The early iron metallurgy in the Siberian Arctic

Raná metalurgie železa v sibiřské Arktidě

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Archaeological excavations conducted at the settlement-sanctuary of Ust-Polui, located just north of the Arctic Circle in Western Siberia yielded the oldest remains of early iron production in the Circumpolar region of Asia. Ust-Polui archaeological finds associated with metallurgy of iron are dated back to the 3rd century BC – 2nd century AD. Hence the finds date the origins of metallurgical technologies used in the north of Western Siberia virtually several centuries back in time and geographically extend the spread of iron metallurgy between the eras significantly. It seems that Ust-Polui is the most northern point on the Earth where iron metallurgy was developed by ancient people. The discovery of new iron production site poses an important question – what are the reasons and ways of appearance of the iron smelting technologies in the Polar North of Siberia? It is possible that all knowledge was obtained from outside via contacts with metal producing societies, who lived in the eastern regions of the Ural Mountains (*to the southwest of Ust-Polui*)*, and knew how to produce iron about two thousand years ago.*

Circumpolar Region – Siberia – iron smelting – Early Iron Age

Archeologické výzkumy osady-svatyně Ust-Polui, nacházející se severně od arktického kruhu v západní Sibiři, odkryly nejstarší pozůstatky rané výroby železa v polárních oblastech Asie. Archeologické nálezy spojené s metalurgií železa jsou datovány od 3. stol. př. n. l. do 2. stol. n. l. Datují tak počátky užívání metalurgických technologií v severozápadní Sibiři prakticky o několik století dříve a geograficky výrazně rozšiřují prostor, v němž se železná metalurgie mezi danými obdobími šířila. Zdá se, že Ust-Polui je nejsevernějším bodem planety, kde byla starověká metalurgie železa rozvinuta. S objevem nové lokality s doklady metalurgie železa vyvstává důležitá otázka – z jakých důvodů a jakým způsobem se metalurgie železa za polárním kruhem na severu Sibiře objevila? Je možné, že veškeré poznání bylo získáno zvenčí prostřednictvím kontaktů se společnostmi vyrábějícími kovy, které žily ve východních oblastech Uralských hor (*na jihozápad od Ust-Polui*) *a které si osvojily znalost výroby železa již před dvěma tisíci lety.*

polární oblast – Sibiř – výroba železa – starší doba železná

1. Introduction

The Iron Age in Arctic Siberia is one of the most interesting and at the same time challenging periods in the study of ancient societies. The challenges are associated, first of all, with the extreme lack of archaeological data on iron metallurgy in the vast territory of Northwestern Siberia.

Another problem has to do with sources being underexplored, in addition to their scarcity. Unfortunately, it should be admitted that most publications make scant mention of the evidence of ancient iron production and hardly ever provide essential information about contexts, slag weight or amount, its type or morphological properties, furnace schemes or cross sections, geochemical data, etc. Most often, Russian researchers simply ignore the huge information potential of slag (*Vodyasov – Zaitceva 2010*; *2017a*). Moreover, even

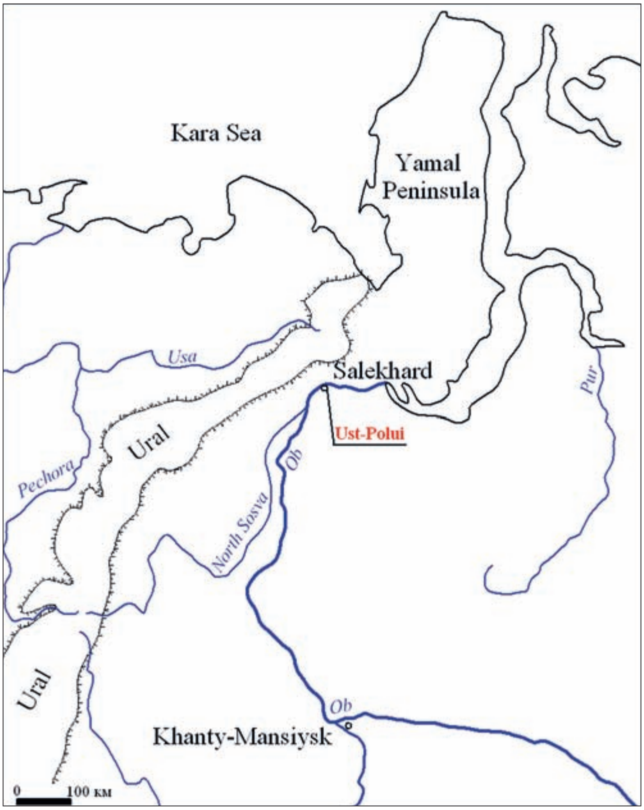

Fig. 1. Location of the Ust-Polui archaeological site.
Obr. 1. Poloha archeologické lokality Ust-Polui.

the existing scarce data remains unavailable for the international scientific community as majority of articles is published in Russian-language journals.

Traditionally it is believed that people of the Arctic Siberia had been unable to produce iron artefacts. Allowing this option was hard for the lack iron production 1000 BC – 1000 AD sites discovered in the region 'Due to the Lower Ob River basin being under-explored, we have no sufficient information to trace back the earliest iron production sites', Valery Chernetsov wrote (*Chernetsov 1953*, 231). Today, as over half a century has passed since Chernetsov's cited work was published, the situation has changed very little. As Sergey Parkhimovich indicates, 'Despite the ample archaeological fieldwork in the taiga zone of Northwestern Siberia conducted over the last decades, the question how local iron metallurgy was born and developed remains under investigated. Hundreds of early Iron Age and medieval artifacts have been excavated to varying extents all over the broad territory that includes the Lower and Middle Ob /Обь/ River areas as well as the Lower Irtysh /Иртыш/ River region, yet evident remains of metallurgical furnaces have only been discovered by the Konda /Конда/ River and in the lower reaches of the Irtysh River' (*Parhimovich 2013*, 100).

The smithies of the first millennium AD in the basin of the Bolshoy Yugan /Большой Юган/ River of Surgut Ob /Сургутское Приобье/ River Region used to be considered the

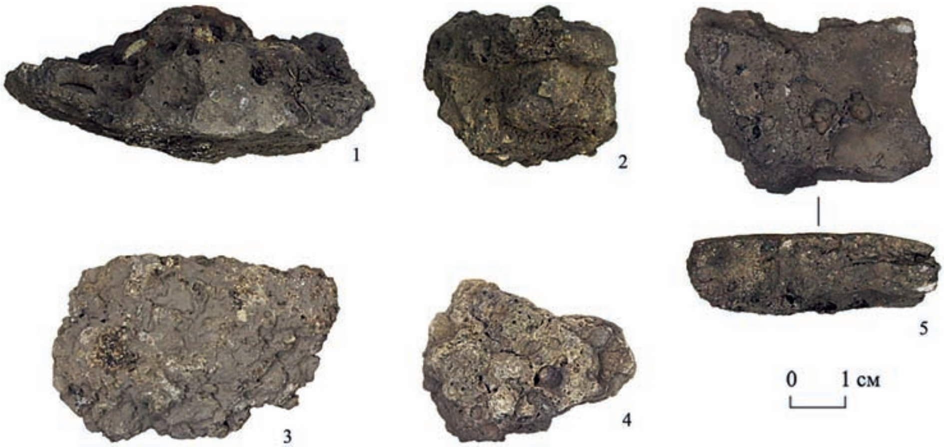

Fig. 2. Slag and furnace wall (lining) from Ust-Polui, Peter the Great Museum of Anthropology and Ethnography (the Kunstkamera). Vasily Adrianov's expedition of 1936. 1–4 – blacksmith slag, 5 – furnace clay wall (lining). Photo by A. Gusev.
Obr. 2. Struska a stěna (výmaz) pece z Ust-Polui, Petrovo velké antropologické a etnografické muzeum (Kunstkamera). Arch. expedice Vasila Adrianova v roce 1936. 1–4 – kovářská struska, 5 – hliněná stěna (výmaz) pece.

most northern and ancient (reliably dated) sources on iron metallurgy in Western Siberia (*Chemjakin 2011*). However, the smithies only proved that the population of Western Siberia's taiga zone had smithing but not smelting technologies.

Evidence of iron metallurgy in the ancient sanctuary of Ust-Polui /Усть-Полуй/ became a prominent scientific discovery. The ancient sanctuary of Ust-Polui is one of the most extraordinary archaeological sites in Western Siberia. An extremely rich cultural layer with numerous finds such as bronze, bone and wooden art objects, along with excellently preserved organic matter, have made Ust-Polui a reference site for studying the Early Iron Age in Northern Eurasia. The site is located to the north of the Arctic Circle (*fig. 1*), in Salekhard /Салехард/ (the lower reaches of the Ob River, Northwestern Siberia), and dates back to the cusp of the eras.

Excavations at Ust-Polui began in 1935–1936 under direction of Vasily Adrianov. The site was also excavated by Valery Chernetsov and Vanda Moshinskaya in 1946, Natalya Fedorova's expedition in 1993–1995 (*Fedorova – Gusev 2008*), and Andrey Gusev in 2006–2015.

There has been ongoing debate whether Ust-Polui is a settlement or a sanctuary, as well as debate over the number of layers and stratigraphic dating. However, iron-smelting and smithing facility remains discovered by Andrey Gusev in 2010, 2012 and 2015, and their further study, making an invaluable contribution to research on the origin of iron metallurgy in the Arctic, is the point of this study. Both radiocarbon and archaeological dating have revealed that both the furnaces and slag come from the period between the 3rd century BC and the 2nd century AD. Up to date, the discovered traces of iron metallurgy are the most ancient and the only dating from the Early Iron Age in the Arctic. The results of the study of the Ust-Polui iron metallurgy are for the first time summarized in this article.

2. Archaeological evidence of iron metallurgy at Ust-Polui

The first fragments of slag and furnaces were found at Ust-Polui by Vasily Adrianov as early as 1936, but Adrianov did not identify his finds as remains of iron production and never revealed them to the public. All the known pieces of slag excavated in 1936 are smithing slag (*fig. 2*). Of special interest is the slag cake (*fig. 2: 1*), 8 cm in diameter and 3 cm thick. The formation of the slag cake marks the necessary stage of an iron bloom processing (*McDonnell 1991*; *Pleiner 2000*, 255). A bloom taken out of furnace and, when still hot, forged immediately to became more compact and free of slag, should later be reheated in a hearth to be forged and cleaned of any remaining slag. At high temperatures in a hearth (over 1200 °C), slag drains down the bloom and solidifies under a tuyere or at the bottom of the hearth in the form of plano-convex 'cake'. Unfortunately, there is no information on whether furnaces themselves were found, or whether all the slag was included in the collection or not. Neither the context nor the location of the finds are known. For this reason, we cannot make any conclusion more precise than that the population of Ust-Polui, regarding the finds from 1936, might have been able to forge 'raw' iron blooms.

3. Archaeological evidence of 2010–2012 and 2015

Remains of iron metallurgy at Ust-Polui were first documented and identified in 2010–2012. An important find made during the 2010 expedition was a large slag cake (*fig. 3: 1*) evidencing iron production at Ust-Polui as such. The cake (sample No. 2438) had a weight of about 2,500 g, a diameter of 20 cm, and a density of 2.6 g/cm^3.

This type of slag (furnace bottom) is formed at the bottom of a bloomery furnace that has no special canal for tapping liquid slag from the hearth. As a result, slag flows down on to the so-called 'carbon bed' (a layer of hot coal), taking the specific plano-convex form. Despite being similar in their form to smithing slag cakes, furnace bottoms are larger in size and can weigh up to a few kilos, while smithing slag cakes weigh on average 300–400 g and rarely exceed 15 cm in diameter (*Pleiner 2000*, 216–217).

The first iron production site at Ust-Polui was explored by Gusev's expedition in 2012 (*Vodyasov – Gusev 2016*). A 2×1.2 m stain of an up to 0.15 m thick carbonaceous layer filled with soot and fish bones was stripped; a fraction of slag was also found within the feature. The furnace might have been right on that spot, but its design is impossible to reproduce as very little has survived. Associations of bloomery walls, fragments of clay lining, and slag were found on the slope and at the bottom of a ditch about 1–3 m to the north.

All the furnace walls and lining fragments have a lot of slag in them, its total weight being about 0.5 kg. Slag is represented by small fractions of smithing cakes no larger than 7 cm in diameter and about 1–3 cm thick (*fig. 3: 3*). Nearly all of them cracked and chipped off. They are likely to have been formed during further smithing operations rather than ore smelting. Most probably, there was a smithing hearth over that part of the ancient ditch.

The iron production site was abandoned as soon as the work was finished, and slag and wall fragments later shifted and slipped down the slope as a result of archaeological processes. It is not improbable, however, that ancient smelters simply disposed of waste by dumping it down the ditch.

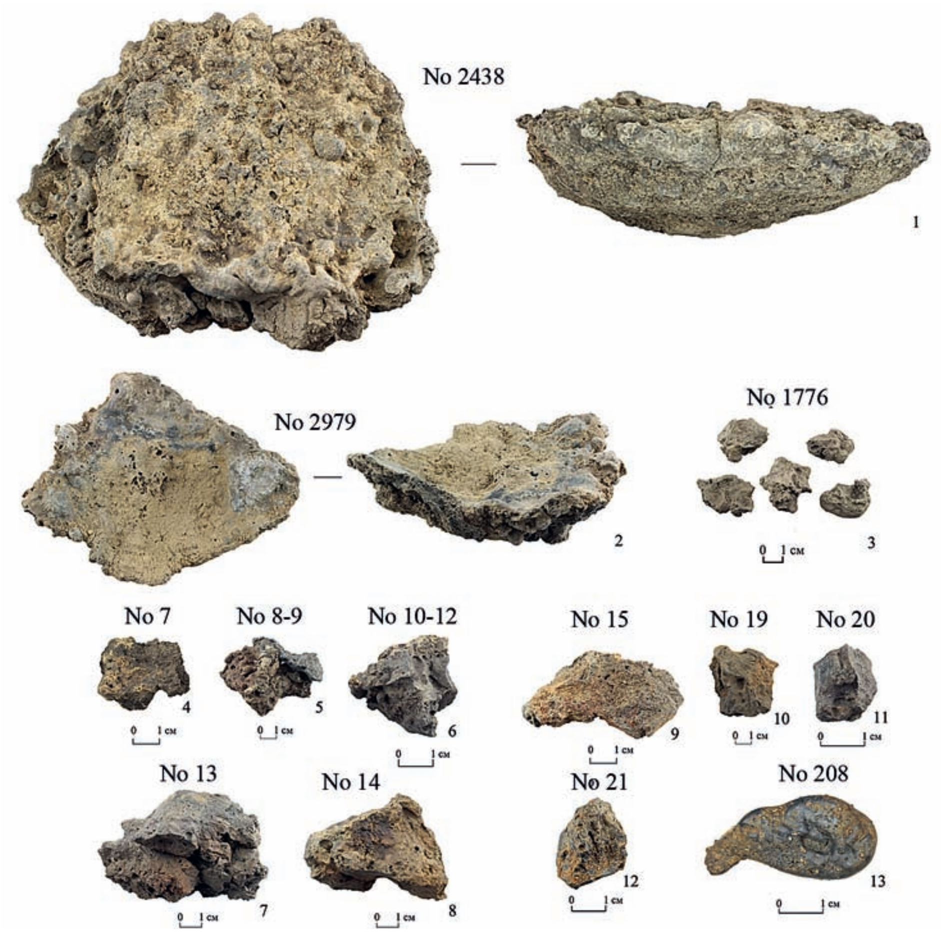

Fig. 3. Slag and bloom fragments. 1–2 – slag excavated in 2010, 3 – slag excavated in 2012, 4–12 – slag excavated in 2015, 13 – bloom excavated in 2015.
Obr. 3. Fragmenty strusky a železných hub. 1–2 – struska z výzkumu z r. 2010, 3 – struska z výzkumu z r. 2012, 4–12 – struska z výzkumu z r. 2015, 13 – železná houba z výzkumu z r. 2015. Foto E. Vodyasov.

For dating purposes, it is especially important that iron was produced at the same time that the ditch was functional, which follows from the context of the iron production remains discovered in 2010–2012 in various parts of Ust-Polui. Even if we assumed that the metallurgical installations could have appeared much later, when the ditch had already been filled with earth and organic matter, it would be hard to explain how the metallurgical waste distributed so evenly along the edges of the ditch and spread to its slopes and bottom, too. One piece of slag was found right next to the bridge over the ditch. Using a wood sample, the Laboratory of Dendrochronology of the Institute of Plant and Animal Ecology (Ural Branch of the Russian Academy of Sciences) determined the chronological date of the bridge to be 77–76 BC (*Gusev – Fedorova 2012*, 21). It should be made clear, however, that dendrochronological dating determines the age of the bridge, not that of the ditch, so

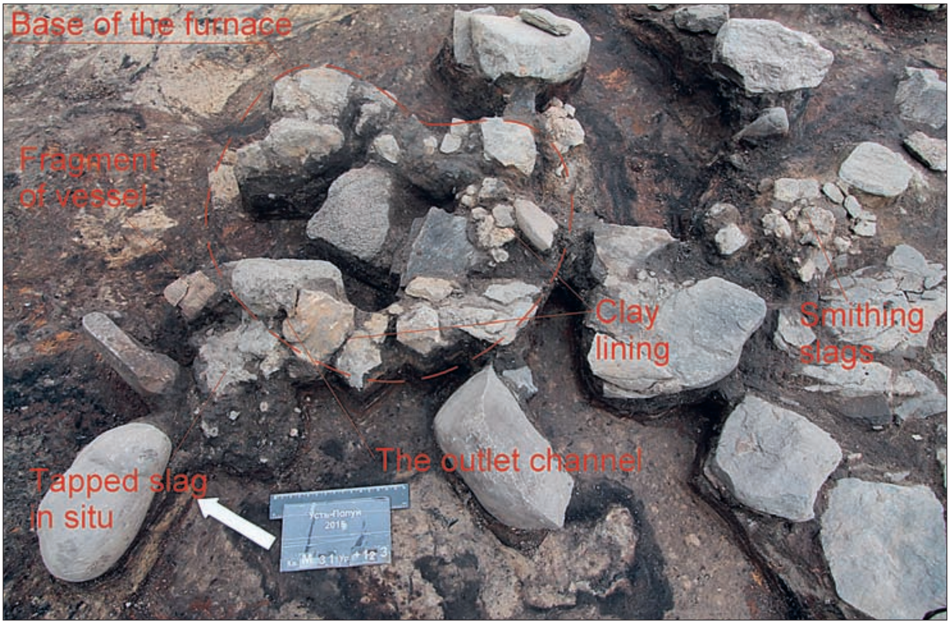

Fig. 4. The ancient sanctuary of Ust-Polui. Remains of a bloomery furnace (expedition of 2015). Photo by A. Gusev.
Obr. 4. Starobylá svatyně v Ust-Polui. Zbytky železářské pece (expedice v r. 2015).

it is entirely possible that the fortification could have existed within a broader time period, namely from the very end of the first millennium BC to the early first millennium AD.

In order to date the iron production site investigated in 2012, two samples of charcoal were taken from the ditch and dated by the Laboratory of Geology and Cenozoic Climate (Siberian Branch of the Russian Academy of Sciences). The resulting calibrated dates are as follows: COAH-9421 – 2030±105 BP (cal 178 BC – 75 AD) and COAH-9422 – 2150±100 BP (cal 236 BC – 88 BC). As we can see, these dates match the period between the 3rd century BC and the 1st century AD.

Since all the remains of iron production found in 2010–2012 were attributed to the ditch, the period of time specified above can be taken as the earliest date of such production. The same timeframe embraces the most of the period when the Ust-Polui cultural layer was accumulated.

The largest metallurgical site at Ust-Polui was explored at the inner side of the ditch in 2015. It was located about 40 m south of the slag accumulations found in 2012.

The finds included remains of an iron-smelting furnace and the smithing hearth (*Vodyasov – Gusev – Asochakova 2017*). The 30–35 cm diameter base made of rock debris and clay has been preserved, and surrounded by furnace walls (*fig. 4*). Some 1–2 cm fragments of clay lining with adhered slag were found on the same spot.

It is difficult to reconstruct the height of the furnace, but it was hardly more than 0.5 m, as judged by the amount of wall fragments. A 1.5 cm tap channel was a curious engineering feature of the furnace (*fig. 4*). The channel for taping liquid slag was located by the

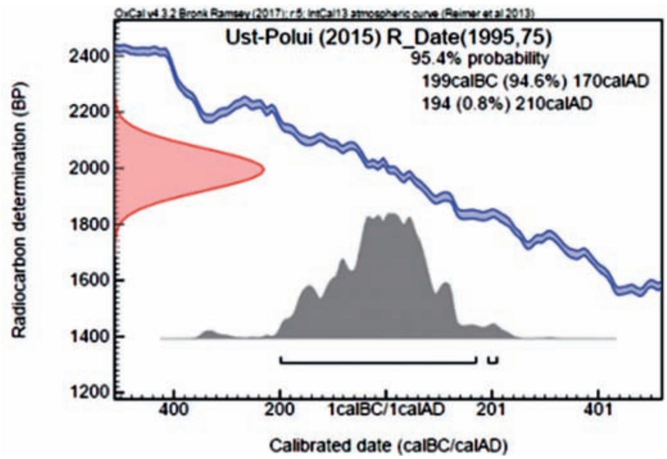

Fig. 5. Radiocarbon dating of the bloomery furnace excavated in 2015 (calibrated in OxCal).
Obr. 5. Radiokarbonové datování železářské pece odkryté v roce 2015 (kalibrované v OxCal).

very base from the western side. A slag monolith was discovered right by the tap hole. That was the first reliably documented record of slag tapping in Northwestern Siberia dating back to the Iron Age. Bloom forging was carried out in immediate proximity to the furnace: an accumulation of tiny slag pieces of 1–3 cm in diameter, small smithing cakes, and a fragment of bloom were found 0.5 m south-east of the furnace (*fig. 3*: *13*).

Apart from iron production waste, the stones and slag also reveal traces of bronze casting: tiny bronze drippings, a small fragment of a flat-bottom crucible, and a wall of a bronze boiler. The fact that remains of bronze casting were discovered together with iron slag might be indicative of the multi-purpose nature of this feature.

A ceramic vessel lip was lying close to the tap channel (*fig. 4*). Numerous similar ceramic fragments have been excavated within the main complex of Ust-Polui (*Moshinskaja 1965*, 23, fig. 11) and in the contemporaneous site of Katravozh /Катравож/. Beyond the lower reaches of the Ob River, such vessels have been found in large numbers in Surgut Ob River Region (*Chemjakin 2008*, 180, fig. 74) and Tomsk Region /Томская область/ (*Chindina 1984*, 249, fig. 43). The latter two studies attribute them to the Sarovo period of the Kulay culture /Кулайская культура/ and date them back to the last centuries BC – first centuries AD. The major Ust-Polui stratum containing such fragments has been dated to the period between the 2nd century BC and 1st century AD.

Dating was performed using a sample of charcoal embedded in smithing slag and other production waste. Upon calibration in OxCal, the investigated complex was dated to the 2nd century BC – 2nd century AD (*fig. 5*).

4. Results of archaeological surveys of iron metallurgy at Ust-Polui

The surviving archaeological evidence of early iron production in the Polar region allow reconstructing some iron-making techniques of the Early Iron Age in the Circumpolar region of Siberia. The metallurgical features and types of slag provide direct evidence of use of iron making and processing technologies by the ancient Ust-Polui society.

No	Slag No	SiO_2	TiO_2	Al_2O_3	*FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	S	Sum
1	**2979**	21.83	0.16	5.16	48.68	0.18	2.48	3.91	1.50	1.37	5.01	0.10	90.37
2	**2438**	29.77	0.25	6.34	44.36	0.17	2.54	7.42	0.72	1.91	2.56	>0.01	96.06
3	**1776**	36.47	0.35	6.68	39.05	0.04	3.16	6.43	0.91	1.57	1.59	0.016	96.28
4	**4/940**	40.37	0.41	11.68	29.66	0.121	5.86	5.87	0.34	0.88	0.60	0.004	95.78
5	**7/1527**	48.06	0.55	8.86	25.86	0.311	3.11	4.49	2.23	2.13	0.79	0.006	96.38
6	**9/912**	33.45	0.43	7.51	40.17	0.037	3.10	4.49	1.65	1.54	1.34	>0.001	93.71
7	**10/1429**	26.20	0.50	7.82	36.06	0.405	3.78	9.39	2.30	2.41	6.40	>0.001	95.26
8	**13/927**	29.39	0.34	7.11	41.23	0.153	2.80	6.73	0.16	1.65	3.66	>0.001	93.21
9	**15/931**	25.50	0.30	6.66	41.93	0.144	2.37	8.75	0.15	1.80	5.62	>0.001	93.23
10	**19/945**	31.67	0.31	6.90	42.45	0.068	3.63	4.21	2.40	0.95	1.02	>0.001	93.61
11	**20/1277**	37.71	0.53	10.69	30.17	0.155	4.51	6.05	2.52	2.06	1.94	0.006	96.34
12	**21/1349**	29.10	0.28	5.21	49.39	0.001	2.42	3.78	0.16	0.27	0.48	0.001	91.11

*FeO = $FeO+Fe_2O_3$. No. 1–2 – slags from excavation 2010, 3 – slag from excavation 2012, 4–12 – slags from excavation 2015.

Tab. 1. Slag XRF analysis (wt%). The analyses were performed on The Oxford ED2000 X-ray fluorescence (XRF) analyzer by E.M. Asochakova (Tomsk State University).
Tab. 1. XRF analýza strusky (hm%).

Two types of furnaces were used to produce iron. The first type is represented by a small heating furnace with no liquid slag tapping. Furnaces of this type have not been found at Ust-Polui, but their existence in the ancient times is proved by large slag cakes excavated in 2010. Such furnaces were made of clay, as judged by associations of wall fragments discovered in 2010–2012. Their original design is impossible to reproduce.

Furnaces of the second type, made of stones and clay, had a small above-ground shaft and a special hole near the base for tapping slag during smelting. This slag-tapping technology increased the furnace productivity, and its use indicates a rather high level of iron production at the time. Only one furnace with a slag trough has been found at Ust-Polui (at an iron production feature excavated in 2015).

Charred bones found in two metallurgical features in 2012 and 2015 had most probably been used by smelters as fluxes to promote slag fluidity and reduce iron losses during slagging. Archaeological remains and radiocarbon dating results reveal that furnaces of different types coexisted between the 3rd century BC and the 2nd century AD Back then, iron production and processing at Ust-Polui was concentrated along the fortified edge of the ditch.

The Ust-Polui slag is characterized by an elevated calcium oxide concentration of 6 %, which is its distinctive feature (*tab. 1*). Concentration of calcium oxide is affected by ore composition, fuels and fluxes (*Crew 2007*). Such a high percentage of calcium in ancient slag is associated with charred animal bones that were added to charge as fluxes. For comparison, average CaO concentration in archaeological slag from other sites in Western

Fe	Mn	Ni	Cu	Zn	Pb	Sum
98.2	1.06	0.06	0.13	0.03	0.51	99.99

Tab. 2. Bloom fragment XRF analysis (wt%). The X-ray fluorescence analysis was performed by Yu.A. Podosenova (Perm Scientific Center, Ural).
Tab. 2. XRF analýza fragmentu železné houby (hm%).

Siberia is only 1.2 % (*Zinyakov 1997*; *tab. 2*). Elevated concentrations of manganese (Mn) in the bloom were also documented by X-ray fluorescence analysis. Manganese passes from ore into slag, substituting some of the iron and combining with $Si0_2$; hence Mn acts as a slag-forming ingredient (see e.g. *Pleiner 2000*, 136).

Phosphorus (P) affects both physical and mechanical properties of iron. Based on the finds from 2010–2015, the average concentration of P_2O_5 in Ust-Polui slag is 2.5 %. Concentration of phosphorus in iron can be estimated using the Piaskowski's formula (*Piaskowski 1965*; *Pleiner 2000*, 265): P (iron) = (0.12–0.35)×P_2O_5 (slag). It follows that iron produced by ancient Ust-Polui smelters contained about 0.3–0.8 % of phosphorus, i.e. it was a high-phosphorus iron (*Piaskowski 1988*). High concentrations of phosphorus enhanced mainly hardness and brittleness of iron (*Pleiner 2000*, 265). Phosphorus in iron ores also prevented iron from carburization during smelting (*Zavyalov – Rozanova – Terehova 2009*, 62). Therefore, smelting high-phosphorus ores yielded iron with low carbon content.

J. Piaskowski believed that the concentration of phosphorus in iron product can be used to identify the type of ore smelted. High-phosphorus iron (0.18–1 % of P) was usually produced from limonites (bog iron ores; *Piaskowski 1988*). Radomír Pleiner states that limonites were an important source of ore in ancient iron making as they got easily deoxidized in furnace and could be found pretty much anywhere in Northern Eurasia (*Pleiner 2000*, 88). Limonites are often referred to as 'bog ores' in Russia, while Scandinavian researchers dub them as 'lake ores'. Bog iron ores normally have high concentrations of phosphorus (0.5–3 %) and manganese (*Pleiner 2000*, 88). As described above, these two elements passed from ores to bloomery iron and slag of Ust-Polui in calculable proportions. Ancient Ust-Polui smelters might have mined limonites in the basin of the River Ob. However, high concentrations of phosphorus in slag could have also been caused by adding fluxes, so any conclusions about the type of ores smelted would be premature today. Unfortunately, no iron ore have been found in any of the expeditions. Raw material must have been prepared outside the site, probably close to ore deposits. Most importantly, identical chemical composition of slag from different Ust-Polui excavations (*tab. 1*) indicates that all of it came from the same deposit.

The weight of slag excavated at Ust-Polui totals about 8 kg. Naturally, such small-scale iron-making operations at Ust-Polui only capture the very first steps in the evolution of iron making technology in the Arctic at the turn of the AD era. However, it cannot yet be excluded that major iron production sites could have been located outside the archaeological site of Ust-Polui. Besides, as mentioned above, the exact amount and weight of slag excavated in all Ust-Polui excavations of the 20th century remains unknown.

5. Phenomenon of the earliest iron production in the Siberian Arctic

Only five iron smelting sites of the Early Iron Age are known today in the whole Western Siberia. All of them are located at least 1,000 km further south than Ust-Polui.

The only Early Iron Age metallurgical site in the basin of the River Ob (before the Ust-Polui site was discovered) had been a furnace dating to the 1st century BC – 4th century AD, which was found at Sarovo /Сарово/ hillfort, modern Tomsk Oblast (*Chindina 1984*, 105–106, 141). Lyudmila Chindina, who led the excavation works, believes that the furnace had been used for iron smelting and concludes that iron had been smelted in pots (!), yet no substantiation is provided (*Chindina 1984*, 141).

In the basin of the Irtysh River, remains of iron production dating to the specified period have been excavated at Rafaylovo /Рафайлово/ and Andreevo-VII /Андреево-VII/ hillforts of the 7th–5th centuries BC and Duvan-II /Дуван-II/ settlement of the first millennium BC – early first millennium AD (*Zinyakov 1997*, 228–229; *Beltikova 2005*, fig. 2). Rafaylovo and Andreevo-VII hillforts are associated with the eastern area of the Itkul /Иткуль/ center of iron production (*Beltikova 2005*). Duvan-II settlement belongs to the Sargat culture /Саргатская культура/ (*Koryakova 1988*). Given the small number of Early Iron Age archaeometallurgical objects in the wide lands of Western Siberia, a question arises naturally, how iron-making technologies could penetrate the territory as far north as to the Siberian Arctic.

We have no other evidence of iron production or processing in the Arctic region at the cusp of the two eras. The Middle Ages are the earliest period to which iron metallurgy sites in the Scandinavian Arctic date, while all the other Early Iron Age furnaces are located much further south of the Polar Circle (*Stenvik 2003*, 125). There is no data on Early Iron Age bloomeries found anywhere in the polar region of North Asia. The earliest evidence of iron production in North America (Newfoundland Island) date to as late as the 10th–11th centuries AD and relates with Vikings' expeditions (*Ingstad 1969*). Ust-Polui may thus be the most northern point on Earth where humans produced iron in the ancient times.

We believe that such unexpected emergence of a small iron production center in the Far North should be associated with the spread of Ural iron-making traditions, which forced out bronze casting in the Ural completely and expanded beyond the region in the 3rd century BC (*Koryakova – Kuzminykh – Beltikova 2011*, 12–14). The conception and development of iron metallurgy in the Ural in the first millennium BC, amidst the Ananyino culture /Ананьинская культура/, was favored by numerous deposits of high quality iron ores. It is important that the Ust-Polui site virtually borders the Polar Urals in the west (the Ural Mountains are 60 km from Ust-Polui). The influence of the Ananyino culture traditions reached as far as the Polar Urals. A number of researchers believe that it was not until the middle of the first millennium BC that iron artifacts appeared on the northern periphery of the Ananyino culture (*Kuzminykh – Chizhevsky 2008*, 37). Unfortunately, no research paper summarizing the results of complex surveys of iron production in this culture has been found. The study of Ural metallurgy of the first millennium BC is much better represented in papers on smithcraft (*Zavyalov – Rozanova – Terekhova 2009*), which touch only slightly upon iron smelting.

The iron-making technology of the Ananyino culture was inherited at the end of the first millennium BC by members of the successive Glyadenovo culture /Гляденовская культура/, contemporaneous to Ust-Polui metallurgy. However, it appears impossible to compare Ust-Polui iron production technology to that of Glyadenovo due to the very low degree of exploration of the latter. Very little is known about Glyadenovo furnaces, iron working characteristics and the level of ancient production development (*Zavyalov – Rozanova – Terekhova 2009*, 87–88). Much more information is available on the Itkul metallurgy of the 8th–3rd centuries BC, the center of which was located on the eastern slopes of the Urals (*Beltikova 2005*; *Koryakova – Epimakhov 2007*, 196; *Koryakova – Kuzminykh – Beltikova 2011*, 13).

Despite varying degrees of exploration of Early Iron Age metallurgy across regions of the Urals, there is no doubt of the fact that iron began to be produced in the Urals much earlier than in Western Siberia. It could have been the Ural traditions that came to the north of Western Siberia along the left tributaries of the River Irtysh (*Vodyasov – Zaytseva 2017b*). A single center of production could have developed at Ust-Polui, in the lower reaches of the Ob River, as a result of culture contacts or even individual migrations of the Ural people, which had mastered new technologies by the cusp of the eras. Anyway, there surely must have been an external cultural impetus that prompted the spread of iron metallurgy to such high northern latitudes. It is hard to think of any other areas in Northern Eurasia apart from the Ural Region that could have been the source of such impetus at that time.

It should also be noted that the spread of iron-making technologies to the north had its natural limits, too. Ust-Polui lies within a climatic zone where forest tundra passes into treeless tundra areas. Iron production could hardly develop at any point in time in tundra without charcoal fuel as a crucial resource. It was the borderline between forest tundra and tundra that became sort of a culture limit to the penetration of iron metallurgy. This ecological niche provided ancient people with all the necessary mineral sources: iron ores and fuelwood.

6. Conclusion

Summing up the results of a complex study of iron metallurgy at Ust-Polui, it makes sense to enumerate the major findings and hypotheses. Firstly, iron production and smithing technologies were born in the Circumpolar Region of Western Siberia as early as on the cusp of the eras. The ancient settlement-sanctuary of Ust-Polui is the most northern and the only point in the Arctic region where evidence of Early Iron Age iron metallurgy has been found. Secondly, ancient Ust-Polui blacksmiths built bloomeries using clay and stone walls, used charred animal bones as fluxes, and knew how to tap liquid slag. Thirdly, the identical geochemical composition of slag from different excavations indicates that the same technology was used all around the region and ores were mined from the same deposit. Limonites in the lower reaches of Ob River could be such sources of ores, but this hypothesis is yet to be verified in a separate study. Fourthly and finally, the development of ancient iron production in the Arctic regions must have been prompted by migrations of metal-producing cultures from the Eastern Urals, where iron metallurgy had developed long before it was transferred to the lower reaches of Ob River.

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References

Beltikova, G. V. 2005: Sreda formirovaniya i pamyatniki zaural'skogo (itkul'skogo) ochaga metallurgii [The formation and environment of Transuralsk (Itkul) iron smelting sites]. Archeology of the Urals and Western Siberia (on the occasion of the 80th anniversary of the birth of Vladimir Fedorovich Gening), Ekaterinburg: USU, 162–186.

Chemjakin, Ju. P. 2008: Barsova Gora: ocherki arheologii Surgutskogo Priob'ja. Drevnost' [Barsova Gora: essays on the archeology of the Surgut Ob Area. Antiquity]. Surgut-Omsk: JSC «Omsk House of Printing».

Chemjakin, Ju. P. 2011: Drevnejshie kuzni v taezhnom Priob'e [The oldest forges in the taiga Ob River]. Proceedings of the III (XIX) All-Russian Archaeological Congress. T. II., Saint Petersburg – Moscow – Great Novgorod: Novgorod Technopark, 110–111.

Chernetsov, V. N. 1953: Ust'-polujskoe vremja v Priob'e [Ust-Polui time in the Ob River Region]. Ancient history of the Lower Ob Region. Materialy i issledovanija po arkheologiy SSSR 35, 221–241.

Chindina, L. A. 1984: Drevnjaja istorija Srednego Priob'ja v jepohu zheleza [Ancient history of the Middle Ob River in the Iron Age]. Tomsk: Publishing House of Tomsk University.

Crew, P. 2007: CaO enhancement in slags: the influence of fluxing or fuel ash?. In: Early Ironworking in Europe, Plas Tan y Bwlch, 50–52.

Fedorova, N. V. – Gusev, A. V. 2008: Drevnee svjatilishhe Ust'-Poluj: na perekrestke kul'turnyh tradicij [Ancient sanctuary Ust-Poluy: at the crossroads of cultural traditions]. Proceedings of the II (XVIII) All-Russian Archaeological Congress in Suzdal. T. II, Moscow: IA RAS, 175–177.

Gusev, A. V. – Fedorova, N. V. 2012: Drevnee svjatilishhe Ust'-Poluj: konstrukcii, dejstvija, artefakty. Itogi issledovanij planigrafii i stratigrafii pamjatnika: 1935–2012 gg. [The ancient sanctuary of Ust-Poluy: structures, actions, artifacts. Results of studies of the planning and stratigraphy of the site: 1935–2012]. Salekhard.

Ingstad, H. 1969: Po sledam Lejva Schastlivogo [In the footsteps of Leive the Happy]. Leningrad: Gidrometeoizdat.

Koryakova, L. N. 1988: Rannij zheleznyj vek Zaural'ja i Zapadnoj Sibiri (sargatskaja kul'tura) [Early Iron Age of the Trans-Urals and Western Siberia (Sargat Culture)]. Sverdlovsk: Publishing House of The Ural University.

Koryakova, L. – Epimakhov, A. V. 2007: The Urals and Western Siberia in the Bronze and Iron Ages. Cambridge: Cambridge University Press.

Koryakova, L. N. – Kuzminykh, S. V. – Beltikova, G. V. 2011: Perehod k ispol'zovaniju zheleza v Severnoj Evrazii [The transition to the use of iron in northern Eurasia]. In: Materials of the Round Table "Transition from the Bronze Age to the Iron Age in Northern Eurasia", St. Petersburg: State Hermitage Publishing House, 10–16.

Kuzminykh, S. V. – Chizhevskij, A. A. 2008: Anan'inskij mir: vzgljad na sovremennoe sostojanie problemy [Ananyinsky world: a look at the current state of the problem]. Archaeology of the Eurasian Steppes 8. At the origins of archeology of the Volga-Kamya (to the 150th anniversary of the discovery of Ananyinsky burial ground), 29–55.

McDonnell, J. G. 1991: A model for the formation of smithing slags. Materiały Archeologiczne XXVI, 23–28.

Moshinskaya, V. I. 1965: Arheologicheskie pamjatniki severa Zapadnoj Sibiri [Archaeological sites of the north of Western Siberia]. Moscow: Science.

Parhimovich, S. G. 2013: Poselenie Ust'-Kamchinskoe 2 na reke Malyj Salym (k probleme vozniknovenija chernoj metallurgii v Severo-Zapadnoj Sibiri) [Settlement Ust-Kamchinskoye 2 on the Maly Salym River (to the problem of the occurrence of iron metallurgy in Northwestern Siberia)]. In: Ancient heritage of the Middle Ob in the territory of economic development of OOO «Yuganskneftegaz», Ekaterinburg: Magellan, 94–115.

Piaskowski, J. 1965: Correlation between the phosphorus content in iron ore or slag and that in bloomery iron. Archaeologia Polona VIII, 83–103.

Piaskowski, J. 1988: Rodzaje rud stosowanych do wytopu żelaza na ziemiach Polski w starozytności i we wczesnym średniowieczu. In: Surowce mineralne w pradziejach i we wczesnym średniowieczu Europy Środkowej, Wrocław: Zakład Narodowy im. Ossolińskich, 63–80.

Pleiner, R. 2000: Iron in Archaeology: The European Bloomery Smelters. Praha: Archeologický ústav AV ČR.

Stenvik, L. F. 2003: Iron Production in Scandinavian Archaeology. Norwegian Archaeological Review 36, 119–134.

Vodyasov, E. V. – Gusev, A. V. 2016: Drevnejshie svidetel'stva osvoenija chelovekom zheleza v Nizhnem Priob'e (po materialam raskopok Ust'-Poluja v 2010–2012 gg.) [The Earliest Evidence of Iron Metallurgy in the Lower Ob River Region (source: Ust-Polui excavations in 2010–2012)]. Bulletin of archaeology, anthropology and ethnography 4 (35), 58–68.

Vodyasov, E. V. – Gusev, A. V. – Asochakova, E. M. 2017: Ust'-Poluj: drevnejshie svidetel'stva chernoj metallurgii v Arktike [Ust-Polui: the earliest evidence of iron metallurgy in the Arctic Region]. Siberian historical research 3, 113–132.
Vodyasov, E. V. – Zaitceva, O. V. 2010: Metallurgicheskij shlak kak arheologicheskij istochnik: problemy i perspektivy izuchenija [Metallurgical slag as an archaeological source: problems and prospects for studying]. In: Culture as a system in a historical context: The experience of the Western Siberian archaeological and ethnographic meetings, Tomsk: Agraf-Press, 400–403.
Vodyasov, E. V. – Zaitceva, O. V. 2017a: Chto mozhet rasskazat' arheologu zheleznyj shlak? [What can iron slag tell an archaeologist?]. Bulletin of Tomsk State University (History) 47, 107–115.
Vodyasov, E. V. – Zaitceva, O. V. 2017b: Ternistyj put' chernoj metallurgii v taezhnom Ob'-Irtysh'e [The treacherous path of ironmaking in the taiga Ob-Irtysh River Region]. Stratum Plus 6, 237–250.
Zavyalov, V. I. – Rozanova, L. S. – Terehova, N. N. 2009: Istorija kuznechnogo remesla finno-ugorskih narodov Povolzh'ja i Predural'ja: K probleme jetnokul'turnyh vzaimodejstvij [History of blacksmith's craft of the Finno-Ugric peoples of the Volga and the Urals: To the problem of ethnocultural interactions]. Moscow: The Sign.
Zinyakov, N. M. 1997: Chjornaja metallurgija i kuznechnoe remeslo Zapadnoj Sibiri: Uchebnoe posobie dlja vuzov po special'nosti «Arheologija» [Black metallurgy and blacksmith's craft of Western Siberia: A textbook for high schools on the specialty «Archeology»]. Kemerovo: Kuzbassvuzizdat.

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