Lead Isotopic Characteristics and Metal Sources for the Jewelry in the Medieval Rural Settlements from the Suzdal Region (Kievan Rus')

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Keywords

Middle Ages, Kievan Rus', metal sources, Pb-isotope analyses, white bronze, silver, lead-tin alloy, long-distance trade

Abstract

The article considers the results of the study of lead isotope composition of 38 non-ferrous artifacts discovered at medieval rural sites of the Suzdal Region (Kievan Rus'). The copper-alloy, silver and pewter artifacts were compared with reference data from geographically and temporally diverse medieval artifacts and ore deposits and revealed differing source regions and supply networks within and between metal types. The identification in some cases was difficult due to the conformity of the lead isotopic composition of deposits of some regions. The copper-alloys, represented mostly by crosses made of high-tin bronze, show close isotopic parallels to contemporary copper alloys from Southern Scandinavia, Westphalia and Lower Saxony. Since the copper alloys contain significant quantities of lead, this lead may have entered the metal by alloying with lead-tin alloys, by smelting mixed copper-lead ore, or through haphazard alloying with lead. The lead isotope ratios for nearly all copper alloys are consistent with deposits in Cornwall and Devon and remobilized ore from the Rhenish Massif. For silver and lead-tin alloy objects, lead isotope analyses point to wide ranging sources. Most silver objects are consistent with mid-to-late 10th century silver stocks circulating in the Baltic area and 10th century Volga-Bulgar silver dirham imitations probably representing mixtures of 9th-10th century Islamic silver. The silver shows a heavy reliance on 10th century mixed stocks and there are little indications of Central and Western European silver, which was common in the 11th century Baltic region. The pewter and lead, however, indicate other sources. Lead isotope ratios are consistent with sources connected to Mediterranean and Baltic networks, some being consistent with sources in England, but it is possible that the lead found in some pewter objects could come from the Olkusz lead district in southern Poland.

The presented results of the lead isotope composition of Suzdal objects of the 10th–13th centuries indicate that the method is promising for the identification of metal sources for medieval materials. It expands the opportunities to identify ways in which raw materials were obtained in the northeastern territory of old Russia and identify economic and cultural contacts both near and far.

Introduction

It is a well-known fact that the Kievan Rus' did not have ore sources of non-ferrous and precious metals. All the raw material was imported. The issues of origin and the ways of delivering of raw materials for craftsmen-jewelers in different cities and regions of the vast Rus' are discussed almost in every fundamental article on metalworking. In the past, written sources were evaluated (for example, Eniosova, Mitoyan and Saracheva, 2008) and salable ingots, the materials of metalworking complexes, were analyzed (Zaytseva and Saracheva, 2011). However, the main basis for discussing of sources and trading networks connected to metal supply to different production centers are the massive datasets on chemical composition of alloys of finished products and production debris of different sites and regions and their comparison (see, for example, Eniosova and Saracheva, 2005; Zaytseva and Saracheva, 2011; Eniosova, 2016; Eniosova and Mitoyan, 2011; Eniosova, Mitoyan and Saracheva, 2008; Eniosova, Mitoyan and Singh, 2017). Particularly thorough work has been done for Novgorod.

Lead isotopic analysis has been actively used by European archaeologists for identifying metal sources of archaeological items (Baker, Stos and Weight, 2006 and others). However, the methods only recently begun to be applied in the study of Russian medieval archaeology and

Figure 1. Analyzed objects from low-melting lead-tin alloys (Pewter). Photo: Institute of Archaeology RAS.

has not be used widely. The origin of three copper ingots of the 15th century from Novgorod which have turned out to be casted from Eastern Alps ore (Gaydukov and Oleynikov, 2014) has been identified by the method of lead isotope analysis. It should be mentioned that some researchers express skepticism about the opportunity of identifying the source of metal for the medieval items as in those times "the way from a raw material to ready-made products had become extremely long" (Koroleva, 2017). While for some objects the link to ore may be direct, others may have been recycled, even repeatedly, and thus could be mixtures of metal from multiple ore sources from diverse areas. This is why it is important not only to look for the ore source but also to compare the lead isotope compositions of metal objects and metal stocks used in potential source regions.

The region of Suzdal Opolye is situated 250 km to the north-east of Moscow. This is one of the most important centers of the Kievan Rus'. Currently it is being thoroughly studied by the Suzdal Archaeological Expedition of the Institute of Archaeology of the Russian Academy of Sciences (RAS). About 370 medieval rural settlements with materials of the second half of the 10th-13th century have been examined (Makarov, 2021). The main settlement structures of different chronological periods have been identified. More than 13,500 items were found in the upper plough zone layers. About a quarter of the items are made of non-ferrous base metals and silver. Using the methods of optical emission spectral analysis, μXRF and SEM-EDX, the chemical composition of metal has been studied for more than 300 items dating back to the second half of the 10th-13th century.

The aim of the present study is the identification of sources of metal for items from the rural settlements and the cemeteries of Suzdal Opolye using lead isotope analysis. The focus of this study is on the pectoral crosses. In addition, the sampling strategy included finds of different categories marking different economic and ethno-cultural relations and also items of supposed local production. The research approach is not simply an applied approach trying to link metals to ore, but includes methodological considerations taking into account recycling, mixing and recasting (see Merkel, 2019).

A total of 38 artifacts from 13 sites of the second half of the 10th – the first half of the 13th century (12 rural settlements and one cemetery) have been selected for the analysis.

Artifacts sampled

Of the objects sampled, seven were made from low-melting lead-tin alloys : five pectoral crosses, a fragment of corolla and a kufic dirham-style pendant (Figure 1: 1-4, 6-7, 34). Silver-based alloys make up 17 of the finds (Figure 2: 5, 8-18, 20, 22, 24-25, 27). There are only three crosses in this group because of the rareness of silver pectoral crosses (Figure 2: 22, 24, 27). For comparison, the following finds were taken:

Finno-Ugrian bracelet-like temple ring (Figure 2: 15) and fire-polished jewelry from destroyed cremations of the 10th – the first half of the 11th century from the cemetery Shekshovo 9: the fragment of a necklace (Figure 2: 10) and a finger-ring (Figure 2: 8); two belt mounts from one kit of Volga-Bulgaria origin (Figure 2: 13, 16); a Byzantine miliaresion of Constantine VII Porphyrogenitus, from the time 945-959 (Figure 2: 17); Volga Bulgar dirham imitation of a Samanid-period issue datable roughly to 920-940 AD (Figure 2: 18); two temple rings and a bead of Rus' origin (Figure 2: 9, 11, 12); the fragment of the temporal-pendant (Figure 2: 14); wire knotted bracelet (Figure 2: 20) and also a marker of local

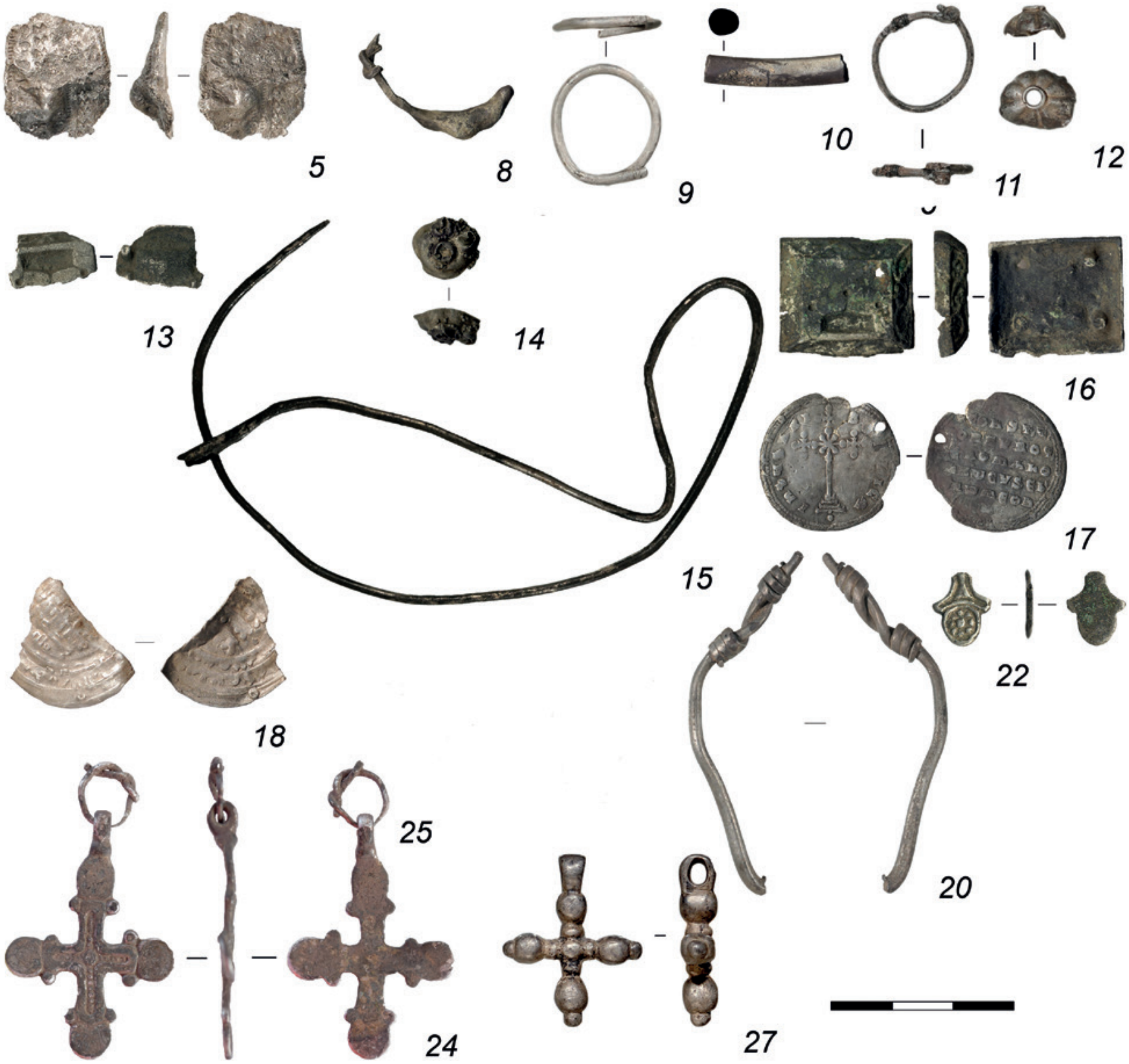

Figure 2. Analyzed objects from silver alloys. Photo: Institute of Archaeology RAS.

production, a flawed, unfinished finger-ring with a geometrical pattern from Shekshovo 2 (Figure 2: 5).

There are 14 items made from copper-based alloys (Figure 3: 19, 21, 23, 26, 28-33, 35-38). Among them nine pectoral crosses (Figure 3), one fragment of a reliquary cross (Figure 3: 23), icon pendant (Figure 3: 38), and a pendant with the image of a curled up beast (Figure 3: 19), and two convex square bezels from finger-rings (Figure 3: 21, 28). The cross from Torki 4 is likely to be of local origin (Figure 3: 35).

Methodology

The metal compositions have been determined by an energy dispersive µXRF (M1 Mistral™, Bruker) in the "no vacuum" mode (Table 1). Before analysis, the area of the object was polished to remove the corrosion layer. The effects from corrosion or surface-related treatments should be minimal, except for one case, explained below.

The study of lead isotope compositions in the selected artifacts has been carried out in the laboratory of isotopic geochemistry and geochronology of the Institute of Geology of Ore Deposits, Petrography, Mineralogy, and Geochemistry RAS, Moscow. A multi-collector mass spectrometer (MC-ICP MS) was used for the analyses. Lead was extracted from metal samples weighing between 0.01-0.03 grams. Before sampling, the surface of each item in the region of sampling was cleared from the surface dirt and oxide films with 3 % solution of HNO_3 and distilled water. The chemical preparation of the sample includes the dissolution in pure 8M HNO_3 + 6M HCL (2:1) mixture in a hermetic PFA-vessel for 12 hours in the atmospheric pressure and the temperature about

Figure 3. Analyzed non-ferrous objects. Photo: Institute of Archaeology RAS.

Tables 1. The metal composition of Suzdal region objects (XRF).

	Type	Reference	Cu	Sn	Pb	Zn	Bi	Ag	Sb	As	Fe	Ni	Co	Au	Hg
1	Pectoral cross	Gnezdilovo2-2014, № 239/151	0.2	91.9	4.4	1.3	-	-	-	0.1	1.4	-	-	-	-
2	Pectoral cross	Gnezdilovo2-2014, № 482/394	-	74.4	25.4	-	-	-	-	-	-	-	-	-	-
3	Corolla	Shekshovo9-2013, burial 3, № 50	0.5	79.5	19.9	0.0	0.04	0.02	-	-	-	-	-	-	-
4	Pendant dirham-style	Shekshovo9-2016, burial 3, № 234/4	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm	nm
6	Pectoral cross	Suvorotskoye8-2014, № 756/60	0.8	92.8	1.9	1.7	-	-	-	0.1	1.5	0.03	-	-	-
7	Pectoral cross	Soroguzino2-2016, № 782/45	0.1	71.0	27.2	0.6	-	-	-	0.3	0.7	-	-	-	-
34	Pectoral cross	Shekshovo2-2014, № 1242/349	-	4.2	95.6	-	-	-	-	-	-	-	-	-	-
5	Finger ring	Shekshovo9-2019, № 93	2.6	1.1	1.6	1.1	0.52	90.6	-	-	2.1	-	-	0.28	0.1
8	Finger ring	Shekshovo9-2013, № 85	1.3	0.3	0.6	-	0.47	96.3	-	-	0.7	-	-	0.32	-
9	Temporal ring	Shekshovo9-2013, burial 5, № 30	6.7	0.9	2.2	1.5	0.23	88.0	0.2	-	0.2	-	-	0.21	-
10	Necklace	Shekshovo9-2013, № 55	2.2	-	0.7	-	0.59	95.9	-	-	0.3	-	-	0.25	-
11	Temporal ring	Shekshovo9-2013, burial 5, № 32	1.1	0.5	0.4	-	0.24	96.3	0.5	-	0.6	-	-	0.42	-
12	Temporal ring	Shekshovo9-2013, № 136	2.0	-	0.0	-	-	97.2	-	-	0.5	-	-	0.34	-
13	Belt fitting	Shekshovo9-2015, p.3, № 164	6.7	0.1	1.5	1.0	0.34	87.7	-	0.2	0.1	-	-	2.44	-
14	Temporal pendant	Shekshovo9-2014, № 15	4.1	-	0.3	-	0.07	94.5	-	-	0.7	-	-	0.33	-
15	Temporal ring	Shekshovo9 -2015, № 162	4.2	0.2	0.2	-	0.58	94.5	-	-	0.1	-	-	0.21	-
16	Belt fitting	Shekshovo9-2015, p. 3, № 127	7.3	0.3	1.1	0.1	0.30	89.9	-	0.1	0.3	0.5	-	0.17	-
17	Miliaresion	Shekshovo9-2013, № 151	4.8	-	0.6	-	0.32	92.8	-	-	0.3	-	-	0.70	-
18	Dirham imitation	Shekshovo9-2019, № 104	6.7	-	0.1	-	0.31	92.9	-	-	-	-	-	-	-
20	Arm ring	Shekshovo9-2019, № 19	17.7	-	1.1	-	0.21	71.6	-	-	-	-	-	-	-
22	Pectoral cross	Suvorotskoye8-2014, № 740/144	9.9	-	1.3	1.6	-	82.8	-	0.1	1.0	-	-	-	-
24	Pectoral cross	Mikhali3-2017, № 363/72	55.3	-	0.7	0.9	-	42.0	-	-	-	-	-	-	-
25	Handle	Mikhali 3-2017, № 363/72	11.0	-	0.9	0.2	0.21	87.2	-	-	-	-	-	0.48	-
27	Pectoral cross	Suvorotskoye8-2013, № 465/29	2.4	-	1.1	0.2	-	95.2	-	-	0.2	0.2	-	0.66	-
19	Pendant	Shekshovo9-2019, № 9, 11	58.5	32.7	1.9	6.3	0.11	0.1	0.04	0.1	0.2	-	0.03	-	-
21	Finger ring	Suvorotskoye8-2015, № 509/28	71.8	17.0	9.7	0.9	0.07	0.19	0.04	-	0.2	0.05	-	-	-
23	Reliquary cross	Mordush1-2012, № 328/73	53.6	40.2	1.9	0.9	-	-	-	0.4	0.6	0.14	-	-	-
26	Pectoral cross	Suvorotskoye8-2012, № 677/74	48.3	43.9	4.1	1.7	-	-	-	0.7	0.7	0.12	-	-	-
28	Finger ring	Semenovskoye2-2018, № 683/65	74.1	21.7	1.8	1.9	0.03	0.11	0.1	0.1	0.1	0.04	-	-	-
29	Pectoral cross	Kubaevo7-2015, № 168/63	65.8	5.5	18.5	5.5	0.07	0.16	0.4	2.4	1.8	-	-	-	-
30	Pectoral cross	Kibol5-2017	84.3	2.7	8.9	2.0	-	-	-	0.6	0.9	-	-	-	-
31	Pectoral cross	Shekshovo9-2019, № 77	48.6	20.1	16.1	9.2	0.11	0.39	0.8	2.9	1.9	-	-	-	-
32	Pectoral cross	Shekshovo2-2015, № 651/42	76.7	10.9	8.1	0.2	0.08	0.28	0.2	1.7	1.8	-	-	-	-
33	Pectoral cross	Shekshovo2-2014, № 1242/349	69.4	3.6	18.2	5.9	-	-	-	1.2	0.6	-	-	-	-
35	Pectoral cross	Torki4-2009, № 29	66.9	26.7	4.1	0.7	-	0.11	0.3	0.8	0.5	-	-	-	-
36	Pectoral cross	Tarbaevo5-2011, № 608	80.1	11.3	5.4	-	-	-	-	0.9	1.0	-	-	-	-
37	Pectoral cross	Krapivie6-2019, № 260/15	80.4	17.3	1.4	-	-	0.67	0.04	0.1	-	0.05	-	-	-
38	Icon pendant	Krapivie6-2019, № 273/28	76.4	18.1	4.0	-	0.03	0.44	0.2	-	0.7	0.05	-	-	0.1

100 °C. In the next step the solution was evaporated to dry salts and dissolved in 1M HBr. Lead separation from the matrix elements was done using a one-step procedure with the HBr medium in PFA-micro columns filled with anion-exchange resin Bio-Rad AG-1X8 (0.1 cm^3) (Chugaev, et al., 2013). The laboratory blank contribution for Pb was about 0.1 ng.

The measurements of lead isotope ratios have been carried out using the multicollector mass-spectrometer NEPTUNE (Thermo Fisher Scientific™) (Chernyshev, et al., 2007). The analyses were performed in the mode "wet plasma" for the sample solutions traced with Tl. The corrections of the effect of the instrumental mass-bias were done using the results of the measurement of the reference $^{205}Tl/^{203}Tl$ ratio which was accepted as 2.3889±1. The analytical errors for isotopic lead ratios were evaluated on the long term reproducibility of SRM 981 (n = 11) and rock sample AGV-2 (n = 4) measured at the same time. The value of analytical error for the $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ ratios did not exceeded ±0.03 % (2SD).

Results: µXRF analysis

Of the seven objects made from low-melting lead-tin alloys, six were analyzed using this method. Five are tin-based pewter alloys with lead in concentrations from 2 to 27 wt. %. One cross was made from a lead-based alloy with about 4 % tin (Figure 1: 34). To protect the integrity of the object, the lead/tin-alloy pendant made in the style imitating a dirham with a loop, was not cleaned, so its composition has not been identified.

The silver can be divided into three categories based on silver content: eight sterling or better, seven moderately debased, and two heavily debased. In eight items, the concentration of silver is more than 92.5 % (92.9 – 97.2 %), the concentration of copper varies from 1.1 to 6.7 %, the bismuth varies from below detection to 0.6 % (the average value is 0.3 %). The concentration of lead ranges from below the detection limit to 1.1 %, which is normal for silver of this purity. In seven objects, silver was between 82 to 91 %. This moderately debased group has much more variable zinc and tin contents, indicating the addition of bronze, brass and/or gunmetal to the alloys. Lead contents are also higher (0.9-2.2 %), so it is possible that small amounts of lead from copper-based alloys could be present. The two heavily debased objects (72 % and 42 %, respectively) are alloyed with pure copper. The gold contents of all silver object typically fall around 0.2-0.4 %, with two objects having above this amount and three below. One object, (Belt fitting № 13), has highly elevated gold, pointing to the unintentional incorporation of gold into the alloy, probably through recycling of gilding or gold inlays.

The elemental compositions of copper-based alloys show a low degree of standardized-alloy use and the most striking feature is the frequently elevated tin contents pointing to the use of so-called "white bronze". The first group of three crosses are quaternary alloys with a dominate contribution of lead (9-19 %) and relatively low tin and zinc contents between 2-6 % (leaded gunmetal, № 29, 30, 33). Two crosses were casted from leaded tin bronze with tin contents in the traditional 10-11 % range, without zinc (№ 32 and 36). Eight objects have high-to-very high tin contents ranging from 17-40 %, the greater the tin content above 20 %, the whiter the alloy becomes (Mecking, 2020). Of these, the Torki 4 "white bronze" cross, which imitates the color of silver, is likely to be of local origin (Figure 3: 35). The reliquary cross, the pendant and two crosses (№ 26, 23, 19 and 31) also have a white color because of the high concentration of tin, also accentuated by zinc and lead contents (see Mecking, 2020). It was found that cross № 26 was tinned, and therefore, the composition determined by µXRF is not representative of the core copper-based alloy.

The use of a white colored copper-based alloy is highly significant, and it is believed by the authors that there was a regional tradition in the Suzdal Opole area for the manufacture of certain types of items from this alloy: crosses imitating Scandinavian-style and rings with large bezels. Work on this topic is currently underway.

Results: Lead isotope analysis

Lead isotope data have been acquired for 38 artifacts (Table 2; Figure 4). The values of measured lead isotope ratios for the studied groups of items have respectively wide ranges: $^{206}Pb/^{204}Pb$ = 18.18-19.02, $^{207}Pb/^{204}Pb$ = 15.61-15.73 and $^{208}Pb/^{204}Pb$ = 38.27-39.41. The revealed variations of the lead isotope composition are significant on a scale: the values of the variation coefficient (ν, %) for the ratios $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ are respectively $\mathbf{\nu}_{6/4}$ = 0.93 %, $\nu_{7/4}$ = 0.18 % and $\nu_{8/4}$ = 0.71 % and by an order exceed the analytical error (0.03 %). Taking into account the composition of the metal, the studied items can be divided into three groups: items are made from low-melting (lead-tin/pewter) alloys, silver and copper-based alloys. The comparison of lead isotope data for these groups shows that copper alloy items are characterized by the most homogeneous lead isotopic compositions. The measured values of lead isotopic ratios vary in the narrowest range: $^{206}Pb/^{204}Pb$ = 18.29-18.54 ($\nu_{6/4}$ = 0.35 %,), $^{207}Pb/^{204}Pb$ = 15.62-15.66 ($\nu_{7/4}$ = 0.05 %) and $^{208}Pb/^{204}Pb$ = 38.27-38.64 ($\nu_{8/4}$ = 0.24 %).

The main contribution to the variation in the measured lead isotopic ratios for the collection is made by the data obtained for silver items ($^{206}Pb/^{204}Pb$ = 18.33-19.02; $^{207}Pb/^{204}Pb$ = 15.61-15.73; $^{208}Pb/^{204}Pb$ = 38.33-39.41) and lead-tin alloy items ($^{206}Pb/^{204}Pb$ = 18.18-18.66; $^{207}Pb/^{204}Pb$ = 15.63-15.69; $^{208}Pb/^{204}Pb$ = 38.32-38.86). For silver items, the values of the variation coefficient for lead isotopic ratios are $\nu_{6/4}$ = 1.12 %, $\nu_{7/4}$ = 0.23 %,

Table 2. The lead isotopic composition in archaeological objects from Suzdal Opolye. The measurement error for isotope ratios did not exceed 0.03 % (±2SD).

№	Object	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$	$^{207}Pb/^{206}Pb$	$^{208}Pb/^{206}Pb$
	Tin-lead objects					
1	Pectoral cross	18.5249	15.6917	38.8045	0.84706	2.09472
2	Pectoral cross	18.4266	15.6259	38.4368	0.84801	2.08594
3	Corolla	18.6648	15.6845	38.8636	0.84033	2.08219
4	Pendant (kufic dirham style)	18.1753	15.6452	38.3239	0.86079	2.10857
6	Pectoral cross	18.4297	15.6282	38.4163	0.84799	2.08448
7	Pectoral cross	18.4114	15.6260	38.4066	0.84871	2.08602
34	Pectoral cross	18.3613	15.6333	38.3563	0.85143	2.08898
	Silver objects					
5	Finger ring (defect)	18.4010	15.6379	38.4497	0.84984	2.08954
8	Finger ring	18.3457	15.6516	38.6800	0.85315	2.10840
9	Temporal ring	18.3680	15.6379	38.4272	0.85137	2.09207
10	Necklace	18.4382	15.6611	38.6529	0.84938	2.09635
11	Temporal ring	18.4003	15.6501	38.5696	0.85054	2.09614
12	Temporal ring	18.4058	15.6059	38.3831	0.84788	2.08538
13	Belt fitting	18.7553	15.7044	38.9186	0.83733	2.07507
14	Temporal pendant	18.4725	15.6580	38.6164	0.84764	2.09048
15	Finno-Ugrian-type temporal ring	18.7561	15.7087	38.9362	0.83752	2.07592
16	Belt fitting	19.0242	15.7302	39.4082	0.82685	2.07148
17	Byzantine miliaresion	18.6495	15.6809	38.8319	0.84082	2.08220
18	Volga Bulgar dirham imitation	18.6051	15.6509	38.7628	0.84122	2.08345
20	Arm ring	18.8826	15.7238	39.3335	0.83271	2.08306
22	Pectoral cross	18.3959	15.6339	38.4017	0.84986	2.08751
24	Pectoral cross	18.4072	15.6284	38.4924	0.84904	2.09116
25	Handle	18.3663	15.6336	38.3943	0.85121	2.09048
27	Pectoral cross	18.4004	15.6340	38.4065	0.84966	2.08726
	Copper-based alloy objects					
19	Scandinavian-type pendant	18.3336	15.6377	38.3254	0.85295	2.09045
21	Finger ring	18.4583	15.6428	38.4316	0.84747	2.08208
23	Reliquary cross	18.3365	15.6352	38.3293	0.85268	2.09033
26	Pectoral cross	18.3667	15.6372	38.3606	0.85139	2.08860
28	Finger ring	18.3759	15.6386	38.3761	0.85104	2.08839
29	Pectoral cross	18.3587	15.6301	38.3507	0.85137	2.08897
30	Pectoral cross	18.3387	15.6363	38.3283	0.85264	2.09002
31	Pectoral cross	18.3948	15.6411	38.4079	0.85030	2.08798
32	Pectoral cross	18.5392	15.6607	38.6371	0.84473	2.08408
33	Pectoral cross	18.3018	15.6365	38.2836	0.85437	2.09179
35	Pectoral cross	18.4163	15.6234	38.4217	0.84835	2.08629
36	Pectoral cross	18.3059	15.6367	38.2874	0.85419	2.09153
37	Pectoral cross	18.3720	15.6330	38.3719	0.85091	2.08861
38	Icon pendant	18.2904	15.6398	38.2729	0.85508	2.09251

and $\nu_{8/4}$ = 0.84 %. Similar values of this parameter were obtained for the lead-tin alloy items: $\nu_{6/4}$ = 0.80 %, $\nu_{7/4}$ = 0.18 % and $\nu_{8/4}$ = 0.84 %.

Wide ranges of the values for $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ ratios determine the significant scatter of the points in the lead isotope correlation diagrams (Figure 4, a, b). On the diagram in the coordinates with uranogenic points plot in the field located between the average crustal growth curve (m_2 = $^{238}U/^{204}Pb$ = 9.74) and the curve with the value m_2 = 10.1 (Figure 4, a). While on the diagram in the coordinates $^{206}Pb/^{204}Pb$-$^{208}Pb/^{204}Pb$ points plot between growth curves with the parameters ω_2 = $^{232}Th/^{204}Pb$ = 36.84, Th/U = 3.78 and ω_2 = 41.0, Th/U = 4.06 (Figure 4, b).

At the same time, the non-uniform character of spreading of the points in the diagrams should be noticed. Simultaneously, it should be noted that the distribution of points on the diagrams is uneven. First of all, compact fields corresponding to the lead isotopic compositions of the copper-alloy items are identified. The most (exception is the sample № 32) points are located in the lower parts of the diagrams close to the average crustal growth curve of Stacey-Kramers model (Stacey and Kramers, 1975). The points of some silver items (№ 5, 22, 24, 25) and the items of lead-tin alloy (№ 2, 6, 7) are close to the field of lead isotopic compositions of the copper-alloys. They are mostly represented by crosses. At the same time, there is no correlation between the lead isotopic compositions of the items mentioned above and

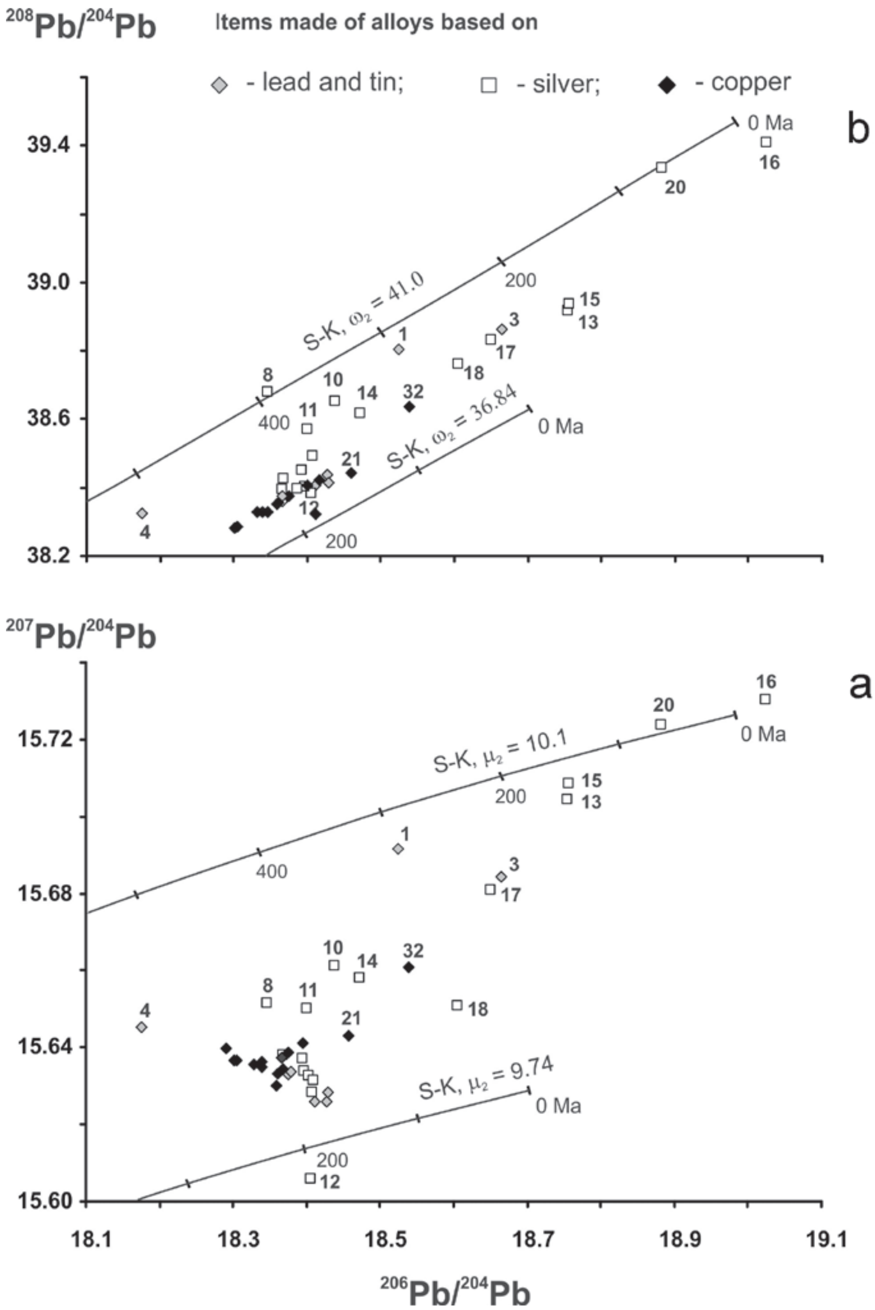

Figure 4. The comparison of lead isotopic composition in objects from the Suzdal Opole. Growth curves of the lead isotopic composition are shown on the diagrams on the model of Stacey-Kramers (1975). The object numbers are given according to Figures 1-3 and Tables 1-3.

the place of their find. It is necessary to point out that there is the group including four silver items (№ 13, 15, 16, 20) with lead containing the highest amounts of radiogenic isotopes ^{206}Pb, ^{207}Pb and ^{208}Pb. These are two belt fittings of Volga Bulgar style and the temple ring and bracelet of Finno-Ugric origin.

The discussion of lead isotope data: the recycling of metal and the origins of ores

One of the most important conditions of the emergence and development of large rural settlements in the 10th–13th century in Suzdal Opolye was the forming of consistent and extensive near and distant economic contacts (Makarov, 2021). As a result, finished goods as well as ingots, wire and scrap were brought to the settlements, and while some metal objects may be closely tied to new metal production, others may have long histories of recycling and re-use. The diversity of metal finds themselves bears witness to the complexity of the metal trade networks, yet, the lead isotope ratios provide further depth and additional tools for exploring these networks and the flow of metal stocks and resources.

Considering the dataset as a whole, it is readily apparent that while the pewter and silver finds have wide-ranges of isotopic variation, the copper-based alloys are isotopically uniform. Taken further, this means that multiple sources are represented by the pewter and silver finds and it is possible that the copper-based alloys predominately originate from a single source or source region.[1] This has implications for our understanding of the metal trade and the identification of possible connections and source regions. It must be emphasized, however, that the lead isotope ratios of metal objects do not necessarily directly relate to the source of the metal as they may be impacted by recycling, mixing and other metallurgical processes (Merkel, 2019; Pernicka, 2014). A direct linkage of metal to ore sources therefore should not be assumed, and argumentation must be built upon supporting evidence. There are two important principles that are useful in constructing an interpretational framework. 1. When metals are mixed together, they are homogenized elementally and isotopically and thus, source-relevant information is partially preserved in the end product. 2. Metal stocks can be geographically and temporally specific; and by comparing metal objects to metal stocks, relationships can be revealed that allow metal to be tracked over time and space (example, Merkel, 2016). These principles will be applied to the datasets from the Suzdal non-ferrous metal artifacts to elucidate trading contacts and supply networks.

The flow of pewter

As stated above, the pewter artifacts are of diverse origins. It is generally argued that since the genesis of tin ore and lead ore are broadly incompatible tin alloys with lead in the percentage range represent anthropogenic alloys and the lead isotope ratios provide information only about the lead found in the metal (Begemann, et al., 1999), but this is not without exception. Usually with pewter, relationships to lead metal and lead ore sources are to be sought, but it is certainly possible that both tin and lead come from the same source region or even ore source, for example in Southwest England where both metals can be found. There are two large datasets of contemporary lead and pewter available as a start. In Northern Europe, the lead trade was highly active. Lead and pewter datasets from Viking Hedeby (Merkel, 2016), Birka (Stos-Gale, 2004a), Gokstad (Pedersen, et al., 2016) as well as unpublished lead and pewter from late 11th-13th century Schleswig (Merkel, in prep.) form a contiguous cluster (Figure 5) and can be linked to lead production in Western Europe, primarily in England. The second major dataset comes from the large-scale analyses of lead-based objects from the Serçe Limani shipwreck off the Turkish coast, dated to the 11th century (Stos-Gale, 2004b). This dataset provides a glimpse into the metal stocks being traded in the Eastern Mediterranean at this time. By comparing the two stocks, it becomes clear that the stocks used in Northern Europe and in the Eastern Mediterranean are fundamentally different (Figure 5). Two of the Suzdal artifacts are more comparable to the Eastern Mediterranean stock (diadem № 3, possibly pectoral cross № 1, but see below). Four objects, all of which are pectoral crosses, are consistent with Northern European lead stocks (№ 2, 6, 7 and 34), and these also are consistent with lead ore from Cornwall and Devon (Figure 6, compare Rohl, 1996), where the tin likely originated – it is possible that lead may have entered the tin by happenstance. A subset of these (№ 2, 6 and 7) are, however, highly homogenous isotopically and also align with the tight isotope cluster of the Olkusz lead ore district near Cracow (compare Church and Vaughn, 1992). This ore district is known to have been mined extensively during this period (Borón and Rozmus, 2014; Godzik and Woch, 2015) and has the potential of being a major lead supplier to Eastern Europe. The prevalence and distribution of Olkusz lead in the early Middle Ages can be explored through lead isotope analysis and is a topic that awaits future research. It would be helpful to analyze Drohiczyn-type lead seals probably used in the fur trade, which are found in large quantities in settlements along the Rus'-Polish border. This could provide evidence that

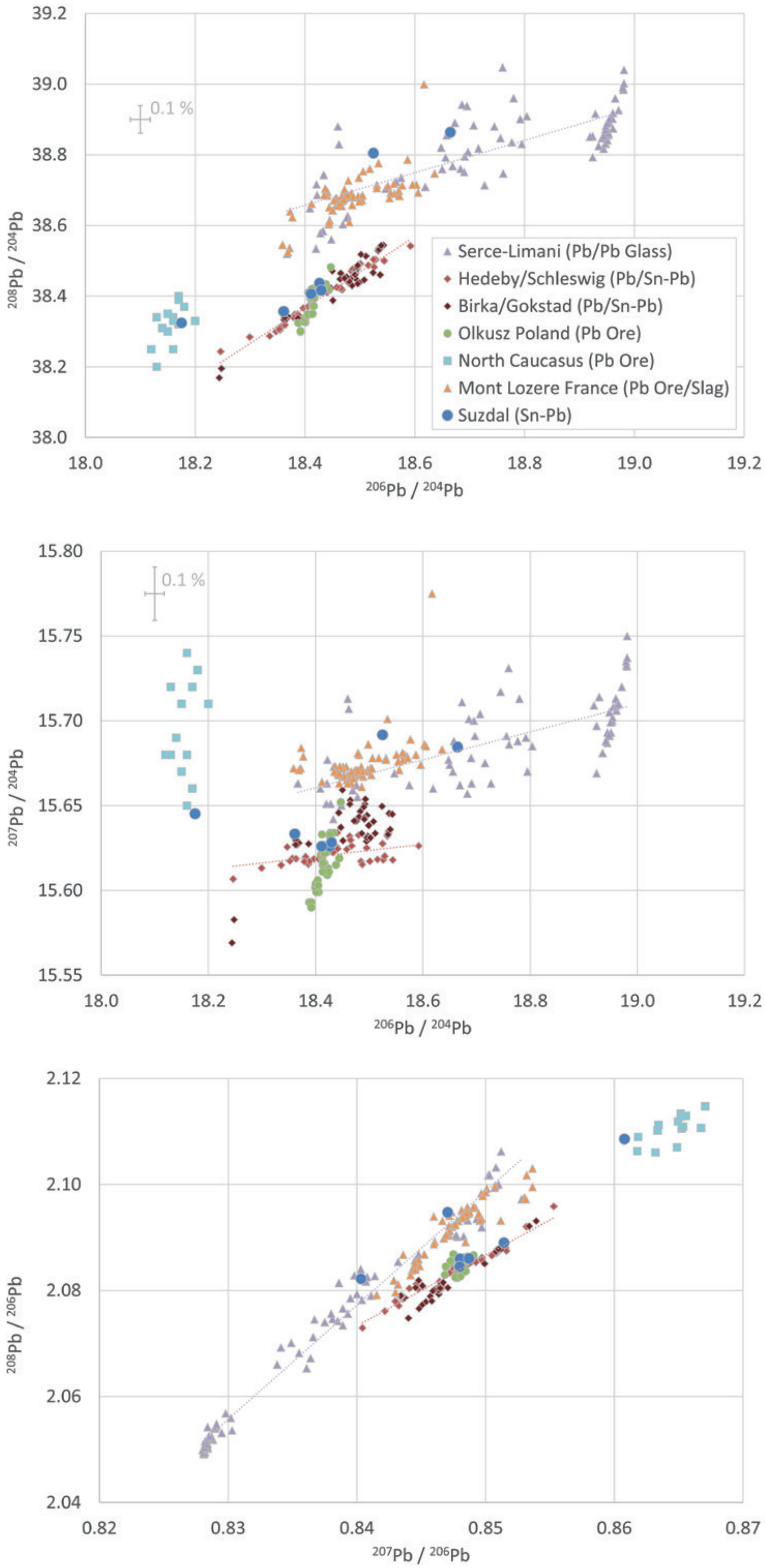

Figure 5. Lead isotope diagram comparing pewter finds (Suzdal Opole) to lead-based objects from the Eastern Mediterranean (Serçe Limani, 11th century), Northern European lead stocks (Scandinavia), and ore from the Olkusz district (Poland) and the Northern Caucasus (North Ossetiya) (references see text).

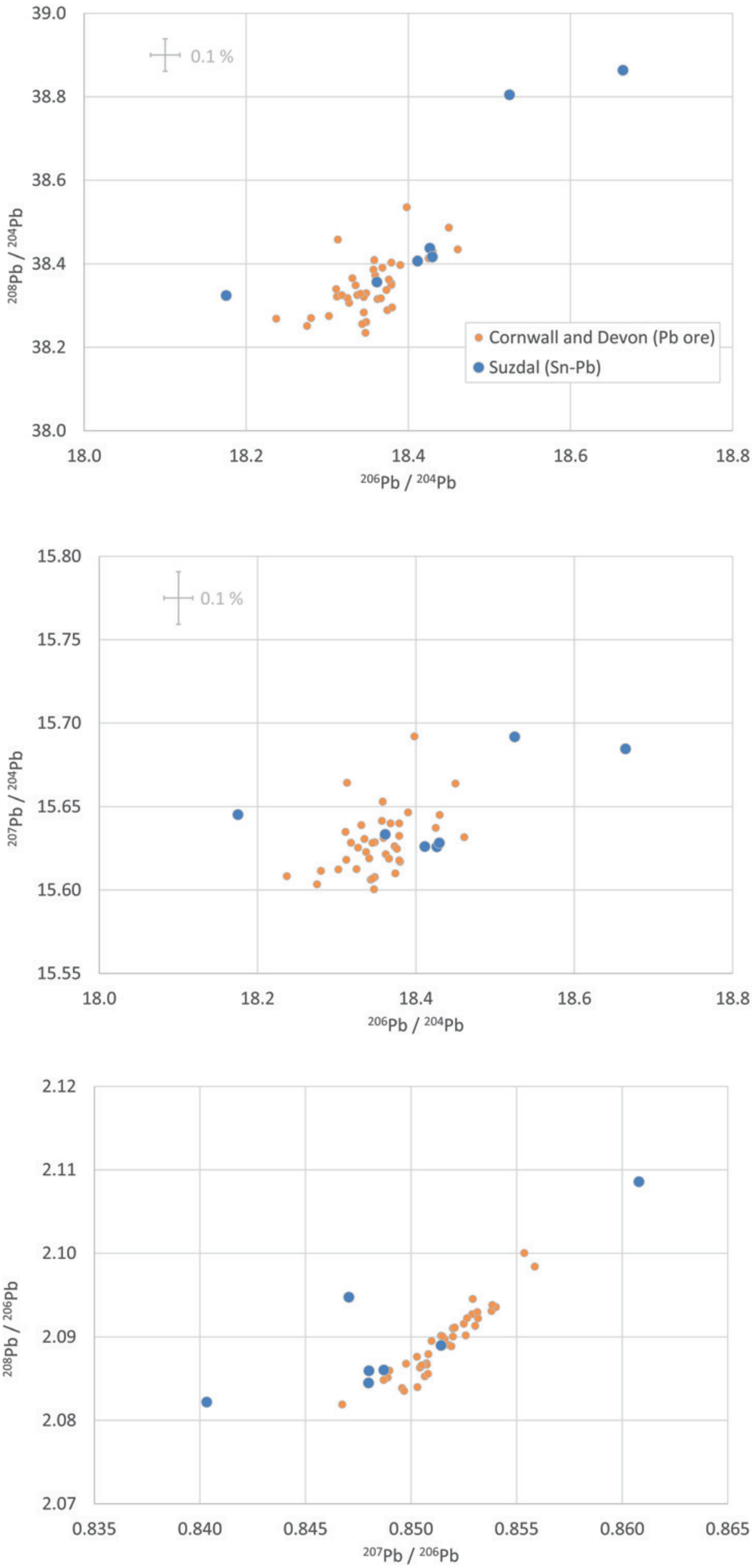

Figure 6. Lead isotope diagram comparing pewter finds (Suzdal Opole) to ore from Cornwall and Devon (Rohl, 1996).

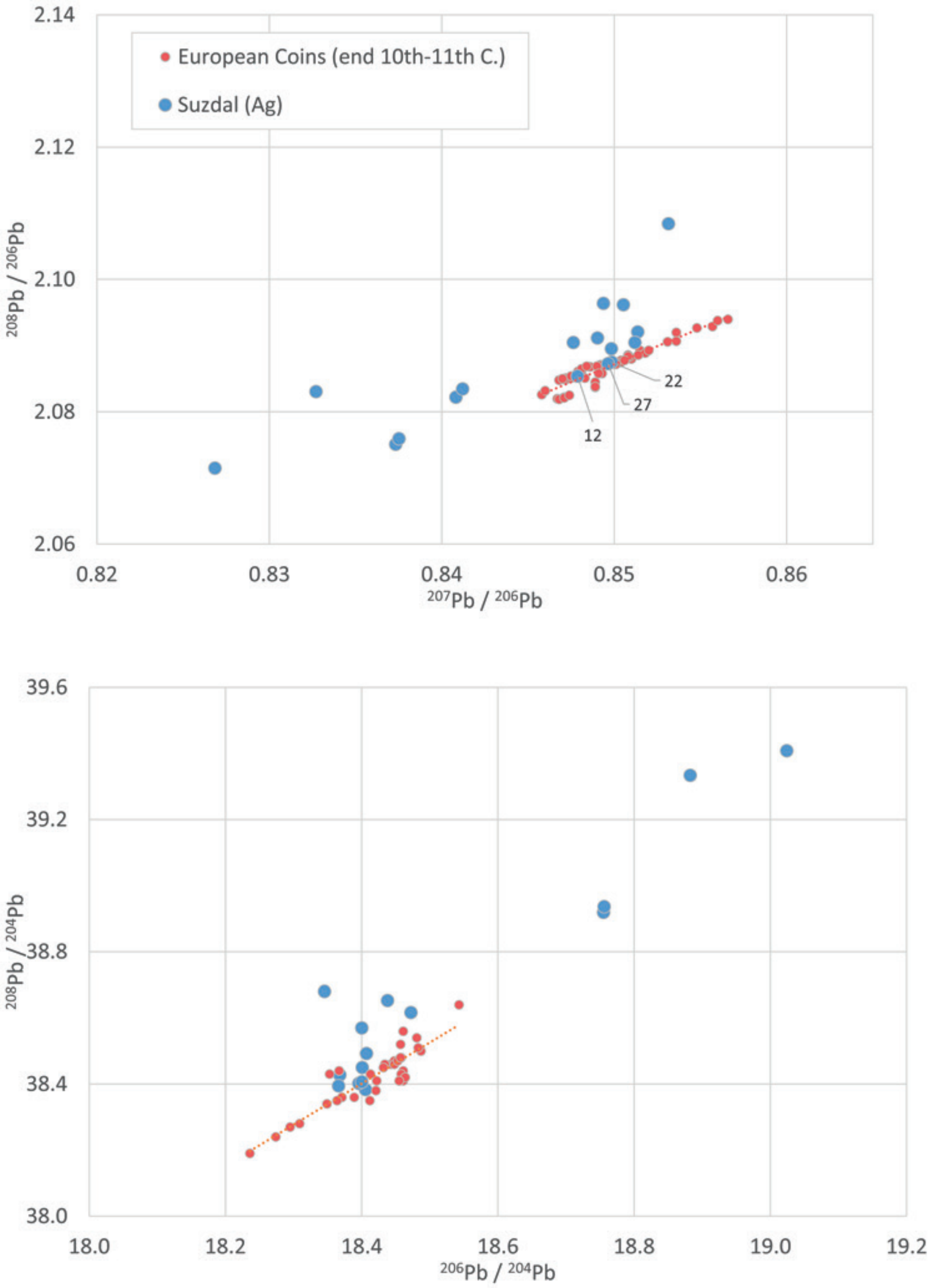

Figure 7. Lead isotope diagrams comparing silver (Suzdal Opole) with West, Central and Northern European silver coins from the late 10th and 11th century (Merkel, 2016). Errors are smaller than the symbol.

Olkusz lead resources were utilized for this purpose, making if feasible that lead from this source was accessible to the Rus'. The large number of Rus' imports discovered in Poland confirms intensive exchange between the two (Wołoszyn, 2006).

Pectoral cross № 1, though being broadly similar to Eastern Mediterranean lead stocks, plots in a low density area of the distribution. Depending on the dating of this particular object, a source in the Cevennes, Mont Lozère, may be possible (compare Baron, et al., 2006), but this object is on the periphery of the isotope field. Beginning in the 11th century, lead and silver ore were mined in large quantities and lead was exported to distant Mediterranean markets (see Galili, et al., 2019) and possibly beyond. This type of lead, however, is not found at Schleswig, in Northern Europe, at the same time, so it appears that this lead was not widely traded in the northern maritime network. Although it must be said that the source of this lead is not clear, it most likely has a southern origin possibly connected to Mediterranean maritime trade and brought north via the Black Sea and Russian river systems.

The final lead-based object, the Kufic dirham style pendent (№ 4) is totally distinct from Eastern Mediterranean and Northern European lead stocks. The form and pseudo-Arabic script with some similarities to Samanid dirhams points to a southerly source, but likely outside of the Caliphate, possibly made in Volga Bulgaria, the Cau-

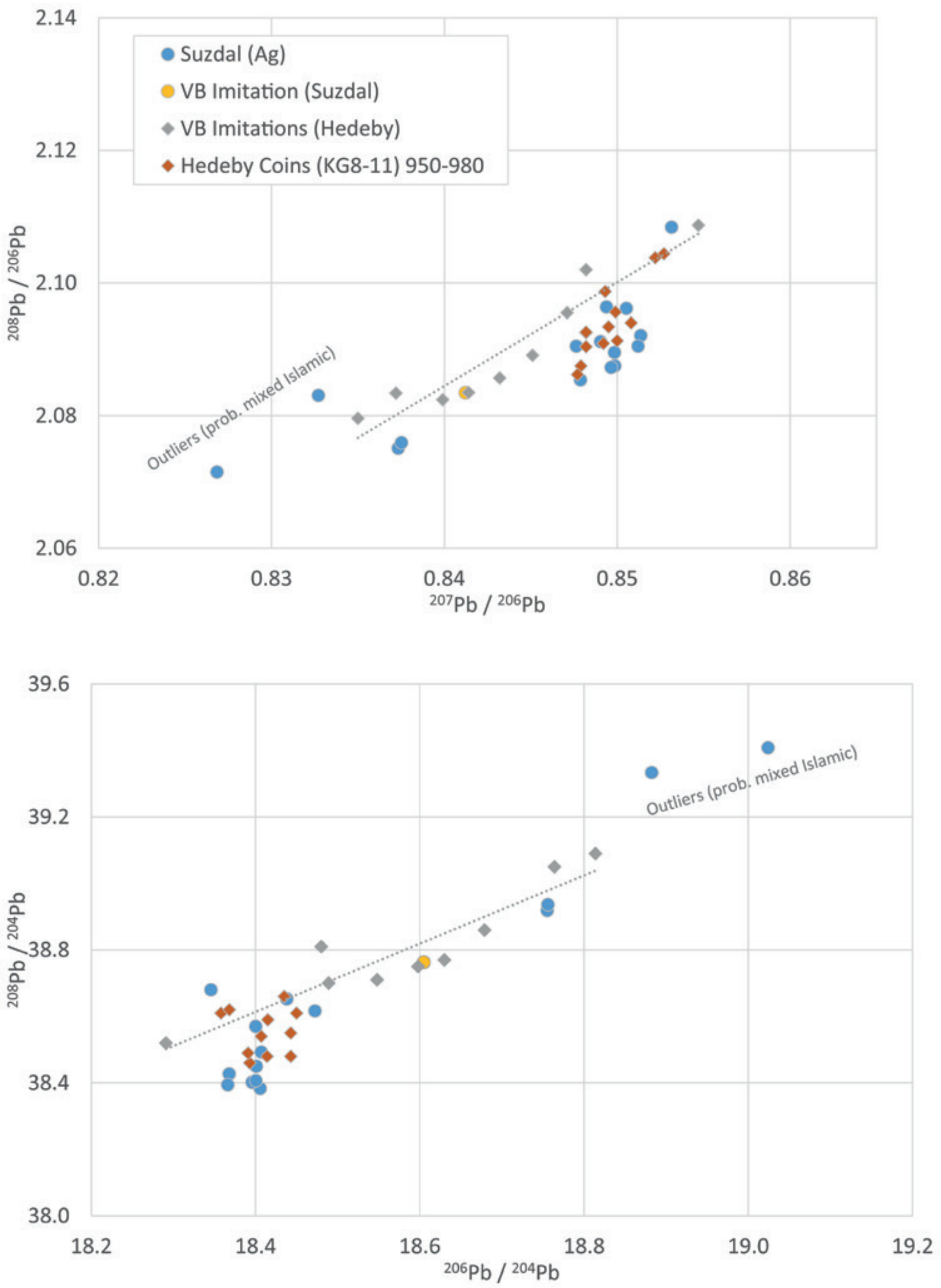

Figure 8. Lead isotope diagrams comparing silver (Suzdal Opole) with Danish Viking coinage (KG8-11) from ca. 950-980 and Volga Bulgar dirham imitations from the first half of the 10th century (Merkel, 2016).

casus or other bordering regions. It is inconsistent with known Abbasid and Samanid dirham isotopic compositions (Merkel, 2016; Merkel, Oravisjärvi and Kershaw, in prep.) and thus not likely to be tied to major lead-silver production in the Islamic-controlled territories. Comparing this object to known lead ore deposits, an isotopic parallel can be found at the Northern Osetiya lead district in the Northern Caucasus (compare Tugarinov, 1977). Its geographic location beyond the fringe of the Islamic Empire makes it a possible source candidate, but the archaeological circumstances connected to this source are unknown. The lead source for this object must be left open due to inadequate archaeological information and the poor data basis for this region.

The flow of silver

In the early medieval period silver became an important metal for both exchange and display over much of Eurasia. The long-distance movement of silver from silver-producing, monetized regions to the non-monetize regions of Northern and Eastern Europe is a topic of active research, and from what is now known about the trade of silver, it has proven to be dynamic and highly sensitive to chronological factors. The 10th century can be seen as a volatile period in the history of silver. While the import of silver to the Northern Lands primarily stems from the Abbasids in the 9th century and the Samanids in the early 10th, by the end of the 10th century there is change of directions, with silver predominantly coming from Western Europe (Steuer, Stern and Goldenberg, 2002; Hardt, 2019; Adamczyk, 2020). Byzantine silver is rare in comparison, but its import in the form of miliaresia reaches its height in the second half of the 10th century (Jankowiak, 2016). Therefore, the main question regarding the Suzdal silver artifacts is how they fit into these broad supra-regional trends in the silver trade.

Certain elemental and isotopic characteristics can be used to identify silver coming from particular source regions and they tend to be chronologically specific. The isotopic characteristics of West/Central European silver coins at the turn of the 10th into 11th century, which dominated the 11th century Northern European maritime network, and are conversely very narrow and are consistent with sources in Germany and England (Merkel, 2016). This narrow range of isotope ratios found in 11th century coinages from England, Saxony and the Rhine region should allow this Western European silver stock to be identified. Contrasting the Suzdal silver finds with European coins from England, Ireland, Denmark, Saxony and the Lower Rhine, only a few Suzdal artifacts are consistent (Figure 7). Of these, № 12, 22 and 27 are highly consistent with this stock. This means for the other artifacts, they are either completely unrelated to the Northern European stock circulating the 11th century Baltic area or are influenced by the contribution of silver from other sources.

Elevated levels of the element bismuth are particularly prevalent in silver coming from the Samanid controlled regions of Central Asia and Afghanistan in the 10th century, but also this silver tends to have higher $^{208}Pb/^{206}Pb$ ratios than 10th-11th century European silver (Merkel, 2016). This silver, in its pure unadulterated form, does not seem to have been used in Scandinavia for the manufacture of coinage or jewelry objects. Instead, it was mixed with other silver stocks, a phenomenon, for example, that occurs at Hedeby in the second half of the 10th century. The same appears to be true for Volga Bulgaria, who did not mint their imitations of Samanid dirhams out of unadulterated Samanid silver – it always was mixed with other silver or does not share a common origin with Samanid sources.

In Figure 8, silver finds from Suzdal are compared to mixed stocks from the second half of the 10th century in Hedeby and Volga Bulgar dirham imitations produced at the end of the 9th into the mid-10th century. This shows that the vast majority of the Suzdal silver artifacts has its closest isotopic parallels in 10th century Volga Bulgaria and silver from the second half of the 10th century in the Baltic area. Many of these objects have elevated levels of bismuth (0.34-0.59 wt. %), particularly № 5, 8, 10, 13, 15 and 16, which would be consistent with a contribution of Samanid silver, widely available across many parts of Eurasia in the early-to-mid 10th century (Noonan, 2001). These items are the earliest in the assemblage, the belt fittings being made in Volga Bulgaria and the rest of the items in Suzdal Opole. Belt fitting No. 16 and Arm-ring № 20 have closest isotopic similarities to Samanid dirhams, the former being nearly isotopically identical to a dirhams struck in Samarqand (892/894) and the later plotting on the Samanid dirham mixing line (compare Merkel, 2016).

A 10th century origin of the stock used for most of the Suzdal artifacts could fit with the end of the Samanid silver trade in the 10th century (Noonan, 2001), but the trade of Islamic silver from other sources and perhaps Byzantine silver seem to have continued under the Kievian Rus' (Roslund, 2015). It must be said that current available datasets do not allow a satisfactory resolution to the issue. Silver stocks from non-Western European sources from the 11th and 12th centuries are poorly characterized or not at all, which means that this is a genuine gap in research. What can be said is that boom of silver export from West/Central Europe to the Baltic in the 11th century did not have a major impact at Suzdal, and thus the movement of silver was blocked. This is seen in the relatively low numbers of Western silver coins, mainly known as stray finds in the Suzdal region (Makarov, Gaydukov and Gomzin, 2016). It is possible that beyond the 10th century silver from other Islamic or Byzantine sources sustained the needs of the Rus', but this is in need of further research.

The Byzantine miliaresion from Suzdal Opole is not necessarily connected to Islamic stocks or those used in Volga Bulgaria. Its compositional similarity to the Suzdal Opole Volga-Bulgar dirham imitation may be coincidental, but there is not enough data to judge this fully. What can be said is that the Suzdal Opole specimen, a Byzantine miliaresion of Constantine VII Porphyrogenitus (945-959), is similar to two previously analyzed miliaresia, one minted by Nicephorus II (963-969) and one by Basil II (977-989) (compare Merkel, 2016). This could mean that these stem from the same source, a source that could be under Byzantine control. Lead isotope ratios such as these are uncommon in the Aegean area, but there are isotopic parallels to lead-silver ore from the Bolkardag/Aladag area of the western Taurus Mountains (compare Taurus 2A, Yener, et al., 1991) and thus could reflect access to resources near to the Byzantine-Arab border (Figure 9). Whether the upsurge in the export of Byzantine silver coinage to the North could be connected to access to silver mining areas in the Taurus is a topic for further study. There

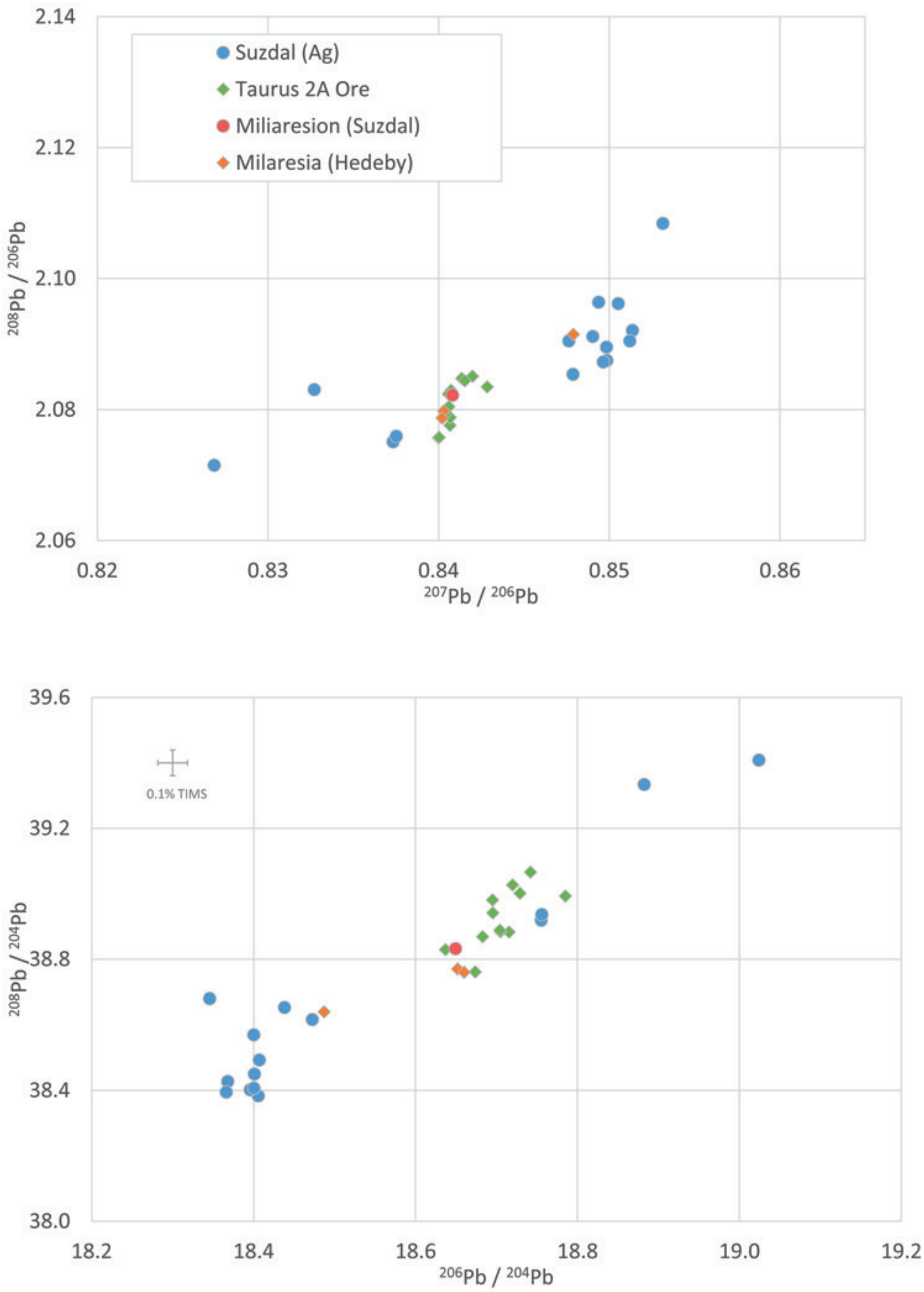

Figure 9. Comparison of Byzantine miliaresia from Suzdal Opole and Hedeby, all minted in the second half of the 10th century. These are compared with ore from the Taurus (2A) (after Yener, et al., 1991) indicating a possible Taurus source.

appears to have been Byzantine military activity in the west Taurus region around this time, leading to the conquest of the directly adjacent Cilicia region in early 960s (Garrood, 2008). Alternatively and solely based on the lead isotope ratios, there is also a close isotopic match with mixed ore from the gold-silver deposits of Roșia Montană in Romania (compare Baron, et al., 2011), but the mines are thought to have been abandoned in the Roman period and is only thought to have been resumed much later by Saxon immigrants in the 13th-14th centuries (Ciugudean, 2012; Vryonis, 1962).

The flow of copper-based alloys

The copper-based alloys form a dense and narrow cluster (13 objects) with one outlier that is isotopically unrelated to the other finds (№ 32). Regardless of the fact that there are a multitude of copper deposits in Eurasia, the lead isotope ratios point to a single source region that has managed to corner the copper-based metal trade. Numerous substantial copper sources used at various times in the past can be excluded as major suppliers for Suzdal Opole based on incompatible lead isotopy, such

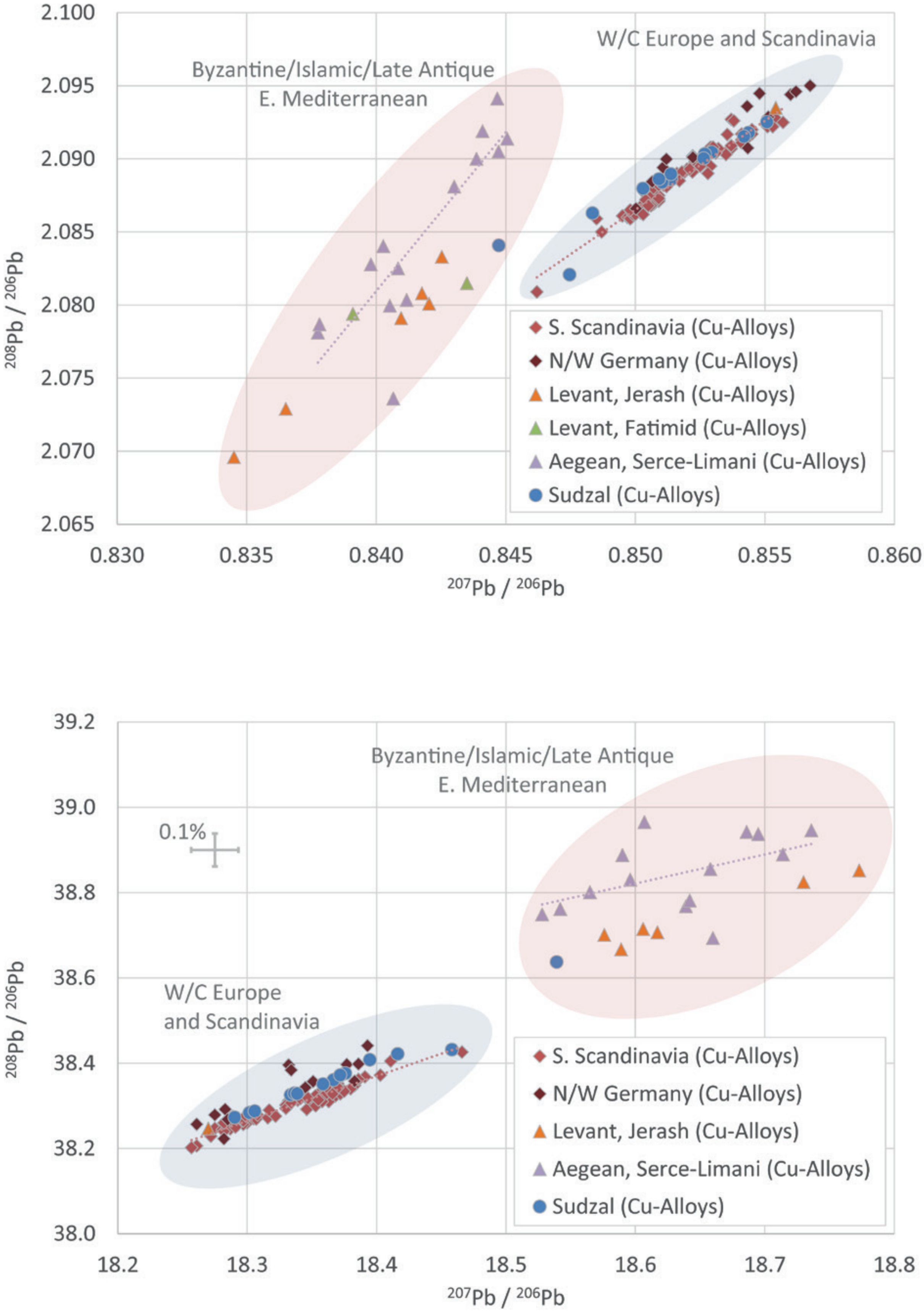

Figure 10. Lead isotope diagrams comparing copper alloys (Suzdal) with copper alloys from the Eastern Mediterranean (Serçe Limani, 11th century, after Barnes, et al. 1986; Stos-Gale, 2004b; Fatimid Levantine metalwork, 12th century, after Ponting, 2003; Late Antique/Early Medieval copper alloys, Jerash Jorden, after Orfanou, et al., 2020). These are compared to 66 copper alloy finds from Southern Scandinavia (Hedeby and Schleswig, 9th-11th and 11th-13th century, after Merkel, in press) and medieval metal finds from Westphalia and Lower Saxony (Höxter and Braunschweig, after Zientek, 1998).

as Aegean, Austrian Alpine and Swedish sources (Gale and Stos-Gale, 1982; Gale, 1999; Pernicka, Lutz and Stöllner, 2016; Forshell, 1992). The closest deposits are in the Urals and recently, numerous traces of copper mining and copper processing in Perm (Cis-Urals) from the Middle Ages have been investigated. These centers were the suppliers of raw materials for the upper class of Volga Bulgaria (Krylasova, 2018). However, despite the respective proximity to Suzdal Opolye of the Ural Region and strong hint of trade links with Volga Bulgaria the markers of which are metal belt fittings of Bulgaria origin found ubiquitously, the lead isotopic composition of the studied copper-alloy items are far from the isotopic parameters of the Ural deposits (compare, Chernyshev, et al., 2008). It is also far from the data obtained on the deposits in Altai.

The one outlier (№ 32) has lead isotope ratios that are likely have a southerly source, and, without orientation, it is impossible to place with any certainty. The high lead content of the bronze means that the isotope ratios reflect either alloying lead metal or from a mixed lead-copper ore source. Comparable lead isotope ratios can be found in several regions, one, for example, in Central Iran (compare Mirnejad, Simonetti and Molasalehi, 2011; Pernicka, et al, 2011) and it is known that Iranian lead-based products were exported and available in the Eastern Mediterranean in the 11th century (Stos-Gale, 2004b). Although there are similarities to ore in Bulgaria (Kouzmanov, 2001; Pernicka, et al., 1997; Stos-Gale, et al., 1998) and it also plots on the periphery of the Cyprus copper ore (Limni/Limasol, compare Gale, et al., 1997; Stos-Gale, et al., 1997), these deposits are low in lead and therefore could not be the source of the lead found in this objects (Stos-Gale, pers. comm. 17. Feb. 2021). Based on the similarity of lead isotope ratios, this object may have ties to Byzantine and/or Eastern Mediterranean copper alloy stocks (Figure 10: compare Barnes, et al., 1986; Orfanou, et al., 2020; Ponting, 2003, p.93; Stos-Gale, 2004b).

There is more information about the main group. The comparison of contemporary copper-based alloys from other regions is essential in the search for the source of the major copper alloy supplier (Figure 10). The key to the discussion are the copper-based alloys of Hedeby and Schleswig (Merkel, in press) and from the western regions of Germany (8th-13th century, Höxter-Corvey, North-Rhine Westphalia and 11th-15th century, Braunschweig, Lower Saxony) (Zientek, 1998). The isotopic range of the main copper-alloy group from the Suzdal region is the same as the dominant source (66 of 71 artifacts) supplying contemporary Hedeby (9th-11th century) and Schleswig (11th-12th century) on the western edge of the Baltic, suggesting that there is a strong link to the Northern European maritime trade network. Both datasets, in turn, match the distribution of lead isotope ratios found in copper-based artifacts (13 of 13) from Westphalia and Lower Saxony. As shown at Hedeby and Schleswig, the Rhine river, and possibly also the Weser and Elbe, were likely to have been the major artery bringing brass to the North and Baltic Sea regions.

In the search for the origin of the copper-based alloys from the Suzdal Opolye, it is important to note that all the objects contain significant amounts of lead in addition to tin, but there is nothing to indicate that the level of lead in the alloy was controlled and could be unintentional. This lead may therefore be associated with the tin-alloys, such as pewter, but could also come from the smelting of polymetallic ores containing both copper and lead, such as described by Theophilus the Presbyter in the 12th century in Germany (Hawthorne and Smith, 1979, pp.139-140, 144-145) or reflect a non-standardized practice of alloying of copper with lead.

In Figure 11, ore from Cornwall and Devon (Rohl, 1996), likely source regions for tin, are plotted with together with a selection of ore from typical Post-Variscan and remobilized deposits in the Rhenish Massif containing copper, lead or both together (compare Bode, 2008; Durali-Müller, 2005; Bielicki and Tischendorf, 1991; Krahn and Baumann, 1996; Schneider, 1994; Wagner and Schneider, 1999). It is possible that pewter alloys from Cornwall and/or Devon could be responsible for the lead isotope ratios of many copper-based alloys from Suzdal. It is also possible that they reflect copper and lead deposits in the Rhine area. The deposits in the North Eifel tend to be dominated by lead and zinc deposits that have been mined during the Roman period and High Middle Ages (Bartels and Klappauf, 2012, pp.169-174; Durali-Müller, et al., 2007), but they can naturally blend with copper ore which were economically viable in historical periods, for example Maubach (Holzapfel, 1911; Pohl, 1977, p.229). On the eastern side of the Rhine, the region of Sauerland contains several lead, copper and silver deposits that were mined in and after the 11th century that were of interest in ecclesiastic and secular politics of the time. The Ramsbeck copper-lead-silver mine is proven to have been mined in the 10th -13th century through ceramic evidence and ^{14}C dating (Strassburger, 2012). The Marsberg copper mine was owned by the Monastery of Corvey, the wealthiest and most influential monastery of Northern Germany in the 12th century, and was known to have been mined intensively during this period (Zientek, 1998, pp.12-16, 20-22). Though the Marsberg copper mineralization themselves are poor in lead, they can be cross cut by lead-bearing mineraliza-

Table 3. The non-ferrous objects from Suzdal Opolye and potential relationships to metal stocks and/or sources.

№	Object	Metal stock / source
	Tin-lead objects	
1	Pectoral cross	Unknown, poss. Mediterranean source
2	Pectoral cross	North European stock / poss. Olkusz district
3	Corolla	East Mediterranean stock
4	Pendant (kufic dirham style)	Unknown, poss. Northern Caucasus?
6	Pectoral cross	North European stock / poss. Olkusz district
7	Pectoral cross	North European stock / poss. Olkusz district
34	Pectoral cross	North European stock
	Silver objects	
5	Finger ring (defect)	W. Europe/Baltic stock, late 10th/early 11th?
8	Finger ring	VB mixed Islamic stock (Samanid 10th C.)?
9	Temporal ring	Mixed Baltic stock, late 10th/early 11th?
10	Necklace	VB or Mixed Baltic stock, 10th C.?
11	Temporal ring	VB or Mixed Baltic stock, 10th C.?
12	Temporal ring	Western/Central European stock? 11th C.?
13	Belt fitting	Mixed Islamic stock? 10th C.?
14	Temporal pendant	Mixed Baltic stock, late 10th/early 11th?
15	Finno-Ugrian-type temporal ring	Mixed Islamic stock? 10th C.?
16	Belt fitting	Mixed Islamic stock? 10th C.?
17	Byzantine miliaresion	Poss. Taurus 2A (Turkey)? 945-959.
18	Volga Bulgar dirham imitation	VB mixed Islamic stock? 920-940.
20	Arm ring	Mixed Islamic stock? 10th C.?
22	Pectoral cross	Western/Central European? 11th?
24	Pectoral cross	Mixed Baltic stock, late 10th/early 11th?
25	Handle	Mixed Baltic stock, late 10th/early 11th?
27	Pectoral cross	Western/Central European? 11th?
	Copper-alloy objects	
19	Scandinavian-type pendant	Western Europe
21	Finger ring	Western Europe
23	Reliquary cross	Western Europe
26	Pectoral cross	Western Europe
28	Finger ring	Western Europe
29	Pectoral cross	Western Europe
30	Pectoral cross	Western Europe
31	Pectoral cross	Western Europe
32	Pectoral cross	Unknown, southern source
33	Pectoral cross	Western Europe
35	Pectoral cross	Western Europe
36	Pectoral cross	Western Europe
38	Icon pendant	Western Europe

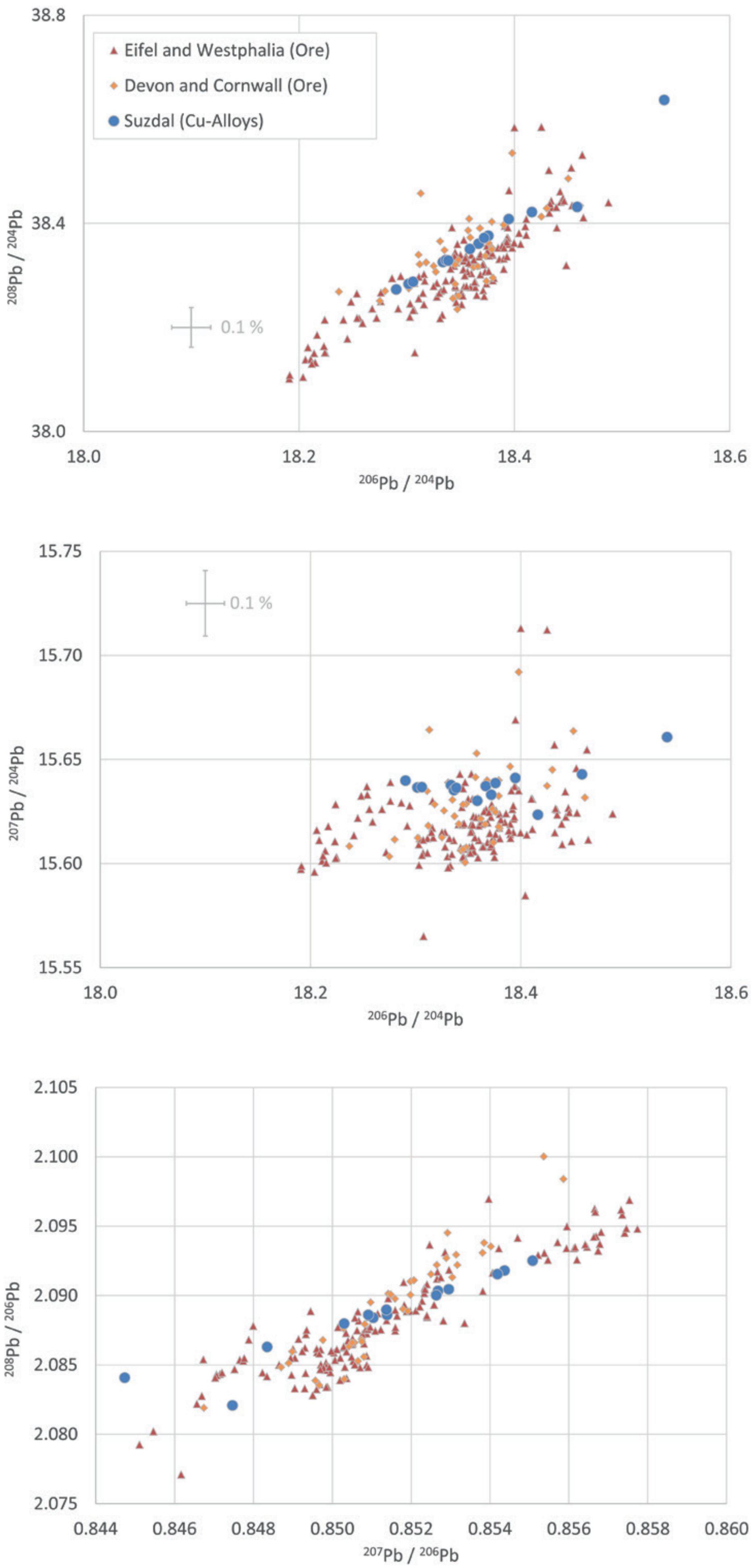

Figure 11. Lead isotope diagrams comparing copper alloys (Suzdal) with ore from Cornwall and Devon (Rohl, 1996) and from select deposits in the Rhenish Massif (references in text). The Rhenish Massif deposits include Brilon (Pb), Ramsbeck (Pb-Cu), Marsberg (Cu), Maubach (Pb-Cu), Rescheid (Pb-Cu), Bleialf (Pb-Cu), Mechernich (Pb) and Antweiler (Cu).

tion similar to those commonly found elsewhere in the region, such as at Brilon (Päckelmann, 1930). According to a document from 1103 AD, the lead mine of Brilon was supplying the Monestary of Corvey (Jülich, 2006, p.56). All of the above mentioned deposits correspond to the isotopic field of the Suzdal copper-based alloys.

This field does not correspond directly to ore deposits in the Harz Mountains (Lehmann, 2011), but could reflect a homogenization of lead isotope ratios typical for Variscan and post-Variscan deposits, and could therefore originate from a mixture of Harz ore. However, this option is less likely than sources in Southwest England and the Rhenish Massif which match the range without systematic mixing of ore of different geological ages.

The narrow range of lead isotope ratios and their dominance at Hedeby and Schleswig, consistent regardless of copper alloy type, from fresh produced high-zinc brasses to leaded mixed alloys and high-tin bell bronzes, could point to near monopoly conditions in the Northern European copper-based alloy market founded on a very limited number of geochemically similar deposits. The finding of these lead isotope ratios in the Suzdal region shows how deeply the supply networks penetrated eastward and may be one of several economic facets emerging during the Viking period leading to the formation of the Hanseatic League later on in the Middle Ages.

Of the data on copper-based alloys from Byzantium and other artifacts from late Antique to the medieval period from the Eastern Mediterranean region, only one (1 of 23) match the Suzdal Opolye main group (Figure 10). The range of lead isotope ratios of copper alloys from the Eastern Mediterranean is distinct from nearly all of the Suzdal artifacts, which comes at some surprise. It was assumed that the origins of stylistic features of the pectoral crosses would be mirrored by the sources of their raw material. There are indications of an artistic connection between the northeastern part of old Russia and Balkan production centers of Christian metal sculptures. It is noticeable that in the studied group of items there are three crosses with recognizable depictions of Crucifixion (№ 30, 33, 36). Recent research shows that Bulgarian products became the patterns for the pectoral crosses of the Rus' type (Makarov, 2018). All three crosses are made from copper-based alloys that probably arrived via a North European trade route, so material from which they are made is independent of the source for their artistic/stylistic conception.

As a final note, it is important to consider the alloys of which they are made. Most of the crosses are made of high-tin bronzes, some of exceptionally high tin "white bronzes". In Western Europe and Southern Scandinavia, high-tin bronze alloys overlapping with these compositions are only found as bell metal, so-called "bell bronze" (Drescher, 1984; Hawthorne and Smith, 1979, p.140), or additionally also cast vessels (Zientek, 1998). Rather than brass alloys, which were most common in in both Hedeby and Schleswig (Merkel, in press), it appears that the people local to Suzdal Opolye preferred high-tin bronzes, which may have been imported to the region as bell metal scrap or they manufactured it themselves through additional alloying with tin or pewter. It therefore appears that preference affects the distribution of alloy types, and while in Southern Scandinavia golden-colored alloys were intentionally chosen for display objects, the Rus' of Suzdal Opolye chose alloys with greater visual affinity to silver.

Conclusion

Through the lead isotope analysis of medieval artifacts from the Suzdal Opolye region, it is possible to connect metals with potential sources and metal stocks used in distant regions and it is a major step in revealing previously unexplored aspects of the Eurasian trade of non-ferrous metals. Despite the limited availability of reference data from contemporary metal stocks used in Europe, Volga Bulgaria, the Eastern Mediterranean and the Islamic World, some major isotopic trends could be established, which highlight the importance of the differentiation and specificity of non-ferrous metal type. Integrated in a historical context, each metal type tells its own story and, thus, the movement and acquisition of non-ferrous metal types appear to be largely independent from one another.

The trade of silver has proven to be extremely complex and is difficult to track because of the high degree of recycling and mixing and deficiencies in available reference data. Based on current available data, the vast majority of silver from Suzdal Opolye is close in lead isotopic composition either in Baltic mixed silver stocks from the second half of the 10th century into the early 11th century and/or 10th century Volga Bulgar dirham imitations. The evidence of stocks arriving from both East and West is an indication of active exchange of silver at Suzdal Opolye from both directions. Over the course of the 11th century, the flow of Saxon and Anglo-Saxon silver inundates the Baltic, entirely replacing 10th century stocks, but there is little sign of this newer silver travelling as far as the Suzdal region in sizable amounts. The collapse of the Eurasian Samanid dirham trade may have greatly reduced the flow of silver by the end of the 10th century. The isotopic characteristics could mean that silver-use in the Suzdal region was mostly based on 10th

century silver stocks, and that afterwards, the lack of new silver resources could mean that silver lost its supremacy in its role as a medium of exchange. A dearth in the access to silver in the 11th and 12th centuries should be explored through more focused and intensive research on the subject. The state of reference data from many potential source regions in the 11th and 12th centuries is insufficient to adequately explore this issue at the present.

The homogeneity and direct correlation of the Suzdal copper-based alloys with contemporary stocks in Southern Scandinavia, Westphalia and Saxony provide powerful evidence of Northern European maritime supremacy in the supply of copper-based alloys. Such a mono-directional trade is not evidenced by the other metals. Pewter alloys show a much greater diversity and show links to 11th century metal stocks in the Eastern Mediterranean, Northern Europe and, most surprising of all, it is possible that some may have been alloyed with lead from the Olkusz district in southern Poland. The deposit is known to have been mined in this period, but the distribution of its products is almost entirely unknown.

The lead isotope analysis of medieval non-ferrous metals from the Suzdal region in Russia, the first study in this period and area, has not only provided substantial information about the state of metal trade and supply, it has marked several promising aspects that can be clarified through future studies. As further studies are carried out, increasing the strength of the data basis, the picture created will shed light on many hitherto unexplored and unidentified facets of medieval economic and cultural history.

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Note

1 The diverse range of isotopic composition variation visible in the pewter and silver artifacts is a clear indication of multiple sources. The deposits of epithermal and stratiform (SEDEX) genetic types often used in the past as lead and silver sources are characterized by homogeneous lead isotopic composition in ores. As a rule, the scale of variation of $^{206}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ isotopic ratios for individual districts does not exceed 0.2-0.3 % and for the $^{207}Pb/^{204}Pb$ ratio – 0.1-0.15 % (Marcoux, et al., 2002; Durali-Müller, et al., 2007; Chernyshev, et al., 2007, pp.1163–1164; Baron, et al., 2011, pp.1097–1098). For the studied silver and lead-tin alloy items, the variation of lead isotopic ratios exceeds the typically values of parameter ν for ore regions. From this it can be concluded that the metal (both lead and silver) was delivered from several districts. It correlates with the fact that experimental points in the $^{206}Pb/^{204}Pb$ - $^{207}Pb/^{204}Pb$ diagram (Figure 4, a) form wide field located between growth curves with the parameter value $\mu_2 = 9.74$ and $\mu_2 = 10.1$. Such a wide range of μ_2 values are not typical for epithermal and stratiform deposits of one district.
On the contrary, the copper-based alloys have a highly homogeneous lead isotopic composition. For example, the values of variation coefficient ($\nu_{6/4} = 0.35$ %, $\nu_{7/4} = 0.05$ % and $\nu_{8/4} = 0.24$ %) are close to the typical values for individual volcanic massive sulfide deposits districts, the main sources of copper in ancient times. For example, the lead isotope data for volcanic massive sulfide deposits of Cyprus (Stos-Gale and Gale, 2009) one of the largest copper mining centers in the ancient world show the variation of lead isotopic ratios is 0.5-1 %. Another famous region with volcanic massive sulfide deposits is Ural. For the region lead isotopic data obtained by of high-precision method MC-ICP-MS (Chernyshev, et al., 2008) show that the variation of lead isotopic composition are 0.1-0.7 %. Thus, it can be assumed that that the lead found in the copper-based alloys come from the same source, if not from a single ore district.

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