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Typology, Chronology and Technology

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Arheološke in naravoslovne raziskave

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16 Raziskave z metodama protonsko vzbujene rentgenske spektrometrije (PIXE) in protonsko vzbujenih žarkov gama (PIGE)

Janka Istenič in Žiga Šmit*

16.1 Izbor in opis metod

Metodo protonsko vzbujene rentgenske spektrometrije (PIXE) smo izbrali za opredeljevanje kovin na rimski vojaški opremi, ker ne zahteva odvzemanja vzorcev, omogoča merjenje velikih predmetov in je primerna za analizo kovin, iz katerih so predmeti narejeni, ter kovinskih površinskih prevlek in emajlov. Pri vzorcih, ki vsebujejo lahke elemente, tj. pri emajlih, smo jo kombinirali z metodo protonsko vzbujenih žarkov gama (PIGE). Meritve smo izvajali na tandemskem pospeševalniku Instituta Jožef Stefan, na žarkovni liniji s protonskim žarkom v zraku.

Odvzem vzorcev bi omogočil uporabo tehnik, ki dajo natančnejše rezultate z višjo mejo občutljivosti, npr. ICP AES (atomska emisijska spektroskopija z induktivno sklopljeno plazmo) in AAS (atomska absorpcijska spektroskopija), vendar bi bil mogoč le pri razmeroma majhnem številu predmetov rimske vojaške opreme oziroma njihovih delov, saj so številni debeli le milimeter ali manj, zato odvzem dovolj velikega vzorca[646] ne bi bil mogoč oziroma bi pomenil nesprejemljivo velik poseg v predmet. Enako velja za primere, ko je kovinsko jedro zelo slabo ohranjeno. Poleg tega odvzem vzorcev ne bi bil primeren za analize prevlek (pozlata, posrebritev, kositrenje) in spajkanja, ki so na rimski vojaški opremi pogosti.

Druge minimalno destruktivne tehnike, kot je LA ICP MS (masna spektrometrija z vzbujanjem v induktivno sklopljeni plazmi z laserskim odparevanjem), niso prišle v poštev zaradi omejitve velikosti preiskovanega predmeta (100 mm × 100 mm × 15 mm).

Metoda PIXE temelji na obsevanju tarče s protonskim žarkom. Ob trku protona z atomom se v notranjih lupinah ustvarjajo vrzeli, ob njihovi zapolnitvi pa se lahko izsevajo rentgenski žarki z značilnimi energijami. Pri obdelavi rentgenskih spektrov najprej določimo energije in jakosti posameznih črt, nato pa iz njih vsebnost posameznih elementov.

Za obdelavo spektrov smo uporabljali program AXIL, vsebnosti pa smo računali s programom, ki smo ga razvili sami. Računska metoda temelji na neodvisnih fizikalnih parametrih in upošteva sekundarno vzbujanje rentgenskih žarkov v kovinskih tarčah. Koncentracije smo normirali s pogojem, da je vsota vseh izmerjenih vsebnosti enaka 100 %.

Meritve smo izvajali s protonskim žarkom v zraku; tega dobimo tako, da protone speljemo na prosto skozi okence iz tanke kovinske folije. Kot okence smo navadno uporabljali 8 μm debel aluminij, nekaj meritev smo izvedli tudi z 2 μm debelo tantalovo folijo, ki jo sicer uporabljamo pri meritvah z žarki gama (metoda PIGE) zaradi majhnega ozadja črt gama. Nominalna energija protonov pri večini meritev je bila 3 MeV, zaradi energijskih izgub v okencu in približno 1 cm široki zračni reži med okencem in tarčo se je na površini tarče zmanjšala na približno 2,77 MeV. Zaradi sipanja protonov na tej poti se je žarek razmazal po kotu (smeri), tako da je imel na tarči približno širino 0,8 mm na polovični višini. V praksi je to pomenilo širino žarka 2–3 mm na tarči. V nekaterih primerih smo žarek dodatno zožili z zaslonko iz aluminija, v kateri je bila luknjica s premerom 0,2 mm. Pri zelo

646 Za analizo, ki bi dala zelo natančne rezultate (npr. ICP AES ali ICP MS), bi potrebovali 30 mg ali v skrajnem primeru 15 mg vzorca (omejujoči faktor je teža vzorca, saj se teže pod 15 mg ne da zanesljivo določiti), kar pri bakrovi zlitini predstavlja kocko s stranico približno 1,6 mm oz. 1,2 mm. Zaradi nujnosti odstranitve površinske plasti bi tak vzorec lahko vzeli s predmetov, pri katerih je kovinsko jedro debelo najmanj 1,8 oz. 1,4 mm, pri tanjših ali slabše ohranjenih predmetih bi morali ustrezno povečati osnovno stranico. Pri predmetu debeline 0,5 mm bi bila tako, ob upoštevanju odstranitve površinske plasti, osnovna stranica odvzetega vzorca približno 3,5 mm (30 mg) oz. najmanj 2,5 mm (15 mg), kar pomeni, da bi morali izrezati 3,5 × 3,5 oz. 2,5 × 2,5 mm velik del predmeta v celi debelini.

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about 2.77 MeV at the target surface. Proton scattering along this path smeared the beam lateral distribution, so it had a width of about 0.8 mm at half-maximum at the target surface. In practice it meant that the beam at the target surface measured 2–3 mm. In a few cases we additionally narrowed the beam using a diaphragm with an opening of 0.2 mm. For a very short distance between the diaphragm and target (about 3 mm) we achieved the beam size at the target of about 0.3 mm. However, as a consequence, the resulting X-ray count rate was very low, therefore we used such a set-up for selected cases only and accepted low counting statistics.

The X-rays were detected by a Si(Li) detector with an energy resolution of 165 eV at 5.89 keV. On the way towards the detector, the X-rays passed an approximately 6 cm wide air-gap, which partly attenuated them. The copper alloys were measured with an additional absorber of 0.3 mm thick aluminum foil, which attenuated copper X-rays lines that appeared rather intensive in comparison with weak, but more penetrative K X-rays of silver, tin and antimony. The disadvantage of this type of measurement was interference of the copper escape peak at 6.30 keV with the Kα line of iron. We were not able to sufficiently distinguish between the two lines, so we generally overestimated the iron content for most of the measurements (typically we determined 0.5–1% Fe instead of a few tenths of percent). In order to get more reliable concentration of the elements lighter than copper, we for most part made another, shorter measurement using the air-gap as the only absorber, thus reducing the relative contribution of the copper escape peak. In this way we also obtained more accurate values for nickel and cobalt. For calculation of concentrations of the elements lighter than copper we then took into account the measurement in the air, while for heavier elements we relied on the measurement with the aluminum absorber. We also made some test measurements using a selective absorber of cobalt foil, which strongly attenuates copper X-rays, but we gave up since we did not dispose of accurate enough X-ray attenuation coefficients in cobalt. The measurements of the objects made of silver alloy with about 90% Ag were made with an aluminum absorber of 0.1 mm thickness. Because of less intense attenuation of iron X-rays in comparison with the thicker aluminum absorber, and due to relatively weak copper lines, an additional measurement without the aluminum absorber was not necessary.

The measurements were performed between the years 1999 and 2017, usually in parallel with the conservation of particular objects or immediately after it. During this period, in accordance with the experience we gained, we varied the experimental setting with the proton beam in air, and improved the documentation of the measured points on the objects. For instance, we abandoned measurement on iron[647] (as on the edges of sword scabbards) because we could recognize it by eye or with magnetic testing, yet the method of PIXE is not able to analyze the composition of iron alloys (steel).

Most of the measurements were made on the surface of the objects or their parts after the end of conservation procedure. Such surfaces were almost without patina.[648] At the points selected for the measurement we removed the patina up to the metal core in area of about 2–3 mm^2. Inspection of the so prepared points under the stereo microscope revealed that a complete removal of the patina is hard to achieve, so one has to be aware that the analytical results from such points refer to the metal core with (minimal) remains of the patina.

16.2 Results of the measurement

The results of the measurements are given in mass % in the tables and for each object separately. The number of given digits is in accordance with accuracy of the measurement. Most of the measurements are given with a precision of three digits, but with two digits only for the case of elements that were measured with an uncertainty larger than 10%. In a few cases, when the concentrations were determined from the very weak X-ray lines sitting on the low-energy tails of intense X-ray lines, the values are given by one digit only. The list of chemical elements in particular tables can be different and involves all elements that were detected in a particular series of measurements. If an element at a particular measurement of the series was not detected, its concentration was below the detection limit, and in the table we denoted it with the sign -.

The measurements in the points, from which the patina was removed, thus exposing the bare metal core, are marked with a star (*) in the tables. The measurements with a narrow proton beam are marked with ¤, both attached to the number that denotes the measured point.

647 When using the expression iron we understand that this is not a chemically clean iron, but it may also contain the admixtures of light elements, such as carbon (compare Chapter 1).

648 The expression patina is used as a synonym for corrosion (surface oxides) at the object surface.

kratki razdalji med zaslonko in tarčo (okoli 3 mm) smo dosegli, da je imel žarek na tarči velikost okrog 0,3 mm. Seveda je bila hitrost štetja rentgenskih žarkov tedaj zelo majhna, zato smo tako nastavitev uporabili le v izbranih primerih in se zadovoljili s slabšo števno statistiko.

Rentgenske žarke smo zaznavali z detektorjem Si(Li) z energijsko ločljivostjo okoli 165 eV pri 5,89 keV. Žarki so do detektorja potovali po približno 6 cm široki zračni reži, kjer so se zaradi absorpcije v zraku oslabili. Bakrove zlitine smo merili z dodatnim absorberjem iz 0,3 mm debele aluminijeve folije, saj smo s tem udušili bakrove črte, ki so močne v primerjavi z zelo šibkimi, a bolj prodornimi črtami K srebra, kositra in antimona. Slabost takšnega merjenja je bila interakcija ubežne bakrove črte pri energiji 6,30 keV s črto Kα železa. Obeh črt nam ni uspelo zadovoljivo ločiti, zato smo pri večini meritev določili prevelike vsebnosti železa (tipično 0,5–1 % Fe, namesto nekaj desetink odstotka). Da bi dobili točnejše vrednosti elementov, ki so lažji od bakra, smo v večini primerov naredili dodatno, krajšo meritev, z zračno režo kot edinim absorberjem, s čimer smo zmanjšali relativni prispevek bakrovega ubežnega vrha. S tem smo dobili tudi natančnejše vsebnosti niklja in kobalta. Pri izračunu vsebnosti elementov, lažjih od bakra, smo upoštevali meritve v zraku, za težje elemente vključno z bakrom pa smo se zanesli na meritev z aluminijevim absorberjem. Nekaj poskusnih meritev smo naredili s selektivnim absorberjem iz kobaltove folije, ki močno uduši ravno bakrove črte, vendar smo tak način merjenja opustili, ker nismo imeli dovolj natančnih podatkov za atenuacijske koeficiente rentgenskih žarkov v kobaltu. Meritve predmetov iz srebrove zlitine z okoli 90 % Ag smo opravili z aluminijevim absorberjem debeline 0,1 mm. Zaradi manjše atenuacije železovih črt, v primerjavi z debelejšim aluminijevim absorberjem, in zaradi razmeroma šibkih bakrovih črt dodatna meritev brez absorberja ni bila potrebna.

Meritve smo izvajali med letoma 1999 in 2017, običajno vzporedno s konservacijo posameznih predmetov oziroma takoj po njej. V tem obdobju smo, v skladu z izkušnjami, ki smo jih pridobivali, spreminjali nastavitve poskusa s protonskim žarkom v zraku in izpopolnjevali dokumentiranje lege merjenih mest na predmetih. Tako smo na primer meritve na železu[647] (npr. robni okovi nožnic mečev) opustili, ker smo ga v večini primerov prepoznali na pogled in z magnetnim preizkusom, poleg tega pa metoda PIXE ni primerna za ugotavljanje sestave železovih zlitin (jekla).

647 Ob rabi izraza železo privzemamo, da ne gre za kemijsko čisto železo, ampak vsebuje primesi lahkih elementov, na primer ogljik (prim. 1. pogl.).

Večino meritev smo naredili na površini predmetov oz. njihovih delov po konservaciji. Take površine so lahko skorajda brez patine[648] ali pa je ta bolj ali manj izrazita. Na izbranih mestih meritev smo (kolikor dobro je bilo ob zmerni invazivnosti mogoče) s površine premera 2–3 mm^2 odstranili površinsko plast do kovinskega jedra. Opazovanje tako pripravljenih mest pod stereomikroskopom je pokazalo, da je popolno odstranitev patine težko doseči, zato se je treba zavedati, da se rezultati meritev takih mest nanašajo na kovinsko jedro z (minimalnimi) ostanki patine.

16.2 Rezultati meritev

Rezultate meritev podajamo v masnih %, v preglednicah in za vsak predmet posebej. Število podanih mest se ujema z natančnostjo meritve. Večina meritev je podana na tri mesta natančno, v primeru elementov, ki so merjeni z napako, večjo od 10 %, pa na dve mesti. V redkih primerih, ko smo vsebnost posameznih elementov razbrali iz šibkih rentgenskih črt na nizkoenergijskih repih močnih rentgenskih črt, so vrednosti podane le z enim mestom. Nabor elementov v posameznih preglednicah je lahko različen in obsega vse elemente, ki smo jih zaznali v izbranem sklopu meritev. Če kakega elementa iz nabora pri posamezni meritvi nismo zaznali, pomeni, da je bila njegova vsebnost pod mejo občutljivosti; v preglednici smo v takih premerih uporabili znak -.

Meritve mest, s katerih je bila s površine odstranjena patina, tako da je izpostavljeno kovinsko jedro, so v preglednicah označene z zvezdico (*), meritve z ožjim protonskim žarkom pa z ¤; oboje ob številki, ki označuje mesto meritve.

Mesta meritev smo številčili z zaporednimi števili, vendar zaradi različnih vzrokov (kovina se je na primer izkazala za železo) nismo vedno izvedli vseh meritev. V takih primerih so številke predvidenih, a neopravljenih meritev v preglednicah rezultatov izpuščene.

Lego in izgled merjenih mest smo fotografsko dokumentirali. V knjigi so merjena mesta praviloma označena na risbah (izjemoma na fotografijah) predmetov in običajno vidna na fotografijah predmetov, kot so bili pripravljeni za analize PIXE. Fotografij predmetov z označenimi mesti meritev PIXE nismo objavili, kadar ne dajejo več podatkov kot risba predmeta z označenimi mesti meritev in

648 Izraz patina uporabljamo kot sinonim za korozijo (površinske okside) na površini predmeta.

The measured points were numbered in sequential order, yet due to different reasons (the metal, for instance, being recognized as iron) we did not execute all measurements. In such cases, the numbers of planned, but not realized measurements are omitted.

The position and appearance of the measured points were photographically documented. In the book, the measured points are as a rule marked on the drawings of the objects (exceptionally on the photographs) and they are usually visible in the photographs of the objects that were prepared for the PIXE analyses. The photographs of the objects with the marked points of measurements were not published if they do not provide more information than the drawing of the object with the marked measured points and a photography of the object in the Catalogue. In the first years of research, the photographic documentation of the measured points was not yet systematic; in such cases, the measured points are given in the publication just in the object drawings.

All tables with the measured results are followed by a commentary that contains an explanation of the results and eventually additional clarification.

To check the accuracy of the method we used the brass standard NIST 1107 that contains 0.037% Fe, 0.098% Ni, 61.2_1% Cu, 37.3_4% Zn, 0.18% Pb and 1.04% Sn (according to the updated data, 1.066% Sn). With an accuracy of a few percent we were able to reproduce the concentration of both major elements Cu and Zn and the concentration of Pb.

We found out that our measurements showed a too high content of Fe (due to the contribution of copper escape peak). For the measurement with the aluminum absorber of 0.3 mm we measured the apparent iron content of about 1%, while for the combined measurement with an Al absorber and without it, the measured value (0.05–0.07%) was only slightly higher than the standard value.

Too high values were also measured for Ni, as its Kα line sits on the tail of the intense copper Kα line; the measured values between 0.1 and 0.18% were close to the detection limit.

For Sn we obtained values between 1.0 and 1.1%. Simulation of the experimental set-up showed that the measured Sn values are rather sensitive to geometrical parameters – proton impact angle and X-ray take-off angle. Since we were not able to control them with an accuracy greater than 10°, the accuracy of small concentrations of Ag, Sn and Sb may be uncertain up to ±10% of the measured values.

The iron concentrations that were only measured by the aluminum absorber, are given in the tables by two digits only (one decimal place).

For the elements that are important for the analysis of copper alloys, we were limited by the detection limits. Iron, cobalt and nickel at concentrations above 0.1% could only be detected if we made an additional measurement without aluminum absorber. The zinc Kα line coincides with the low-energy tail of the copper Kβ line, so the presence of zinc could only be identified from the presence of zinc Kβ line. This determines the detection limit of zinc for our measurements, which was approximately 0.4%.

The detection limits for lead (Pb), bismuth (Bi), arsenic (As) and selenium (Se) were about 0.05%, while the arsenic K lines could only be resolved from the lead L lines through the arsenic Kβ line. The detection limits for silver (Ag), tin (Sn) and antimony (Sb) were 0.1–0.2%; the main reason for this was low counting statistics as a consequence of small ionization cross sections. The detection limits worsened by an order of magnitude when we cut the beam with the 0.2 mm diaphragm.

Results obtained from the repeated measurements on the same object spots often varied more than we expected according to the described limitations and findings (see *Table A7: 2, 7*). We explain this by the spots that were prepared for the measurement not always being uniform (for example, non-uniformly distributed remains of patina on the prepared spot, or for the measurement on patina, its non-uniform composition in a small area) and by the variation of geometrical parameters at our measurements. The most variable was the iron content, which was rather high for the measurement on patinated surfaces of the copper-alloy objects. From the iron intensities we even guessed how well we hit the pre-prepared measured spot with the proton beam, or how thoroughly the patina was removed from the spot.[649] In a few examples, when we measured a tiny color-alloy structure on an iron substrate, the main contribution of the iron signal was attributed to the substrate and was not taken into account for the calculation of concentrations.

The range of 1 MeV protons in copper is 7 micrometers (7 μm; 0,007 mm), and for 3 MeV protons it is 35 μm. As the ionization cross section is a rapidly decreasing function of the decreasing proton energy, and the induced X-rays are attenuated in the target,

649 Patina could be defined as the accumulation of corrosion products and other materials from the environment (Scott 2002, 9). We conjecture that the main source of iron in the patina was the iron of the mud or from the surrounding object (cf. Ingo et al. 2006, 586).

fotografije predmeta v Katalogu. V prvih letih raziskav fotografsko dokumentiranje merjenih mest še ni bilo sistematično; v takih primerih so mesta meritev v objavi podana le na risbah predmetov.

Vsaki preglednici z rezultati meritev sledi komentar, ki vsebuje razlago rezultatov in morebitna dodatna pojasnila.

Za preverjanje točnosti metode smo uporabljali medeninast standard NIST 1107, ki vsebuje 0,037 % Fe, 0,098 % Ni, $61{,}2_1$ % Cu, $37{,}3_4$ % Zn, 0,18 % Pb in 1,04 % Sn (po novejših podatkih 1,066 % Sn). Pri tem smo z natančnostjo nekaj % reproducirali vsebnosti obeh prevladujočih elementov Cu in Zn ter koncentracijo Pb.

Ugotovili smo, da naše meritve pokažejo previsok delež Fe (zaradi prispevka bakrovega ubežnega vrha). Pri meritvah z aluminijevim absorberjem 0,3 mm smo izmerili navidezno vsebnost Fe okrog 1 %, s kombiniranima meritvama z Al absorberjem in brez njega pa je bila izmerjena vsebnost železa (0,05–0,07 %) le malo višja od standardne vrednosti.

Prevelike vsebnosti smo izmerili tudi pri Ni, saj njegova črta K*α* sedi na repu močne bakrove črte K*α*; izmerjene vsebnosti med 0,1 in 0,18 % so bile na meji zaznave.

Za vsebnosti Sn smo dobili vrednosti med 1,0 in 1,1 %. S simulacijo eksperimentalne nastavitve smo se prepričali, da na izmerjene vsebnosti Sn močno vplivajo geometrijski parametri – vpadni kot protonov in izstopni kot rentgenskih žarkov. Ker ju nismo mogli nadzorovati bolj kot na 10° natančno, so vrednosti majhnih vsebnosti Ag, Sn in Sb lahko negotove do ±10 % izmerjene vrednosti.

Vsebnosti železa pri meritvah, ki smo jih opravili le z aluminijevim absorberjem, so v tabelah podane le z dvema mestoma (eno decimalko).

Pri elementih, ki so pomembni za analizo bakrovih zlitin, smo bili omejeni z mejami zaznave. Železo, kobalt in nikelj smo pri vsebnostih nad 0,1 % lahko ugotavljali le, če smo naredili dodatno meritev brez aluminijevega absorberja. Cinkova črta K*α* sovpada z nizkoenergijskim delom bakrove črte Kβ, zato smo na prisotnost cinka sklepali po prisotnosti cinkove črte Kβ. Ta določa mejo, pri kateri so naše meritve zaznale cink, pri približno 0,4 %.

Pri svincu (Pb), bizmutu (Bi), arzenu (As) in selenu (Se) je bila meja zaznave okoli 0,05 %, pri čemer smo arzenovi črti K lahko ločili od svinčevih črt L le po arzenovi črti Kβ. Meja zaznave za srebro (Ag), kositer (Sn) in antimon (Sb) je bila 0,1–0,2 %, k čemur je prispevala slaba števna statistika zaradi majhnih ionizacijskih presekov. Meja zaznave je bila za velikostni red slabša, kadar smo žarek obrezali z zaslonko 0,2 mm.

Pri ponavljanju meritev na istih mestih predmetov so se rezultati včasih (npr. *pregl. A7: 2, 7*) razlikovali bolj, kot bi pričakovali glede na opisane omejitve oziroma ugotovitve. To si razlagamo tako, da za meritev pripravljena oziroma izbrana mesta niso povsem enotna (npr. neenakomerno razporejeni ostanki patine na za meritev pripravljenem mestu ali pri meritvah na patini njena neenakost na razmeroma majhnih površinah), vzrok za odstopanje bi lahko bilo tudi spreminjanje geometrijskih parametrov pri meritvah. Najbolj so se spreminjale vsebnosti železa, ki so bile izrazito visoke pri meritvah na patinirani površini predmetov iz bakrovih zlitin, tako da smo po izmerjenih vrednostih železa sklepali, kako dobro smo zadeli za meritev pripravljeno mesto brez patine oziroma kako temeljito je bila patina z njega odstranjena.[649] V nekaterih primerih, npr. ko smo merili drobno strukturo iz barvne zlitine v železni podlagi, smo večino železovega signala pripisali podlagi in ga nismo upoštevali pri izračunu vsebnosti.

Doseg protonov z energijo 1 MeV v bakru je 7 mikrometrov (7 μm; 0,007 mm), pri energiji 3 MeV pa 35 μm. Ionizacijski presek zelo hitro pada z energijo protonov, rentgenski žarki pa se v snovi absorbirajo, zato je efektivna debelina za produkcijo rentgenskih žarkov še manjša: pri pravokotnem vpadu protonov z energijo 1 MeV v baker znaša 1,4 μm, pri 3 MeV protonih pa je 7,1 μm. V čistem kositru, ki seva prodornejše žarke, so efektivne debeline nekoliko večje, in sicer 2 μm pri 1 MeV in 12,5 μm pri 3 MeV. Efektivni doseg protonskih žarkov v srebru je med vrednostma za baker in kositer.

Metodo PIXE lahko uporabimo tako, da v isti točki opravimo več zaporednih meritev z različnimi energijami, pri čemer vzbujamo rentgenske žarke pri več efektivnih globinah. To nam omogoči, da iz rezultatov zaporedja meritev izračunamo profile vsebnosti za posamezne merjene kemijske elemente (diferencialna metoda PIXE).[650] Tako smo ugotavljali debelino pokositrenja na bronasti pločevini nožnice A9 in srebrne prevleke na okovu spone H2 (glej spodaj).

649 Patino sestavljajo korozijski produkti in materiali iz okolice (Scott 2002, 9). Domnevava, da so bili glavni vir železa v patini železni predmeti v bližini ali železo v mulju (prim. Ingo et al. 2006, 586).
650 Šmit, Istenič, Knific 2008.

the effective thickness for X-ray production is even smaller: at perpendicular impact of 1 MeV protons it is 1.4 μm, and for 3 MeV protons it is 7.1 μm. In pure tin, which emits more penetrative X-rays, it is slightly greater, 2 μm at 1 MeV and 12.5 μm at 3 MeV. The effective range of protons in silver is between the values for copper and tin.

The method of PIXE can also be applied in such a way that we make a series of measurements on the same spot with different impact energies, thus inducing X-rays at different effective depths. This allows us to de-convolute the series of measurements into the concentration profiles of the particular chemical elements (differential PIXE method).[650] In this way we determined the thickness of tinning on the bronze sheet of scabbard A9 and of the silver plating on the buckle plate H2 (see below).

A. Swords and scabbards

A1 (*Table A1; Fig. 61*)

Measurements were taken immediately after conservation. There was no visible patina on the measured scabbard fittings.

All fittings are of brass, containing from ca. 15% to 21% zinc (*Table A1: 4–7, 9, 10, 13–16, 18–24*). This variation in zinc content which is largely attributable to the traces of patina not visible with the naked eye. Because of de-zincification, the proportion of zinc in the corrosion layer on objects of brass or gunmetal is expected to be smaller than in the metal core,[651] hence even the smallest remains of corrosion products influence the measured zinc content.

Table A1
Preglednica A1

Spot/ Mesto	Fe	Cu	Zn	Sn	Pb
1	1.78	7.3	0.43	69.2	21.2
2	1.21	88.0	-	9.8	1.0
3	1.16	86.8	-	10.8	1.2
4	0.57	77.3	20.4	1.3	0.3
5	0.29	82.5	15.5	1.0	0.7
6	0.37	78.9	19.3	1.3	0.1
7	1.09	79.5	16.9	1.9	0.5
8	3.2	14.0	1.5	55.0	26.3
9	0.35	83.4	15.2	0.9	0.1
10	0.29	82.2	16.5	0.9	0.1
11	0.68	72.7	-	25.3	1.31
12	8.6	4.1	0.4	75.0	11.9
13	0.31	79.1	19.9	0.3	0.4
14	0.52	80.8	17.2	0.6	0.8
15	0.63	81.0	16.8	1.4	0.2
16	0.75	79.7	18.1	1.2	0.2
17	0.82	93.7	-	5.3	0.1
18	0.38	79.7	18.6	0.4	0.9
19	0.46	84.3	14.9	0.3	0.04
20	1.14	82.9	14.9	0.9	0.1
21	0.49	80.2	18.5	0.7	0.1
22	0.61	77.6	20.7	0.8	0.2
23	0.47	78.4	20.0	0.9	0.2
24	1.8	79.1	18.2	0.7	0.2

The scabbard's brass guttering is composed of five pieces, with bronze lining at the joints (*Table A1: 2–3, 11, 17*). The interior (concave) surface of the lining is not contaminated with soldering (*Table A1: 17*), hence the measurement there is relevant for estimating the actual composition of the lining.

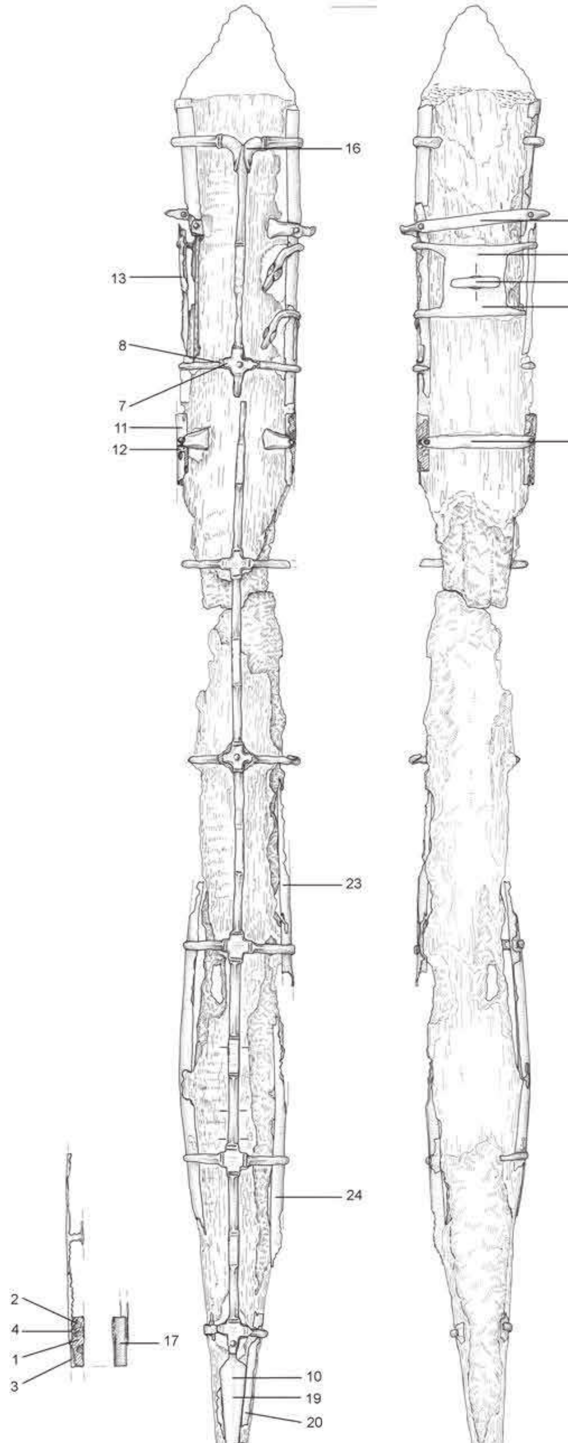
Pieces of the guttering and the net-like fitment were soldered together using a tin-lead alloy (*Table A1: 1, 8, 11, 12*). The measured tin and lead contents vary greatly. This is in part due to the solder only surviving in small patches that were very difficult to hit with the proton beam and the presence of copper indicates that in some instances the surrounding area was measured as well. We can also not exclude the possibility that the solder was less than 0.01 mm thick and the proton beam penetrated to the underlying metal.

The exceptionally high iron content measured on Spot 12 shows that the patina was not well removed here.

The rivets were not measured; their appearance corresponds with that of the brass fittings.

650 Šmit, Istenič, Knific 2008.
651 Pollard, Heron 1996, 211; Scott 2002, 27–31.

Figure 61
Scabbard A1: the measured spots.
Slika 61
Nožnica A1, lega merjenih mest.



A. Meči in nožnice

A1 (*pregl. A1; sl. 61*)

Meritve smo naredili na sveže konserviranem predmetu. Na površini merjenih okovov nožnice s prostim očesom ni bilo videti patine.

Vsi okovi so iz medenine, ki vsebuje od najmanj okoli 15 do 21 % cinka (*pregl. A1: 4–7, 9, 10, 13–16, 18–24*). Glavni vzrok za precejšnje razlike v izmerjenih vrednostih so verjetno ostanki patine na merjenih mestih. Vsebnost cinka v korodirani površini predmetov iz medenine (in drugih bakrovih zlitin s cinkom) je namreč bistveno nižja kot v kovinskem jedru,[651] zato že majhni ostanki korozije na analiziranem mestu vplivajo na izmerjeni delež cinka.

Medeninast robni okov je sestavljen iz petih delov. Na stikih je podloga iz brona (*pregl. A1: 2–3, 11, 17*). Delež kositra, izmerjen na notranji (vbočeni) površini podloge (5,3 %; *pregl. A1: 17*), je primeren za oceno dejanskega deleža kositra in svinca v podlogi, ker ta površina ni kontaminirana s spajkanjem.

Za spajkanje delov robnega okova in mrežastega okova so uporabili zlitino kositra in svinca (*pregl. A1: 1, 8, 11, 12*). Na različnih mestih izmerjeni deleži kositra in svinca se močno razlikujejo. To je med drugim verjetno posledica dejstva, da je lot ohranjen na majhnih površinah, ki jih je bilo s protonskim žarkom težko zadeti (zato je zadel tudi okolico, kar jasno kažejo izmerjeni deleži bakra); ni izključeno, da je lot tenak manj kot 0,01 mm in je zato protonski žarek lahko dosegel podlago.

Visok odstotek na mestu 12 izmerjenega železa kaže, da je bila tam patina odstranjena slabše kot drugje.

Zakovic nismo merili; po izgledu povsem ustrezajo robnemu in drugim okovom iz medenine.

651 Pollard, Heron 1996, 211; Scott 2002, 27–31.

A2 (*Table A2, Figs. 62, 63*)

Measurements were taken immediately after conservation. There was no visible patina on the measured spots.

The suspension band (*Table A2: 2, 4*) and the two rivets (*Table A2: 1, 5*) fastening it to the guttering are of brass containing ca. 16–18% zinc.

The guttering is of iron (*Table A2: 3*). The measured copper, zinc and arsenic were presumably transferred onto the guttering during conservation.

Spot/ Mesto	Fe	Cu	Zn	As	Pb	Ag	Sn
1	2.4	80.6	16.0	0.02	0.07	0.1	0.8
2	1.8	79.3	18.1	0.02	0.17	-	0.6
3	98.2	1.3	0.2	0.04	-	-	-
4	1.8	80.8	16.4	0.03	0.15	-	0.7
5	2.5	78.6	16.7	0.02	0.05	0.1	1.0

Table A2
Preglednica A2

A3 (*Table A3, Figs. 64, 65a, b*)

The metals were measured on spots where the patina had largely been removed.

The suspension band (*Table A3: 1*), rivets (*Table A3: 3*) and ring on the suspension band (*Table A3: 4*) are of brass with at least ca. 19% zinc. The guttering is of iron (*Table A3: 2*).

The iron content measured on Spots 1, 3 and 4 is uncertain, as single measurements were taken with a 0.3 mm thick aluminium absorber. The values in the table show that either the patina was not entirely removed or the proton beam hit the area around the spot prepared for measurement.

Spot/ Mesto	Fe	Ni	Cu	Zn	As	Pb	Sn
1*	1.3	0.23	78.1	19.5	-	0.27	0.62
2	97.6	-	0.91	1.44	0.05	0.05	-
3*	1.5	0.22	78.7	18.6	-	0.14	0.76
4*	1.5	0.19	78.2	19.2	-	0.38	0.53

Table A3
Preglednica A3

A5 (*Table A5, Figs. 66, 67a–i*)

Measurements were taken immediately after conservation. There was no visible patina on the measured spots.

The sword's handguard plate is of copper (*Table A5: 1, 2*). The shiny surface on the underside is a very thinly (1.5 µm at Spot 4, 1.1 µm at Spot 5) applied layer of tin through which the beam penetrated to the underlying copper (*Table A5: 4, 5*). The traces of a tin-lead alloy on the upper side (*Table A5: 3*) suggest remains of soldering.

The sheet metal covering the front of the scabbard is of brass with at least ca. 24.6% zinc (*Table A5: 9, 10*). Its well-preserved shiny silvery surface revealed ca. 11 and 19% tin, indicating that the sheet brass was tinned, while the beam also penetrated to the underlying brass (*Table A5: 7, 8*).

The mouth band (*Table A5: 14*), all three crossbands (*Table A5: 15–17*), the ring on one of the suspension bands (*Table A5: 20*), the openwork chape (*Table A5: 12*) and the terminal knob (*Table A5: 13*) are of brass.

Spot/ Mesto	Fe	Cu	Zn	As	Pb	Sn
1	0.6	98.6	0.4	0.13	0.11	0.1
2	0.6	98.4	0.4	0.15	0.13	0.1
3	-	28.8	1.5	-	5.7	64.0
4	1.3	83.8	0.3	0.13	0.19	14.2
5	0.6	88.2	0.3	0.14	0.17	10.5
6¤	1.1	67.8	16.2	0.08	0.58	14.1
7	1.1	66.2	21.5	0.01	0.05	11.1
8	0.6	60.8	18.8	-	0.21	19.5
9	0.8	73.6	24.7	-	0.03	0.8
10	0.6	73.3	24.6	0.01	0.03	1.3
11	93.5	4.4	1.4	-	0.1	0.6
12	0.8	77.2	21.2	0.19	0.07	0.5
13	1.0	71.8	26.4	0.21	0.08	0.4
14	0.5	78.4	20.4	0.06	0.10	0.5
15	0.5	75.2	23.3	0.17	0.12	0.6
16	0.3	75.4	23.3	0.19	0.08	0.7
17	0.9	75.0	23.3	0.19	0.08	0.5
18¤	1.2	96.8	1.4	0.36	0.04	0.2
19	1.0	97.1	1.1	0.39	0.02	0.3
20	0.6	75.2	23.3	0.17	0.06	0.6

Table A5
Preglednica A5

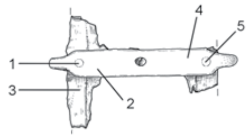


Figure 62
Sword scabbard fragment A2: the measured spots.

Slika 62
Nožnica A2, lega merjenih mest.

Figure 63
Spots measured on the A2 sword scabbard fragment: measured Spots 1 and 5 on the rivet, Spots 2 and 4 on the suspension band and cross band and Spot 3 on the guttering.

Slika 63
Nožnica A2, mesta 1 in 5 (zakovica), 2, 4 (prečni okov) in 3 (robni okov).

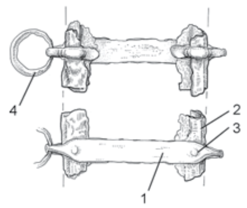


Figure 64
The A2 sword scabbard fragment: the measured spots.

Slika 64
Nožnica A3, lega merjenih mest.

Figure 65a
Spots measured on the A3 sword scabbard fragment: measured Spot 1 on the suspension band, Spot 2 on the guttering and Spot 3 on the rivet.

Slika 65a
Nožnica A3, mesta 1 (prečni okov), 2 (robni okov) in 3 (zakovica).

Figure 65b
Sword scabbard fragment A3: measured Spot 4 on the suspension ring.

Slika 65b
Nožnica A3, mesto 4 (obroček na prečnem okovu).

A2 (*pregl. A2, sl. 62, 63*)

Meritve smo naredili na sveže konserviranem predmetu. Na merjenih mestih ni bilo očitnih sledov patine. Rezultati kažejo, da so prečni okov (*pregl. A2: 2, 4*) in zakovici (*pregl. A2: 1, 5*), ki sta ga pripenjali na robni okov, iz medenine z najmanj okoli 16 do 18 % cinka. Robni okov je iz železa (*pregl. A2: 3*). Izmerjeni deleži bakra, cinka in arzena so bili na robni okov najverjetneje zaneseni med konservacijo.

A3 (*pregl. A3, sl. 64, 65a, b*)

Barvne kovine smo merili na mestih, s katerih smo v glavnem odstranili patino.

Rezultati kažejo, da so prečni okov (*pregl. A3: 1*), zakovici (*pregl. A3: 3*) in obroček na prečnem okovu (*pregl. A3: 4*) iz medenine, ki vsebuje najmanj okoli 19 % cinka. Robni okov je železen (*pregl. A3: 2*).

Na mestih 1, 3 in 4 izmerjene vsebnosti železa so negotove, ker smo naredili le po eno meritev z 0,3 mm debelim Al absorberjem. Vrednosti v tabeli tudi dopuščajo, da patina ni bila povsem odstranjena z merjenih površin ali/in pa je protonski žarek pri meritvah zadel tudi okolico za meritve pripravljenega mesta.

A5 (*pregl. A5, sl. 66, 67a–i*)

Meritve smo izvajali na sveže restavriranem predmetu. Na merjenih mestih ni bilo očitnih sledov patine.

Ščitnik branika meča je iz bakra (*pregl. A5: 1, 2*). Svetleča se površina na spodnji strani je izredno tenko (1,5 μm v točki 4 in 1,1 μm v točki 5) nanesena plast kositra, skozi katero je žarek segel do bakrene podlage (*pregl. A5: 4, 5*), ostanki zlitine kositra in svinca na zgornji strani (*pregl. A5: 3*) pa nakazujejo ostanke spajkanja.

Pločevina, ki prekriva sprednjo stran nožnice, je iz medenine z najmanj okoli 24,6 % cinka (*pregl. A5: 9, 10*). Meritve na dobro ohranjeni srebrno svetleči se površini so pokazale okoli 11 oziroma 19 % kositra, ki govori za to, da je bila medeninasta pločevina na zunanji strani prekrita z zelo tenko plastjo kositra, skozi katero je žarek dosegel podlago (*pregl. A5: 7, 8*).

Okov ob ustju (*pregl. A5: 14*), vsi trije prečni okovi (*pregl. A5: 15–17*), obroček na prečnem okovu (*pregl. A5: 20*) ter okov s predrtim okrasom na konici (*pregl. A5: 12*) in zaključni gumb (*pregl. A5: 13*)

The measured zinc content varies between 20.4 and 26.4%. The low iron content (0.3–1.0%) indicates that not much patina remained on the measured spots.

Measurements of the mouth band (*Table A5: 6*) show that the overlapping ends were most likely soldered together with tin; the measured copper, zinc and arsenic indicate that the beam also hit a large part of the brass surrounding the soldering and, where solder was thin, even the underlying brass.

The rivets on the suspension bands are most likely of copper. The measured iron indicates traces of patina, while the zinc content shows the beam also hit the brass suspension band (*Table A5: 18, 19*).

Figure 67a
The upper side of the A5 handguard plate: measured Spots 1 and 2 (without patina) on the metal from which the object was made and Spot 3 on the patch with silvery appearance.

Slika 67a
Ščitnik branika ročaja meča A5, zgornja stran, mesta 1–2 (osnovna zlitina, brez patine) in 3 (srebrno sijoče mesto na površini).

Figure 67b
The underside of the A5 handguard plate: measured Spots 4 and 5 on the coating with silvery appearance.

Slika 67b
Ščitnik branika ročaja meča A5, spodnja stran, mesti 4 in 5 (srebrno sijoča prevleka na površini).

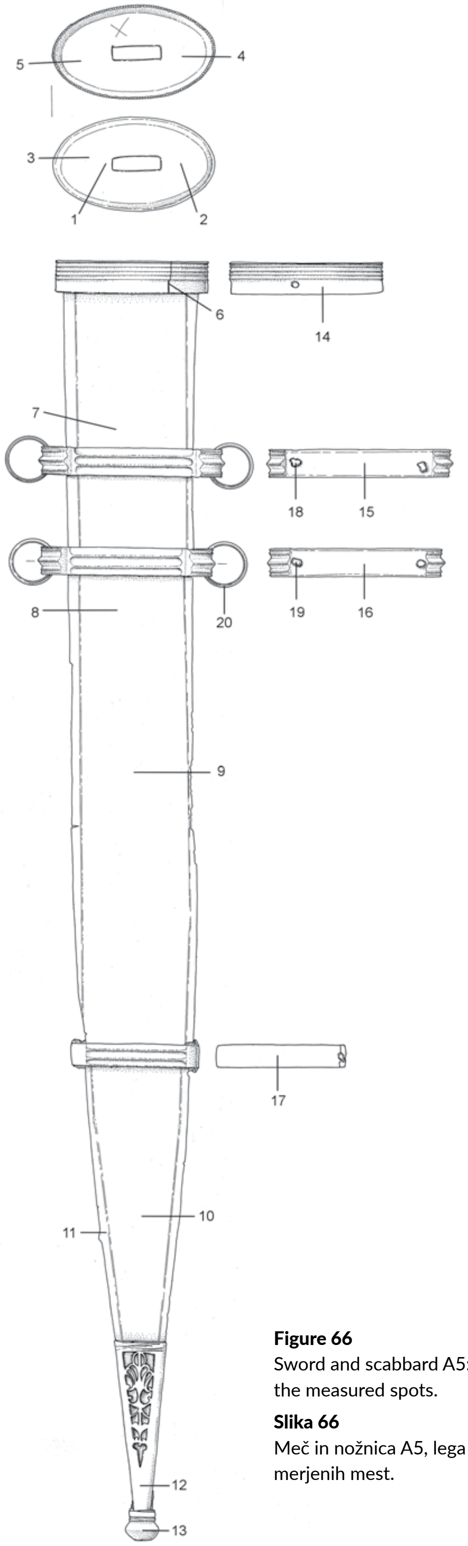


Figure 66
Sword and scabbard A5: the measured spots.

Slika 66
Meč in nožnica A5, lega merjenih mest.

Figure 67c
The front of the A5 scabbard: measured Spot 6 on the solder on the mouth band and Spot 7 on the silvery coating on the front sheet metal.

Slika 67c
Nožnica A5, sprednja stran, mesti 6 (spajkanje okova ob ustju) in 7 (srebrno sijoča prevleka na pločevini).

Figure 67d
The front of the A5 scabbard: measured Spot 8 on the silvery coating of the sheet metal and Spot 9 on the sheet metal.

Slika 67d
Nožnica A5, sprednja stran, mesti 8 (srebrno sijoča prevleka na pločevini) in 9 (rumena pločevina).

Figure 67e
The front of the A5 scabbard: measured Spot 10 on the sheet metal and Spot 11 on the traces of corroded iron guttering.

Slika 67e
Nožnica A5, sprednja stran, mesti 10 (rumena pločevina) in 11 (sledovi korodiranega robnega okova).

Figure 67f
The front of the A5 scabbard: measured Spot 12 on the chape and Spot 13 on the terminal knob.

Slika 67f
Nožnica A5, sprednja stran, mesti 12 (rumena površina okova na konici) in 13 (rumena površina gumba na konici).

so iz medenine. Izmerjeni deleži cinka nihajo med 20,4 in 26,4 %. Izmerjeni odstotki železa (0,3–1,0 %) nakazujejo, da na merjenih mestih ni bilo veliko ostankov patine.

Rezultat meritve spajkanja na okovu ob ustju (*pregl. A5: 6*) govori za to, da sta bila presegajoča se zaključka tega okova najverjetneje spajkana s kositrom; izmerjeni baker, cink in arzen kažejo, da je žarek zadel tudi razmeroma velik del medenine okoli spajkanja in na tankih delih spajkanja morda tudi podlago pod lotom. Zakovice na prvem in drugem prečnem okovu so najverjetneje iz bakra, izmerjeni odstotki železa kažejo na ostanke patine, odstotki cinka pa, da je žarek zadel tudi medeninasti okov (*pregl. A5: 18, 19*).

Figure 67g
The back of the A5 scabbard: measured Spot 14 on the mouth band, Spot 15 on the upper suspension band and Spot 18 on the rivet.

Slika 67g
Nožnica A5, hrbtna stran, mesta 14 (rumena površina okova ob ustju), 15 (rumena površina prvega prečnega okova) in 18 (zakovica).

Figure 67h
The back of the A5 scabbard: measured Spot 16 on the second suspension band and Spot 19 on the rivet.

Slika 67h
Nožnica A5, hrbtna stran, mesti 16 (rumena površina drugega prečnega okova) in 19 (zakovica).

Figure 67i
The back of the A5 scabbard: measured Spot 17 on the cross band.

Slika 67i
Nožnica A5, hrbtna stran, mesto 17 (rumena površina tretjega prečnega okova).

A6 (*Table A6, Figs. 68, 69a–d*)

Three spots were measured on the upper side of the sword's handguard plate: 15 (measured twice, the second time after removing the surface layer down to the shiny metal core), 14 (surface of a silvery appearance) and 13 (patina). The results show that the handguard plate is of bronze (*Table A6: 15*) and bears patches of a tin layer on the upper surface (*Table A6: 14*).

The sheet metal and fittings of the scabbard are very poorly preserved. We presumed that the metal core did not survive due to the advanced corrosion, hence measurements were taken on the surface of the front sheet metal, fittings and rivets after conservation. As expected, the results show a (very) high iron content (*Table A6: 1, 2, 5, 6–11, 19–20*; cf. Chapter 16.2).

The sheet metal on the scabbard front is of brass (*Table A6: 1, 4, 8*). The measured tin content and the analogy with other Mainz type scabbards (e.g. A5) point to tinning on the front (*Table A6: 1, 4, 8*).

The mouth band (*Table A6: 5, 12*) and the suspension band (*Table A6: 9*) are also of brass. The rivet on the suspension band is of copper (*Table A6: 11*). The mouth plate is soldered to the mouth band with tin-lead alloy (*Table A6: 17*). The guttering is of iron (*Table A6: 3*).

Table A6
Preglednica A6

Spot/ Mesto	Fe	Cu	Zn	As	Pb	Ag	Sn
1	9.1	80.4	9.1	0.08	0.16	-	1.1
2	65.1	33.4	1.3	0.05	0.11	-	-
3	92.9	3.9	2.0	0.10	-	-	1.1
4	3.9	78.9	16.3	0.06	0.04	-	0.8
5	6.7	77.3	15.4	0.04	0.12	0.1	0.4
6	88.9	9.5	1.2	0.14	0.23	-	-
7	94.5	3.9	0.7	0.06	0.07	-	0.7
8	5.6	73.7	19.7	0.05	0.06	-	0.9
9	6.6	77.5	15.6	0.07	0.15	-	-
10	8.3	76.7	14.6	0.02	0.07	0.1	0.2
11	8.6	90.2	1.1	-	0.05	-	-
12	1.0	79.4	18.9	0.07	0.11	-	0.5
13	0.3	92.5	0.6	0.08	0.26	-	6.2
14	2.6	72.2	0.5	0.14	0.24	-	24.2
15	1.2	91.5	0.8	-	0.37	-	6.1
15*	0.7	92.5	0.7	0.09	0.14	-	5.9
17	4.5	10.2	2.1	-	34.8		48.3
19*	94.0	4.60	1.12	-	0.9	0.04	0.10
20*	81.7	16.9	0.77	-	0.34	0.03	0.18

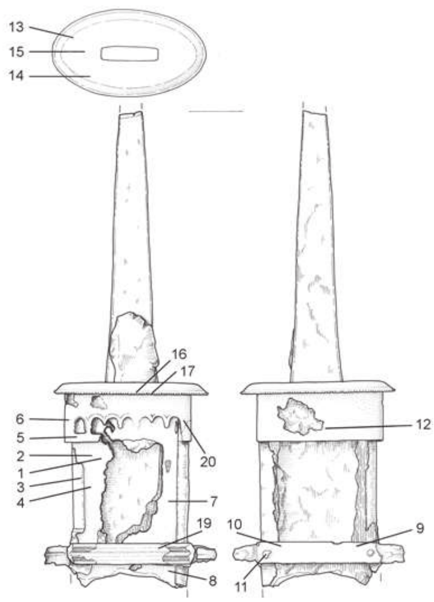


Figure 68
Sword and scabbard A6: the measured spots.
Slika 68
Meč in nožnica A6, lega merjenih mest.

A7 (*Table A7, Figs. 70, 71a–f*)

The sword's handguard plate is of bronze (*Table A7: 9/22*). The measurements on the poorly surviving, slightly silvery surface of the underside revealed tinning (*Table A7: 7/20, 8/21*). The measurements on the upper side, with the standard and the narrow beam, show that the two small silvery patches are tin-lead alloy (*Table A7: 10/23*). The differences in the lead content or the lead-tin ratio between the measurements are probably largely attributable to an inhomogeneous alloy (results of wide beam measurements are therefore closer to the real values), while the differences in the copper content probably show that the beam did not hit the prepared spot only.

The very thin sheet metal covering the front of the scabbard is brass with at least 20.3% zinc (*Table A7: 16, 19*); the measurement in the area of a poorly preserved thin grey layer on the front shows tinning (*Table A7: 15*).

A6 (*pregl. A6, sl. 68, 69a–d*)

Na zgornji strani ščitnika meča smo merili tri mesta: 15 (dvakrat – drugič po tem, ko smo površinsko plast odstranili do sijočega kovinskega jedra), 14 (površina srebrnega videza) in 13 (patina). Rezultati meritev kažejo, da je ščitnik iz brona (*pregl. A6: 15*) in da so na zgornji strani ostanki plasti kositra (*pregl. A6: 14*).

Pločevina in okovi nožnice so zelo slabo ohranjeni. Ocenili smo, da kovinsko jedro zaradi napredovale korozije verjetno ni ohranjeno, zato smo meritve izvedli na površini pločevine, okovov in zakovice po konservaciji. V skladu s pričakovanji so meritve pokazale (zelo) visoke odstotke železa (*pregl. A6: 1, 2, 5, 6–11, 19–20*; prim. zgoraj, pogl. 16.2).

Iz rezultatov meritev sklepamo, da je bila pločevina na sprednji strani nožnice iz medenine (*pregl. A6: 1, 4, 8*). Izmerjene vsebnosti kositra in primerjava z drugimi nožnicami tipa Mainz (npr. A5) nakazujejo, da je bila na sprednji strani pokositrena (*pregl. A6: 1, 4, 8*).

Iz medenine sta tudi okov ob ustju nožnice (*pregl. A6: 5, 12*) in prečni okov (*pregl. A6: 9*). Zakovica na prečnem okovu je bakrena (*pregl. A6: 11*). Ovalni okov na vrhu nožnice in okov ob ustju nožnice sta spajkana z zlitino kositra in svinca (*pregl. A6: 17*). Robni okov je železen (*pregl. A6: 3*).

Figure 69a
The front of the A6 sword and scabbard: measured Spots 1, 2, 4, 7 and 8 on the metal sheet, Spot 3 on the guttering, Spots 5, 6 and 20 on the mouth band, Spot 17 on the solder attaching the mouth plate to the mouth band and Spot 19 on the upper suspension band. Spot 16 was not measured.

Slika 69a
Meč in nožnica A6, sprednja stran, mesta 1, 2, 4, 7, in 8 (pločevina), 3 (robni okov), 5, 6 in 20 (okov ob ustju), 17 (spajkanje okova ob ustju in ovalnega okova) ter 19 (prvi prečni okov). Mesto 16 ni bilo merjeno.

Figure 69b
The back of the A6 sword and scabbard: measured Spots 9 and 10 on the suspension band, Spot 11 on the rivet of the suspension band and Spot 12 on the mouth band.

Slika 69b
Meč A6, hrbtna stran, točke 9 in 10 (prečni okov), 11 (zakovica na prečnem okovu) in 12 (okov ob ustju).

Figure 69c
The upper side of the A6 handguard plate: measured Spots 13 and 15 (patina) on the metal from which the object was made and Spot 14 on the badly preserved silvery patch on the surface.

Slika 69c
Ščitnik branika ročaja meča A6, zgornja stran, mesta 13, 15 (patina še ni odstranjena) in 14 (slabo ohranjeno srebrnkasto mesto na površini).

Figure 69d
The upper side of the A6 handguard plate: measured Spot 15 after the patina was removed.

Slika 69d
Ščitnik branika ročaja meča A6, zgornja stran, mesto 15 (patina odstranjena).

A7 (*pregl. A7, sl. 70, 71a–f*)

Ščitnik branika ročaja meča je iz brona (*pregl. A7: 9/22*). Rezultati meritev na slabo ohranjeni, rahlo srebrni plasti na spodnji strani kažejo, da je bil na spodnji strani pokositren (*pregl. A7: 7/20, 8/21*). Drobna ostanka srebrne barve na zgornji površini branika sta, glede na meritvi (z običajnim in zoženim žarkom), zlitina kositra in svinca (*pregl. A7: 10/23*). Razlike v deležu svinca oziroma v razmerju med svincem in kositrom pri obeh meritvah so verjetno posledica nehomogenosti razporeditve svinca v zlitini (glede tega so bližje dejanski vrednosti rezultati meritve s širšim žarkom), razlike v deležu bakra pa verjetno izvirajo iz dejstva, da je bilo z običajnim žarkom nemogoče zadeti le površino spajkanja brez okolice.

Zelo tenka pločevina, ki je prekrivala sprednjo stran nožnice, je iz medenine z najmanj 20,3 % cinka (*pregl. A7: 16, 19*); meritev na mestu, kjer je slabo ohranjena tenka plast sive barve (na sprednji strani pločevine), govori za to, da je bila pločevina na sprednji strani pokositrena (*pregl. A7: 15*).

The mouth band and surviving crossbands are of brass (*Table A7: 4, 8, 9, 12, 14, 18*). The ends of the bands overlap at the back and are soldered with tin (*Table A7: 11, 17*) or tin-lead alloy (*Table A7: 2*). Tin is also used for soldering the mouth band to the mouth plate (*Table A7: 1, 7*).

The rivets are of copper (*Table A7: 3, 13*).

Spots 5 and 6 were not measured quantitatively, as they were found to be of iron after a short (ten-second) measurement.

Spot / Mesto	Fe	Ni	Cu	Zn	Pb	Ag	Sn
1	2.6	-	18.1	3.7	0.3	-	75.4
2	-	-	3.6	0.6	5.9	-	89.9
2	0.6	-	2.3	0.5	4.9	-	91.8
3	0.51	-	97.6	1.9	-	-	-
4	1.1	-	76.7	21.5	0.2	0.08	0.4
7	22.2	-	7.4	1.6	0.17	-	68.7
7	13.0	-	8.3	1.8	0.19	-	76.6
8	2.2	-	74.4	22.8	0.25	-	0.4
9	2.0	-	77.4	19.4	0.36	0.1	0.3
11¤	3.1	-	0.8	0.5	0.17	-	95.4
12*	1.8	-	-	21.1	0.16	-	0.3
13	1.2	-	98.5	-	0.11	0.1	0.1
14	1.7	-	75.4	22.3	0.19	0.1	0.4
15	1.4	-	68.7	19.6	-	-	10.1
16	1.1	-	77.4	20.8	0.20	-	0.4
17	1.9	-	8.8	2.1	0.18	-	86.7
17¤	0.66	-	10.9	2.5	0.16	-	85.7
18	1.0	0.11	77.3	20.8	0.38	0.04	0.4
19	2.6	0.09	76.5	20.3	0.17	0.03	0.2
7/20	4.1	-	74.4	0.4	0.9	-	20.1
8/21	4.5	0.14	74.6	0.4	1.2	-	19.3
9/22*	0.54	0.13	94.2	-	0.5	-	4.6
10/23	7.04	-	33.7	-	6.5	-	52.7
10/23¤	0.87	-	17.1	-	12.9	-	69.1

Table A7
Spots 2 and 7 were measured twice. The measured spots on the handguard plate were initially marked as Nos. 7–10 (cf. *Fig. 71a, b*).

Preglednica A7
Na mestih 2 in 7 smo merili dvakrat. Merjena mesta na ščitniku branika ročaja meča so bila prvotno označena s št. 7–10 (prim. *sl. 71a, b*).

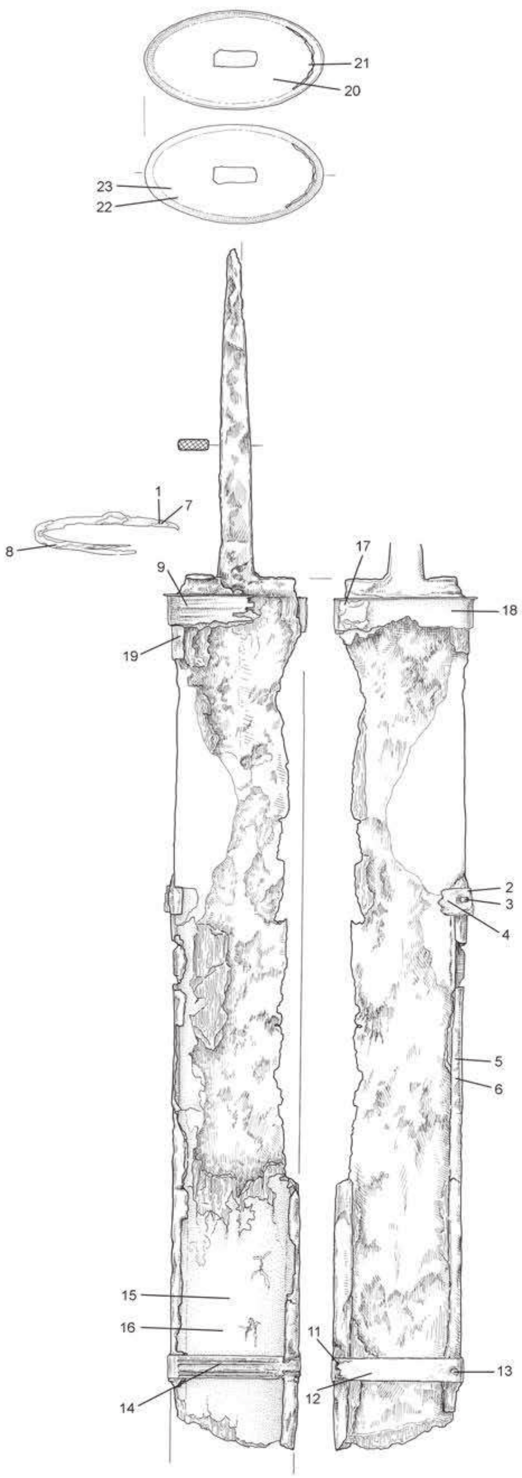


Figure 70
The A7 sword and scabbard: the measured spots.

Slika 70
Meč in nožnica A7, lega merjenih mest.

Okov ob ustju nožnice in oba ohranjena prečna okova so iz medenine (*pregl. A7: 4, 8, 9, 12, 14, 18*). Presegajoči se konci teh okovov se na hrbtni strani nožnice prekrivajo in so spajkani s kositrom (*pregl. A7: 11, 17*) ali zlitino kositra in svinca (*pregl. A7: 2*). Kositer so uporabili tudi za spojitev okova ob ustju nožnice z medeninastim ovalnim okovom (*pregl. A7: 1, 7*).

Zakovici sta bakreni (*pregl. A7: 3, 13*).

Mest 5 in 6 nismo merili kvantitativno, ker smo po kratki meritvi (10 sekund) ugotovili, da sta železni.

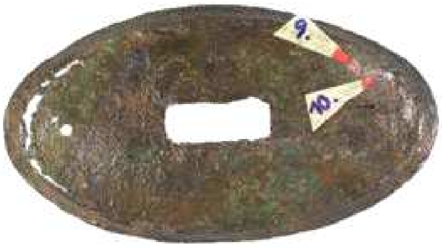


Figure 71a
The upper side of the A7 handguard plate: measured Spot 9 on the base metal and Spot 10 on the silvery patch; in *Table A7* they are referred to as Spots 9/22 and 10/23 respectively.

Slika 71a
Ščitnik branika ročaja meča A7, zgornja stran, mesti 9 (ščitnik) in 10 (ostanki mesta srebrnega videza), ki sta v *pregl. A7* označeni kot 9/22 in 10/23.

Figure 71b
The underside of the A7 handguard plate: measured Spots 7 and 8, the last one on the relatively well surviving silvery coating; in *Table A7* they are referred to as Spots 7/20 and 8/21.

Slika 71b
Ščitnik branika ročaja meča A7, spodnja stran, mesti 7 in 8 (zadnje z dobro vidno prevleko srebrnega videza), ki sta v *pregl. A7* označeni kot 7/20 in 8/21.

Figure 71c
The A7 swords scabbard: measured Spot 7 on the solder that fixed the mouth band to the mouth plate (left of the marked spot) and Spot 8 on the remains of the mouth plate.

Slika 71c
Nožnica A7, mesti 7 (spajka na okovu ob ustju, levo od označenega mesta) in 8 (sledovi ovalnega okova).

Figure 71d
The back of the A7 sword scabbard: measured Spots 2 and 3 (solder and rivet on the upper cross band) and Spot 4 on the upper cross band; measurements on Spots 5 and 6 were abandoned.

Slika 71d
Nožnica A7, hrbtna stran, prvi prečni okov, mesta 2 (spajkanje), 3 (zakovica) in 4 (okov); mesti 5 in 6 na robnem okovu nista izmerjeni.

Figure 71e
The lower suspension band of the A7 sword scabbard: measured Spot 11 on the solder, Spot 12 on the suspension band and Spot 13 on the rivet.

Slika 71e
Nožnica A7, hrbtna stran, drugi prečni okov, mesta 11 (spajka), 12 (prečni okov) in 13 (zakovica).

Figure 71f
The front of the A7 sword scabbard: measured Spot 9 on the mouth band and Spot 19 on the sheet metal.

Slika 71f
Nožnica A7, sprednja stran, mesti 9 (okov ob ustju) in 19 (pločevina).

A8 (*Table A8, Figs. 72, 73a–c*)

Measurements were taken after conservation.

The sword's handguard plate is of bronze (*Table A8: 1*). The shiny silvery remains on its upper side are tin-lead alloy (*Table A8: 3*). The horizontal metal plate on the grip was measured on the spot where surface accretions were removed to expose the metal core; measurements show the plate to be of iron (*Table A8: 8*) or steel.

The scabbard's mouth plate is of brass (*Table A8: 4*). The shiny silvery layer along its upper edge is tin-lead alloy (*Table A8: 6*) used to solder the band to the mouth plate.

Spot/ Mesto	Fe	Ni	Cu	Zn	As	Pb	Ag	Sn
1	1.6	0.21	86.4	0.46	0.03	1.75	-	9.56
3	2.2	-	1.35	0.26	-	11.4	-	84.8
4	2.1	0.17	76.9	19.9	-	0.55	0.06	0.24
6	15	-	6.19	1.83	-	20.4	-	56.5
8*	99.9	-	-	0.01	-	0.07	-	-

Table A8
No. 7 was accidentally left out when assigning numbers to measured spots.

Preglednica A8
Pri številčenju mest meritev je bila št. 7 pomotoma izpuščena.

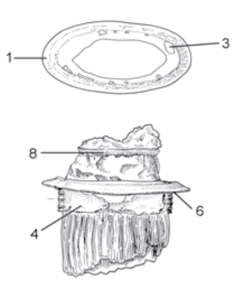


Figure 72
Sword and scabbard A8: the measured spots.

Slika 72
Meč in nožnica A8, lega merjenih mest.

A9 (*Table A9, Figs. 74, 75a–d*)

The scabbard guttering is of iron (*Table A9: 5*).

The front of the scabbard is covered with a sheet of bronze containing ca. 6–7% tin (*Table A9: 1, 6*) and tinned (*Table A9: 3, 4*). The differential PIXE analyses show that the layer of tin is very thin (ca. 1.2 µm = 0.0012 mm).[652]

The suspension band is of brass with at least 22% zinc (*Table A9: 1/7, 3/9*). The metal core of the band's suspension ring could not be measured due to its poor condition; the results on the corroded metal indicate it was of brass (*Table A9: 2/8*).

Spot/ Mesto	Fe	Cu	Zn	As	Pb	Ag	Sn	Br
1	4.9	87.8	0.5	0.06	0.15	-	6.6	-
3	0.9	79.3	0.3	0.07	0.10	-	19.3	-
4	2.1	72.7	0.2	0.04	0.07	-	24.9	-
5	98.9	0.9	0.1	0.02	0.02	-	-	-
6	1.2	92.3	-	-	0.18	-	6.4	-
1*/7*	2.3	73.7	22.0	-	0.21	-	0.3	1.5
2/8	3.3	88.8	6.1	0.11	0.52	-	1.2	-
3*/9*	0.8	72.5	26.1	0.04	0.08	0.08	0.34	-

Table A9
The measured spots on the suspension band were initially marked with Nos. 1–3 (cf. *Fig. 75a, b*).

Preglednica A9
Merjena mesta na prečnem okovu so bila prvotno označena s št. 1–3 (prim. *sl. 75a, b*).

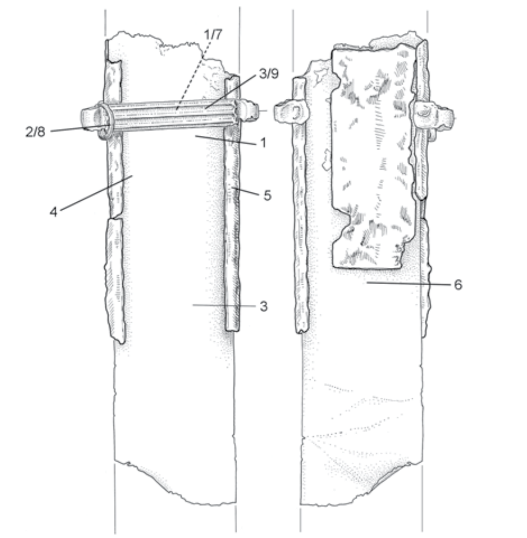


Figure 74
Sword and scabbard A9: the measured spots.

Slika 74
Nožnica A9, lega merjenih mest.

Figure 75a
The back of the A9 suspension band: measured Spot 1, referred to as Spot 1/7 in *Table A9*.

Slika 75a
Nožnica A9, hrbtna stran prečnega okova, mesto 1, ki je v *pregl. A9* označeno kot 1/7.

Figure 75b
The front of the A9 suspension band: measured Spot 3 on the suspension band and Spot 2 on the suspension ring, referred to as Spots 3/9 and 2/8 in *Table A9*.

Slika 75b
Nožnica A9, mesti 3 (sprednja stran prečnega okova) in 2 (obroček), ki sta v *pregl. A9* označeni kot 3/9 in 2/8.

652 Šmit, Istenič, Knific 2008, 2330, Fig. 1.

Figure 73a
The upper side of the A8 handguard plate: measured Spot 1 on the base metal and Spot 3 on the patch with silvery appearance.

Slika 73a
Zgornja stran ščitnika branika ročaja meča A8, mesti 1 (rumena sijoča površina) in 3 (srebrno svetleče se mesto na površini).

Figure 73b
The back of the A8 sword and scabbard: measured Spot 4 on the mouth band and Spot 8 on the metal plate or mount on the grip.

Slika 73b
Meč in nožnica A8, hrbtna stran, mesti 4 (okov ob ustju) in 8 (kovinski vložek v ročaju).

Figure 73c
Sword and scabbard A8: measured Spot 6 on the soldering attaching the mouth plate to the mouth band.

Slika 73c
Meč in nožnica A8, mesto 6 (spajka med ovalnim okovom in okovom ob ustju).

Figure 75c
The front of the A9 scabbard sheet metal and guttering: the Spot 2 on the base metal, Spots 3 and 4 on the coating of the sheet metal and Spot 5 on the guttering. Spot 2 was not measured.

Slika 75c
Nožnica A9, sprednja stran, pločevina – mesta 2 (brez prevleke), 3 in 4 (prevleka) in robni okov – mesto 5. Mesto 2 ni bilo merjeno.

Figure 75d
The back of the A9 scabbard sheet metal: measured Spot 6.

Slika 75d
Nožnica A9, hrbtna stran pločevine nožnice, mesto 6.

A8 (*pregl. A8, sl. 72, 73a–c*)

Meritve smo izvajali na konserviranem predmetu.

Rezultati kažejo, da je ščitnik branika ročaja meča iz brona (*pregl. A8: 1*). Srebrno svetleči se ostanki na njegovi zgornji površini so zlitina kositra s svincem (*pregl. A8: 3*). Na vodoravnem kovinskem obroču, ki je viden na ročaju, smo merili na mestu, kjer je bila površina odstranjena do kovinskega jedra; meritve so pokazale, da je iz železa (*pregl. A8: 8*) oziroma jekla.

Okov ob ustju nožnice je iz medenine (*pregl. A8: 4*). Srebrno sijoča plast na njegovem zgornjem robu je zlitina kositra s svincem (*pregl. A8: 6*), s katero je bil nanj prispajkan ovalni okov na vrhu nožnice.

A9 (*pregl. A9, sl. 74, 75a–d*)

Robni okov nožnice je iz železa (*pregl. A9: 5*).

Sprednja stran nožnice je prekrita s pločevino iz brona z okoli 6–7 % kositra (*pregl. A9: 1, 6*). Na sprednji strani je pokositrena (*pregl. A9: 3, 4*). Diferencialne analize PIXE so pokazale, da je plast kositra zelo tenka (okoli 1,2 μm = 0,0012 mm).[652]

Prečni okov je iz medenine z najmanj 22 % cinka (*pregl. A9: 1/7, 3/9*). Na nanj pritrjenem obročku zaradi slabe ohranjenosti ni bilo mogoče meriti kovinskega jedra; rezultati na korodirani kovini nakazujejo, da je bil iz medenine (*pregl. A9: 2/8*).

652 Šmit, Istenič, Knific 2008, 2330, sl. 1.

A10 (*Table A10, Figs. 76, 77a, b*)

Measurements were taken during conservation. There was no visible patina on Spots 4, 6, 8 and 10.

The sheet metal covering the scabbard front is brass with at least ca. 21% zinc (*Table A10: 4, 8*).

The tin content on the patina-covered sheet metal front (*Table A10: 1–3, 5*) differs little from that of the patina-covered back of the sheet metal (*Table A10: 9*), i.e. it does not indicate tinning on the front. In contrast, the EDS XRF measurements taken prior to conservation indicate precisely that, on one spot showing 4% tin.[653]

The decorative strip covering the neck of the terminal knob is of brass (*Table A10: 6*).

Spot/ Mesto	Fe	Cu	Zn	As	Sr	Ag	Sn	Pb
1	8.03	80.2	10.2	0.077	0.049	0.06	0.55	0.80
2	0.33	80.0	18.7	-	-	0.04	0.50	0.37
3	1.49	83.8	13.7	0.030	-	0.07	0.61	0.38
4	0.33	76.7	21.9	-	-	0.05	0.49	0.47
5	0.47	78.1	20.7	-	-	0.05	0.35	0.25
6	0.89	79.7	18.1	-	0.087	0.07	0.98	0.19
8	0.33	77.9	21.0	-	-	0.05	0.34	0.43
9	8.62	73.7	16.7	-	-	0.06	0.54	0.31
10	0.42	78.5	20.2	-	-	0.05	0.43	0.39

Table A10
Spot 7 was not measured.

Preglednica A10
A10. Na mestu 7 meritev nismo izvedli.

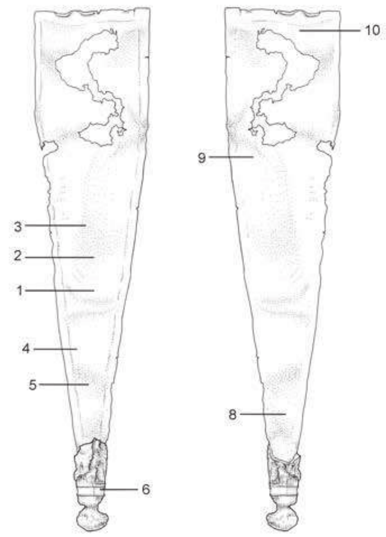


Figure 76
The A10 scabbard fragment: the measured spots.

Slika 76
Ostanki nožnice A10, lega merjenih mest.

A11 (*Table A11, Figs. 78, 79a, b*)

Measurements were taken immediately after conservation. With the exception of Spot 5, they were taken on the patina-covered surface, hence the high iron content comes as no surprise.

The openwork scabbard chape is of brass with ca. 22% zinc (*Table A11: 5*). The measurements of the patina-covered front show it was not plated (*Table A11: 1–3*). The tin and lead detected in the patina on two spots at the back of the chape (*Table A11: 4, 9*) suggest it was soldered to the underlying part with tin-lead alloy.

The cuboid element at the neck of the terminal knob is covered in sheet brass (*Table A11: 7, 8*).

The guttering is of iron (*Table A11: 6*).

Spot/ Mesto	Fe	Cu	Zn	As	Pb	Sn
1	54.3	40.6	4.3	-	0.78	-
2	53.2	42.0	4.2	0.18	0.28	-
3	3.4	87.2	8.7	0.06	0.07	0.5
4	92.9	2.1	0.4	-	2.82	1.8
5*	1.91	74.4	21.9	-	0.48	1.31
6	99.9	0.1	-	-	0.02	-
7	53.3	38.6	7.8	0.03	0.04	0.3
8	11.8	78.9	8.3	0.04	0.07	0.9
9	65.1	6.73	1.32	-	15.20	11.6

Table A11

Preglednica A11

653 The measured spot has a diameter of ca. 11 mm. On the apparatus and measurements, see Ch. 3, Fn. 45.

Figure 77a
The front of the A10 scabbard fragment: measured Spots 1–5 on the sheet metal and Spot 6 on the neck of the terminal knob.
Slika 77a
Ostanki nožnice A10, sprednja stran, lega merjenih mest 1–5 (površina pločevine z različnimi deleži patine) in 6 (rumena pločevina na vratu gumba).

Figure 77b
The back of the A10 scabbard fragment: measured Spots 7–10 on the sheet metal.
Slika 77b
Ostanki nožnice A10, hrbtna stran pločevine, lega merjenih mest 7–10 (površina pločevine z različnimi deleži patine).

A10 (*pregl. A10, sl. 76, 77a, b*)

Meritve smo naredili med konservacijskim postopkom. Na merjenih mestih 4, 6, 8 in 10 na površini ni bilo očitne patine.

Pločevina, ki je prekrivala sprednjo stran nožnice, je iz medenine z najmanj okoli 21 % cinka (*pregl. A10: 4, 8*).

Rezultati meritev na patinirani površini sprednje strani pločevine (*pregl. A10: 1–3, 5*) se po vsebnosti kositra bistveno ne razlikujejo od meritev na patini hrbtne strani (*pregl. A10: 9*), torej ne kažejo, da je bila sprednja stran pokositrena. Vendar pa sledove kositrenja nakazujejo meritve EDS XRF na sprednji strani pločevine pred začetkom konservacije, ki so na enem mestu pokazale 4 % kositra.[653]

Okrasni trak na vratu gumba na zaključku nožnice je iz medenine (*pregl. A10: 6*).

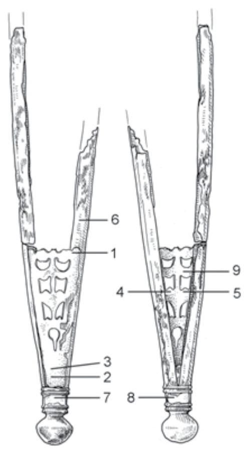


Figure 78
The A11 sword scabbard fragment: the measured spots.
Slika 78
Ostanki nožnice A11, lega merjenih mest.

A11 (*pregl. A11, sl. 78, 79a, b*)

Meritve so bile narejene po konservaciji predmeta. Razen na mestu 5 smo meritve naredili na patinirani površini, zato izmerjene visoke vsebnosti železa ne presenečajo.

Predrti okov na konici nožnice A11 je iz medenine z okrog 22 % cinka (*pregl. A11: 5*). Meritve patine na njegovi sprednji strani kažejo, da ni imel prevleke (*pregl. A11: 1–3*). Izmerjeni odstotki kositra in svinca na patini na dveh mestih hrbtne površine tega okova (*pregl. A11: 4, 9*) govorijo za to, da je bil na podlago prispajkan z zlitino kositra in svinca.

Kvadratni del konice predmeta je prevlečen s pločevino iz medenine (*pregl. A11: 7, 8*).

Robni okov nožnice je železen (*pregl. A11: 6*).

Figure 79a
The front of the A11 sword scabbard fragment: measured Spots 1–3 on the chape, Spot 6 on the guttering and Spot 7 on the terminal knob.
Slika 79a
Ostanki nožnice A11, mesta 1, 2 in 3 (površina sprednje strani predrtega okova, različni deleži patine), 6 (robni okov) in 7 (zlato sijoča pločevina na vratu gumba).

Figure 79b
The back of the A11 sword scabbard fragment: measured Spots 4–5 on the chape and Spot 8 on the terminal knob.
Slika 79b
Ostanki nožnice A11, mesta 4 in 5 (hrbtna stran predrtega okova) in 8 (zlato sijoča pločevina na vratu gumba).

653 Premer merjene površine je bil približno 11 mm. Glede naprave in meritev glej pogl. 3, op. 45.

A12 (*Table A12, Figs. 80, 81a, b*)

The sheet metal covering the scabbard's iron guttering and terminal knob is silver alloy with ca. 4% copper and a low share of gold.[654] The results show the sheet silver to be thick enough for the beam not to have penetrated to the underlying metal (*Table A12: 1–3*).[655]

Table A12
Preglednica A12

Spot/ Mesto	Fe	Cu	Zn	Au	Pb	Ag
1	0.49	4.79	0.03	0.75	0.43	93.5
2	0.18	4.08	0.05	0.60	0.45	94.7
3	0.36	2.44	0.02	0.67	0.42	96.1

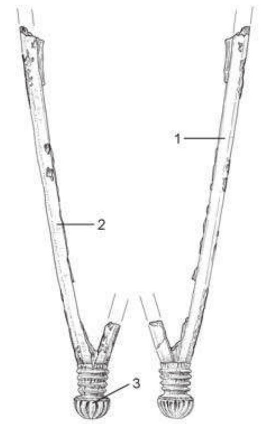


Figure 80
Scabbard A12: the measured spots.
Slika 80
Ostanki nožnice A12, lega merjenih mest.

A13 (*Table A13, Fig. 82*)

Measurements were taken immediately after conservation. The patina on the measured spots was largely removed (*Table A13: 1, 2*).

The suspension band is of silver alloy with less than 3% copper (*Table A13: 2*). Remains of gilding survive under the patina on the front (*Table A13: 5*; Catalogue, *Fig. A13.2a*); the gilding is thin (estimated 0.7–1.5 µm) and the beam penetrated to the underlying metal. The measurements on the patina-covered back (*Table A13: 4*) show an absence of gilding.[656] In Roman silver alloys, low gold content is not indicative of gilding or intentional addition of gold, but rather the consequence of extracting silver from lead ore.[657]

The high iron content of the tin filling (*Table A13: 1*; Catalogue, *Fig. A13.2b*), with which the craftsman reinforced the spot of a small flaw that occurred during embossing, shows that the beam hit not only the surface of removed patina, but also the surrounding area. The patina or the surface around the measured spot is also the origin of the detected silver and copper; the filling is thus probably pure tin.[658]

Table A13
Preglednica A13

Spot/ Mesto	Fe	Cu	Au	Pb	Ag	Sn
1*	7.9	2.30	-	0.39	1.20	88.1
2*	0.9	2.30	0.70	0.51	95.6	-
2*¤	0.82	2.80	0.74	0.48	95.2	-
4	8.1	1.30	1.00	0.42	89.1	-
5¤	1.8	1.10	33.9	0.20	63.0	-

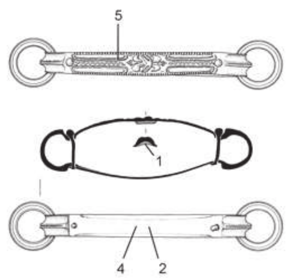


Figure 82
The A13 sword suspension band: the measured spots.
Slika 82
Prečni okov nožnice A13, lega merjenih mest.

A15 (*Table A15, Figs. 83, 84a, b*)

Measurements were taken after conservation. There was no visible patina on Spots 1–4.

The shiny silvery patches on the upper side of the sword's handguard plate are of tin (*Table A15: 1, 2*). The high copper content in two measurements suggest that the beam either hit the surrounding area or penetrated to the underlying metal.

The basic alloy of the handguard plate can be deduced from the measurements on two spots without discernible tin, from which we did not remove the surface layer. The results (*Table A15: 3–4*) indicate that the handguard plate is of bronze with less than 2% tin.

Table A15
Preglednica A15

Spot/ Mesto	Fe	Cu	Zn	As	Pb	Sn
1	-	52.7	0.2	-	0.60	46.5
2	2.5	93.2	0.6	0.13	0.36	3.3
3	1.9	95.4	0.5	0.12	0.13	2.0
4	2.9	94.7	0.4	0.13	0.18	1.7
5	5.5	92.8	0.4	0.05	0.11	1.2

654 Cf. A13.
655 Šmit, Istenič, Knific 2008, 2331, 2332, Fig. 5.
656 For more details, see Istenič, Milić, Šmit 2003.
657 Hughes, Hall 1979, 325–335; Craddock 1995, 213, 231.
658 For more details, see Istenič, Milić, Šmit 2003.

Figure 81a
The A12 sword scabbard fragment: measured Spot 1 on the coating of the guttering.

Slika 81a
Odlomek nožnice A12, mesto 1 (prevleka srebrnega videza na robnem okovu).

Figure 81b
The A12 sword scabbard fragment: measured Spot 2 on the guttering coating and Spot 3 on the terminal knob coating.

Slika 81b
Odlomek nožnice A12, mesti 2 (prevleka srebrnega videza na robnem okovu) in 3 (prevleka srebrnega videza na zaključnem gumbu).

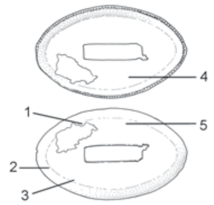


Figure 83
The A15 sword handguard plate: the measured spots.

Slika 83
Ščitnik branika ročaja meča A15, lega merjenih mest.

Figure 84a
The upper side of the A15 sword handguard plate: measured Spots 1 and 2 on the grey surface, Spot 3 on the base metal and Spot 5 on the dark grey patina. Spot 2 was not measured.

Slika 84a
Ščitnik branika ročaja meča A15, zgornja stran, mesta 1 in 2 (siva snov na površini), 3 (površina brez prevleke), 5 (temnosiva patina). Mesto 2 ni bilo merjeno.

Figure 84b
The underside of the A15 sword handguard plate: measured Spot 4 on the base metal.

Slika 84b
Ščitnik branika ročaja meča A15, spodnja stran, mesto 4.

A12 (*pregl. A12, sl. 80, 81a, b*)

Pločevina, s katero sta prevlečena železen robni okov in gumb na koncu nožnice, je iz srebrove zlitine, ki vsebuje okoli 4 % bakra in majhen delež zlata.[654] Rezultati kažejo, da je srebrna pločevina tako debela, da protonski žarek ni dosegel podlage (*pregl. A12: 1–3*).[655]

A13 (*pregl. A13, sl. 82*)

Meritve smo naredili po konservaciji predmeta; z dveh mest smo v glavnem odstranili površinsko patinirano plast (*pregl. A13: 1, 2*).

Okov je narejen iz srebrove zlitine, ki je vsebovala manj kot 3 % bakra (*pregl. A13: 2*). Na sprednji strani so pod patino ohranjeni ostanki pozlate (*pregl. A13: 5*; Katalog, *sl. A13.2a*), ki je tako tenka, da je protonski žarek dosegel podlago; njena ocenjena ohranjena debelina je 0,7–1,5 µm. Meritev na patinirani površini hrbtne strani (*pregl. A13: 4*) kaže, da tu okov ni imel pozlate.[656] Pri rimskih srebrovih zlitinah namreč nizka vsebnost zlata ne kaže na pozlato ali namerno dodajanje zlata zlitini, temveč je posledica pridobivanja srebra iz svinčeve rude.[657]

Visok odstotek železa v rezultatu meritve zalivke (*pregl. A13: 1*; Katalog, *sl. A13.2b*), s katero je na hrbtni strani zalito mesto, kjer je med izdelavo okrasa nastala napaka, kaže, da je merilni žarek poleg površine, s katere smo odstranili patino, zadel tudi okolico. Iz patine oziroma površine v okolici merjenega mesta najverjetneje izvirajo tudi izmerjeni odstotki srebra in bakra. Zalivka je torej verjetno iz čistega kositra.[658]

A15 (*pregl. A15, sl. 83, 84a, b*)

Meritve smo naredili na konserviranem predmetu. Na merilnih mestih 1–4 ni izrazite patine.

Meritve na srebrno sijoči plasti, ki je na več mestih vidna na zgornji strani ščitnika, so pokazale, da gre verjetno za ostanke plasti kositra (*pregl. A15: 1, 2*). Iz visokega odstotka bakra pri teh dveh meritvah sklepamo, da je žarek zadel tudi okolico srebrno svetleče se plasti oziroma da je dosegel podlago.

Za opredelitev osnovne zlitine ščitnika branika ročaja meča so merodajne meritve na dveh mestih, kjer ni

654 Prim. A13.
655 Šmit, Istenič, Knific 2008, 2331, 2332, sl. 5.
656 Podrobneje: Istenič, Milić, Šmit 2003.
657 Hughes, Hall 1979, 325–335; Craddock 1995, 213, 231.
658 Podrobneje: Istenič, Milić, Šmit 2003.

The dark grey surface on the upper side of the handguard plate (*Table A15: 5*) presumably occurred because of the corrosion processes in the water.

A16 (*Table A16, Figs. 85, 86a, b*)

Measurements were taken after conservation. The surface layer on Spot 2 was largely removed.

The sword's handguard plate is of bronze with ca. 11% tin (*Table A16: 1–2*). The measurements on the well-preserved silvery surface of the underside indicate a very thin layer of tin, through which the beam penetrated to the underlying bronze (*Table A16: 3–4*).

Table A16
Preglednica A16

Spot/ Mesto	Fe	Ni	Cu	Zn	As	Pb	Sn
1	0.6	-	87.0	-	0.13	1.82	10.5
2*	1.0	0.14	85.7	-	0.13	1.83	11.2
3	1.0	-	73.4	-	0.13	1.33	24.1
4	1.2	-	64.3	0.40	0.08	1.04	33.0

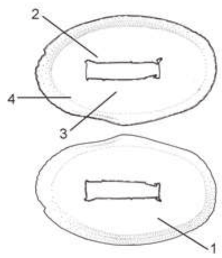


Figure 85
The A16 sword handguard plate: the measured spots.
Slika 85
Ščitnik branika ročaja meča A16, lega merjenih mest.

A19 (*Table A19, Figs. 87, 88a–c*)

Measurements were taken after conservation. The patina was largely removed from Spots 1–3 and 5.

The handguard plate is of brass with at least 16% zinc (*Table A19: 1–2*; the result for Spot 2 suggests that the beam hit a large part of the surrounding area).

The thin disc on the pommel was measured with the standard and the narrow beam on a spot where the patina had previously been removed (*Table A19: 3*) and on a surface with patina still present (*Table A19: 4*). The results show that the disc is of brass. The tin measured on Spot 3 appears likely to be originally present in the brass, but may also originate in the remains of patina transferred from the adjacent pommel.

The sub-square pommel plate was measured on spots with and without patina; the two results show that the plate is of bronze and not plated (*Table A19: 5, 6*).

Table A19
Preglednica A19

Spot/ Mesto	Fe	Cu	Zn	Pb	Ag	Sn
1*	1.6	81.3	16.0	0.59	0.1	0.5
2*	1.4	91.5	6.1	0.59	0.1	0.2
3*	0.7	89.7	7.7	0.24	-	1.7
3*¤	1.1	87.3	9.7	0.38	0.1	1.5
4	2.6	88.1	6.9	0.66	-	1.8
5*	0.79	90.1	-	0.34	-	8.7
6	0.22	92.4	-	-	-	7.4

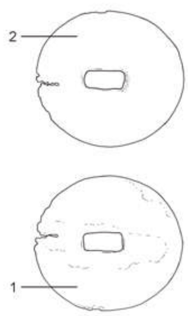


Figure 87
Sword A19: the measured spots on the handguard plate and pommel.
Slika 87
Meč A19, lega merjenih mest na braniku ročajnega ščitnika in glaviču ročaja.

bilo videti prevleke, a površinske plasti nismo dodatno odstranili. Rezultati (*pregl. A15: 3–4*) nakazujejo, da je ščitnik iz brona z manj kot 2 % kositra.

Za temnosivo površino na zgornji strani branika (*pregl. A15: 5*) domnevamo, da je posledica korozijskih procesov v vodi.

A16 (*pregl. A16, sl. 85, 86a, b*)

Meritve smo naredili na konserviranem predmetu. Z mesta 2 smo v glavnem odstranili površinsko plast.

Ščitnik branika ročaja meča je iz brona, ki vsebuje približno 11 % kositra (*pregl. A16: 1–2*). Meritve na dobro ohranjeni površini srebrne barve na spodnji strani ščitnika kažejo na zelo tenko plast kositra, skozi katero je žarek dosegel bronasto podlago (*pregl. A16: 3–4*).

A19 (*pregl. A19, sl. 87, 88a–c*)

Meritve smo naredili na konserviranem meču. Z mest 1–3 in 5 smo v glavnem odstranili patino.

Ščitnik branika je iz medenine, ki vsebuje najmanj 16 % cinka (*pregl. A19: 1–2*; mesto 2 je imelo majhno površino, rezultat nakazuje, da je žarek zadel velik del okolice).

Spodnjo, krožno ploščico na vrhu glaviča smo merili z običajnim in ozkim žarkom na mestu, kjer smo odstranili patino z zelo majhne površine (*pregl. A19: 3*), in na površini s patino (*pregl. A19: 4*). Rezultati kažejo, da je ploščica iz medenine. Za vsebnost kositra, izmerjeno na mestu 3, se zdi verjetneje, da je sestavni del medenine, vendar ni mogoče izključiti, da izvira iz ostankov patine, kamor bi prišla iz zgoraj ležeče štirikotne ploščice.

Zgornjo, štirikotno ploščico na glaviču smo merili na površini, s katere je bila v glavnem odstranjena patina, in na patini; rezultata kažeta, da je ploščica iz brona in da ni imela prevleke (*pregl. A19: 5, 6*).

Figure 86a
The upper side of the A16 sword handguard plate: measured Spot 1 on the base metal.

Slika 86a
Ščitnik branika ročaja meča A16, zgornja stran, mesto 1 (brez prevleke).

Figure 86b
The underside of the A16 sword handguard plate: measured Spot 2 on the base metal and Spots 2–3 on the shiny silvery coating.

Slika 86b
Ščitnik branika ročaja meča A16, spodnja stran, mesta 2 (branik brez prevleke) ter 3 in 4 (siva sijoča prevleka).

Figure 88a
The upper side of the A19 handguard plate: measured Spot 2.

Slika 88a
Ščitnik branika ročaja meča A19, zgornja stran, mesto 2.

Figure 88b
The underside of the A19 handguard plate: measured Spot 1.

Slika 88b
Ščitnik branika ročaja meča A19, spodnja stran, mesto 1.

Figure 88c
The A19 sword pommel: measured Spots 3 and 4 on the disc and Spots 5–6 on the sub-square plate.

Slika 88c
Glavič ročaja meča A19, mesta 3 in 4 (krožna ploščica) ter 5 in 6 (štirikotna ploščica).

A20 (*Table A20, Figs. 89, 90a, b*)

The handguard plate is of brass (*Table A20: 2*). The two measurements on the patina-covered upper side indicate a poorly and patchily surviving layer of tin (*Table A20: 3–4*). The measurement on the underside shows no such layer (*Table A20: 1*).

Spot/ Mesto	Fe	Cu	Zn	Ag	Sn	Pb
1	6.40	80.8	11.4	0.07	0.80	0.63
2*	0.59	80.4	17.6	0.07	0.78	0.62
3	3.35	77.3	11.9	0.14	6.88	0.45
4	0.82	82.0	15.8	0.08	0.89	0.39

Table A20

Preglednica A20

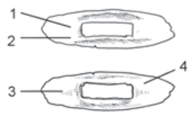


Figure 89
The A20 sword handguard plate: the measured spots.

Slika 89
Ščitnik branika ročaja meča A20, lega merjenih mest.

Figure 90a
The underside of the A20 sword handguard plate: measured Spots 1 on the surface with patina and Spot 2 on the surface without patina.

Slika 90a
Ščitnik branika ročaja meča A20, spodnja stran, mesti 1 in 2.

Figure 90b
The upper side of the A20 sword handguard plate: measured Spots 3 and 4 on surface with patina.

Slika 90b
Ščitnik branika ročaja meča A20, zgornja stran, mesti 3 in 4.

MM A22 (*Table MM A22, Fig. 91*)

The front plate of the scabbard is of brass with ca. 16% zinc (*Table MM A22: 1, 2*). Measurements on the spots with patina and those without it revealed very few differences, which corresponds well with the observation that there is almost no patina on the scabbard.

The sword's handguard plate, peen block plating and the measured rivet on the suspension band are of brass with 18–19% zinc (*Table MM A22: 5, 7, 8*).

The iron rungs forming the front of the laddered chape bear layers of bronze with ca. 4–7% tin (*Table MM A22: 11a, 12a, 13, 15*) on their inside. There are iron corrosion products on the underside of the crossbars and between the crossbars and the sheet brass (*Table MM A22: 12b, 16*).[659]

The layers of bronze in the front rungs examined in full detail show that several layers of iron were soldered with bronze. This suggests that the laddered chape was made by first forging a 'net' that was then folded lengthwise and its rungs soldered together on the front.[660]

The symmetrical arrangement of the brass and bronze lining of the U sectioned part of the laddered chape on the left and right sides of the scabbard (at the level of the ninth bridge) suggests the laddered chape was made in at least two parts, which were assembled by soldering onto the underlying brass or bronze lining (*Table MM A22: 9, 14*).

Spot/ Mesto	Fe	Ni	Cu	Zn	As	Ag	Sn	Sb	Pb
1	0.62	0.14	81.1	16.7	-	0.1	0.8	-	0.68
2*	0.42	-	81.3	16.4	-	0.1	0.8	-	1.00
3	0.59	-	81.2	16.8	-	0.1	0.7	-	0.71
4*	0.41	-	81.8	16.3	-	0.1	0.7	-	0.75
5	0.34	-	78.9	19.1	-	0.15	1.1	-	0.47
7*	1.54	0.11	77.8	18.5	-	0.1	0.9	-	0.98
8	1.90	0.11	78.1	18.1	-	0.1	0.9	-	0.71
9	3.57	0.13	90.8	4.60	-	0.04	0.4	--	0.42
11	4.2	-	87.9	0.49	-	0.17	7.1	0.09	0.15
12a	2.98	0.2	92.8	0.47	-	-	3.6	-	-
12b	93.9	-	3.5	2.31	0.16	-	3.6	-	-
13	4.14	0.1	88.9	0.86	-	0.12	5.7	-	0.11
14	5.11	-	88.0	-	-	0.20	6.3	0.33	0.11
15	7.13	-	87.6	-	-	0.09	4.7	-	0.48
16	96.8	-	1.80	1.19	-		-	-	0.17

Table MM A22
Spots 6 and 10 were not measured. On Spots 2, 4–7, 9, 12a and 14, the low-energy part of the spectra was measured with a narrow beam.

Preglednica MM A22
Na mestih 6 in 10 meritev nismo izvedli. Pri meritvah (2, 4–7, 9, 12a, 14) smo nizkoenergijski del spektra izmerili z malim žarkom.

659 Istenič 2010; Šmit, Istenič, Perovšek 2010, 166–169, Fig. 1, Table 1; Istenič, Kosec, Perovšek, Gosar, Nagode 2011; Istenič, Šmit 2014, 211–218, Figs. 3–9.

660 Istenič, Kosec, Perovšek, Gosar, Nagode 2011; Istenič, Šmit 2014, 211–218, Figs. 3–9.

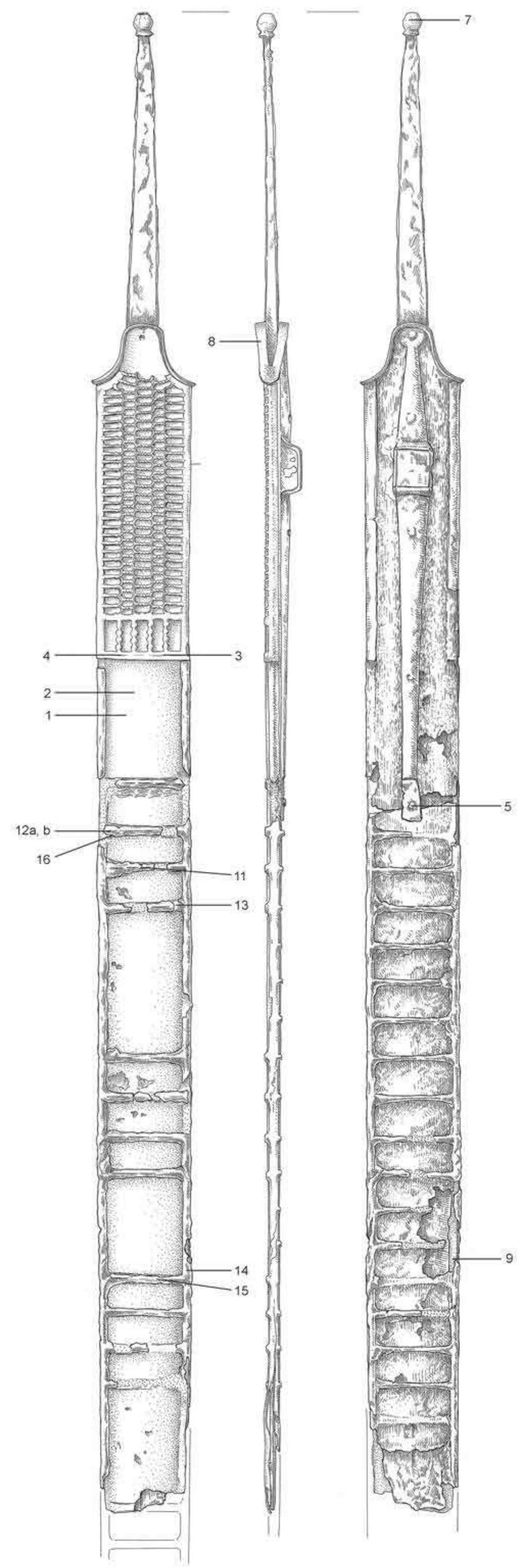


Figure 91
Sword and scabbard MM A22: the measured spots.

Slika 91
Meč in nožnica MM A22, lega merjenih mest.

A20 (*pregl. A20, sl. 89, 90a, b*)

Ščitnik branika ročaja meča je iz medenine (*pregl. A20: 2*). Meritvi na patini zgornje strani branika kažeta na slabo in le mestoma ohranjeno plast kositra (*pregl. A20: 3–4*). Meritev na površini spodnje strani (*pregl. A20: 1*) ne kaže take plasti.

MM A22 (*pregl. MM A22, sl. 91*)

Sprednja platica nožnice je iz medenine z okoli 16 % cinka (*pregl. MM A22: 1, 2*). Med analizami na mestih s patino oziroma brez nje so le majhne razlike, kar se dobro ujema z dejstvom, da na nožnici skorajda ni patine.

Ščitnik branika ročaja meča in obloga gumba na ročaju ter izmerjena zakovica na okovu z zanko za obešanje nožnice so bili narejeni iz medenine, ki vsebuje 18–19 % cinka (*pregl. MM A22: 5, 7, 8*).

V železnih prečkah na sprednji strani nožnice so plasti brona s pribl. 4–7 % kositra (*pregl. MM A22: 11a, 12a, 13, 15*). Na spodnji strani prečk in med prečkami ter medeninasto pločevino je plast železovih korozijskih produktov (*pregl. MM A22: 12b, 16*).[659]

Plasti brona v podrobno raziskani prečki na sprednji strani nožnice kažejo, da je bilo več plasti železa (oz. jekla) spajkanih z bronom. Sklepamo, da so lestvičasti okov naredili tako, da so skovali »mrežo«, ki so jo nato po dolžini ob obeh straneh zapognili in sklenili s spajkanjem sprednjih prečk.[660]

Medenina oziroma bron pod železnim (jeklenim) robnim okovom, simetrično na levi in desni strani nožnice (v višini devete sprednje prečke), govori za to, da so okov naredili najmanj v dveh delih, ki so ju sestavili s spajkanjem na medeninasto oziroma bronasto podlago (*pregl. MM A22: 9, 14*).

659 Istenič 2010; Šmit, Istenič, Perovšek 2010, 167, 168, 173, sl. 1, pregl. 1; Istenič, Kosec, Perovšek, Gosar, Nagode 2011; Istenič, Šmit 2014, 211–218, sl. 3–9.

660 Istenič, Kosec, Perovšek, Gosar, Nagode 2011; Istenič, Šmit 2014, 211–218, sl. 3–9.

MM A34 (*Table MM A34, Figs. 92, 93a, b*)

Measurements were taken before conservation. Patina was only removed on Spot 1.

The measurements taken on the corroded surface of the sword's handguard plate (*Table MM A34: 9*) and the comparison with other handguard plates of the same sword type show that the handguard plate is either of copper or of bronze with a layer of tin-lead alloy on the upper side.

The scabbard's mouth band is of brass (*Table MM A34: 1*). The corrosion products on the band show copper and a high amount of iron (*Table MM A34: 2, 4, 5*).

Measurements on Spots 6–8 and 11 reveal copper (and the iron originating in the corrosion products), a low zinc content and 4.2–12.1% tin. This suggests that the beam hit the corroded sheet metal covering the front of the scabbard and underlying the openwork locket; this sheet metal in the Mainz type scabbards (such as MM A34) is usually made of brass and tinned on the outer surface (cf. A5). The presence of lead on Spot 8 cannot be explained.

Spot/ Mesto	Fe	Ni	Cu	Zn	As	Sn	Pb
1*	1.6	0.21	85.3	12.7	-	0.2	-
1*¤	1.9	0.23	77.3	20.3	-	0.2	0.09
2	3.6	0.21	89.9	5.5	-	0.6	0.26
4	23.9	-	70.6	3.5	1.92	-	-
5	21.2	-	71.7	6.8	0.20	-	-
6	4.5	-	82.3	0.8	0.09	12.1	-
7	26.0	-	68.3	1.4	0.04	4.2	-
8	17.4	-	69.2	1.9	-	7.7	3.70
9	6.3	-	67.1	0.7	0.12	20.7	5.02
11	0.9	-	86.9	0.9	0.03	11.3	-

Table MM A34
Preglednica MM A34

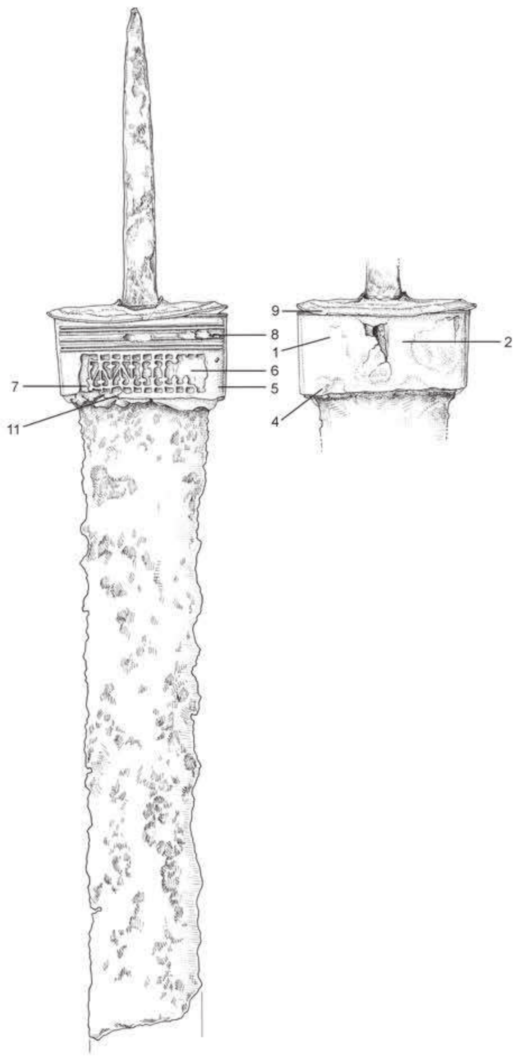


Figure 92
Sword and scabbard MM A34: the measured spots.
Slika 92
Meč in nožnica MM A34, lega merjenih mest.

B. Daggers and sheaths

B1 (*Tables B1.1–2, Figs. 94, 95a–c*)

Measurements were taken after conservation. The patina was not additionaly removed before measuring.

The strips at the sides of the iron dagger handle (*Table B1.1: 13, 14*) are of brass (*Table B1.1: 15, 16*); the high iron content on Spot 16 is most likely caused by the remains of patina (cf. Catalogue, *Fig. B1.2d*). The inlays on the sheath are also of brass (*Table B1.1: 5, 6*).

Part of the front surface on the sheath's disc terminal is covered with an alloy of tin and lead in a 1 : 1 ratio (*Table B1.1: 1*). Measurements show that the parts of the sheath that obtained a silvery metallic shine during conservation, including the loops and rivets, are of iron (*Table B1.1: 2–4, 10, 11*).

Figure 93a
The front of the MM A34 sword and scabbard: measured Spots 5–8 and 11 on the mouth band and the sheet metal underneath.

Slika 93a
Sprednja stran nožnice MM A34, mesta 5–8 in 11 na okovu ob ustju in na pločevini pod njim.

Figure 93b
Sword and scabbard MM A34: measured Spots 1, 2 and 4 on the back of the scabbard and Spot 9 on the upper side of the sword handguard plate. All the measurements were made on surfaces with patina except for Spot 1 from where the patina was removed after the photo was taken.

Slika 93b
Meč in nožnica MM A34, mesta 1, 2 in 4 na hrbtni strani okova ob ustju nožnice ter mesto 9 na zgornji strani okova branika meča. Z mesta 1 je bila naknadno odstranjena patina, ostala mesta so bila merjena na patinirani površini.

MM A34 (*pregl. MM A34, sl. 92, 93a, b*)

Meritve so bile narejene pred začetkom konservacije, zato je na vseh merjenih mestih izrazita plast patine, le na mestu 1 je bila patina v glavnem odstranjena.

Iz rezultatov meritev na korodirani površini ščitnika branika ročaja meča (*pregl. MM A34: 9*) in primerjave z drugimi ščitniki mečev istega tipa sklepamo, da je ščitnik iz bakra ali brona in je imel na površini zgornje strani plast zlitine kositra in svinca.

Okov ob ustju nožnice je iz medenine (*pregl. MM A34: 1*), na kateri so nastali korozijski produkti, v katerih je poleg bakra veliko železa (*pregl. MM A34: 2, 4, 5*).

Na mestih 6–8 in 11 so meritve poleg bakra (in železa, ki izvira iz korozijskih produktov) in majhnega deleža cinka pokazale 4,2 do 12,1 % kositra. Sklepamo, da je žarek na teh mestih zadel korodirano pločevino, ki je prekrivala lice nožnice in je bila pod okovom s predrtim okrasom ob ustju nožnice; ta pločevina je pri tipu Mainz (ki ji pripada nožnica MM A34) običajno iz medenine, ki je bila na licu pokositrena (prim. A5). Vsebnosti svinca na mestu 8 ne znamo pojasniti.

B. Bodala in nožnice

B1 (*pregl. B1.1–2, sl. 94, 95a–c*)

Meritve smo izvajali na konserviranem predmetu. Na merilnih mestih patine nismo odstranjevali.

Železni ročaj bodala (*pregl. B1.1: 13, 14*) je ob straneh zaprt s trakom pločevine iz medenine (*pregl. B1.1: 15, 16*; visok delež na mestu 16 izmerjenega železa je najverjetneje povezan z ostanki patine (prim. Katalog, *sl. B1.2d*). Nožnica je tavširana z medenino (*pregl. B1.1: 5, 6*).

Del površine sprednje strani zaključka nožnice je prekrit z zlitino kositra in svinca v razmerju 1 : 1 (*pregl. B1.1: 1*). Za več delov nožnice (vključno z zankami in

Table B1.1
Results of metal analyses.

Preglednica B1.1.
Rezultati analiz kovin.

Spot/ Mesto	Fe	Cu	Zn	As	Pb	Bi	Ag	Sn
1	-	0.31	-	-	49.4	0.28	-	50.0
2*	99.6	0.19	0.15	0.06	0.03	-	-	-
3*	99.9	0.06	-	0.04	-	-	-	-
4*	99.8	0.13	-	0.11	-	-	-	-
5	7.4	74.6	15.8	0.08	1.09	0.03	0.07	1.0
6	3.9	78.3	16.1	0.11	0.75	-	0.05	0.8
10*	99.9	-	0.05	0.04	-	-	-	-
11*	99.8	0.08	0.08	0.04	0.02	-	-	-
13	99.9	0.12	-	0.01		-	-	-
14	99.9	0.10	-	0.01	0.01	-	-	-
15¤	0.3	75.7	25.0	-	-	-	-	-
16	5.6	71.0	22.6	0.03	0.18	-	0.03	0.6

Table B1.2
Results of the PIXE/PIGE analyses of red enamel.

Preglednica B1.2.
Rezultati analiz rdečega emajla z metodama PIXE in PIGE.

Spot/ Mesto	Na_2O	MgO	Al_2O_3	SiO_2	Cl	K_2O	CaO	TiO_2	MnO	Fe_2O_3	CuO	SnO_2	Sb_2O_3	PbO
7	6.75	0.57	1.49	45.0	1.11	0.47	4.85	0.23	0.06	12.4	5.96	0.29	0.64	20.2
8	7.54	0.61	1.13	46.6	1.05	0.47	4.47	0.17	0.06	10.4	7.39	0.13	0.56	19.5
9	5.01	0.39	0.93	45.0	1.12	0.54	4.17	0.19	0.13	13.6	5.73	0.20	0.70	22.3
12	9.02	0.69	1.42	46.3	1.44	0.84	5.36	0.23	0.0.9	4.68	5.73	0.21	0.72	23.2

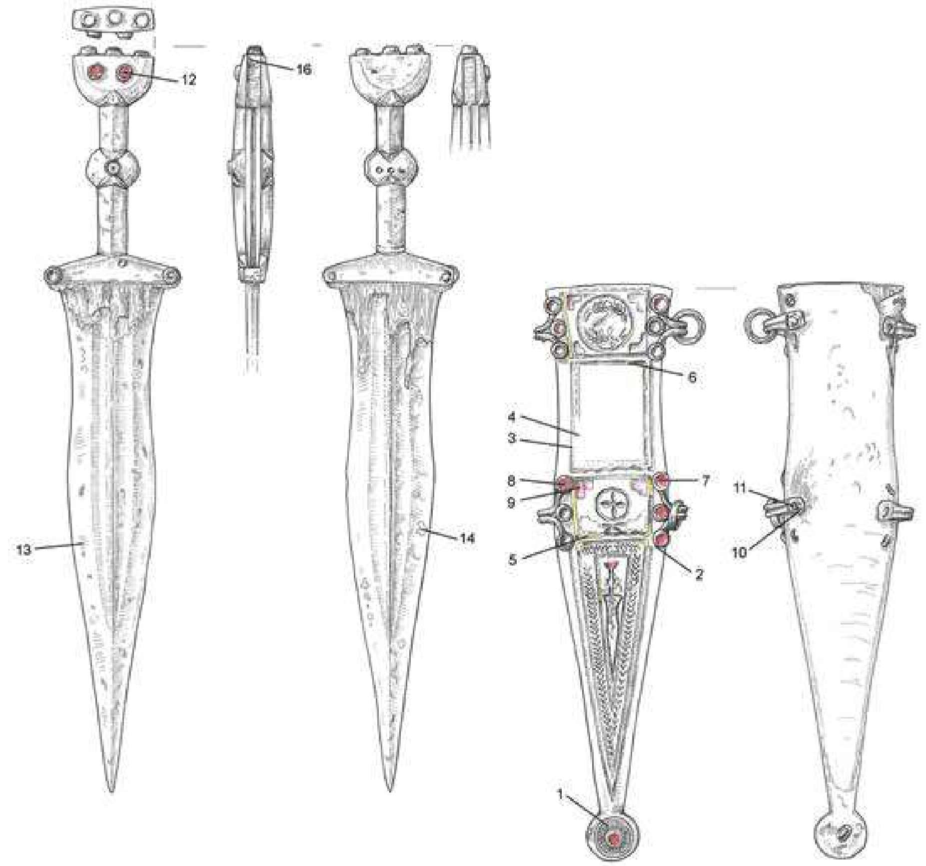


Figure 94
Dagger and scabbard B1: the measured spots.

Slika 94
Bodalo in nožnica B1, lega merjenih mest.

The elemental composition of the enamel on the B1 dagger and sheath was examined on four spots (*Table B1.2: 7–9, 12*). The low potassium and magnesium contents reveal the use of natron glass, which was common in the Roman period.[661] The measured values of SiO_2 suggest that glass comprises roughly two thirds of the mass. The red colour was obtained by adding copper (5.73–7.39%) and possibly also lead oxides (19.5–23.2%). The latter probably improved the melting of broken glass, as they are present in most of the analysed enamel. The iron oxide content measured on Spot 12 deviates considerably from that measured on Spots 7–9. It is not possible to exclude the possibility that some of the measured spots were contaminated with the iron corrosion (rust) from the surrounding area or that the beam hit the iron surrounding the enamel.

B2 (*Tables B2.1–2, Figs. 96, 97a–c*)

Measurements on Spots 1, 2, 4 and 5 were taken before conservation, on patina-covered surfaces. This is reflected in the high iron content, which is particularly high on Spots 2 and 4 because the very small surviving enamel pieces made it impossible to avoid

Spot/ Mesto	Fe	Cu	Zn	As	Mo	Pb	Ag	Sn
1	13.3	0.74	-	-	-	0.32	85.7	-
2	18.2	0.57	-	-	-	0.27	81.0	-
4	77.5	-	0.10	0.04	-	0.09	22.3	-
5	7.9	-	0.07	-	-	0.42	-	91.6
6	-	89.2	9.74	-	-	0.35	0.72	-
7	-	82.3	17.2	0.12	-	-	-	0.07
8	-	5.39	1.05	0.18	0.12	1.77	91.5	-
9	-	1.15	0.10	-	-	0.47	98.3	-

Table B2.1
Spot 6 was initially on the handle, but after ten seconds of measuring we realised that the material was iron and did not proceed with the quantitative measurement. The number 6 was then used for a spot on the sheath. On Spots 7 and 8 cf. *Fig. 96* and Catalogue, *Fig. B2.4a* (Spot 8) and *Fig. B2.4b* (Spot 7).

Preglednica B2.1
Mesto 6 je bilo prvotno označeno na ročaju, kjer smo po kratki meritvi (10 sekund) ugotovili, da gre za železo, zato kvantitativne meritve nismo izvedli. S številko 6 smo nato označili mesto na nožnici. Glede merilnih mest 7 in 8 primerjaj *sl. 96* in Katalog, *sl. B2.4a* (mesto 8) in *sl. B2.4b* (mesto 7).

661 Istenič, Šmit 2012, 302. Henderson (2013, 80), in contrast, writes that glass with plant ash as flux was commonly used in the Roman period to obtain brown-red enamel.

zakovicami), ki so med postopkom konservacije dobile srebrn kovinski sij, so meritve pokazale, da so iz železa (*pregl. B1.1: 2–4, 10, 11*).

Elementno sestavo emajla na bodalu/nožnici B1 smo ugotovili na štirih mestih (*pregl. B1.2: 7–9, 12*). Nizka deleža kalija in magnezija kažeta, da so uporabili natronovo steklo, ki je bilo v rimski dobi običajno.[661] Iz izmerjenih vsebnosti SiO_2 sklepamo, da je bil delež stekla v masi približno dve tretjini. Rdečo barvo so dosegli z dodatkom bakrovih (5,73–7,39 %) in morda tudi svinčevih oksidov (19,5–23,2 %). Zadnji so verjetno pripomogli k boljšemu taljenju zmletega stekla, saj so prisotni v večini analiziranih emajlov. Na mestu 12 izmerjeni odstotek železovega oksida močno odstopa od vsebnosti tega oksida na mestih 7–9. Ne moremo izključiti, da so bila nekatera merjena mesta kontaminirana z rjo iz okolice, niti možnosti, da je žarek ob robu zadel železno okolico emajla.

B2 (*pregl. B2.1, sl. 96, 97a–c*)

Meritve na mestih 1, 2, 4 in 5 smo naredili pred konserviranjem predmeta, ko je bilo na merjenih mestih še precej patine. To med drugim odsevajo visoki odstotki na teh mestih izmerjenega železa. Pri meritvah mest 2 in 4 je delež železa še višji, ker se zaradi izredno majhnih mest, ki smo jih ciljali, ni dalo izogniti temu, da protonski žarek poleg namerjenega mesta ne bi zadel še železne okolice. Zadnje velja tudi za meritve v točkah 6–9, ki so poleg tavširanega okrasa zajele velik del okolice, ki je železna, zato so v tabeli podani rezultati meritev preračunani tako, da izmerjeni delež železa ni upoštevan (vsota izmerjenih elementov brez železa = 100 %); te rezultate je smiselno obravnavati previdno.

Rezultati meritev (preračunani tako, da je izmerjeno železo izločeno) kažejo, da je železna nožnica okrašena z vložki iz srebrove zlitine visoke kvalitete (*pregl. B2.1: 1, 2, 4, 8, 9*), medenine (*pregl. B2.1: 6, 7*) in emajla (*pregl. B2.2: 3*), ki je narejen iz natronovega stekla,[662] zeleno barvo pa mu je dal bakrov oksid. Različne vrste bakrovih oksidov so namreč steklo oziroma emajle obarvale različno.

Sprednja stran okroglega zaključka nožnice je pokositrena (*pregl. B2.1: 5*).

Figure 95a
The front of the B1 dagger scabbard: measured Spots 2, 3 and 4 on the shiny silvery surface without patina, Spots 5 and 6 on metal inlay of golden appearance, Spots 7–9 on red inlays. Spot 15 on the suspension ring was not measured.

Slika 95a
Nožnica bodala B1, sprednja stran, mesta 2, 3 in 4 (srebrno svetleča se površina), 5 in 6 (zlato svetleč se kovinski vložek), 7–9 (rdeči vložki); na mestu 15 (obroček na zanki) nismo merili.

Figure 95b
The back of the B1 dagger scabbard: measured Spot 11 on the rivet shank and Spot 10 on the suspension loop.

Slika 95b
Nožnica bodala B1, hrbtna stran, mesti 11 (trn zakovice) in 10 (zanka za pripenjanje).

Figure 95c
The front of the B1 dagger scabbard: measured Spot 1 on the silvery coating of the disc terminal.

Slika 95c
Nožnica bodala B1, sprednja stran, mesto 1 (srebrna plast na površini konice).

Table B2.2
Results of the PIXE/PIGE analyses of green enamel. In addition to the elements in the table, it also contained 0.24% Cr_2O_3, 0.06% Ag, 0.03% ZnO and 0.004% NiO. Iron content is not given, as it originated from the beam hitting the surrounding area.

Preglednica B2.2.
Rezultati analiz zelenega emajla z metodama PIXE in PIGE. Poleg elementov v preglednici so v njem še 0,24 % Cr_2O_3, 0,06 % Ag, 0,03 % ZnO in 0,004 % NiO. Železa nismo določili, ker je žarek oplazil železno okolico.

Spot/ Mesto	Na_2O	MgO	Al_2O_3	SiO_2	Cl	K_2O	CaO	TiO_2	MnO	Fe_2O_3	CuO	SnO_2	Sb_2O_3	PbO
3	16.9	1.46	2.87	49.0	0.71	0.94	8.14	0.11	0.58	-	5.00	0.67	1.51	12.0

661 Istenič, Šmit 2012, 302. Henderson (2013, 80) navaja nasprotno, da so za rimske emajle rjavordeče barve pogosto uporabili steklo, pri katerem je bilo talilo rastlinski pepel.

662 Prim. B1.

the surrounding iron. The same holds true of the measurements on Spots 6–9, hence the results in the table are given without the iron content (the sum of the measured elements without iron = 100%); these results should be treated with caution.

The results when disregarding the iron content show that the iron sheath was decorated with inlays of a high-quality silver alloy (*Table B2.1: 1, 2, 4, 8, 9*), brass (*Table B2.1: 6, 7*) and enamel (*Table B2.2: 3*); the enamel is made of natron glass,[662] and coloured using copper oxide. Different copper oxides could produce different colours.

The front of the sheath's disc terminal is tinned (*Table B2.1: 5*).

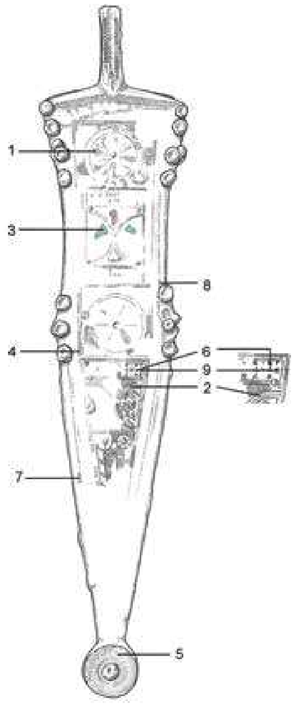


Figure 96
Dagger and sheath B2: the measured spots.
Slika 96
Bodalo in nožnica B2, lega merjenih mest.

B3 (*Table B3, Figs. 98, 99*)

Measurements were taken immediately after conservation on spots where the patina had largely been removed.

The measured rivet and both loops on the sheath are of brass (*Table B3: 1–3*). The measured iron content on Spots 2 and 3 suggest traces of patina.

Spot/ Mesto	Fe	Cu	Zn	Pb	Ag	Sn
1*¤	0.7	77.4	21.6	0.27	-	-
2*	2.8	73.7	22.6	0.48	-	0.1
3*	1.7	76.2	21.0	0.57	0.07	0.5

Table B3
Preglednica B3

B4 (*Table B4, Figs. 100, 101*)

Measurements were taken immediately after conservation, without additionally removing the upper layers.

Both measured rivets are of brass (*Table B4: 1, 2*). The iron content suggest traces of patina.

Spot/ Mesto	Fe	Ni	Cu	Zn	As	Pb	Ag	Sn
1	2.2	0.1	78.5	18.4	0.08	0.12	-	0.6
2	2.1	0.2	79.4	17.3	0.04	0.46	0.09	0.5

Table B4
Preglednica B4

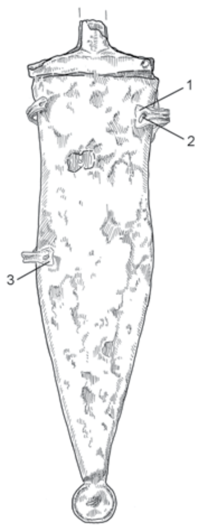


Figure 98
Dagger scabbard B3: the measured spots.
Slika 98
Nožnica B3, lega merjenih mest.

Figure 99
The back of the B3 dagger scabbard: measured Spot 1 on the rivet shaft as well as Spots 2 and 3 on the suspension loops.
Slika 99
Nožnica B3, hrbtna stran, mesta 1 (trn zakovice) ter 2 in 3 (zanki za obešanje).

662 Cf. B1.

Figure 97a
The front of the B2 dagger scabbard: measured Spots 1, 2 and 4 on the shiny silvery inlays as well as Spot 3 on the green inlay. The measurement on Spot 6 on the handle revealed in a few seconds that it was iron, therefore the quantitative measurement was omitted. Number 6 was then assigned to the metal inlay in the scabbard (cf. *Fig. 97c* and *Table B2: 6*).

Slika 97a
Nožnica B2, sprednja stran, mesta 1, 2 in 4 (srebrno svetleči se vložki) in 3 (zelen vložek). Na mestu 6 na ročaju (vidno na fotografiji) smo po kratki meritvi (10 sekund) ugotovili, da gre za železo, zato kvantitativne meritve nismo izvedli. S številko 6 smo nato označili tavširan kovinski okras na nožnici (prim. *sl. 97c* in *pregl. B2: 6*).

Figure 97b
The front of the B2 dagger scabbard: measured Spot 2 on the shiny silvery inlay and Spot 5 on the disc terminal coating.

Slika 97b
Nožnica B2, sprednja stran, mesti 2 (srebrno svetleč se vložek) in 5 (prevleka na površini konice).

Figure 97c
The front of the B2 dagger scabbard: measured Spot 6 on the yellow shiny metal inlay and Spot 9 on the inlaid cross (the measured spot is not marked with a number).

Slika 97c
Nožnica B2, sprednja stran, mesti 6 (rumen svetleč se kovinski vložek) in 9 (tavširan križček; oznaka merjenega mesta na posnetku je brez številke).

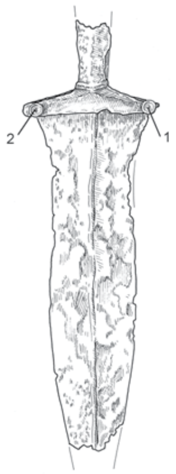


Figure 100
Dagger B4: the measured spots.

Slika 100
Bodalo B4, lega merjenih mest.

Figure 101
The front of the B4 dagger scabbard: measured Spots 1 and 2 on the rivet heads.

Slika 101
Nožnica B4, sprednja stran, mesti 1 in 2 (glavici zakovic).

B3 (*pregl. B3, sl. 98, 99*)

Meritve smo naredili neposredno po zaključku konservacije na mestih, s katerih smo v glavnem odstranili patino.

Rezultati kažejo, da so izmerjena zakovica in obe izmerjeni zanki nožnice iz medenine (*pregl. B3: 1–3*). Iz izmerjenih odstotkov železa v točkah 2 in 3 sklepava, da so bili na merjenih mestih ostanki patine.

B4 (*pregl. B4, sl. 100, 101*)

Obe zakovici smo merili na sveže očiščeni površini, brez dodatnega odstranjevanja vrhnjih plasti.

Rezultati kažejo, da sta zakovici iz medenine (*pregl. B4: 1, 2*); iz izmerjenih odstotkov železa sklepava, da so bili na merjenih mestih ostanki patine.

C. Helmets

C1 (*Table C1, Figs. 102, 103a–d*)

Measurements were taken several years after conservation. On Spots 1–4, a thin surface layer was removed before measuring so as to expose the metal core.

The helmet bowl is of bronze with ca. 11–12% tin (*Table C1: 1–2*) and the cheek piece hinges of bronze with a lower tin content (*Table C1: 3–4*). Both measured rivets are of copper (*Table C1: 5–6*).

Spot/ Mesto	Ni	Cu	As	Pb	Sn
1*	0.3	88.1	0.10	0.12	11.4
2*	0.3	87.6	0.14	0.07	11.9
3*	0.3	91.7	0.35	0.08	7.6
4*	0.6	95.1	0.06	-	4.3
5	0.4	99.1	0.41	0.07	-
6	0.3	99.3	0.04	0.15	0.2

Table C1
Iron (Fe) is not included in the table as its content was too low to distinguish its peak from the copper escape peak.

Preglednica C1
Železo (Fe) ni vključeno v preglednico, ker ga je bilo izmerjenega tako malo, da ga ni bilo mogoče ločiti od bakrovega ubežnega vrha.

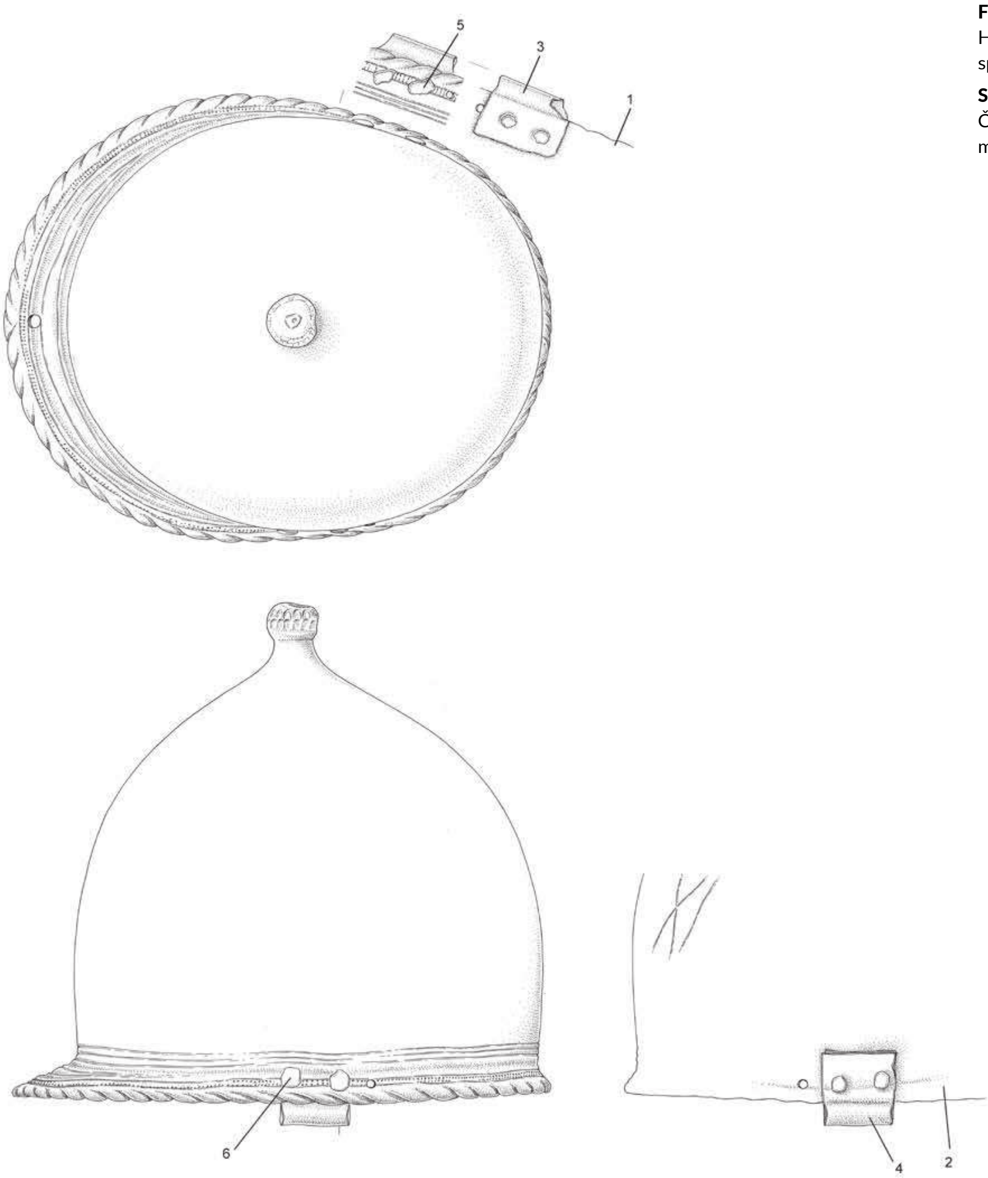


Figure 102
Helmet C1: the measured spots.

Slika 102
Čelada C1, lega merjenih mest.

Figure 103a
The right inner side of helmet C1: measured Spot 1 on the rim of the bowl and Spot 3 on the cheek-piece hinge, both without patina.

Slika 103a
Čelada C1, notranjost desne strani, mesti 1 (rob kalote) in 3 (zanka tečaja), obe brez patine.

Figure 103b
The left inner side of helmet C1: measured Spot 2 on the rim of the bowl and Spot 4 on the cheek-piece hinge, both without patina.

Slika 103b
Čelada C1, notranjost leve strani, mesti 2 (rob kalote) in 4 (zanka tečaja), obe brez patine.

Figure 103c
The right outer side of helmet C1: measured Spot 5 on the rivet head.

Slika 103c
Čelada C1, desna stran, mesto 5 (glava zakovice).

Figure 103d
The left outer side of helmet C1: measured Spot 6 on the rivet head.

Slika 103d
Čelada C1, leva stran, mesto 6 (glava zakovice).

Spot/ Mesto	Fe	Ni	Cu	Zn	As	Se	Pb	Ag	Sn
1*	1.8	0.3	87.2	-	0.14	-	-	-	10.5
2*	-	0.5	99.2	-	0.17	-	-	-	0.1
3*	-	0.4	99.4	-	0.18	-	-	-	-
4*	-	0.5	93.5	-	0.19	-	0.44	-	5.4
5*	1.9	0.6	92.2	-	0.18	-	0.37	-	4.7
6	-	0.1	97.6	1.7	0.03	-	0.18	0.04	0.3
7*	-	0.1	85.5	14.0	0.03	0.11	0.11	0.04	0.2
8	8.5	-	4.9	1.0	0.11	0.03	24.0	-	61.4
9	2.0	-	0.72	0.1	0.08	0.04	46.3	-	50.7
10	-	0.3	91.1	8.2	0.05	0.01	0.06	0.06	0.3
11*	-	0.2	76.1	23.2	-	-	0.07	0.11	0.4
12	-	0.3	89.8	9.3	0.04	-	0.19	0.08	0.3
13*	3.0	-	0.93	0.25	0.16	-	52.9	0.16	42.7
14*	1.3	0.2	75.0	22.4	0.08	-	0.25	0.25	0.25

Table C2

Preglednica C2

C. Čeladi

C1 (*pregl. C1, sl. 102, 103a–d*)

Meritve smo naredili več let po konservaciji predmeta; z mest 1–4 smo odstranili tanek površinski sloj.

Rezultati meritev kažejo, da je kalota čelade iz brona, ki vsebuje približno 11–12 % kositra (*pregl. C1: 1–2*), tečaja pa sta iz brona z manjšim odstotkom kositra (*pregl. C1: 3–4*). Obe izmerjeni zakovici sta bakreni (*pregl. C1: 5–6*).

C2 (*pregl. C2, sl. 104, 105a–c*)

Meritve smo delali po konservaciji. Z mest 1–5, 7, 11, 13–14 smo v glavnem odstranili tenko površinsko plast; visoke vsebnosti železa, ki jih kažejo meritve na mestih 1, 5 in 13, so najverjetneje povezane z nepopolno odstranjeno patino.

Rezultati meritev kažejo, da je kalota čelade iz brona, ki vsebuje okoli 10–11 % kositra (*pregl. C2: 1*).

Nastavki za okras ob straneh in na zadnjem delu čelade so iz medenine, v kateri smo izmerili okoli 22–23 % (*pregl. C2: 11, 14*) oziroma 14 % cinka (*pregl. C2: 7*).

Nastavki za okras so bili na kaloto čelade prispajkani z zlitino kositra in svinca (*pregl. C2: 8, 9, 13*).

Tečaja za pritrditev ličnih ščitnikov sta iz brona z okoli 5 % kositra (*pregl. C2: 4–5*) in sta bila na kaloto pritrjena z bakrenimi zakovicami (*pregl. C2: 2–3*).

C2 (*Table C2, Figs. 104, 105a–c*)

Measurements were taken after conservation. Spots 1–5, 7, 11, 13–14 were prepared by removing patina so as to expose the metal core; the high iron content on Spots 1, 5 and 13 most likely indicates incomplete patina removal.

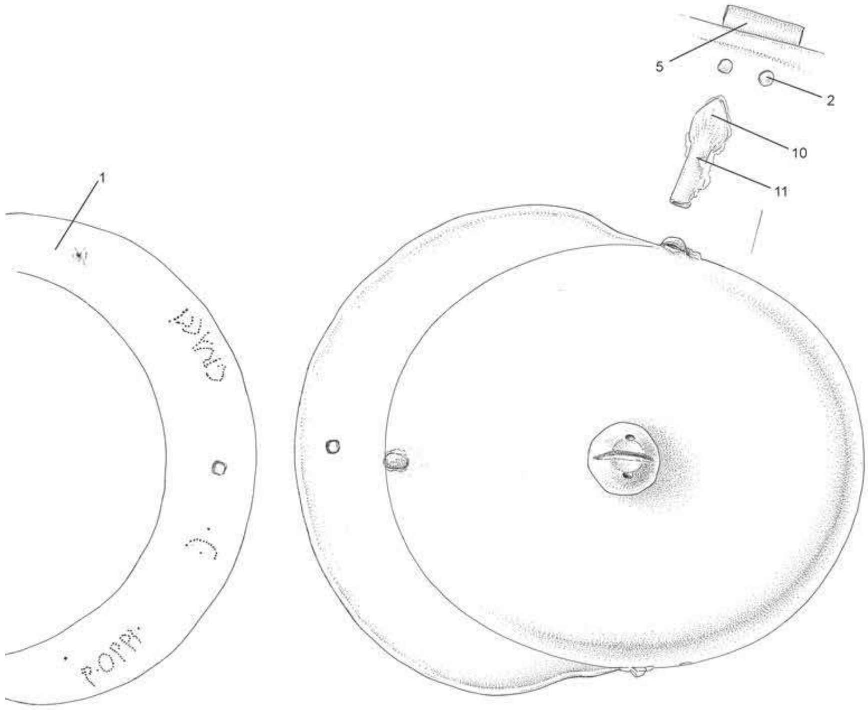
The helmet bowl is of bronze with ca. 10–11% tin (*Table C2: 1*).

The plume tubes at the sides and the back are of brass with ca. 22–23% (*Table C2: 11, 14*) and 14% zinc (*Table C2: 7*), respectively.

The plume tubes were fastened to the bowl with a tin-lead alloy solder (*Table C2: 8, 9, 13*).

The cheek piece hinges are of bronze with ca. 5% tin (*Table C2: 4–5*) and were fastened to the bowl with copper rivets (*Table C2: 2–3*).

We could not reach the dark grey material inside the crest knob (Catalogue, *Fig. C2.2g*) with the proton beam, hence some of it was scraped off with a piece of cotton that was then measured. The results reveal an alloy of lead (95%) and tin (4.5%). For comparison, we repeated the procedure with a modern lead-tin solder in a 40 : 60 ratio and the measurement showed a considerably higher percentage of lead (80 : 20) with respect to its actual share in the alloy. This suggests that the same may hold true of the alloy used to fill the crest knob; the said filling can therefore be seen as made of a tin-lead alloy in which lead probably predominates.



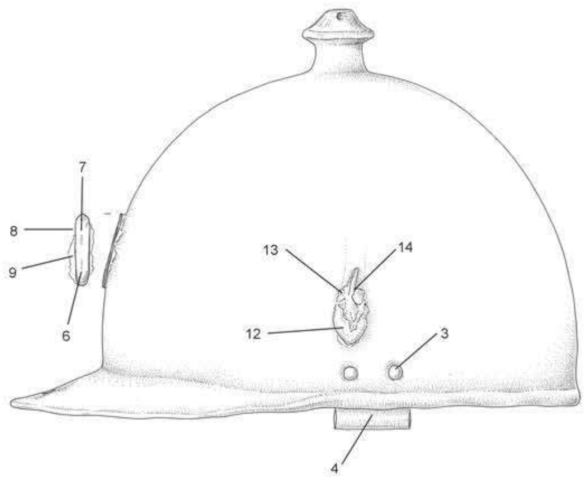


Figure 104
Helmet C2: the measured spots.

Slika 104
Čelada C2, lega merjenih mest.

H. Pieces of military belts

H1 (*Table H1, Figs. 106, 107*)

Measurements were taken during conservation. Patina was removed on Spots 1–3.

Measurements on spots without patina reveal that the belt plate is made of an alloy with at least 95% silver (*Table H1: 1*); the same is true of the measurements on the patina (*Table H1: 4, 6*). The differences in the contents measured on the patina and on surfaces without patina are relatively small. It is not unusual for

Spot/ Mesto	Fe	Cu	Au	Pb	Ag
1*¤	0.36	3.20	0.99	0.24	95.2
2*	0.30	3.20	1.00	0.27	95.2
3*	0.30	3.40	0.93	0.29	95.1
4	1.3	1.50	0.88	0.16	96.2
5	0.72	2.80	0.86	0.32	95.3
6	0.93	1.60	0.95	0.19	96.3
7	0.18	0.76	0.69	0.38	98.0
8	0.90	0.14	0.30	0.14	98.5
9	0.42	0.22	0.46	0.16	98.7
10	0.56	1.20	1.10	0.22	96.9
11	1.5	1.00	7.3	0.10	90.0
12	2.3	0.91	20.7	0.07	76.0
13	2.9	3.90	2.70	0.69	89.9
14	0.77	3.50	1.30	0.34	94.1

Table H1
Measurements were taken with a 0.1 mm thick aluminium absorber except on Spots 2 and 12, where a 0.3 mm thick absorber was employed. Measurements with a narrow beam were not taken with an absorber.

Preglednica H1
Meritve so bile opravljene z aluminijevim absorberjem debeline 0,1 mm, razen na mestih 2 in 12, kjer je bila debelina absorberja 0,3 mm. Pri meritvi z ozkim žarkom absorberja nismo uporabili.

Temnosive snovi v gumbu čelade (Katalog, *sl. C2.2g*) nismo mogli doseči s protonskim žarkom, zato smo njeno približno elementno sestavo skušali ugotoviti tako, da smo jo na majhnem delu podrgnili s kosmom vate ter tega nato merili. Rezultati so pokazali zlitino svinca (95 %) s kositrom (4,5 %). Za primerjavo smo enako naredili s sodobnim svinčevo-kositrnim lotom v razmerju 40 : 60. Izkazalo se je, da je meritev ostrgane plasti na vati pokazala bistveno višji odstotek svinca (80 : 20). Sklepamo, da je (lahko) enako pri zlitini, s katero je bil zalit gumb čelade C2, za katerega torej lahko rečemo le, da je iz zlitine svinca in kositra, v kateri verjetno prevladuje svinec.

Figure 105a
The left side of helmet C2: measured Spot 1 on the neckguard, Spot 3 on the rivet head, Spot 4 on the cheek-piece hinge, Spots 12 and 14 on the plume tubes, as well as Spot 13 on the solder that fixed the plume tubes to the bowl.

Slika 105a
Čelada C2, leva stran, mesta 1 (vratni ščitnik), 3 (glavica zakovice), 4 (zanka tečaja), 12 in 14 (nastavek za okras) ter 13 (lota ob nastavku).

Figure 105b
The right side of helmet C2: measured Spot 2 on the rivet head, Spot 5 on the cheek-piece hinge as well as Spot 10 and Spot 11 on the plume tubes.

Slika 105b.
Čelada C2, desna stran, mesta 2 (glavica zakovice), 5 (zanka tečaja) ter 10–11 (nastavek za okras).

Figure 105c
The back of helmet C2: measured Spots 6 and 7 on the plume tubes as well as Spots 8 and 9 on the solder.

Slika 105c.
Čelada C2 zadaj, mesta 6–7 (nastavek za okras) ter 8–9 (lot).

H. Deli vojaških pasov

H1 (*pregl. H1*, *sl. 106, 107*)

Meritve smo naredili med postopkom konservacije; z mest 1–3 smo dodatno odstranili tenko površinsko plast.

Meritve na mestih brez patine so pokazale, da je okov iz zlitine z najmanj 95 % srebra (*pregl. H1: 1*); enako kažejo meritve na patini (*pregl. H1: 4, 6*). Razlike v vsebnosti posameznih elementov med meritvami na patini in na mestih brez patine so razmeroma majhne. Majhen delež zlata je pri rimskih srebrovih zlitinah pogost.[663] Iz rezultatov meritev na patini gumbov na tečajih in glavi zakovice v sredini okova sklepamo, da so iz enake ali zelo podobne zlitine kot okov (*pregl. H1: 7–9*). Iz podobne srebrove zlitine sta tudi zatiča zakovic, pri katerih smo izmerili patino (*pregl. H1: 13–14*).

Na s krogci punciranem osrednjem delu lica okova so meritve potrdile s prostim očesom vidno pozlato (*pregl. H1:11–12*; prim. Katalog, *sl. H1.1a*).

Meritev na reliefno dvignjenem delu okrasa je pokazala v primerjavi z meritvami na mestih 1–3 minimalno povečan odstotek zlata (*pregl. H1: 10*). Pregled teh delov okova pod mikroskopom je pokazal zelo slabo ohranjene, a nedvomne ostanke pozlate (prim. Katalog, H1).

Večje povečanje deleža zlata smo ugotovili na trnih zakovic s polkrožnimi okrasnimi glavicami (*pregl. H1:*

663 Prim. zgoraj, A13.

Roman silver to contain substantial traces of gold.[663] The results on the patina of the spherical terminals and of the rivet head in the centre of the plate suggest they are of the same or very similar alloy as the rest of the plate (*Table H1: 7–9*). We also measured the patina on two rivet shanks, which were found to be of a similar silver alloy (*Table H1: 13–14*; the relatively high gold content, particularly on Spot 13, is difficult to explain as the measurements were taken on the patina).

Measurements confirmed the visually detected gilding on the central front part of the plate, which is chased with tiny circles (*Table H1:11–12*; cf. Catalogue, *Fig. H1.1a*).

The measurements on the raised parts of the decoration show a minimal increase in gold content (*Table H1: 10*) in comparison with the measurements on Spots 1–3 (*Table H1:* 1–3). A repeated examination of this part under the microscope revealed poorly surviving, but positively identifiable remains of gilding (cf. Catalogue, H1).

Higher gold content has been established on the shanks of the rivets with decorative hemispherical heads (*Table H1: 13–14*); the heads bear no traces of gilding (cf. measurement on the central rivet: *Table H1: 9*), which suggests that gold spread there either while gilding other parts or during conservation (surfaces with and without gilding were cleaned with the same tool).

The results of the XRF analyses correspond with those of the PIXE analyses.[664]

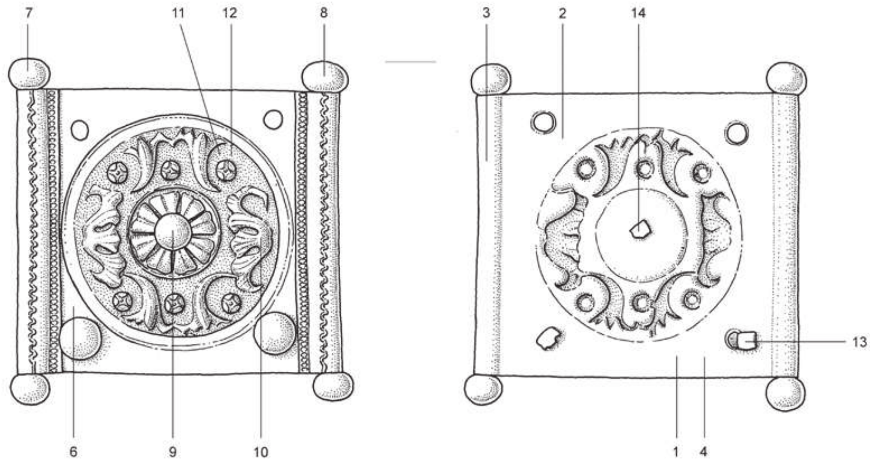


Figure 106
Belt-plate H1: the measured spots.
Slika 106
Pasni okov H1, lega merjenih mest.

Spot/ Mesto	wFe	Ni	Cu	Zn	As	Ag	Sn	Sb	Au	Pb
1	5.8	-	3.8	0.4	0.05	89.1	-	-	0.67	0.13
2	3.7	-	5.6	0.2	0.07	89.4	-	-	0.60	0.42
3	0.97	-	80.6	16.3	0.078	0.31	1.2	-	-	0.52
3*¤	0.56	-	79.6	18.3	0.043	0.22	1.0	-	-	0.32
4	0.83	0.21	76.3	20.3	0.066	0.18	1.1	0.38	-	0.59
4*¤	0.61	0.22	77.2	20.0	0.038	0.12	1.0	0.27	-	0.43
5	46.4	-	48.8	2.1	0.23	0.49	1.3	-	-	0.70
6*	-	-	99.8	-	-	-	-	-	-	0.19
7*	-	-	100.0	-	-	-	-	-	-	0.02

Table H2
Preglednica H2

H2 (*Table H2, Figs. 108, 109a–c*)

Measurements were taken on three occasions, all after conservation. The second measurements on Spots 3 and 4 were taken on surfaces after the patina had been removed (cf. *Fig. 109b, c*). The table only gives the last measurement for each spot.

The buckle and associated plate are both of brass (*Table H2: 3, 4*). They are silvered on the front (*Table H2: 1, 2*). The differential PIXE analyses on the well-preserved shiny silvery surface show the layer of high-quality silver alloy to be relatively homogeneous and thick enough for the excitation of X-rays in the substrate to be negligible; the silver layer is estimated to be more than 30 μm thick. The silver

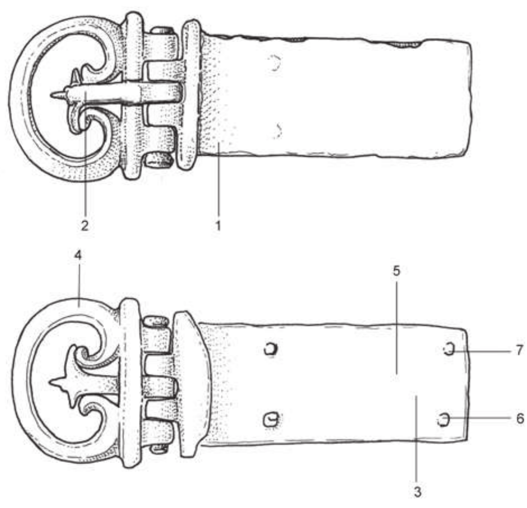


Figure 108
The H2 belt-plate and buckle: the measured spots.
Slika 108
Pasna spona in okov H2, lega merjenih mest.

663 Cf. above, A13.
664 Cf. Istenič, Milić, Šmit 2003, 291–293, Table 3.

Figure 107
The back of the H1 belt-plate: measured Spots 1–3 on the surfaces without patina.

Slika 107
Pasni okov H1, lega merjenih mest 1–3 z odstranjeno patino na spodnji strani.

Figure 109a
The front of the H2 belt-plate and buckle: measured Spots 1 and 2 on the coating with silvery appearance.

Slika 109a
Pasna spona z okovom H2, zgornja stran, mesti 1 in 2 (srebrna plast na površini).

Figure 109b
The back of the H2 belt-plate and buckle: measured Spots 3 and 4 before the removal of the patina, Spot 5 on the dark grey layer, as well as Spots 6 and 7 on the rivets.

Slika 109b
Pasna spona z okovom H2, spodnja stran, mesta 3–4 na okovu oz. sponi (patina še ni odstranjena), 5 (temnosiva plast na površini okova) ter 6–7 (zakovici).

Figure 109c
The back of the H2 belt-plate and buckle: measured Spots 3 and 4 after the removal of the patina.

Slika 109c
Pasna spona z okovom H2, mesti 3 in 4 z odstranjeno patino na spodnji strani spone oz. okova.

13–14); ker na glavicah ni sledov pozlate (prim. meritev na osrednji zakovici: *pregl. H1: 9*), domnevava, da je zlato tja zašlo med zlatenjem sprednje strani oziroma med konservacijo (pozlačene in nepozlačene dele namreč čistijo z istim orodjem).

Z rezultati meritev PIXE so skladne analize XRF.[664]

H2 (*pregl. H2, sl. 108, 109a–c*)

Meritve smo izvajali trikrat, vse po konservaciji. Po prvih meritvah smo z mest 3 in 4 bolje odstranili patino (prim. *sl. 109b, c*). V preglednici rezultatov so navedene le zadnje meritve na vsakem mestu.

Spona in pripadajoči okov sta iz medenine (*pregl. H2: 3, 4*). Njuna sprednja stran je posrebrena (*pregl. H2: 1, 2*). Diferencialne analize PIXE na dobro ohranjeni srebrno sijoči površini so pokazale, da je plast visokokvalitetne srebrove zlitine razmeroma homogena in tako debela, da je bilo vzbujanje rentgenskih žarkov v podlagi zanemarljivo – debelino srebrne plasti ocenjujeva na večjo od 30 µm. Na površini izmerjena vsebnost srebra je – verjetno zaradi kontaminacije s patino – malo manjša od dejanske.[665]

Meritve na temnosivi plasti, vidni na več mestih na hrbtni strani okova, nakazujejo, da ta stran ni bila posrebrena (*pregl. H2: 5*).

Zakovice so bakrene (*pregl. H2: 6, 7*).

H3 (*pregl. H3, sl. 110, 111a, b*)

Z mest 1–3 smo odstranili površinsko plast, vendar meritve na mestu 3 nismo izvedli. Žarek tarče namreč ne bi zadel pod ustreznim kotom.

Rezultati meritev kažejo, da sta ploščica in zanka iz zelo kvalitetne srebrove zlitine, ki vsebuje okrog 97 % srebra (*pregl. H3: 1–2*); zelo nizka vsebnost zlata je za rimske srebrove zlitine običajna.[666] Na zgornji strani ploščice so ostanki pozlate (*pregl. H3: 4–5*). Glede na odsotnost živega srebra domnevava, da so za zlatitev uporabili zlate lističe.[667]

664 Prim. Istenič, Milić, Šmit 2003, 297–298, tabla 3.
665 Šmit, Istenič, Knific 2008, 2331, 2332.
666 Prim. zgoraj, A13.
667 Šmit, Istenič, Knific 2008, 2331, 2332.

content measured on the surface is – probably due to a contamination with patina – slightly lower than actual.[665]

The measurement on the dark grey layer visible in several areas on the back of the plate suggests that the back was not silvered (*Table H2: 5*).

The rivets are of copper (*Table H2: 6, 7*).

H3 (*Table H3, Figs. 110, 111a, b*)

The surface layer on Spots 1–3 was removed, but Spot 3 was not measured as we found the beam would not hit the target at the appropriate angle.

The head and the loop are of silver alloy with ca. 97% silver (*Table H3: 1–2*); it is common for Roman silver alloys to contain traces of gold.[666] The upper side of the head bears traces of gilding (*Table H3: 4–5*). The absence of mercury suggests that gold leaves were used to gild the fastener.[667]

Spot/ Mesto	Fe	Cu	Au	Pb	Bi	Ag
1*	0.2	1.59	0.54	0.32	-	97.3
2*	1.0	1.08	0.79	0.19	0.03	96.9
4	10.4	0.93	16.4	0.27	-	72.0
5	5.2	0.96	12.8	0.28	0.03	80.8

Table H3
Preglednica H3

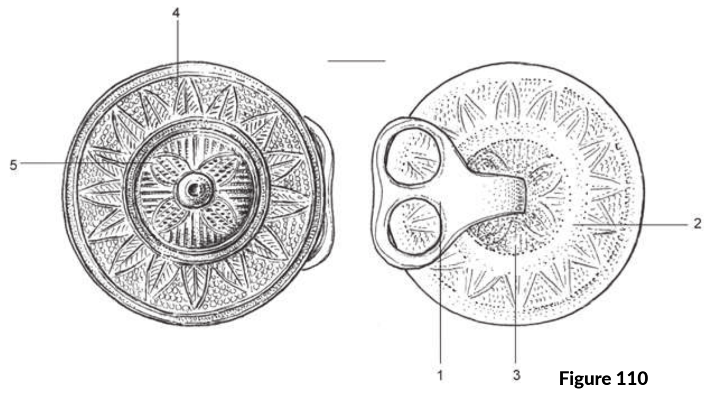


Figure 110
The H3 button and loop fastener: the measured spots.

Slika 110
Ploščica z dvojno zanko H3, lega merjenih mest.

H4 (*Table H4, Figs. 112, 113a–c*)

The head of the fastener was cast of an alloy of tin and lead roughly in a 1 : 1 ratio (*Table H4: 3*). The surviving part of the loop at the back is of brass (*Table H4: 5*).

Measurements on two other spots of the patina-covered front of the head show tin and lead, as well as iron that mainly originates in the patina (*Table H4: 1–2*). Great differences in the ratio between tin and lead probably reflect the inhomogeneity of the alloy.

Spot/ Mesto	Fe	Cu	Zn	As	Ag	Sn	Pb
1	55.0	2.5	0.3	0.10	0.14	12.8	29.2
2	7.4	1.04	0.13	-	-	55.7	35.8
3*	0.4	1.41	0.06	-	-	48.8	49.3
5*¤	0.22	78.9	19.9	0.023	0.11	0.7	0.13
5*	0.26	76.9	21.7	0.025	0.12	0.6	0.42

Table H4
Spot 4 was not measured.

Preglednica H4
Meritev na mestu 4 ni bila izvedena.

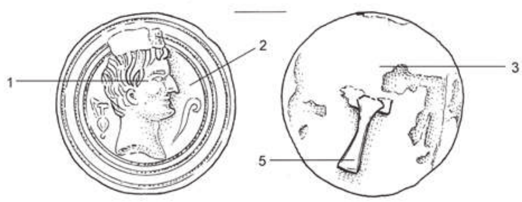


Figure 112
The H4 button and loop fastener: the measured spots.

Slika 112
Ploščica z zanko H4, lega merjenih mest.

665 Šmit, Istenič, Knific 2008, 2331, 2332.
666 Cf. above, A13.
667 Šmit, Istenič, Knific 2008, 2331, 2332.

Figure111a
The back of the H3 button and loop fastener: measured Spot 1 on the loop and Spot 2 on the head; the Spot 3 was not measured.

Slika 111a
Ploščica z dvojno zanko H3, spodnja stran, lega mest 1 (na zanki), 2 in 3; na mestu 3 meritev ni bila opravljena.

Figure 111b
The upper side of the H3 button and loop fastener: measured Spots 4 and 5, both with patina.

Slika 111b
Ploščica z dvojno zanko H3, zgornja stran, lega mest 4 in 5, obe s patino.

H4 (*pregl. H4, sl. 112, 113a–c*)

Ploščica je ulita iz zlitine kositra in svinca v razmerju približno 1 : 1 (*pregl. H4: 3*). Nastavek z odlomljenim zaključkom na hrbtni strani predmeta je iz medenine (*pregl. H4: 5*).

Meritev na dveh mestih na patini na licu je, poleg železa, ki izvira predvsem iz patine, pokazala kositer in svinec (*pregl. H4: 1–2*). Velika razlika v razmerju med kositrom in svincem v meritvah je verjetno posledica nehomogenosti zlitine kositra s svincem.

Figure 113a
The front of the H4 button and loop fastener: measured Spots 1 (on the cheek of the man's head) and 2.

Slika 113a
Ploščica H4, sprednja stran, lega mest 1 (merjeno na licu portreta, pod konico puščice, ki označuje mesto 1) in 2.

Figure 113b
The back of the H4 button and loop fastener: measured Spots 3 and 4 on the head (the patina was removed from Spot 3) and Spot 5 on the loop, before the patina was removed.

Slika 113b
Ploščica H4, hrbtna stran, mesta 3 in 4 (ploščica; na mestu 3 je patina odstranjena) ter 5 (zanka, pred odstranitvijo patine).

Figure 113c
The back of the H4 button and loop fastener: Spot 5 on the loop.

Slika 113c
Ploščica H4, hrbtna stran, lega mesta 5 na zanki.

H5 (*Table H5, Figs. 114, 115a, b*)

Commentary

The head is of tin-lead alloy (*Table H5: 3*). The measurement on the patina-covered front (*Table H5: 1*) shows no significant deviations from the measurements on the surface without patina (*Table H5: 3*). This is clear when recalculating the results by disregarding iron: Spot 1 reveals 37.1% tin and 58.3% lead, while Spot 3 reveals 35.5% tin and 59.4% lead. This shows that the front was most likely not plated either with tin or other metals.

The surface on the back is rather uneven and its patina has a considerably lower lead content (*Table H5: 2*); this may reflect an inhomogeneous alloy or a different ion transport in the patination process.

Spot/ Mesto	Fe	Cu	Zn	Sn	Pb
1	11.0	0.48	0.18	57.5	30.8
2	13.9	7.81	0.32	59.9	18.0
3*	2.6	0.71	0.05	61.6	35.1

Table H5

Preglednica H5

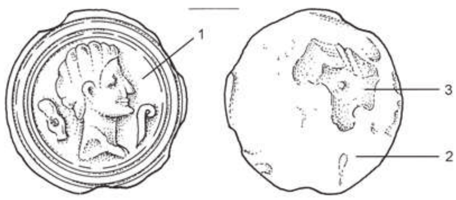


Figure 114
Button and loop fastener H5: the measured spots.

Slika 114
Ploščica H5, lega merjenih mest.

H6 (*Table H6, Figs. 116, 117*)

The buckle is of brass with at least ca. 16% zinc.

Spot/ Mesto	Fe	Ni	Cu	Zn	As	Ag	Sn	Pb
1*	0.34	0.10	83.2	15.8	-	0.07	0.3	0.19
1*¤	0.33	0.08	82.7	16.2	0.011	0.07	0.4	0.22

Table H6

Preglednica H6

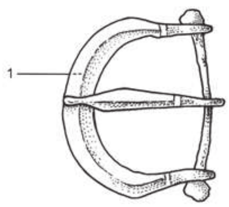


Figure 116
Buckle H6: the measured spot.

Slika 116
Pasna spona H6, lega merjenega mesta.

I. Decorations

I1 (*Table I1, Fig. 118*)

The medallion is made of an alloy of tin and lead roughly in a 2 : 1 ratio (*Table I1: 8, 9*). The measured iron most likely indicates that the proton beam hit the surrounding area, where the patina had not been removed. The measurements on Spots 12 and 13 also indicate a tin-lead alloy, but in a different ratio; here, the patina was removed from areas of damage to the original surface. Spots 12 and 13 are smaller than Spots 8 and 9, hence the proton beam also hit the surrounding area. This shows that the latter two spots are relevant in terms of the alloy used to cast the object.

The front is silvered (*Table I1: 1, 2, 12, 13*). The differences in the measured silver content on the surface are caused by uneven preservation of the silvering and possibly also the uneven thickness of the silvering layer, as the beam penetrated to the underlying metal; if the silvering layer were ca. 30 µm thick or more, the measurements would only show silver. The traces of gold in the silver (*Table I1: 2, 13*) are not indicative of intentional addition, but rather originate in the ore.[668]

Spot/ Mesto	Mn	Fe	Cu	Zn	Ag	Sn	Au	Pb
1	0.6	8.0	0.8	-	40.0	32.1	-	18.6
2	0.3	16.4	0.6	-	65.8	9.2	0.3	7.3
3	0.4	11.3	0.1	0.05	-	75.5	-	12.6
4	0.1	6.7	0.5	-	-	92.2	-	0.4
5	0.3	6.8	13.4	0.6	9.2	47.6	-	22.0
6	0.1	6.5	0.4	0.05	-	86.9	-	6.0
7*¤	0.1	3.5	7.44	0.3	1.0	53.1	-	34.4
8*¤	0.1	3.2	0.25	0.2	-	60.3	-	35.9
9*¤	0.2	6.9	0.27	0.2	-	61.4	-	30.9
10*¤	0.1	6.0	0.34	0.3	-	92.1	-	1.0
11*¤	0.1	4.3	3.45	0.4	1.1	53.8	-	36.8
12*¤	0.2	5.9	0.47	0.4	11.6	38.4	-	42.9
13*¤	0.3	10.8	0.82	0.3	30.9	19.6	0.5	36.8

Table I1

Preglednica I1

668 Hughes, Hall 1979, 325–335; Istenič 2003b, 283; Šmit, Istenič, Knific 2008, 2331.

H5 (*pregl. H5, sl. 114, 115a, b*)

Figure. 115a
The front of the H5 button and loop fastener: measured Spot 1.
Slika 115a
Ploščica H5, sprednja stran, lega mesta 1.

Figure. 115b
The back of the H5 button and loop fastener: measured Spots 2 (with patina) and 3 (the patina was removed).
Slika 115b
Ploščica H5, lega mest 2 in 3 (patina je odstranjena) na hrbtni strani.

Ploščica je iz zlitine kositra in svinca (*pregl. H5: 3*). Meritev na patini na licu (*pregl. H5: 1*) ni pokazala pomenljivih odstopanj od meritev na mestu brez patine (*pregl. H5: 3*). To postane jasno, če rezultata preračunamo tako, da zanemarimo železo: na mestu 1 dobimo 37,1 % kositra in 58,3 % svinca, na mestu 3 pa 35,5 % kositra in 59,4 % svinca. Sprednja stran torej najverjetneje ni imela kositrne ali druge prevleke.

Na patini hrbtne strani, ki ima precej neenotno površino, smo izmerili bistveno manjši delež svinca (*pregl. H5: 2*). Vzrok je morda nehomogenost zlitine ali drugačen transport ionov po tvorbi patine.

H6 (*pregl. H6, sl. 116, 117*)

Figure 117
The back of the H6 buckle: measured Spot 1 (patina was removed).
Slika 117
Pasna spona H6, hrbtna stran, lega mesta 1 (patina je odstranjena).

Predmet je iz medenine z najmanj okoli 16 % cinka.

I. Odlikovanji

I1 (*pregl. I1, sl. 118*)

Figure 118
Medallion I1: the measured spots on the front and back.
Slika 118
Ploščica I1 z reliefnim okrasom, lega merjenih mest.

Predmet je iz zlitine kositra in svinca približno v razmerju 2 : 1 (*pregl. I1: 8, 9*). Izmerjeno železo najverjetneje nakazuje, da je protonski žarek zadel tudi okolico površine, s katere je bila odstranjena patina. Na zlitino kositra in svinca, vendar v drugačnih razmerjih, kažeta tudi meritvi na mestih 12 in 13. Tu smo patino odstranili s površine mest, kjer je bila prvotna površina predmeta že poškodovana. Merjeni mesti sta manjši kot mesti 8 in 9, zato je protonski žarek poleg za meritev predvidene površine zadel tudi okolico; za predstavo o zlitini, iz katere je bil predmet ulit, sta merodajnejši meritvi na mestih 8 in 9.

Sprednja stran predmeta je bila posrebrena (*pregl. I1: 1, 2, 12, 13*). Razlike v izmerjenem deležu srebra na površini so povezane z neenakomerno ohranjenostjo posrebritve in lahko tudi z neenakomerno debelino prvotnega sloja srebra na površini – žarek je namreč dosegel in izmeril plast pod srebrom. Pri debelini srebrne prevleke okoli 30 μm ali več bi meritve pokazale le srebro. Izmerjeni sledovi zlata v srebru (*pregl. I1: 2, 13*) niso posledica namernega dodajanja, temveč izvirajo iz rude.[668]

668 Hughes, Hall 1979, 325–335; Istenič 2003b, 294; Šmit, Istenič, Knific 2008, 2331.

Measurements on the back (*Table I1: 5, 7, 11*) also reveal the presence of silver, which indicates that silver was transferred there either during the original silvering of the front or during conservation (cf. above, H1).

Measurements on the part of the back bearing traces of incised furrowing (Surface 3, cf. Chapter 12.1, *Fig. 50: 3*) reveal the presence of copper (*Table I1: 5, 7, 11*). This may indicate the use of tools of copper alloy for treating the back surface of the medallion or the surface of the backing.[669] This is supported by the highest copper content measured on the surface (*Table I1: 5*) and a lower one in areas where the surface layer had been removed (*Table I1: 7, 11*).

Surface 2 (*Fig. 50: 2*; cf. Chapter 12.1) revealed a high tin content (92.1, 92.2 and 86.9%), which indicates the area where the medallion adhered well to the backing of either tin or an alloy of tin and a low share of lead (*Table I1: 4, 6, 10*).

The measurement on Surface 1 (*Table I1: 3; Fig. 50: 1*) indicates the area where the back of the medallion adhered very poorly to the backing.

The alloy of tin and lead roughly in a 2 : 1 ratio, which was used for the I1 medallion, has the lowest melting point in the Sn-Pb binary system, at 183 °C. This made it highly fluid and suitable for filling small sunken areas (e.g. embossed decoration) during casting. The melting point of the backing, made of either tin or an alloy with tin predominant, was higher, roughly 220–235 °C. The medallion was presumably fastened to the backing in either of two ways: a) by pressing it against the backing previously heated to the temperature that made it malleable/plastic, or b) by heating the backing together with the medallion and thereby indirectly heating the back of the medallion which (partly) fused with the backing because of the lower melting point. Surfaces 1, 2 and 3 (*Fig. 50*) indicate that the back only adhered to the backing in a small part (Surface 2).[670]

The relatively high contents of iron and manganese possibly originate from the patina, which formed in the prolonged exposure to water and was apparently not completely removed on Spots 7–13.

I2 (*Table I2, Figs. 119, 120*)

The object is well preserved and conservation was not necessary. Spot 1 was prepared by removing a thin layer of surface.

The object is made of an alloy of tin with ca. 2% copper and less than 1% lead (*Table I2: 1*). The measurement on the surface without visible patina, where the surface layer was not removed (*Table I2: 2*), shows a higher copper content.

Table I2
Preglednica I2

Spot/ Mesto	Fe	Cu	Pb	Au	Sn
1*	0.3	1.96	0.07	0.010	97.7
2	0.4	4.13	0.33	0.009	95.1

Figure 119
Torque I2: the measured spots.
Slika 119
Torkves I2, lega merjenih mest.

669 Dobršek 2003.
670 Dobršek 2003.

Na več mestih izmerjeni delež srebra nakazuje, da se je pri posrebritvi lica ali med konservatorskim postopkom (prim. zgoraj, H1) malo posrebritve zaneslo na hrbet predmeta (*pregl. I1: 5, 7, 11*).

Meritve na hrbtni strani so na površini s sledovi brazdanja (površina 3, prim. pogl. 12.1, *sl. 50: 3*) pokazale prisotnost bakra (*pregl. I1: 5, 7, 11*). Morda je to povezano z obdelavo površine hrbtne strani predmeta I1 ali pa z obdelavo površine, na katero je bil predmet prispajkan, z orodjem iz bakrove zlitine.[669] Temu v prid govori dejstvo, da smo najvišji odstotek bakra izmerili na površini (*pregl. I1: 5*), bistveno manjšega pa na mestih z odstranjenim površinskim slojem (*pregl. I1: 7, 11*).

Na površini 2 (*sl. 50: 2*; prim. pogl. 12.1) smo izmerili visok odstotek kositra (92,1, 92,2 oz. 86,9 %), kar kaže, da se je tu predmet dobro sprijel s podlago, ki je bila iz kositra ali zlitine kositra z majhnim deležem svinca (*pregl. I1: 4, 6, 10*).

Meritev na površini 1 (*pregl. I1: 3; sl. 50*: 1) nakazuje, da se je tam hrbet predmeta I1 slabo sprijel s podlago.

Za predmet I1 uporabljena zlitina kositra in svinca v razmerju približno 2 : 1 ima v binarnem sistemu Sn-Pb najnižje tališče, tj. 183 °C, zato je imela visoko fluidnost (tečnost) in je bila zelo primerna za zapolnjevanje majhnih površin (npr. pri reliefnem okrasu) pri ulivanju. Tališče podlage, ki je bila iz kositra oz. iz zlitine, v kateri je prevladoval kositer, je bilo višje, okoli 220–235 °C. Domnevamo, da je bil predmet I1 na podlago pritrjen tako, a) da so ga pritisnili na podlago, ki so jo pred tem segreli do temperature, pri kateri je postala plastična, ali pa tako, b) da so segrevali podlago in nanjo nameščen predmet I1, pri čemer se je posredno segrel tudi hrbet predmeta I1, ki se je zaradi nižjega tališča (delno) zlil s podlago. Na hrbtni strani ugotovljene površine 1, 2 in 3 (*sl. 50*) nakazujejo, da je bil hrbet predmeta I1 le na majhnem delu (površina 2) dobro sprijet s podlago.[670]

Razmeroma visoki deleži železa in mangana so najverjetneje povezani s patino, ki je nastala med dolgotrajno lego v vodi in očitno z mest 7–13 ni bila povsem odstranjena.

I2 (*pregl. I2, sl. 119, 120*)

Predmet je tako dobro ohranjen, da konservacija ni bila potrebna. Z mesta 1 smo odstranili tanek sloj površine.

Predmet je iz zlitine kositra z okoli 2 % bakra in manj kot 1 % svinca (*pregl. I2: 1*). Meritev na površini brez vidne patine, s katere pa nismo odstranili površinskega sloja (*pregl. I2: 2*), kaže višji odstotek bakra.

Figure 120
Torque I2: measured Spots 1 and 2.
Slika 120
Torkves I2, mesti 1 in 2.

669 Dobršek 2003.

670 Dobršek 2003.

SG. SCHIELD BOSS

MM SG (*Table MM SG, Figs. 121, 122a, b*)

The shield boss (*Table MM SG: 3, 4*) and the heads of its rivets (*Table MM SG: 1, 2*) are of brass with just over 2% tin. The measurements on Spots 5, 6 and 7 show the rivet shanks to be of iron.

Spot/ Mesto	Fe	Ni	Cu	Zn	As	Se	Sn	Pb
1	3.8	0.2	77.0	15.4	0.56	0.06	2.7	0.19
2	-	0.2	86.8	9.82	-	-	2.8	0.38
3	2.0	0.2	77.2	16.8	0.15	-	3.2	0.43
4*	1.7	0.2	74.2	21.0	0.11	-	2.2	0.60
4*¤	1.3	0.3	74.2	21.3	0.08	-	2.1	0.69

Table MM SG

Preglednica MM SG

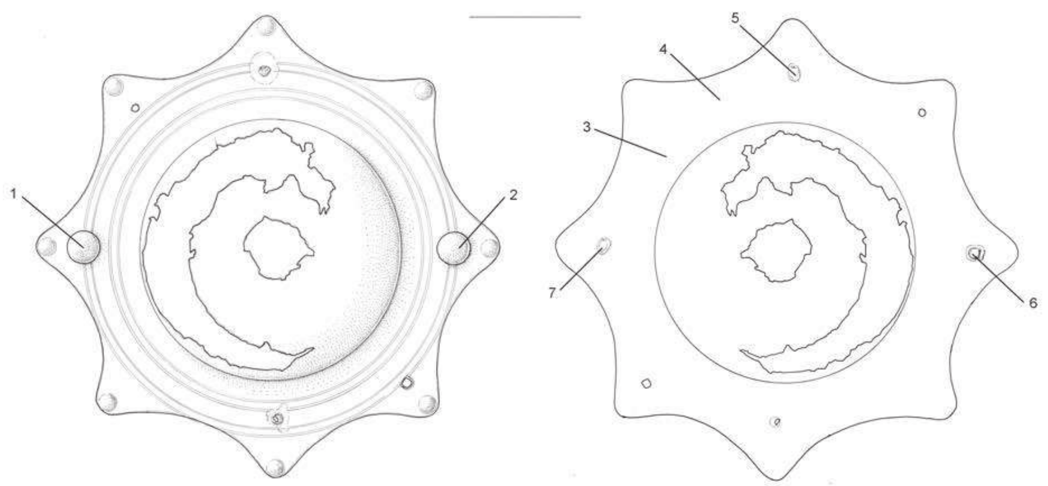


Figure 121
Shield boss MM SG: the measured spots.

Slika 121
Ščitna grba MM SG, lega merjenih mest.

SG. ŠČITNA GRBA

MM SG (*pregl. MM SG, sl. 121, 122a, b*)

Ščitna grba (*pregl. MM SG: 3, 4*) in glavici zakovic (*pregl. MM SG: 1, 2*) so iz medenine, ki vsebuje malo več kot 2 % kositra. Meritve na mestih 5, 6 in 7 so pokazale, da so trni zakovic železni.

Figure 122a
The front of the MM SG shield boss: measured Spots 1 and 2 (both with patina) on the rivet heads.

Slika 122a
Ščitna grba MM SG, zgornja stran, lega mest 1 in 2 na glavicah zakovic.

Figure 122b
The back of the MM SG shield boss: measured Spots 3 (on patina) and 4 (cleared of patina) on the flange; Spots 5–7 on the corroded iron rivet shanks were not measured.

Slika 122b
Ščitna grba MM SG, spodnja stran, lega mest 3 in 4 na spodnji strani okrajka ter mest 5–7 na korodiranih trnih zakovic; na mestih 5–7 nismo merili.

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