneva (1990) for the artifacts from Siny Gai A. The low concentration of lead in the samples indicates that the isotopic values principally reflect the composition of the original copper sources rather than the deliberate

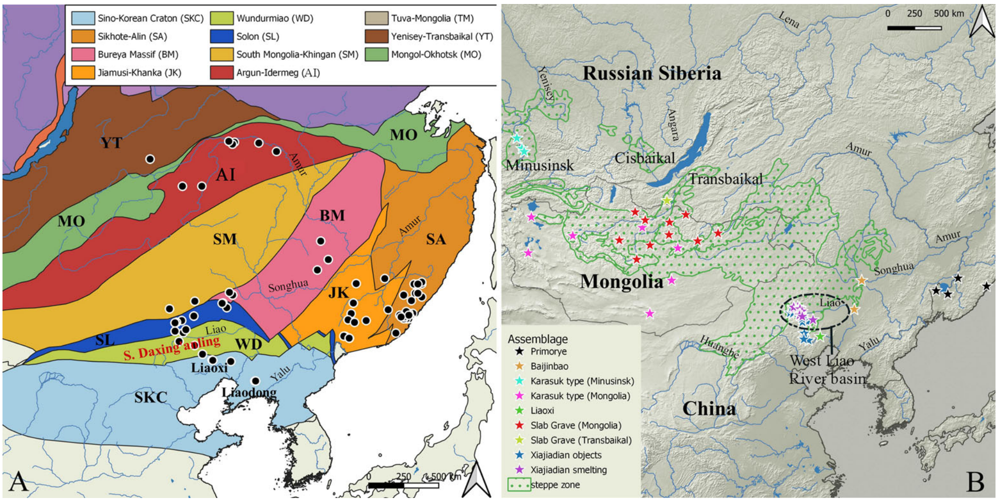

Figure 6. (A) Map showing major tectonic terranes in eastern Eurasia and occurrence of ore deposits from which lead isotope data were obtained, based on Nokleberg (2010); and (B) map showing the distribution of sites with copper-based artifacts from which chemical and lead isotope data were collected.

addition of lead during the manufacturing processes. A striking feature is that each site has a distinct distribution that can be clearly distinguished along the model age. The Siny Gai A objects yield a range of ages from ca. 500 to 700 Ma as opposed to the younger model ages of Elizavetovka-1 (ca. 350 Ma) and Vetrodui (ca. 150 Ma). There is even variation observable within a single site, as SG6 is readily distinguishable from the other Siny Gai A samples, which are also divided into two distinct clusters by the Th/U ratio. This variability, along with the distinct trace element patterns that define each site, suggest that metallurgy was practiced at the regional level, with each site having its own links with metal sources outside the region.

It is worth noting that the legacy data produced using thermal ionization mass spectrometry (TIMS) by Kon'kova, Fefelov, and Zarudneva (1990) demonstrate systematically lower $^{207}Pb/^{204}Pb$ ratios than the present study's results using HR-ICP-MS. Lead isotope studies conducted prior to the last two decades had difficulty measuring the less abundant isotope ^{204}Pb accurately (Albarède, Desaulty, and Blichert-Toft 2012, 854). Additionally, before samples were routinely spiked with Tl, lead isotope analysis by mass spectrometry suffered from the significant effect of mass fractionation, which causes the measured isotopic compositions to be enriched with lighter isotopes (Chernyshev, Chugaev, and Shatagin 2007, 1066). The analytical errors of Kon'kova's TIMS data range from 0.1 to 0.3%, which is far larger than in the present study. Consequently, the following discussion does not include the legacy data, as it is difficult to compare measurements of such different qualities.

Raw material sources for Primorye metalwork

There are three avenues by which people in the Primorye could have produced their bronzes: (1) primary production using local ore sources; (2) secondary production

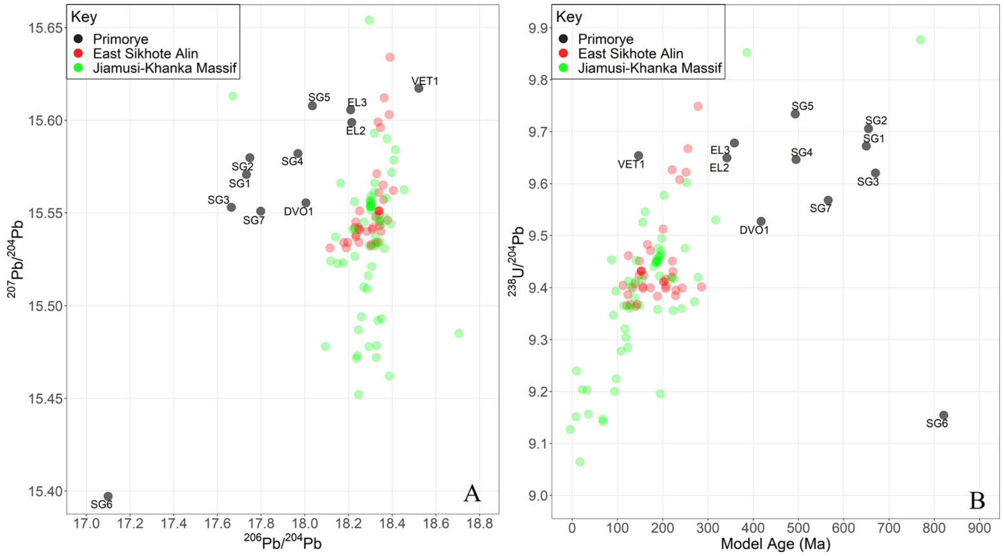

Figure 7. (A) Conventional plot of $^{206}Pb/^{204}Pb$ versus $^{207}Pb/^{204}Pb$ for the data from the present study and ore samples in the vicinity of the Primorye (Rasskazov et al. 2002); and (B) plot of the model age versus $^{238}U/^{204}Pb$.

through the mixing and recycling of imported metals; and (3) direct import of finished objects from other metal-producing communities. Lead isotope geochemistry can be used to discriminate potential ore sources with the assistance of a referenced data base. Hence, a substantial lead isotope data set for sulfidic ores in the modern metallogenic districts of Northeast China, the Russian Far East, and Siberia, as well as analyses of copper-based artifacts from relevant archaeological communities, was collated to explore these possibilities. The distribution of referenced geological sources (classified as tectonic terranes) and metal artifacts are shown in Figure 6, and the corresponding raw data and literature can be found in the online supplementary material (S2).

The Primorye is situated in a contact zone between the terranes of the Jiamusi-Khanka Massif (JK) and East Sikhote Alin (SA). Base metals in these units are hosted in hydrothermal vein and skarn deposits, which could have sustained local metal production (Rasskazov et al. 2002). Despite the presence of these local ore bodies, lead isotope ratios from the JK and SA deviate markedly from the signatures of the Primorye artifacts, as they have younger model ages (<300 Ma) and lower U/Pb ratios (<9.5) (Figure 7). Hence, the possibility that raw materials from within the Primorye were used can be excluded, meaning that the appearance of bronze metalwork in this region derived from non-local sources.

A supply network that relies on external metal sources would require the existence of an exchange network that connected the Primorye with other ore-rich regions. There were two potential routes along which metal could have flowed during the Paleometal period: (1) an inland route across Northeast China; and (2) a steppe route from the Transbaikal/Mongolia to the Amur River basin. The inland route has been highlighted as the principal path for the dispersal of millet agriculture from the West Liao River basin in Northeast China to the Russian Far East during the Neolithic (Tao et al. 2020).

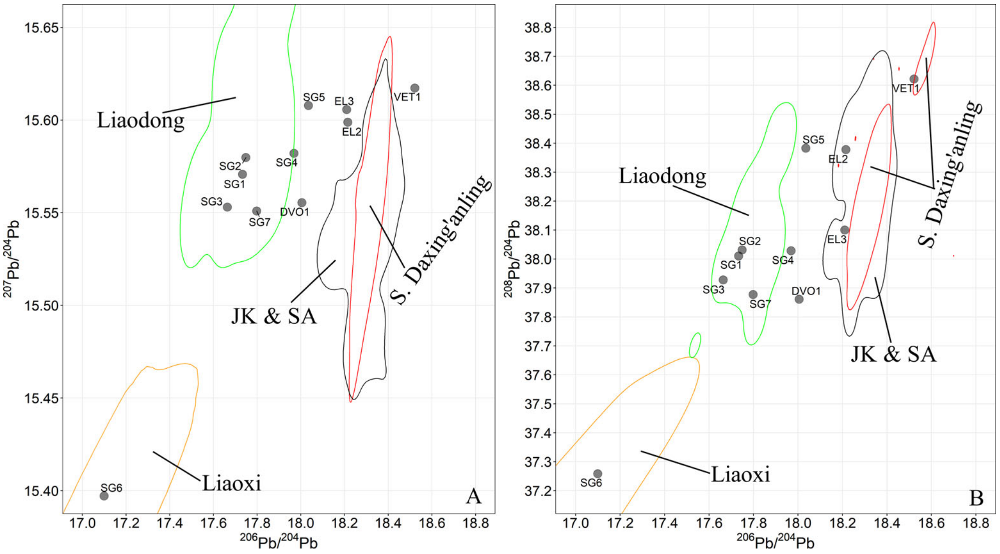

Figure 8. (A) Conventional plot of ^{206}Pb/^{204}Pb versus ^{207}Pb/^{204}Pb for the data from the present study and ore samples along the inland transportation route. The circled areas correspond to the kernel density estimation at 95% confidence levels; and (B) conventional plot of ^{206}Pb/^{204}Pb versus ^{208}Pb/^{204}Pb.

The West Liao River area sits within the southern Daxing'anling metallogenic belt, which is characterized by abundant polymetallic deposits (Niu et al. 2007). South of the Daxing'anling belt is the Sino-Korean Craton (SKC), which hosts rich gold and lead-zinc ore mineralization, particularly in the Liaoxi corridor and Liaodong Peninsula (Li and Santosh 2014). Figure 8 shows that, while the isotopic array of the Daxing'anling ores does not overlap with any artifacts, the Liaodong and Liaoxi data overlap with SG1, SG2, SG3, and SG6 from the Siny Gai A assemblage. Among these, SG6 is the only specimen that contains >1% lead, and its overlap with the Liaoxi ores might suggest the mixing of lead ores from this area. Overall, it is highly likely that an inland route across Northeast China fed Primorye metallurgy, particularly at the settlement of Siny Gai A. Alternatively, copper from the Liaodong could have been transferred along a coastal route via the northern part of the Korean Peninsula, but this route remains hypothetical due to a lack of published archaeological research from North Korea.

In addition, the SKC is one of eastern Eurasia's major Archean cratons; therefore, the ore-forming process in this geological setting involved sources of lead older than those in other orogenic tectonic terranes, such as the Daxing'anling, JK, and SA. This is evidenced by the lower radiogenic lead signature, which corresponds to an older model age of ore bodies from the SKC in comparison with the terranes presented above.

The other route, here designated as the "steppe" route, lies along the Amur River valley and it could have linked the Primorye with the steppe zone of Siberia. A series of ore deposits hosted in the superterranes of the Bureya Massif (BM) and Argun-Idermeg (AI) are located between the Primorye and contemporary steppe communities, such as the Slab-Grave culture in central/eastern Mongolia and the Transbaikal. However, modern ores from the BM and AI exhibit a more radiogenic component, which is

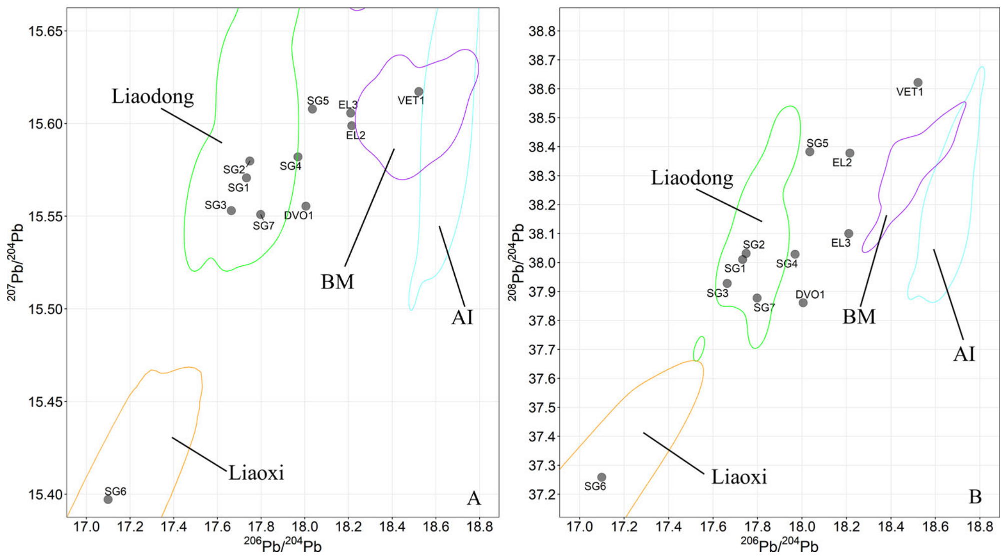

Figure 9. (A) Conventional plot of ^{206}Pb/204Pb versus ^{207}Pb/^{204}Pb for the data from the present study and ore samples along the steppe route. The circled areas correspond to the kernel density estimation at 95% confidence levels; and (B) conventional plot of ^{206}Pb/^{204}Pb versus ^{208}Pb/^{204}Pb.

characteristic of younger lead sources (Figure 9). Consequently, there appears to be no direct link between these modern ore-rich steppe areas and the Primorye metalwork.

One of the most challenging tasks in the study of ancient metal is identifying potential recycling and mixing of metal, activities that are indicative of complex systems of metal circulation rather than a simple pathway between the origin and the deposition of artifacts (Pollard et al. 2018, 46). It is likely that the Primorye objects (SG4, SG5, DVO1, EL3, and EL2) that do not overlap with the modern ore signatures arrived in the region as the result of complex inter-regional interactions between archaeological communities instead of directly from any geological deposit.

The flow of metal artifacts along supply networks

While modern ore data can hint at the origins of prehistoric materials, it cannot provide a true picture of ancient exploitation, as modern ore geology focuses primarily on large economic deposits that were potentially not accessible to ancient miners. Moreover, provenance reflects only one episode of metal circulation and simply establishing the origin of ore does not explain how the people of the Primorye region engaged with metal. It is possible that people were unaware that some of their metal came from ore deposits several thousand kilometers away in modern Northeast China. More probably, they dealt with intermediaries who had immediate access to the mines and procured the metal for them. Such an exchange network would be based on the circulation of finished or semi-finished products that could be easily reworked into the desired form. To explore this, we compared the data produced in this study with metal objects from contemporary communities, with a particular goal of identifying source regions and their distribution among the Primorye assemblage. The metal-production powerhouses that could have supplied metal to the Primorye include the archaeological

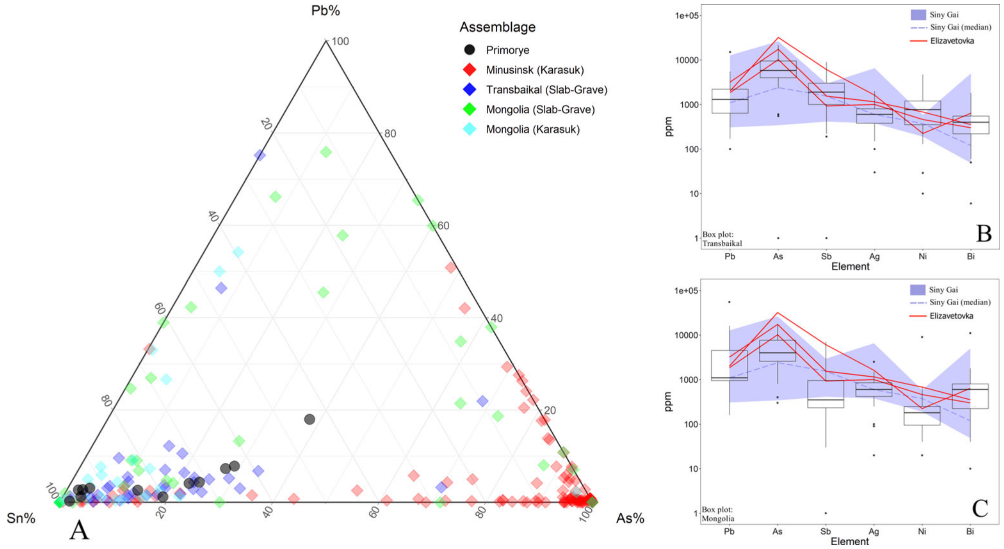

Figure 10. (A) Ternary diagram Sn + Pb + As of metal assemblages from the Primorye, Karasuk, and Slab Grave cultures. The plot displays reactions, not exact values; (B) comparison of trace element signatures for artifacts from the Primorye (Siny Gai and Elizavetovka) and Slab Grave (Transbaikal) sites; and (C) comparison of trace element signatures for artifacts from the Primorye (Siny Gai and Elizavetovka) and Slab Grave (Mongolia) sites.

communities referred to as Upper Xiajiadian (1000–600 BC), Baijinbao (1100–800 BC), Karasuk (1400–900 BC), and the Slab Grave culture (1000–300 BC).

The first step in establishing connections between metal assemblages is the classification of alloy practices, as different combinations of alloy elements cause color variation in the final product, which prehistoric peoples will have been aware of and made choices accordingly. Primorye metallurgy shows a preference for copper-tin alloys with traces of arsenic (Figure 10A), which is fairly consistent with the Slab Grave artifacts from Mongolia and the Transbaikal. The compositions of metal artifacts from both regions are also observable in the trace element patterns (Figure 10(B, C). This stands in stark contrast to the arsenical copper used by the Karasuk communities in the Minusinsk Basin. Although L. Kon'kova (1989) suggested that metallurgy in the Primorye was probably adopted from the Karasuk culture, the chemical results presented here do not support this hypothesis. Instead, a close connection with Mongolia and the Transbaikal region is more likely, though it is difficult to establish whether the Primorye objects arrived in the region as finished products or were made locally from recycled metal.

Other candidates that potentially contributed to alloy practices in the Primorye are archaeological communities in Northeast China, including the Upper Xiajiadian culture in the West Liao River region (Jaffe 2020) and the Baijinbao culture in present-day Jilin and Heilongjiang provinces (IAHP and DAJU 2009; IAJP 2011; Nelson 1995, 228–231). In Northeast China, the Upper Xiajiadian culture is the most significant late Bronze Age metallurgical center identified so far, and a full spectrum of metallurgical activity is attested, from the extraction of metal to the manufacture of finished products (Dong 2012). As shown in Figure 11(A), Upper Xiajiadian assemblages comprise a variety of

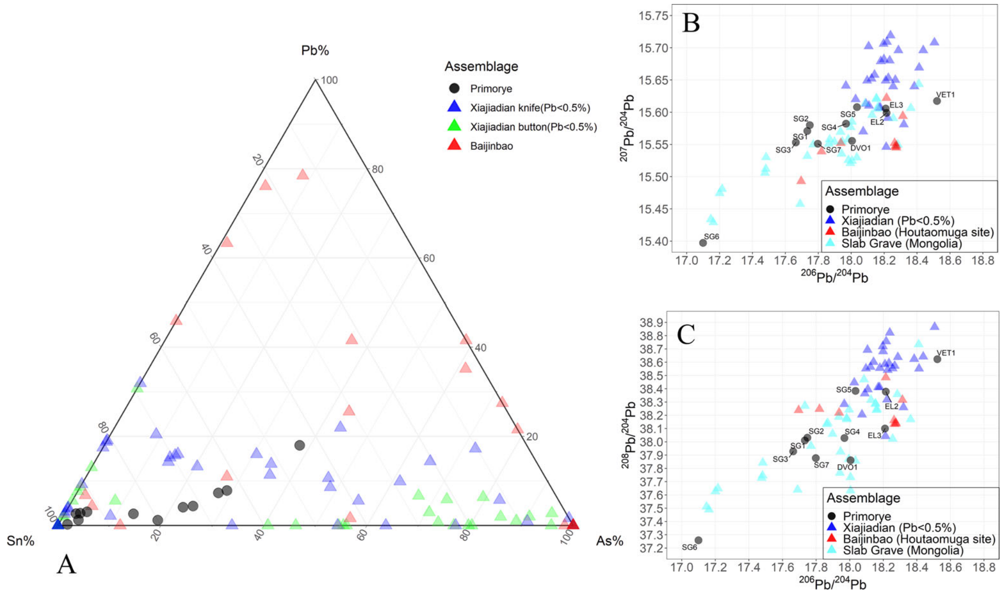

Figure 11. (A) Ternary diagram Sn + Pb + As of metal assemblages from the Primorye, Upper Xiajiadian, Baijinbao, and Slab Grave cultures. The plot shows relations, not exact values; (B) conventional plot of ^{206}Pb/^{204}Pb versus ^{207}Pb/^{204}Pb for the data from the present study and artifacts from the Upper Xiajiadian, Baijinbao and Slab Grave cultures; and (C) conventional plot of ^{206}Pb/^{204}Pb versus ^{208}Pb/^{204}Pb.

copper alloys, including copper-tin, copper-tin-lead, copper-arsenic, and copper-tin-lead-arsenic, which has been suggested as being indicative of the smelting of polymetallic sulfidic ores (Yang 2015). Upper Xiajiadian knives and buttons are characterized by different proportions of tin and arsenic, resembling the general trend in Primorye metallurgy. Similarly, metal objects from some Baijinbao sites are composed of a copper-tin alloy with arsenic. This indicates a connection between the Upper Xiajiadian culture and the Primorye metalwork due to: (1) direct import of finished metal products from Northeast China through trade and/or population migration; or (2) the mixing of imported scrap metal from various regions. The second scenario seems more probable, as the lead isotope results suggest that the Primorye metal had at least two origins (Figure 11(B, C)). The combined Upper Xiajiadian, Baijinbao, and Slab Grave isotopic field either covers the extent of the Primorye objects' distribution or exhibits a similar alignment (exceptions are SG6 and VET1). The alignments of Primorye and Baijinbao with the Slab Grave metals, characterized by lower radiogenic lead signatures, is particularly striking.

So far, archaeometallurgical investigation has allowed us to broadly identify two source regions for Primorye copper metallurgy: the West Liao River basin in Northeast China and the steppe region of Mongolia/Transbaikal. The Upper Xiajiadian culture in the West Liao River area has a varied bronze inventory, particularly notched, single-bladed knives and buttons that are typologically similar to their counterparts in the Primorye (Figure 12). These types of metal objects also appear at Baijinbao culture sites, attesting to the influence of Upper Xiajiadian metalwork in other regions. The mismatch of isotopic compositions of Xiajiadian-type objects in the Primorye (SG1, SG2,

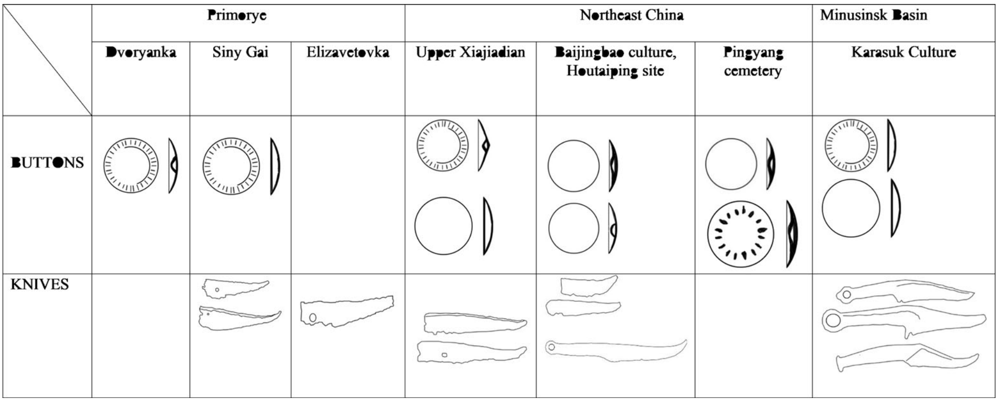

Figure 12. Typological comparison of copper-based knives and buttons of the Primorye, Minusinsk Basin, and Northeast China (Drawn after Chlenova 1972; Yang 2015; IAJP (Institute of Archaeology of Jilin Province) 2011; Yang, Hao, and Li 1990).

SG3, SG7, and DVO1), however, suggests local people may have reproduced similar knives and buttons using raw material from other regions, probably from Mongolia/Transbaikal (see discussion below). The typological similarity between Primorye and Xiajiadian metalwork may therefore represent the movement of ideas rather than the import of metal objects finished completely in the West Liao River basin.

Primorye cultural groups can be linked to archaeological communities in Northeast China through two main types of evidence apart from metal. The first is pottery, as assemblages from Elizavetovka-1 and Baijinbao-type sites are similar (IAHP and DAJU 2009; IAJP 2011; Nikitin 2012). Shared features include the vessel shape, characterized by a relatively narrow, defined neck, a bulging body with concave shoulders, and a pointed, narrow base. The neck of the vessel has a tube-like shape that sometimes widens slightly at its base. In some cases, a pair of handles is attached at the level of the neck base.

The other type of archaeological evidence connecting the Primorye with Northeast China is the appearance of stone-built burials. At present, only one such burial has been found in the Paleometal period of Primorye at Dvoryanka-1, where it was used for a secondary burial. Such graves, however, are more characteristic of funerary practices at Xituanshan and Baoshan sites in neighboring Jilin Province of Northeast China (Nelson 1995, 147–250). Primorye's links to Northeast China echo the intensive population movement occurring around the same time due to climatic changes and subsistence adaptation processes in Northeast Asia more broadly (Ning et al. 2020; Zhao 2012). The Primorye, at least the western part, was involved in drastic social transformations that caused the appearance of varied material culture, which included metallurgy.

Alternatively, the connection with the Eurasian steppe, specifically the Slab Grave community in Mongolia/Transbaikal, is another likely source from which Primorye metal could have come. Nevertheless, there is so far no archaeological evidence that explicitly links the steppe and the Primorye during the Paleometal period. Diagnostic elements of steppe cultures (e.g., horse domestication and zoomorphic motifs) are totally absent from all the excavated Primorye sites. Even though some metal knives and buttons from the Slab Grave and Karasuk cultures somewhat resemble those in the

Primorye assemblages (Figure 12), a connection with the metallurgical traditions of Northeast China seems more likely. However, the process by which the metal with chemical and isotopic signatures closer to that of the Slab Grave culture arrived in the Primorye remains unclear, particularly as there is no discernable steppe influence in Paleometal sites. Alternatively, steppe metalwork could have been transferred to the Primorye through the archaeological communities in Northeast China, where bronze objects decorated with zoomorphic figures were a typical artistic display of the mobile pastoralists in the Eurasian steppe during the first millennium BC (Nelson 1995, 147–250; Yang, Hao, and Li 1990).

Conclusions

Both the elemental and isotopic compositions of copper alloys from the Primorye region attest to a non-local origin for metallurgy during the Paleometal period in the Russian Far East. Variation is discernable between the different sites, and Siny Gai A, Elizavetovka-1, Dvoryanka-1, and Vetrodui each form a distinct group that supposedly had its own supply network showing individual contact with external communities. The uniqueness of each site's metal consumption and use corresponds to the cultural diversity of Paleometal societies.

The major source region for Primorye metallurgy is Northeast China, specifically the West Liao River basin, which features the densest concentration of sites attributed to the contemporary Upper Xiajiadian culture. Using ore deposits exploited in the southern Daxing'anling, Liaoxi corridor, and on the Liaodong Peninsula, the Xiajiadian people forged an extensive metal network that reached communities belonging to the Baijinbao culture and in the Primorye, which is suggested by the production of Xiajiadian-type buttons and knives in the Primorye. This route of technological transfer may have followed the same path along which millet was spread in the Neolithic, a process that would involve the movement of people with the technological capabilities to make metal artifacts. The deviation of lead isotope ratios in the Primorye knives and buttons from similar Xiajiadian counterparts hints at the imitation of artifact types, where metals from different sources, mainly the Slab Grave culture in Mongolia and the Transbaikal region, were used to make objects seen in the Xiajiadian culture. Another possibility for the transmission of metal could have been a route via the coastal areas of Northeast China and the northern part of the Korean Peninsula as shown by the presence of Liaodong ore's isotopic signatures in the Primorye metal objects. However, more archeometallurgical evidence of northern Korean ores and artifacts will be needed to verify this hypothetical connection. Finally, despite a lack of direct evidence for metal production in the early Paleometal settlements investigated in this study, it is clear that the Primorye was a dynamic "metallurgical landscape" (Radivojević et al. 2019), with multiple concurrent metal flows feeding the diverse metallurgical practices observed in this study.

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