Depo Kanalski Vrh - študija o metalurškem znanju in kovinah na začetku 1. tisočletja pr. n. š.

Neva TRAMPUŽ OREL in David John HEATH

Izvleček

Namen študije je podrobnejša analiza kemijskih in arheoloških podatkov o poznobronastodobnem depoju Kanalski Vrh (11./10. st. pr. n. š.). Depo zavzema pomembno mesto med depoji Ha B obdobja na jugovzhodnoalpskem ozemlju; poleg velike količine polizdelkov (ingoti) vsebuje tudi številen, dobro ohranjen nakit (kolesasti obeski itd.) in vrsto drugih dragocenih izdelkov, ki ga dobro povezujejo ne samo z območjem Caput Adriae, ampak tudi s širšim področjem Srednje Evrope, posebej z zahodnimi predeli. Študija utemeljuje njegovo pomembnost predvsem na podlagi tehnologije nakita in ingotov (kositrenje, izkoriščanje polimetalne rude za pridobivanje specialne kovine, t. i. speiss). Predstavljene so možnosti za obstoj delavnice v bližini depoja in podatki, ki omogočajo rekonstrukcijo smeri nekdanjih tovornih poti za kovino med Vzhodnimi Alpami, severnim Jadranom in zahodnim delom Panonske nižine.

Abstract

The study is initiated into a detailed analysis of chemical and archaeological data about the Late Bronze Age hoard Kanalski Vrh, dated to 11th / 10th cent. BC. The hoard-find takes an important place among the Ha B hoards in the Southeastern Alpine region (the present Slovenia); it contains a large quantity of metal semi- pro-ducts (cast ingots), numerous, well preserved jewellery (wheel-shaped pendants etc.) and other prestige objects, which exhibit the best connections not only to the Caput Adriae region but also to the broader territories of Middle Europe, particularly to its western part. The study tries to apply the importance of this hoard on the basis of the technology of its jewellery and ingots (tinning, the use of polymetallic ore sources for producing a special metal, i.e. speiss). Possibilities for a metal workshop in the vicinity of the hoard are discussed and data enabling the reconstruction of ancient routes for metal trade between the Eastern Alps, the northern Adriatic and the western edge of the Pannonian plain are presented.

UVOD

Odkrivanje trgovskih stikov in prometnih poti v prazgodovinskih obdobjih sloni na študijah tipologije in razprostranjenosti predmetov ter na predpostavljenih modelih njihovega razširjanja in izmenjave, ki so odvisni tudi od vrste in razloga zakopa (Coles, Harding 1979). Dobrodošle so primerjave pisnih virov iz zgodovinskih obdobij in primerljivi podatki drugih strok: etnologije, geografije, gospodarske zgodovine. Marsikdaj pa so odločilnega pomena tudi rezultati naravoslovnih raziskav, pri čemer tukaj mislimo predvsem na tiste, ki se ukvarjajo s sestavo materialov. Spektralne analize kemijske sestave in metalografske analize prazgodovinskih kovin iz Slovenije prinašajo številne podatke, ki dopolnjujejo naše znanje o sestavi predmetov iz bakra in bakrovih zlitin ter našo predstavo o metalurškem znanju ob koncu pozne bronaste dobe. Če omenjene rezultate premišljeno povežemo z ustreznimi arheološkimi podatki in izbranimi arheološkimi ugotovitvami, lahko dopolnimo kulturno-zgodovinsko podobo določenega prostora tudi z gospodarskega vidika. V našem primeru se je na tem področju odprla vrsta hipotez - o izbiri rudišč in transportnih poti, o vlogi metalurških središč in livarskih delavnic, o me-talurškem znanju in njegovi ekskluzivnosti. In to naj bi bil cilj naših arheometričnih raziskav - ne samo stotine analiz, ampak tudi primerjalna, sintetična obdelava arheoloških in kemijskih rezultatov. Pričujoča študija predstavlja takšen poskus.

Depo Kanalski Vrh je bil že pred časom v celoti objavljen, kemijsko analiziran in izčrpno interpretiran (v: Teržan (ed.) 1995, t. 95-118 in 1996, 31 ss, 165 ss). Sestavljata ga pravzaprav dve enoti, ki sta bili najdeni na različnih, toda bližnjih lokacijah, vendar ga v tej študiji obravnavamo kot celoto. Njegova dvojnost se namreč v tem primeru ne zdi pomembna, kar pa ne pomeni, da ni pomenljiva za študij razlogov zakopa. Vsebuje številne predmete - sekire, okrasne plošče, ovratnice, kolesaste obeske, obroče, cevčice, in občudovanja vredno količino polizdelkov in nekaj surovine - 50,45 kg razlomljenih ingotov, eno celo pogačo ter nekaj surovcev. Glede na predmete je dobro datiran na začetek 1. tisočletja pr. n. š. oziroma v prehodno obdobje Ha A2/Ha B1 (Žbona-Trkman, Bavdek 1996, 64), po sestavi pa je uvrščen med velike depoje III. časovnega horizonta (Turk 1996, 112 ss) na prostoru med Furlanijo in Transdanubijo, katerih novost je prav veliko število večinoma fragmentiranih, v kalup odlitih ingotov bikonične oblike.

ARHEOLOŠKE IN KEMIJSKE ZNAČILNOSTI IZDELKOV

Opazovanje zunanje podobe in značilnosti predmetov ter študij njihove razprostranjenosti je prineslo zanimive podatke, ki jih tukaj povzemamo po avtoricah prve objave (Žbona-Trkman, Bavdek 1996). Že ob odkritju depoja je vzbudila pozornost svetleča srebrnosiva površina večine kolesastih obeskov in obročev, ki se je odločno razlikovala od temnozelene barve ostalih predmetov, in zaradi katere je prišlo do domneve, da gre za dve različni zlitini.[1] Primerjava oblike, velikosti in teže obeskov ter obročev je pokazala uporabo istega kalupa pri vlivanju nekaterih predmetov. Zaradi najdbe kalupa za obroč, enakega tistim iz kanalskega depoja, v naselbini Sermin pri Kopru, in kalupov za plavutaste sekire s poudarjenim prehodom iz nasadišča v list, kakršna je v Kanalskem Vrhu, in ki so značilne za širše območje ob severnem in vzhodnem Jadranu, prav tako v Serminu in v depoju iz Šempetra, pa je bila nakazana možnost, da so takšne predmete izdelovale delavnice na območju Caput Adriae.

Veliko pozornost so vzbudili ingoti tako zaradi velikega števila kot tudi zaradi oblik. Tovrstni polizdelek je bil pri nas do tega odkritja takorekoč neznan, z izjemo ingotov iz Velikega Otoka, ki pa do tedaj niso kazali prave povezave s sicer bogatimi najdbami surovega bakra v obliki surovcev in pogač iz starejših Ha A depojev. Ingoti bikonične oblike, kot tudi obeski, ovratnice in okrasne plošče so povezali depo Kanalski Vrh s podobnimi najdbami predvsem v italskem in zahodnoalpskem prostoru, manj v Karpatskem bazenu.

Kemijske analize (z metodo ICP-AES) so omenjena opažanja še podkrepile in dopolnile (Trampuž Orel et al. 1996). Razkrile so uporabo enake vrste bakra pri izdelavi zlitin in večkrat enake litine pri obeskih, sekirah in ovratnicah, kar je kazalo na izdelke iste livarske delavnice, ki so bili zakopani, še preden so prišli v obtok. Nakazana je bila tudi razlaga za nenavadno svetlo površino nakita - relativno visoka vsebnost kositra (nad 10 %). Analize so razkrile tudi močno povišane vrednosti svinca predvsem v ingotih, in tako potrdile splošno mnenje, da so se bakrove zlitine s svincem (tudi do 27 %) uveljavile v Vzhodnem Sredozemlju in v Evropi prav na prehodu v 1. tisočletje pr. n. š., ko se je uporaba svinca močno povečala (Pernicka 1995, 54, sl. 16). Ker se izdelki tega depoja, kakor tudi nekateri drugi izdelki z jugovzhodnoalpkega ozemlja z zelo visoko vsebnostjo svinca, tipološko praviloma navezujejo na gradivo z italskega prostora ali pa vsaj s prostora zahodno od našega ozemlja, je bila postavljena teza, da se je tehnološka novost - uporaba svinca pri izdelavi bakrovih zlitin - pri nas začela širiti na prehodu Ha A2/Ha B1 ob posredniški vlogi Italskega polotoka.

Kolesasti obeski

V nadaljevanju bodo obravnavane tipološke in kemijske značilnosti tistih predmetov s Kanalskega Vrha, ki najbolj prepričljivo opredeljujejo pomen te najdbe v okviru Caput Adriae, kakor tudi v širšem prostoru Vzhodnih Alp in srednje Italije. Kot je bilo že omenjeno, je ob odkritju depoja vzbudila pozornost nenavadna svetla površina večine kolesastih obeskov in obročev, zato je bila tem predmetom posvečena posebna študija (Heath et al. 2000). Med objavljenimi izdelki ima svetlečo površino kar 35 obeskov (od 43) in 56 obročev (od 62). Prvotno se je

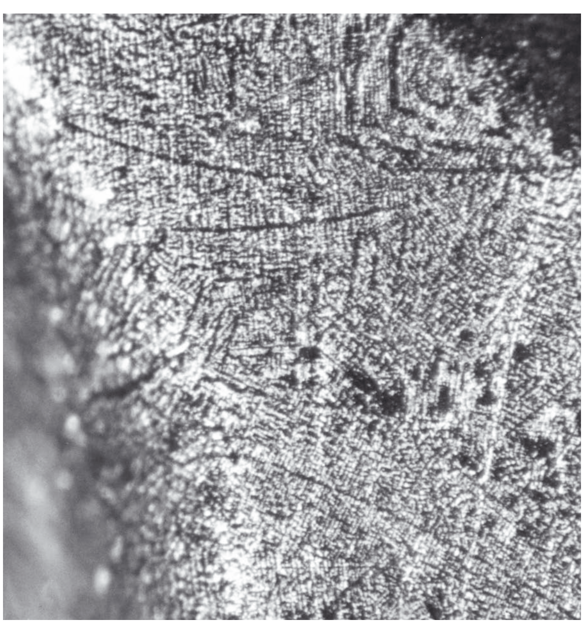
Sl. 1: Kanalski Vrh. Detajl kolesastega obeska (GM 6370) z ostanki temnosive plasti na površini (fotografija: Tomaž Lauko).
Fig. 1: Kanalski Vrh. A detail of the wheel-shaped pendant GM 6370 showing a dark gray layer on the surface (photo: T. Lauko).

[1] V konservatorskem poročilu Goriškega muzeja za leto 1990 je Jana Šubic Prislan zapisala, da je bilo “dolgotrajno čiščenje pri večini predmetov nagrajeno z odkritjem brezhibne, gladke površine, prevlečene z zdravo zelenorjavo patino ...” in da so bili med obeski in obroči predmeti “s sivo in sivorumeno patino”.

metoda/ method	vzorec št./ sample no.	površina / surface	Cu [%]	Sn [%]	Ni [%]	Pb+As [%]	Sb [%]
XRF	1	rumena / yellow	78.7	13.2	3.3	4.2	0.6
XRF	3	rumena / yellow	79.5	12.8	2.9	4.2	0.6
XRF	4	rumena / yellow	78.1	13.7	3.9	3.7	0.7
XRF	2	temnosiva / dark grey	48.9	36.1	5.6	8.1	1.4
XRF	5	temnosiva / dark grey	52.1	32.9	5.2	8.4	1.2
ICP-AES			79.2	12.73	0.93	2.37	0.94

Sl. 2: Kanalski Vrh. XRF analiza površine kolesastega obeska (GM 6348), izvršena na 5 mestih, in primerjava z ICP-AES analizo notranjosti (iz Heath et al. 2000).
Fig. 2: Kanalski Vrh. XRF analyses of the surface of the wheel-shaped pendant GM 6348, performed on 5 spots, compared to ICP-AES analysis of the interior.

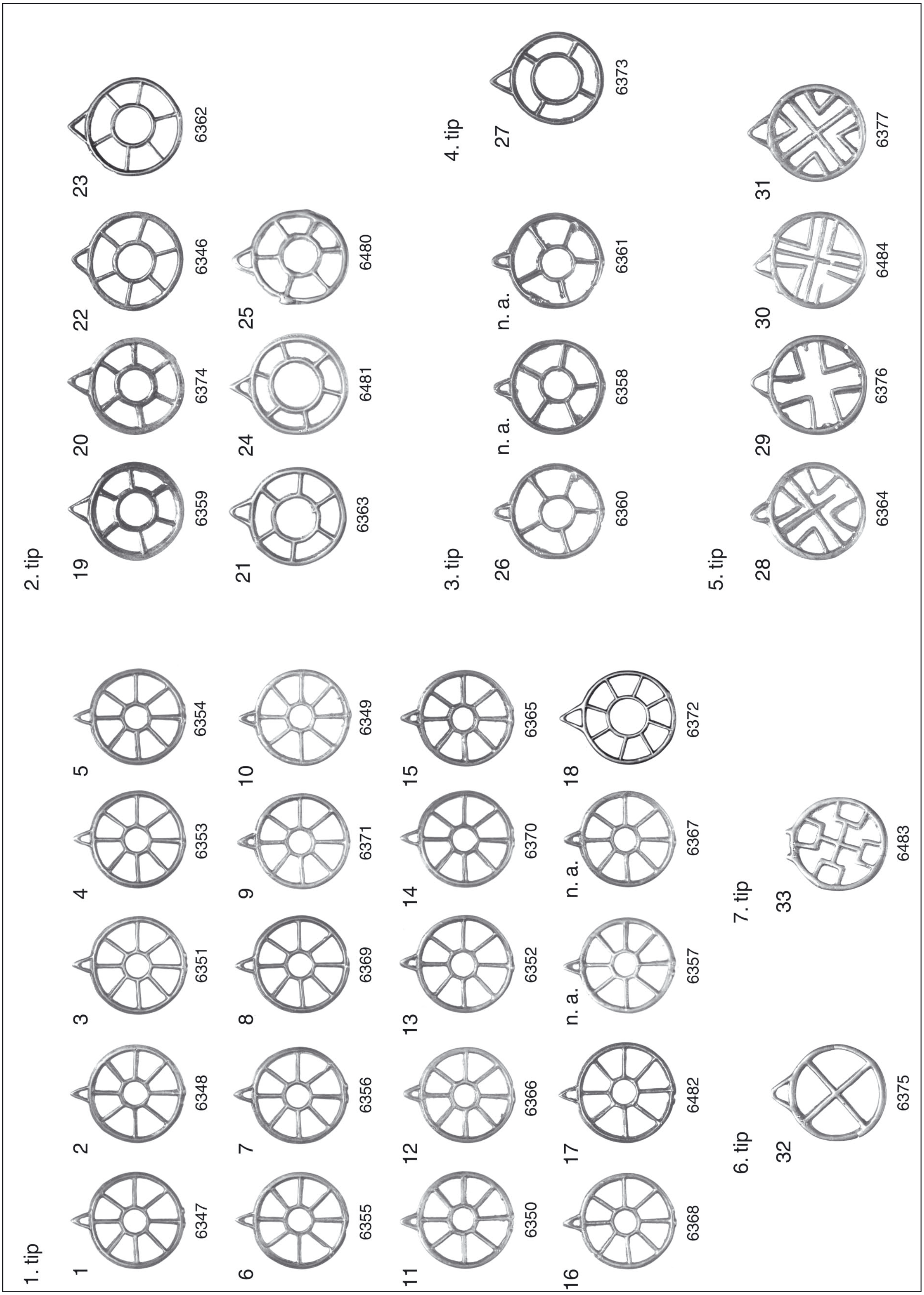
zdelo, da je vzrok več kot 10 % vsebnost kositra, vendar se pravilo ni ujelo s tistimi predmeti, ki imajo podobno vsebnost kositra pa so kljub temu prekriti z zeleno patino. Natančnejše opazovanje obeskov je razkrilo, da so predeli zgornje in spodnje strani prekriti s temnosivo plastjo (*sl. 1*). Analiza površine enega od obeskov (P 6348) z rentgensko fluorescenco (XRF) je pokazala, da je vsebnost kositra na temnem predelu skoraj trikrat višja kot na ostali svetli površini in kot v notranjosti predmeta (*sl. 2*). Primerjava mikroskopskega posnetka tega predela s posnetkom pokositrenega rimskega zrcala (Meeks 1993, 258, sl. 21: 11) je nakazala možnost, da gre pri obeskih s Kanalskega Vrha za *kositrenje* (*sl. 3*). Tehnika kositrenja in drugi postopki izdelave bronastih predmetov s površino srebrnega videza, odporno proti koroziji, so bili že temeljito raziskani (Meeks 1993). Srebrn



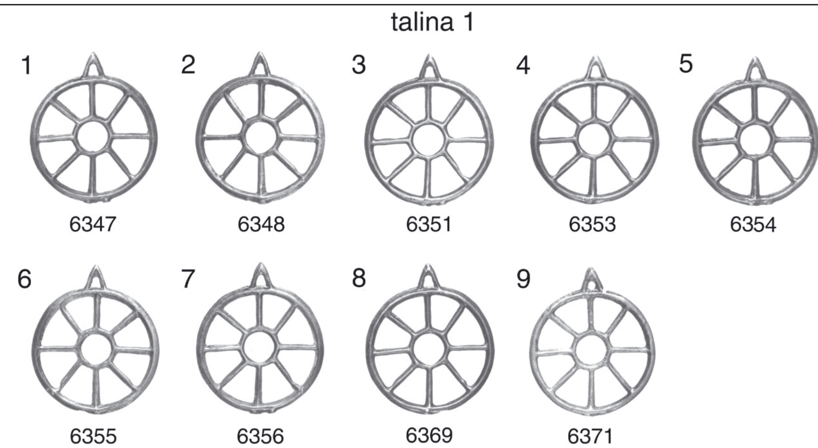
Sl. 3: Kanalski Vrh. Mikroskopski posnetek mikrostrukture površine kolesastega obeska (GM 6348) (iz Heath et al. 2000).
Fig. 3: Kanalski Vrh. The microstructure of the surface of the wheel-shaped pendant GM 6348, taken by binocular microscope (after Heath et al. 2000).

videz je mogoče doseči z zlitino, ki ima razmeroma nizek kositer (okrog 14 %), če se nato površina izdelka kositri - ob segrevanju se nanese na površino staljen kositer, ki deluje tudi kot protikoro-zijska zaščita. Druga možnost je zlitina z visoko vsebnostjo kositra (19-27 %), površino izdelka pa je potrebno spolirati. Zlitine obeskov kakor tudi obročev s Kanalskega Vrha vsebujejo le od 10-20 % kositra, najpogosteje 12-13 %, kar jih bolj uvršča med nizkokositrne brone. Zato je mogoče sklepati, da gre pri večini za srebrn videz, ki je posledica kositrenja, vendar bi bile za dokončen dokaz potrebne tudi metalografske analize (SEM, EDX).

Pozornost so pritegnile tudi pogoste skupine enakih zlitin. Da bi dobili pregled nad razmerjem zlitin do oblik, smo obeske razvrstili glede na število in obliko prečk v sedem skupin (*sl. 4*). Od vseh so se izkazali obeski *1. tipa z osmimi prečkami* kot najprimernejši za kombinirano arheološko-kemijsko preučevanje. So najštevilnejši, srebrno-svetlečega videza in s sledovi kositrenja (razen 17. obeska, ki je prekrit z zeleno patino). Njihova oblika je popolnoma enaka, simetrična in elegantna, kar govori za isti model in enak kalup. Njihova kemijska sestava pa je - presenetljivo - različna (*sl. 5*). Na prvi pogled so očitne skupine obeskov iz enakih zlitin (kar kažejo zelo podobne vrednosti kositra, svinca in nečistoč), ki predstavljajo posamič pripravljeno talino ali "šaržo" - to je količina zlitine, pripravljena za vlivanje v kalup. Mogoče je ločiti štiri, morda celo pet talin, ki se med seboj razlikujejo po vsebnosti kositra in svinca in po bolj ali manj čistem bakru. Na prvi pogled je največ enakih zlitin v prvi skupini obeskov od 1.-9. (*talina 1*), kar kažejo zelo podobne vsebnosti kositra, svinca in nečistoč (Sn 10,5 -12,3 %, Pb 1-2 % in pribl. vrednosti nečistoč: Sb 0,9 %, Ni 0,9 %, As 1 %, Co 0,2 %). Količine svinca, ki so manjše od 3 %, zaenkrat veljajo za naravno vsebovane v bakrovi rudi (Rychner 1990, 210), zato te sestave opredeljujemo kot binarno zlitino bakra s kositrom. Uporabljeni baker ima razmeroma visoke nečistoče, če ga primerjamo s tistim v naših Ha A predmetih, kjer



Sl. 4: Kanalski Vrh. Kolesasti obeski, razporejeni po obliki v 7 tipov.
Fig. 4: Kanalski Vrh. Wheel-shaped pendants, grouped by shape into 7 types.



talina 1 / batch 1

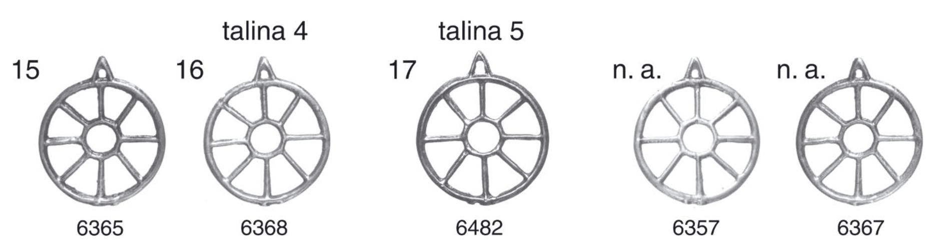
inv. št./inv. no.	št./no.	Sn [%]	Pb [%]	As [%]	Ni [%]	Sb [%]	Co [%]	Bi [%]	Fe [%]	Zn [%]
6347	1	12.3	1.97	1.20	1.02	1.19	0.30	0.07	0.27	0.08
6348	2	12.7	1.21	1.16	0.93	0.94	0.27	0.03	0.27	0.06
6351	3	12.7	1.30	1.08	1.02	0.99	0.29	0.05	0.25	0.06
6353	4	11.9	1.24	1.08	0.92	0.95	0.27	0.04	0.25	0.08
6354	5	12.3	1.24	1.10	0.93	0.89	0.28	0.04	0.27	0.06
6355	6	12.5	1.27	1.08	1.01	0.98	0.29	0.02	0.29	0.06
6356	7	11.9	1.14	1.08	0.92	0.87	0.26	0.02	0.27	0.06
6369	8	12.2	1.22	1.04	1.00	0.97	0.28	0.03	0.28	0.06
6371	9	10.5	1.02	0.88	0.84	0.82	0.23	0.08	0.22	0.07

talina 2 / batch 2

6349	10	12.6	14.61	0.24	0.10	0.32	0.03	0.04	0.12	0.06
6350	11	12.9	14.84	0.23	0.11	0.40	0.03	0.04	0.15	0.14
6366	12	12.9	16.44	0.28	0.11	0.37	0.03	0.02	0.12	0.08

talina 3 / batch 3

6352	13	14.2	14.50	0.38	0.12	0.88	0.03	0.04	0.14	0.06
6370	14	15.6	11.30	0.36	0.13	0.99	0.03	0.03	0.17	0.06



talina 4 / batch 4

6365	15	16.7	6.68	0.81	0.08	1.16	0.02	0.04	0.06	0.06
6368	16	17.1	6.51	0.80	0.08	1.21	0.02	0.06	0.05	0.06

talina 5 / batch 5

6482	17	3.5	1.7	1.28	0.10	3.31	0.02	0.07	0.07	0.05

Sl. 5: Kanalski Vrh. Kolesasti obeski 1. tipa in primerjava z ICP-AES analizami njihove sestave, razporejenimi glede na enake zlitine v 5 talin (po Heath et al. 2000).

Fig. 5: Kanalski Vrh. Wheel-shaped pendants of type 1 compared to the results of their ICP-AES analyses, grouped after similar alloys into 5 batches (after Heath et al. 2000).

vsebuje več kot polovica predmetov le od 0,2-0,5 % antimona in nik-lja ter manj kot 0,7 % arzena (Trampuž Orel et al. 1998a, 229 ss in sl. 7). Naslednji obeski 10.-14. imajo rahlo višjo vsebnost kositra (Sn 12,6-15,6 %) in zelo visoko vsebnost svinca (Pb 14-16 %); uporabljeni baker ima precej nižje nečistoče kot tisti v talini 1. Za njihovo izdelavo je bila pripravljena ternarna zlitina bakra s kositrom in svincem, morda celo dve talini (*talina 2*, *talina 3).* Iz podobne zlitine so tudi obeski 15.-16. (*talina 4*), le da je v njej precej manj svinca (Pb 6 %). Najrevnejša je zlitina v 17. obesku (*talina 5*), ki ima zelo malo kositra (Sn 3,5 %) in

Tip / Type	Talina/ Batch	Inv. št./ Inv. no.	Št./ no.	Teža [g]/ Weight	Sn [%]	Pb [%]	As [%]	Ni [%]	Sb [%]	Co [%]	Bi [%]	Fe [%]	Zn [%]
1	1	6347	1	32.8	12.3	1.97	1.20	1.02	1.19	0.30	0.07	0.27	0.08
		6348	2	33.8	12.7	1.21	1.16	0.93	0.94	0.27	0.03	0.27	0.06
		6351	3	33.6	12.7	1.30	1.08	1.02	0.99	0.29	0.05	0.25	0.06
		6353	4	33.1	11.9	1.24	1.08	0.92	0.95	0.27	0.04	0.25	0.08
		6354	5	33.7	12.3	1.24	1.10	0.93	0.89	0.28	0.04	0.27	0.06
		6355	6	32.7	12.5	1.27	1.08	1.01	0.98	0.29	0.02	0.29	0.58
		6356	7	34.5	11.9	1.14	1.08	0.92	0.87	0.26	0.02	0.27	0.06
		6369	8	33.3	12.2	1.22	1.04	1.00	0.97	0.28	0.03	0.28	0.06
		6371	9	34.3	10.5	1.02	0.88	0.84	0.82	0.23	0.08	0.22	0.07
	2	6349	10	27.5	12.6	14.61	0.24	0.10	0.32	0.03	0.04	0.12	0.06
		6350	11	27.1	12.9	14.84	0.23	0.11	0.40	0.03	0.04	0.15	0.14
		6366	12	27.5	12.9	16.44	0.28	0.11	0.37	0.03	0.02	0.12	0.08
	3	6352	13	26.3	14.2	14.50	0.38	0.12	0.88	0.03	0.04	0.14	0.06
		6370	14	27.1	15.6	11.30	0.36	0.13	0.99	0.03	0.03	0.17	0.06
	4	6365	15	26.5	16.7	6.68	0.81	0.08	1.16	0.02	0.04	0.06	0.06
		6368	16	26.9	17.1	6.51	0.80	0.08	1.21	0.02	0.06	0.05	0.06
	5	▲ 6482	17	31.5	3.5	1.7	1.28	0.10	3.31	0.02	0.07	0.07	0.05
		6372	18	29.7	19.4	0.55	0.14	0.03	0.11	0.04	0.01	0.04	0.10
2		▲ 6359	19	28.3	1.1	2.99	4.30	2.54	4.32	0.03	0.04	0.03	0.06
		▲ 6374	20	23.6	0.2	2.80	4.00	2.32	4.04	0.02	0.01	0.03	0.06
		6363	21	23.9	14.0	0.22	1.92	0.12	1.76	0.02	0.05	0.03	0.06
		▲ 6346	22	23.4	9.7	0.33	0.05	0.02	0.17	0.03	0.05	0.04	0.08
		6362	23	19.7	15.6	0.62	0.78	0.09	0.91	0.04	0.04	0.11	0.07
		6481	24	24.2	18.2	0.60	0.26	0.18	0.62	0.05	0.04	0.26	0.11
		6480	25	22.7	17.8	0.35	0.08	0.04	0.31	0.02	0.05	0.10	0.10
3		▲ 6360	26	29.5	3.6	6.42	0.78	0.43	2.25	0.03	0.04	0.03	0.05
		▲ 6358		32.4				ni analiziran / not analysed					
		▲ 6361		32.1				ni analiziran / not analysed					
4		6373	27	23.3	9.9	0.90	0.57	0.25	0.52	0.04	0.03	0.06	0.06
5		6364	28	23.4	7.3	4.33	0.59	0.40	1.42	0.10	0.08	0.06	0.06
		6376	29	24.5	12.7	1.10	0.18	0.05	0.17	0.06	0.07	0.19	0.09
		6484	30	27	11.7	0.60	0.17	0.05	0.12	0.04	0.04	0.03	0.06
		6377	31	28.3	16.7	0.34	0.36	0.04	0.16	0.07	0.04	0.10	0.05
6		6375	32	19.3	10.6	0.69	0.23	0.21	0.48	0.06	0.06	0.34	0.07
7		6483	33	14.9	14.8	0.39	0.16	0.06	0.12	0.04	0.03	0.07	0.06

Sl. 6: Kanalski Vrh. ICP-AES analize kolesastih obeskov, razporejene po tipih v 7 skupin; ▲ zelena površina.
Fig. 6: Kanalski Vrh. ICP-AES analyses of wheel-shaped pendants, grouped after types into 7 groups; ▲ green surface.

takorekoč nič svinca (Pb 1.7 %) ter spet baker z višjimi nečistočami, posebej antimonom (Sb 3,31 %) in arzenom (As 1,28 %) - obesek je zelen. Obeska 18. in 19. žal nista bila analizirana.

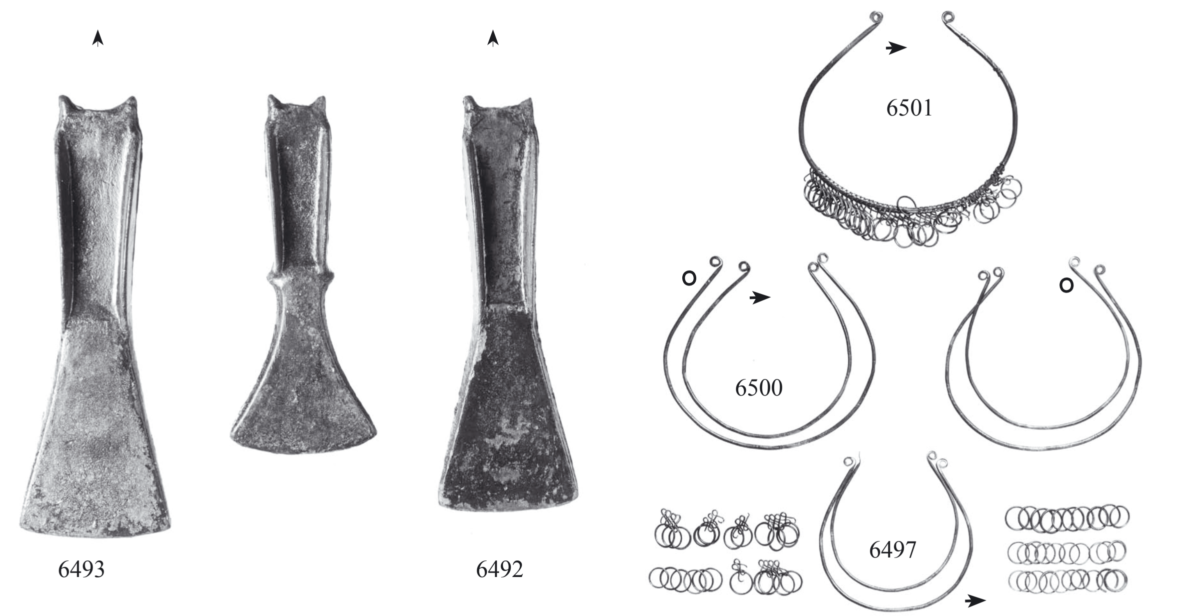
Tudi nekateri obeski *2. tipa s šestimi prečkami* so bili vliti v enakem kalupu (*sl. 4:* 19-25). Od sedmih so svetlečega videza štirje obeski (21,23-25), preostali trije so zeleni (19,20,22). Analize (*sl. 6*) kažejo, da obeska nista zlitini (Sn le 0,2-1,1 %); vlita sta bila iz bakra z zelo visokimi nečistočami (As 4 %, Ni 2 %, Sb 4 %), ki je morda naravno vseboval tudi svinčevo rudo (Pb 2,99 %) - pomenljiv podatek, h kateremu se bomo vrnili pri obravnavi ingotov. Ostali obeski so bronasti - binarne zlitine s kositrom (Sn 9,7-18,2 %). Po izdelavi se močno razlikujejo od obeskov *1. tipa*. So manj elegantni, rahlo asimetričnih oblik, z različnimi debelinami prečk in krogov, kar govori za slabši kalup, ki se je hitreje kvaril ob ponovni uporabi, in morda manj kvalitetne zlitine (pomanjkanje zadovoljive količine svinca).

Tudi za tri *obeske 3. tipa s petimi prečkami* je bil uporabljen enak kalup (*sl. 4:* 26 in dva obeska, ki nista bila analizirana). Vsi imajo patino zelene barve, zlitina je nizkokositrni bron (Sn 3,6 %) z nekaj več svinca (Pb 6,4 %). Preostali obeski *4. - 7. tipa* (*sl. 4:* 27-33) so individualnih oblik in imajo vsi površino srebrnega videza. Zanje je bil uporabljen baker z nižjimi nečistočami, vsebujejo dosti kositra (Sn 9,9-16,7 %), svinec pa ni bil dodan, razen manjše količine (Pb 4,3 %) v obesku 28.

Iz opisanih značilnosti zlitin in oblik je pri nekaterih tipih obeskov mogoče sklepati o postopkih izdelave. Za elegantne obeske *z osmimi prečkami 1.*

	Inv. št./ Inv. no.	Predmet/ Object	Sn [%]	Pb [%]	As [%]	Ni [%]	Sb [%]	Co [%]	Bi [%]	Fe [%]	Zn [%]
↑	6492	sekire /axes	1.3	2.58	1.12	0.88	1.93	0.08	0.06	0.03	0.06
↑	6493		1.4	2.68	1.21	0.90	2.01	0.09	0.06	0.03	0.06
	6494		1.7	2.27	1.13	0.92	1.85	0.10	0.05	0.03	0.06
o	6495	ovratnice/ torcs	7.0	0.47	0.35	0.34	0.51	0.03	0.05	0.08	0.07
o	6496		7.0	0.47	0.31	0.35	0.51	0.03	0.04	0.08	0.10
➤	6497		7.1	0.68	0.29	0.54	0.49	0.04	0.06	0.06	0.06
	6498		6.1	0.56	-	0.44	0.43	0.03	0.05	0.08	0.07
	6499		7.1	1.83	0.53	0.35	1.64	0.04	0.04	0.09	0.08
➤	6500		7.4	0.73	0.31	0.55	0.51	0.04	0.05	0.06	0.06
➤	6501		7.9	0.70	0.36	0.54	0.47	0.04	0.06	0.06	0.09

↑, o, ➤ enake zlitine, ista vrsta bakra / the same alloys, the same kind of copper



Sl. 7: Kanalski Vrh. Primerjava enakih zlitin v sekirah in ovratnicah.
Fig. 7: Kanalski Vrh. Comparison of similar alloys in axes and torcs.

tipa sta bila izdelana odličen matičen model in kvaliteten kalup - za prvih devet obeskov najbolj verjetno več popolnoma enakih, med seboj povezanih kalupov. Izdelava modela izkazuje veščega in natančnega mojstra, saj so vsi izdelki simetričnih, elegantnih oblik. Vliti so bili brez napake, kar govori tudi za kvalitetne zlitine - torej za livarja z velikim znanjem in izkušnjami. Vlivanje se je odvijalo postopno, kajti izdelal je več litin. Zelo verjetno je imel na voljo ingote iz najmanj dveh vrst bakra - z naravno vsebovanim svincem (Pb 1-2 %) ter visokimi nečistočami in z namerno dodanim svincem (Pb 6-16 %). Kositer je verjetno dodajal v obliki s kositrom bogate bronaste zlitine (Sn 10-17 %). Očitno je vešče izbiral in odmerjal sestavne dele posamezne taline, saj obeski te serije kljub precejšnjim razlikam v vsebnosti svinca ne kažejo nikakršnih razlik v zunanjem videzu, pa tudi razlike v težah so relativno majhne. Obeske je na koncu postopka potopil v staljen kositer, da so dobili srebrnosvetleč videz. Obeski *s šestimi in petimi prečkami 2. in 3. tipa* so manj kvalitetni vlitki. Izdelki kažejo napake, ki so lahko posledica manj natančno izdelanega modela ali slabšega kalupa, morda tudi "napačne"zlitine (med njimi so namreč kar trije, ki niso ohranili svetleče površine).

Sekire in ovratnice

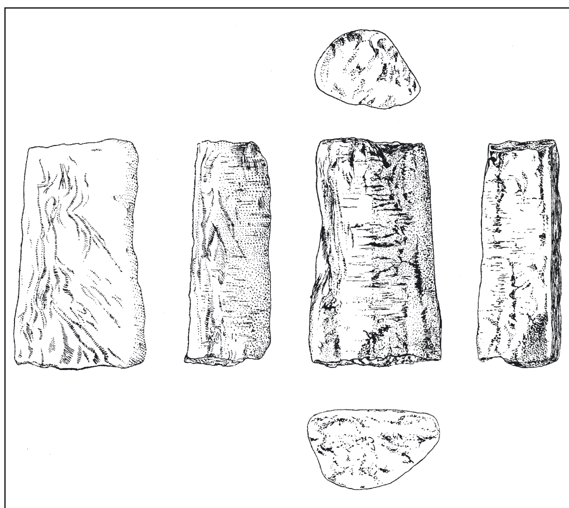
Enake zlitine in iste litine so bile ugotovljene tudi pri drugih predmetih s Kanalskega Vrha (*sl. 7*). Ista litina je bila pripravljena za sekiri P 6492 in 6493. Vse tri sekire imajo izredno malo kositra (Sn <2 %) in svinca, ki je na ravni naravne vsebnosti (Pb <3 %). Pač pa baker vsebuje razmeroma visoke vrednosti arzena, antimona in niklja (As1,1-1,2 %, Sb 1,85-2,01 %, Ni 0,8-0,9 %), podobno kot v obeskih 1. tipa *z osmimi prečkami*. Zaradi nizkega kositra sekire niso bile primerne za uporabo.

Tudi med ovratnicami so enake in podobne zlitine ter iste litine (*sl. 7*). Iz ene litine sta bili vliti ovratnici P 6495 in 6496, iz druge pa ovratnice P 6497, 6501 in 6500. Tako je tokrat metalurška opredelitev demantirala arheološko - ovratnica z nanizanimi obročki P 6501 je bila namreč tipološko opredeljena kot izdelek druge delavnice,[2] njena sestava pa kaže, da je bila vlita hkrati z ostalima dvema ovratnicama, torej v isti delavnici. Drugače kot sekire so bile ovratnice vlite iz tršega brona s precej več kositra (Sn 7 %), kot bi ga bilo potrebnega za nakit, svinec pa ni bil dodan zlitini. Njihov baker vsebuje nižje vrednosti nečistoč (As 0,3-0,5 %, Sb 0,4-0,5 %, Ni 0,3-0,5 %) kot tisti v sekirah in obeskih 1. tipa.

Ingoti

Ingoti s Kanalskega Vrha se uvrščajo med dvojnokonične tipe, katerih skupna oblikovna lastnost - dvojni konus, je bolj ali manj podobna klasičnim primerkom dvojnih sekir s Cipra in Sardinije iz 12.-11. st. pr. n. š. Analize kanalskih ingotov so vzbudile pozornost zaradi nenavadno visokih količin svinca in nečistoč. Sprva so bili opredeljeni kot binarne zlitine bakra s svincem, nečistoče pa pripisane uporabi bakrovih rud tipa *Fahlerz* (Trampuž Orel et al. 1996, 194, 202 ss). Oboje je mogoče slediti v kovinah začetnega Ha B obdobja tudi drugod po Evropi.[3] *Fahlerz* - izraz, ki ga bomo uporabili tudi tukaj, predstavlja obsežno skupino kompleksnih sulfidov z najpomembnejšima mineraloma tetraedritom in te-nantitom, lahko pa vsebuje tudi mešane kristale med obema s precejšnjimi vsebnostmi cinka, železa, nik-lja, kobalta, mangana in drugih elementov (t. i. poli-metalne ali tudi kompleksne rude). Rude skupine Fahlerz so zelo razširjene, nastopajo kot primes na svinčevo-cinkovih rudiščih in so pogosto nosilke srebra v svinčevem sijajniku (galenitu). Med znanimi nahajališči v Evropi sta Schwaz in Brixlegg na Tirolskem ter Grimentz v Val d'Annivier v Švici (Schröcke, Weiner 1981, 169 ss; Jaffé 1986, 47).

Koncentracije kobalta (do 8 %) in niklja (do 19 %) v kanalskih ingotih so bile videti previsoke, da bi jih lahko pripisali taljenju Fahlerza z običajno sestavo. Primerjave z ingoti iz Guschaua (*sl. 8a*) na Saškem (Otto, Witter 1952, 44; Tylecote 1987, 199 ss) in z



Sl. 8a: Guschau (Guzow), območje Saalfeld: ingoti iz špajze (*speiss*), bronasta doba (iz Otto, Witter 1952, 44).
Fig. 8a: Guschau (Guzow), the Saalfeld region: ingots from speiss, dated to Bronze Age (after Otto, Witter 1952, 44).

[2] Prim. Žbona-Trkman, Bavdek 1996, 62 in t. 163: 1 s t. 163: 2,8.
[3] Rychner, Kläntschi 1995, 86 s.

odpadnim materialom s prostora za praženje rude v južni Franciji pri Lascoursu iz 2.-1. st. pr. n. š. (Maréchal 1985) so opozorile, da je kovina kanalskih ingotov lahko t. i. *speiss* ali slovensko *špajza* (*sl. 8b*). Špajza je kompleksna trdna raztopina arzenidov - zmesi arzena z bakrom, nikljem, kobaltom in železom, ki nastane kot stranski produkt taljenja - v tem primeru z železom bogatega Fahlerza in z dovolj veliko koncentracijo arzena ali/in antimona (Craddock 1995, 290). Špajza se tvori poleg kamna kot posebna plast, ki je lažja, navadno srebrne barve in se jo da odstraniti podobno kot žlindro. Ohlajena je trda zaradi visokih vsebnosti arzena in antimona in zato krhka ter neprimerna za izdelavo uporabnih predmetov. Nasploh velja v metalurgiji za nezaželen stranski proizvod, ki zadržuje drage kovine, in je težko predelovati. Kljub temu so v 19. stoletju iz špajze pridelovali srebro. Špajza je bila že odkrita tudi na arheoloških najdiščih, vendar povečini kot odpadni material pri ta-ljenju svinčevih rud v antičnem času (Monte Romero, Rio Tinto). V obliki ingotov, torej kot polizdelek, je bila do zdaj najdena le v depoju iz Guschaua iz verjetno pozne bronaste dobe, če ne upoštevamo rudarskega najdišča Palaia Kavala v se-verni Grčiji, kjer se zdijo argumenti za polizdelke šibki pa tudi datacija je negotova (Kassianidou 1998, 70 ss).

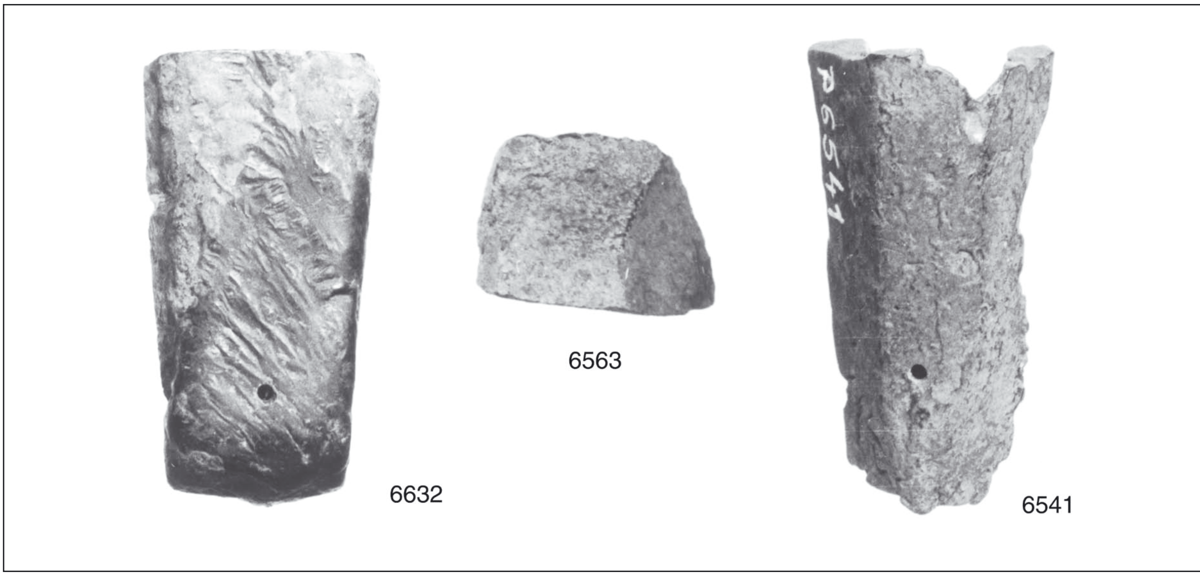
Da bi dokazali, da se špajza nahaja tudi v kanalskih ingotih, so bile narejene metalografske analize ingota P 6584 in ingotov P 6632, 6563 ter 6541 (*sl. 9a* in *9b*). Analize z optično in elektronsko mikroskopijo prvega ingota (EDX), ki po obliki zelo spominja na ingote iz Guschaua, so potrdile, da je ta ingot iz čiste

najdišče/site Kanalski Vrh (11th/10th c. BC)	inv. št./ inv. no.	Cu [%]	Sn [%]	Pb [%]	As [%]	Ni [%]	Sb [%]	Co [%]	Fe [%]	Other [%]
	6504	37.2	0.05	28.66	7.60	6.13	9.55	3.09	2.65	0.13
	6525	47.2	0.22	19.42	10.04	11.34	2.62	4.12	1.80	0.07
	6541	34.5	0.36	14.61	13.19	14.96	5.52	5.03	2.09	0.10
	6555	37.9	0.04	29.45	9.59	9.17	2.86	2.58	0.61	0.11
	6563	17.8	0.09	4.73	20.58	19.32	6.06	8.28	4.19	0.10
	6584	16.0	0.04	0.56	26.17	19.45	16.20	8.09	5.68	0.15
	6632	52.1	0.14	0.23	15.40	13.82	6.59	6.53	2.23	0.09

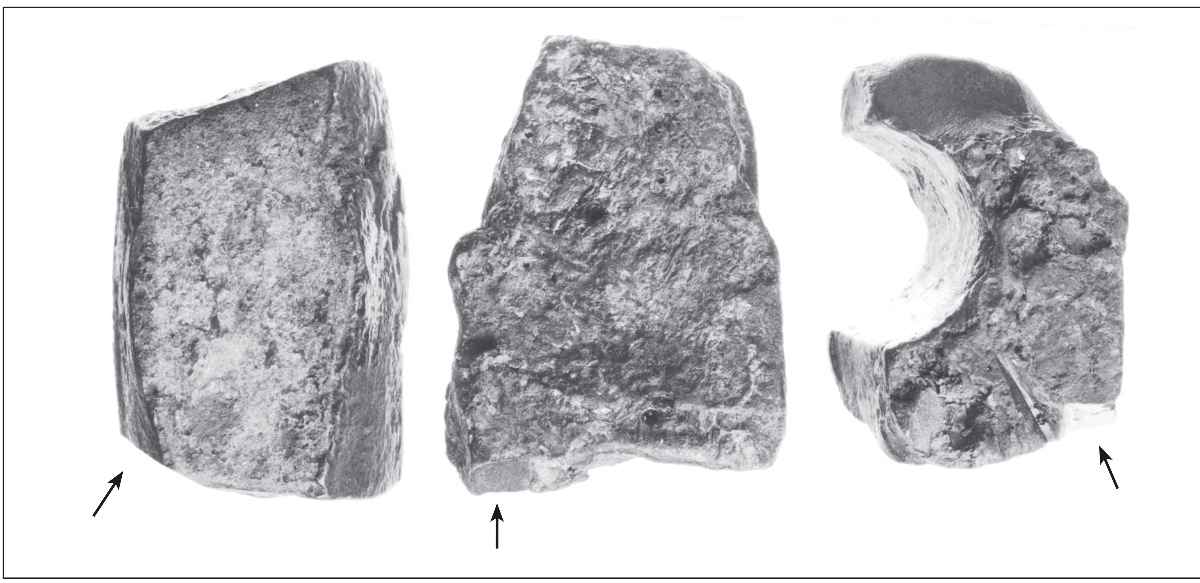
najdišče/site	Cu [%]	Sn [%]	Pb [%]	As [%]	Ni [%]	Sb [%]	Co [%]	Fe [%]	S [%]	Ag [%]
Oker (20th cent.)	51.7	-	35.2	2.75	0.13	3.3	0.24	1.6	1.4	-
Oker (20th cent.)	25.9	-	16.7	11.0	1.60	13.5	1.1	22.7	4.1	-
Mansfeld (20th c.)	10.7	-	3.8	-	16.8	-	9.6	-	-	-
Guschau (Br. Age)	33.17	-	0.07	16.76	19.10	13.09	-	5.72	4.38	0.43
Guschau (Br. Age)	44.54	-	0.83	16.49	15.92	12.97	-	0.55	2.23	0.58
Lautenthal (20th c.)	33.50	-	28.5	8.20	1.2	17.0	-	7.20	-	-
Mange-Homme (2nd-1st c. BC) "granular waste"	30	-	8	20	20.5	20 (by differ.)	-	-	1.5	-
Mange-Homme "thick plate"	50	-	12	11.6	10	15 (by differ.)	-	-	1.4	-
Mange-Homme "conical waste"	64	-	1.98 (by differ.)	19.4	14	1.98	-	-	0.22	-

Sl. 8b: Primerjava kemijske sestave ingotov iz špajze s Kanalskega Vrha s sestavo špajze iz 20. st., nastale kot stranski proizvod pri taljenju bakra in svinca, ter špajz iz arheoloških kontekstov Guschau in Mange Homme (prirejeno po Paulin et al. 1999, 616).
Fig. 8b: Chemical contents of speiss-ingots from Kanalski Vrh compared to the contents of speisses from the 20 th century (as by products of copper and lead smelting) and to the archaeological speisses from Guschau and Mange Homme (adapted after Paulin et al. 1999, 616).

Sl. 9a: Kanalski Vrh. Spolirana, svetleča površina ingota GM 6584, pripravljena za metalografsko analizo.
Fig. 9a: Kanalski Vrh. Polished, shiny surface of the ingot GM 6584, prepared for the metallographic analysis.



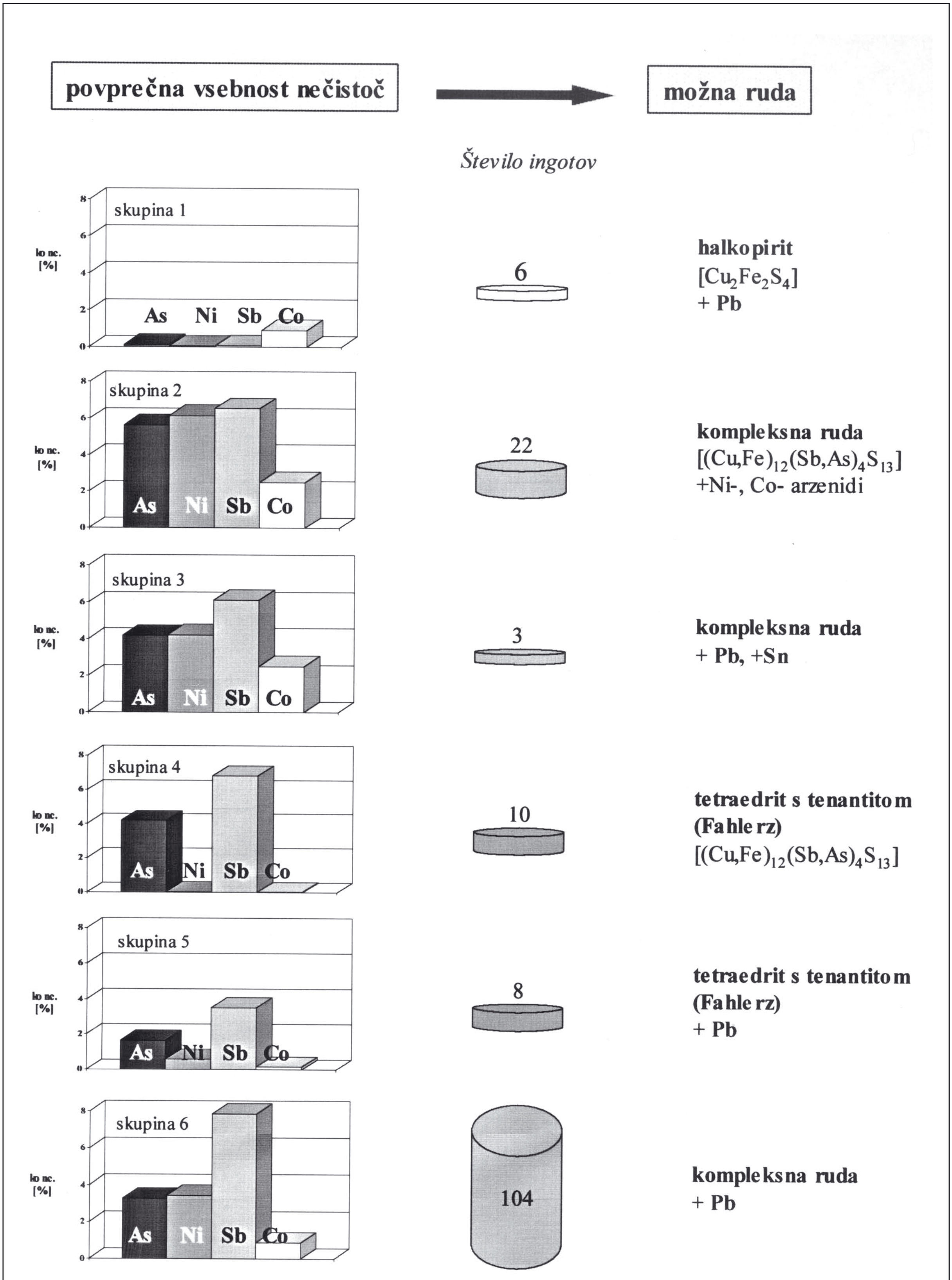
Sl. 9b: Kanalski Vrh. Ingoti P 6632, 6563 in 6541, preiskani z DTA metodo.
Fig. 9b: Kanalski Vrh. The ingots GM 6632, 6563 and 6541 analysed by DTA method.



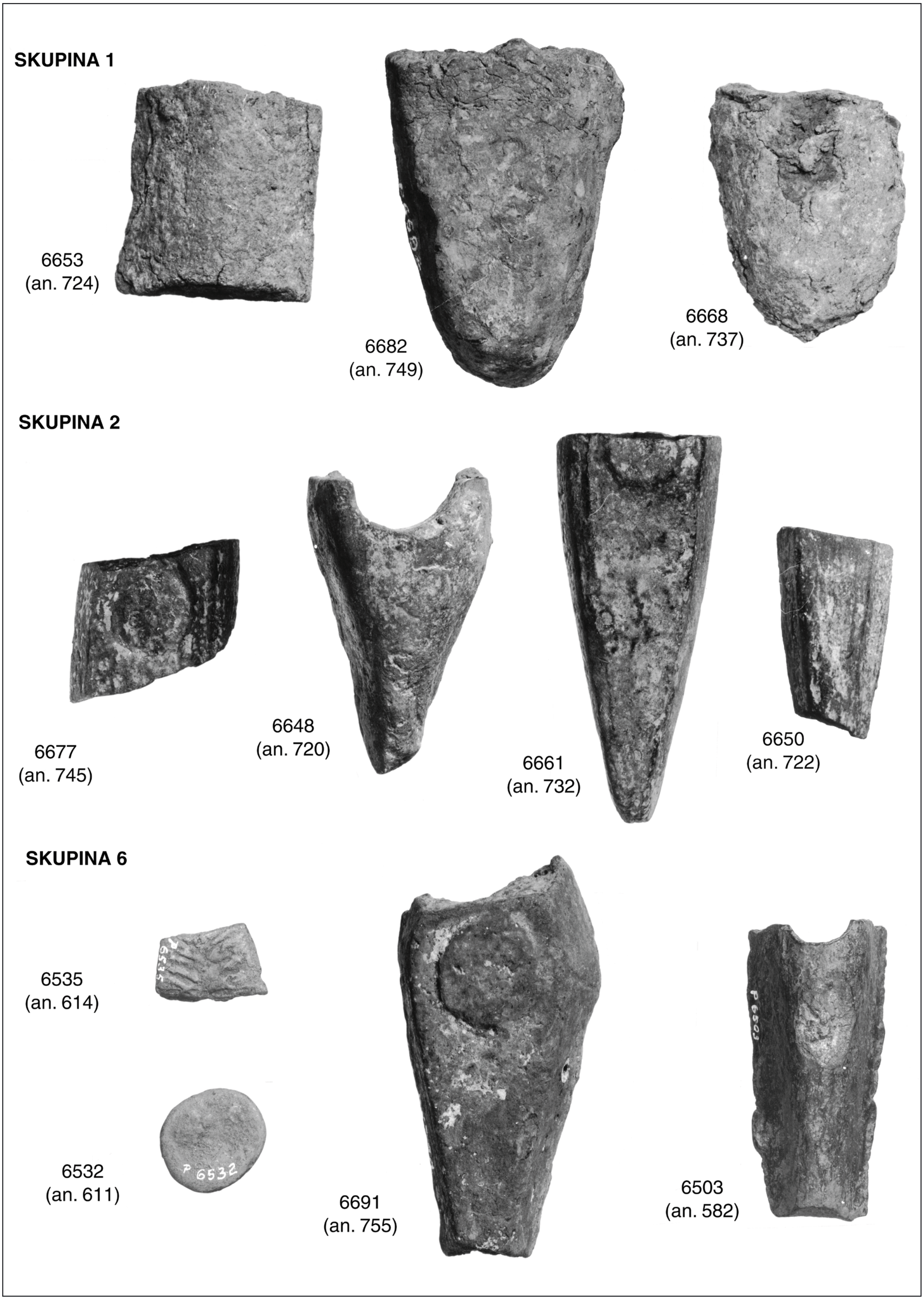
Sl. 9c: Veliki Otok. Ingoti P 6485b, 6487 in 6494 z označenim mestom odvzema vzorca za metalografske analize - ➔.
Fig. 9c: Veliki Otok. The ingots P 6485b, 6487 and 6494 sampled for metallographic analysis - ➔.

skupina/ group	št. ingotov/ no. of ingots	As [%]			Sb [%]			Ni [%]			Co [%]			Pb [%]			Sn [%]		
		min./ min.	maks./ max.	povp./ aver.	min./ min.	maks./ max.	povp./ aver.	min./ min.	maks./ max.	povp./ aver.	min./ min.	maks./ max.	povp./ aver.	min./ min.	maks./ max.	povp./ aver.	min./ min.	maks./ max.	povp./ aver.
1	6	0.01	0.21	0.10	0.02	0.09	0.06	0.02	0.05	0.03	-	0.03	0.02	21.10	46.20	36.60	-	0.04	0.02
2	22	2.15	26.17	5.64	1.81	16.20	6.54	2.70	19.45	6.17	0.90	8.09	2.49	0.10	0.70	0.26	0.02	0.92	0.15
3	3	2.67	6.78	4.19	3.15	9.03	6.11	2.43	6.98	4.23	0.83	0.94	0.87	18.65	49.63	31.95	1.17	3.32	2.18
4	10	3.17	6.57	4.53	2.69	13.69	6.83	0.01	0.07	0.03	-	0.03	0.02	0.02	0.31	0.15	-	0.04	0.03
5	8	1.12	2.02	1.65	2.12	5.59	3.50	0.07	0.96	0.59	0.04	0.27	0.15	19.35	89.1	36.04	0.01	0.09	0.05
6	104	0.90	20.85	3.28	1.18	22.60	7.87	1.07	19.32	3.44	0.02	8.28	0.88	1.86	58.27	28.17	0.01	4.95	0.12

Sl. 10: Kanalski Vrh. Minimalne, maksimalne in povprečne vsebnosti nečistoč (As, Sb, Ni, Co), svinca in kositra v izbranih ingotih.
Fig. 10: Kanalski Vrh. Minimal, maximal and average values of impurities (As, Sb, Ni, Co), of lead and tin in the selected ingots.



Sl. 11: Kanalski Vrh. Ingoti, razporejeni v 6 skupin glede na značilnosti kemijske sestave, ki odseva možno izvorno rudo.
Fig. 11: Kanalski Vrh. The ingots grouped in 6 groups according to the average values of impurities (As, Ni, Sb, Co) which reflect the possible origine of ore.



Sl. 12: Kanalski Vrh. Značilni predstavniki 1., 2. in 6. skupine ingotov.
Fig. 12: Kanalski Vrh. Typical representatives of ingots of the group 1, 2 and 6.

špajze, ki se je izločila, podobno kot tudi bakrov kamen, pri prvem taljenju kompleksne rude (primarna špajza). Majhna količina kamna v tem vzorcu špajze namreč pomeni, da sta se ob taljenju rude tvorila kamen in špajza in iz špajze so nato vlili ingot. Merjenje trdote tega vzorca je pokazalo primerljivost z jeklom (Paulin et al. 1999). Diferenčno termične analize naslednjih treh ingotov (DTA) pa so odkrile nove produkte taljenja - in sicer špajzo, ki je nastala s ponovnim oksidacijskim taljenjem primarne špajze, in žlindro, ki je nastala pri tem taljenju špajze (Paulin et al. 2000). To pomeni, da niso vlivali le ingotov iz primarne špajze, ki so jo dobili pri prvotnem taljenju kompleksne rude, ampak tudi iz ponovno taljene špajze in celo iz žlindre, ki je nastala pri tem taljenju. Primerjalne analize treh ingotov iz Velikega Otoka (*sl. 9c*), katerih kemijska sestava prav tako govori za špajzo, so naše odkritje potrdile (Northover, neobjavljeno).

Analize ingotov s Kanalskega Vrha je mogoče že na pogled ločiti v več skupin,[4] ki se razlikujejo med seboj po vrsti in količini nečistoč - (As, Ni, Sb in Co)[5] - ter po kombinacijah bakra s svincem oziroma brez svinca, izjemoma tudi s kositrom. Očitno v nekaterih skupinah nastopa razmeroma čist baker, v drugih pa baker z zelo visokimi koncentracijami nečistoč - včasih le arzena in antimona, največkrat pa arzena, antimona, niklja in kobalta (*sl. 10*).[5] Tako je v *1. skupini* 6 ingotov iz bakra z zelo nizkimi nečistočami (povpr. vse-bnost: As 0,10 %, Sb 0,06 %, Ni 0,03 %, Co 0,02 %) in z visokim svincem (povpr. vsebnost Pb 36,6 %).V *2. skupini* je 22 ingotov iz bakra z visokimi nečistočami (povpr. vse-bnost As 5,64 %, Ni 6,17 %, Sb 6,54 %, Co 2,49 %) in brez svinca (povpr. vsebnost Pb 0,26 %). V *3. skupini* so le 3 ingoti iz bakra z visokimi nečistočami, z visokim svincem (povpr. vsebnost Pb 31,95 %) in nizkim kositrom (povpr. vsebnost Sn 2,18 %). V *4. skupini* je 10 ingotov iz bakra z visokim arzenom in antimonom in zelo nizkim nikljem in kobaltom (povpr. vsebnost As 4,53 %, Sb 6,83 %, Ni 0,03 %, Co 0,02 %) ter brez svinca (povpr. vsebnost Pb 0,15 %). V *5. skupini* je 8 ingotov s podobnim vzorcem nečistoč vendar z visokim svincem (povpr. vsebnost Pb 36,06 %). V *6. skupini* so 104 ingoti iz bakra s podobno visokimi nečistočami kot v 2. skupini (povpr. vsebnost As 3,28 %, Ni 3,44 %, Sb 7,87 %, Co 0,88 %), vendar - z razliko od te - z dodanim svincem (povpr. vsebnost Pb 28,17 %).

Če pogledamo sestavo ingotov, in še posebej nečistoč, v luči kemijskih formul rudnin, zagledamo v naštetih skupinah povezavo z rudami, iz katerih je morda nastala kovina naših ingotov (*sl. 11*). V *1. skupini* ingotov, kjer sta baker in svinec v sestavi večinska elementa (v razmerju 1:1 ali celo 1:2 v korist Pb) in nečistoč takorekoč ni, bi to lahko bil *halkopirit* $Cu_2Fe_2S_4$ z dodanim *galenitom* PbS, včasih morda tudi s *sfaleritom* Zn(Fe)S. V *2. skupini* ingotov, v kateri baker predstavlja približno dve tretjini sestave, ena tretjina pa pripada zelo visokim nečistočam arzenu, antimonu, niklju in kobaltu, bi lahko videli Fahlerz, (t. j. *tetraedrit s tenantitom* $(Cu, Fe)_{12}$ $(Sb, As)_4$ S_{13}) z *nikljevimi* ter *kobaltovimi arzenidi* - t. i. kompleksno rudo.Tudi v *3. skupini*, ki je s 3 ingoti najmanjša, je kompleksna ruda z dodatkom galenita in kositra. V *4. skupini* in *5. skupini* ingotov je čisti Fahlerz - torej *tetraedrit s tenantitom*, z in brez *galenita*. V *6. skupini*, ki je s 104 ingoti največja, pa je ponovno *kompleksna ruda - tetraedrit s tenantitom, nikljevimi ter kobaltovimi arzenidi* in z dodanim *galenitom*. Na *sl. 12* je nekaj značilnih predstavnikov ingotov *11. skupine* iz bakra in svinca (ploščati ingoti) ter *2.* in *6. skupine* iz kompleksne rude (bikonični ingoti z odprtino ali brez odprtine na sredini, prednovčne oblike itd.).

RAZPRAVA

Znano je, da *kolesasti obeski* časovno niso ozko omejeni, saj so bili v rabi več stoletij, pa tudi njihove oblike so raznovrstne.[6] Če omejimo izbor na tiste, ki so najpodobnejši primerkom s Kanalskega Vrha, najdišča oblikujejo lok, ki se razteza v smeri Alp (*sl. 13*), od francoskih Centralnih Alp ter njihovega obrobja na zahodu (v depojih Beaurière, Loubière in Villethierry), čez severni del švicarske visoke planote (v naselbinah ob Neuchâtelskem jezeru Auvernier, Estavayer in v Montlingenbergu južno od Bodenskega jezera), do jugovzhodnih Alp s Caput Adriae (v depojih oziroma naselbinah Kanalski Vrh, Frattesina-Fratta Polesine), seže proti jugu v Srednjo Italijo (Tolfa, Costa del Marano) in izzveni na vzhodu na panonskem obrobju (v depojih Ivanec Bistranski in Velem Szent Vid).[7] Zanimivo je, da lok zajema tudi najdbe ovratnic z žičnatim prepletom in obročki ter ingote specifičnih oblik bikoničnega tipa.

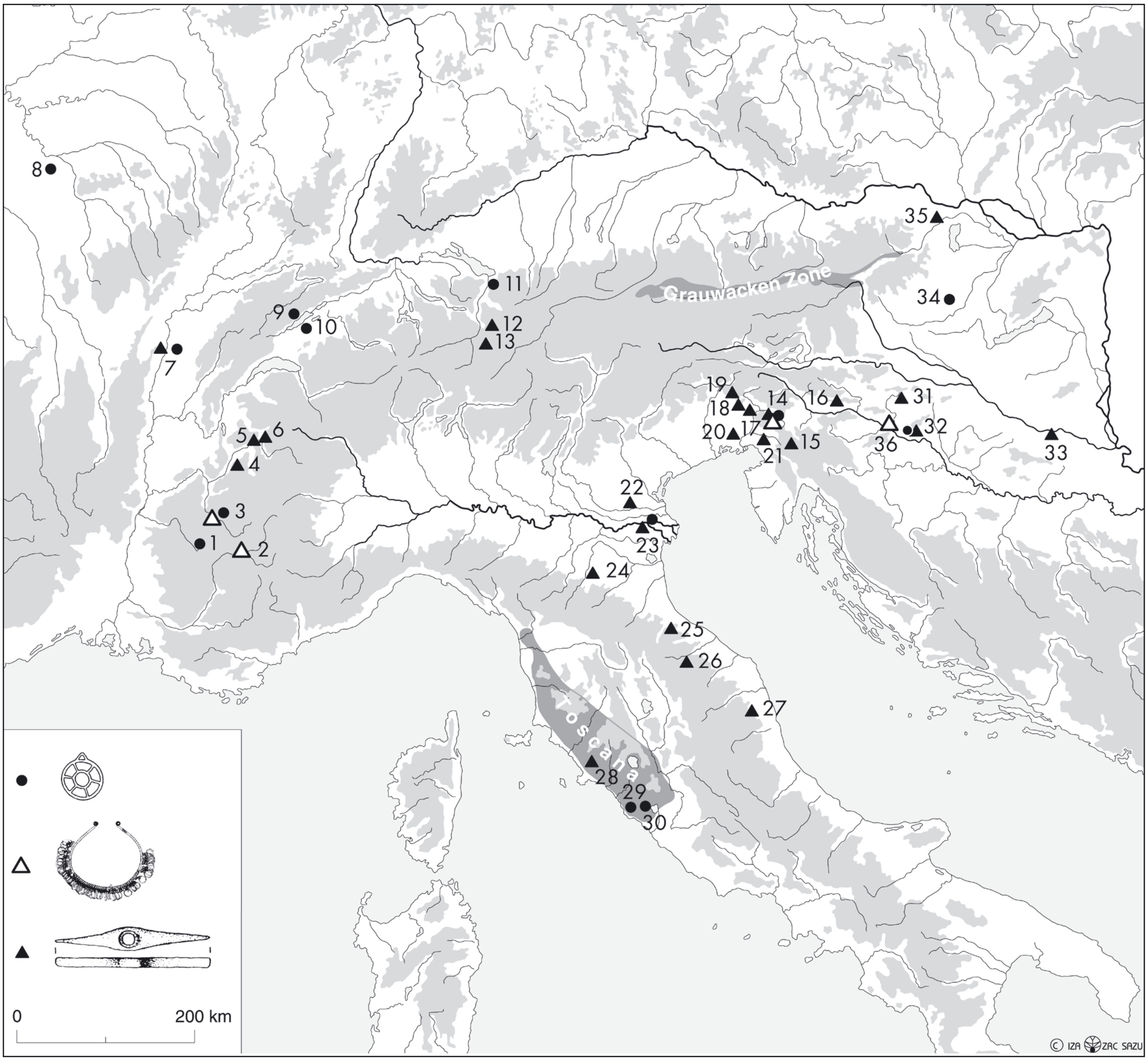
---

[4] Za določitev skupin ingotov glede na vsebnost nečistoč smo uporabili rezultate analiz, navedenih v objavi Trampuž Orel et al. 1996, 227-230.

[5] Podatki na *sl. 10* izvirajo iz analiz izbranih ingotov (104 kom.), ki najbolj odgovarjajo kemičnim značilnostim posameznih skupin.

[6] Žbona-Trkman, Bavdek 1996, 63 s citirano literaturo o kolesastih obeskih.

[7] Razprostranjenost kolesastih obeskov je povzeta po Žbona-Trkman, Bavdek 1996, 70, sl. 5 z dopolnitvami za Beaurière (Courtois 1976, 85, sl. 7: 12,14.), Loubière in Larnaud (Muller 1991, 121-122), Villethierry (Mordant, Prampart 1976, 169 ss), Coste del Marano (Peroni 1961, I 1(6) 32.), Velem Szent-Vid (Bándi, Fekete 1977-1978, 120-122, sl. 20-22). Za nekatera dodatna opozorila se zahvaljujem Petru Turku.



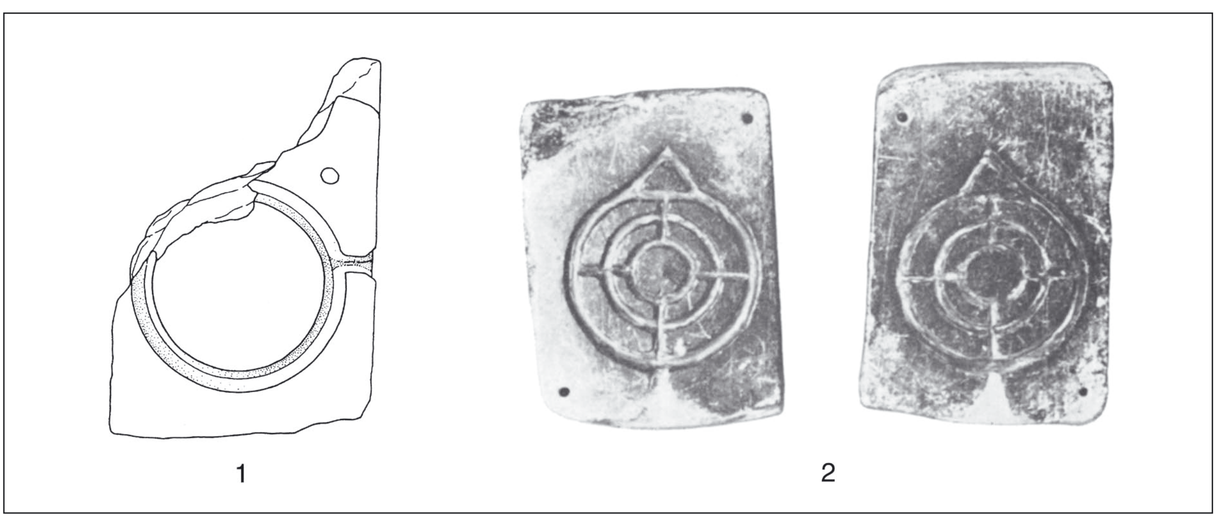
Sl. 13: Razprostranjenost kolesastih obeskov (podobnih tipom s Kanalskega Vrha), ovratnic z žičnatim prepletom in ingotov bikoničnega tipa. Za literaturo gl. op. 7 in 9.
Fig. 13: The spread of wheel-shaped pendants (similar to those from Kanalski Vrh), torcs with threaded circlets and biconical ingots. For bibliography see n. 7 and 9.

D = depo / hoard, N = naselbina / settlement, G = grob / grave.

1 Beaurière (D)
2 Réallon (D)
3 Loubière (D)
4 Goncelin (D)
5 Albertville (D)
6 Thénesol (D)
7 Larnaud (D)
8 Villethierry-Yvone (D)
9 Auvernier (N)
10 Estavayer (N)
11 Montlingerberg (D, N)
12 Schiers (D)
13 Filisur (D)
14 Kanalski Vrh (D)
15 Veliki Otok (D)
16 Dragomelj (D, N)
17 Madriolo (D)
18 Purgessimo (D?)
19 Nimis (D?)
20 Porpetto (D)
21 Redipuglia
22 Montagnana (D)
23 Frattesina-Fratta Polesine (D, N)
24 Bologna - San Francesco (D)
25 Poggio Berni (D)
26 Chiuse di Frontone
27 Marsia
28 Manciano (Grosseto, Piano di Talone) (D)
29 Tolfa
30 Coste del Marano (D)
31 Miljana (D)
32 Ivanec Bistranski (D)
33 Kapelna (D)
34 Velem Szent Vid (D)
35 Mahrersdorf (D)
36 Dobova (G) (Stare 1975, t. 41: 5)

Čeprav med zbranimi obeski najdemo enake tipe, kot na primer obeske s šestimi prečkami ali dvojnokrižne obeske, pa površne primerjave kažejo, da med njimi takorekoč ni identičnih izdelkov, ker so jih očitno izdelovale številne lokalne delavnice. Pač pa jih povezuje obstojna svetleča površina kovine, iz katere so bili vliti prenekateri primerki. Nanje je opozorila že Primasova, ki je ob poudarjanju pomena prazgodovinskih izdelkov iz čistega kositra, pokazala tudi na izdelke iz "bele kovine" (bakrove zlitine z več kot 10 % kositra, včasih obogatene s svincem), ki naj bi služila kot nadomestek za kositer. Prepoznavanje in izdelava takšnih zlitin naj bi bila omejena na osebe s posebnim znanjem o lastnostih in predelavi kovin. Ker so bili iz "bele kovine" še posebej pogosto vlivani predmeti simbolične vrednosti in votivnega pomena, kot so kolesasti obeski, je tovrstno metalurško znanje prisodila začetkom alkimije v domeni posameznikov, posvečenih v religiozno sfero bronastodobne Evrope (Primas 1985, 559 s). Analize sestave in izdelave kanalskih obeskov (predvsem tistih z osmimi prečkami) so v celoti potrdile njene ugotovitve, ki zadevajo potrebno posebno in ekskluzivno metalurško znanje, obenem pa so razkrile še novo metalurško veščino v pozni bronasti dobi - kositrenje. Dokazi o kositrenju nizkokositrnih bronov v Evropi so maloštevilni (Meeks 1993, 248 ss), največ naj bi jih bilo iz hal-štatskega, latenskega (fibule, zapestnice, novci), helenističnega in mlajšega rimskega obdobja (zrcala). Obeski in morda tudi obroči s Kanalskega Vrha so gotovo med prvimi prepoznanimi najdbami te vrste iz pozne bronaste dobe in verjetno ne med redkimi, vendar jih je med objavljenim gradivom težko razpoznati zaradi pogosto nepopolnih opisov površine in malo-številnih analiziranih primerkov. Za primer švicarskih obeskov iz Zürich-Wollishofna in Hitzkircha (Primas 1984), ki so bili vliti iz visokokositrnega brona z dodatkom svinca, lahko samo sklepamo, da so izdelovalci površino predmeta tudi spolirali in jo tako uspeli zaščititi pred korozijo.[8] Tak postopek dokazuje primer iz depoja Villethierry, kjer so pri obeskih iz visokokositrnega brona (Sn 20-25 %) opazili zglajeno površino (Mordant, Prampart 1976). Izdelovalec obeskov z osmimi prečkami iz Kanalskega Vrha pa je varčeval s kositrom, ker je uporabil nizkokositrni bron, vendar je dosegel enak učinek s kositrenjem. Kanalski obeski so med najlepšimi te vrste in so mojstrski izdelek odlične delavnice, ki jo vidimo na prostoru Caput Adriae, njene vzornike pa v italskem prostoru, v bližnjih tehnološko razvitih rokodelskih središčih protovillanovskega časa (11.-10. st. pr. n. š.). Domnevo podpirajo tudi najdbe kalupov npr. iz Sermina pri Kopru ali iz depoja Freghera-Cermenate pri Comu (*sl. 14*).

Podobno elegantnega stila in kvalitetne izdelave so tudi *ovratnice*. Njihova zunanja podoba se zaradi preciznosti izdelave kot tudi minuciozne izvedbe vrezanega ornamenta približuje videzu faler iz tega depoja in jih povezuje s podobnimi izdelki v francoskem, švicarskem in južnotirolskem prostoru (Žbona-Trkman, Bavdek 1996, 61, sl. 4). Razen primerka z grobišča v Dobovi (Stare 1975, t. 41: 5) je zelo podobne ovratnice z nanizanimi obročki (*sl. 13*) najti na popolnoma drugem delu Alp, v dveh depojih v

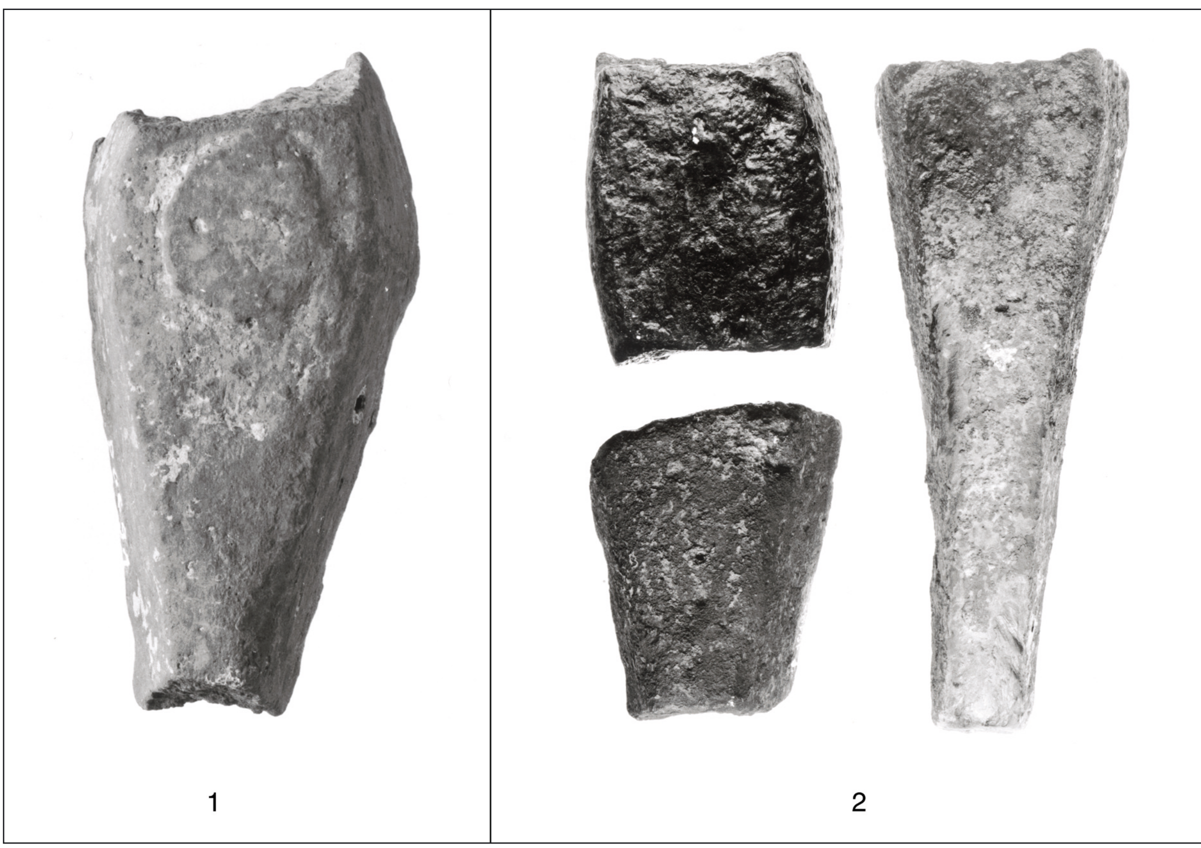


Sl. 14: 1 Sermin pri Kopru, kalup iz peščenca (po Snoj 1992, 100, t. 7); 2 Freghera-Cermenate pri Comu, kamnit kalup (po Frigerio 1981, sl. 16)
Fig. 14: 1 Sermin by Koper, a sand-stone mould (after Snoj 1992, 100, Pl.7); 2 Freghera-Cermenate near Como, a stone mould (after Frigerio 1981, Fig. 16)

[8] Podatek o nenavadno visoki vsebnosti kositra in svinca v omenjenih predmetih je potrebno obravnavati z rezervo, ker v članku ni omenjena uporabljena metoda analiziranja in ker so navedene le približne vrednosti obeh elementov - Sn ca. 60 %, Pb ca. 30 %.

francoskih Centralnih Alpah - v Loubièru in Réallonu (Müller 1991, 117-118, 121). Kemijska sestava podpira njihov tuj značaj v našem prostoru. Uporabljeni baker z nizkimi nečistočami jih oddaljuje od bakra tipičnih izdelkov zahodnega obrobja jugovzhodnih Alp in venetsko-furlanskega prostora, kot so kanalske plavutaste sekire s trnasto poudarjenim prehodom telesa v list (Žbona-Trkman, Bavdek 1996, 59 ss, sl. 3; Bietti Sestieri 1997, 390). Če upoštevamo tudi njihovo s kositrom bogato zlitino, ki je v nasprotju s tradicijo varčnega ravnanja s kositrom v jugovzhodnoalpskem in karpatskem prostoru, se nam bo morda zdela sprejemljiva misel, da so ovratnice izdelek druge delavnice in morda tudi namenjene drugim, oddaljenim prostorom.

Tudi razširjenost *bikoničnih ingotov* se pokriva z Alpami in dopolnjuje sliko kolesastih obeskov in ovratnic (*sl. 13*). Najdemo jih v depojih francoskih Severnih Alp (Goncelin, Albertville, Thénesol), v depoju Larnaud ob Saôni skupaj s kolesastimi obeski, v švicarskih depojih Schiers in Filisur, v depojih zahodne Slovenije Kanalski Vrh (skupaj s kolesastimi obeski in ovratnicami), Veliki Otok, Dragomelj, v furlanskih depojih Madriolo, Purgessimo, Nimis, Redipuglia, Porpetto, v padski nižini v depojih Montagnana in Frattesina-Fratta Polesine skupaj s kolesastimi obeski, v srednji Italiji v Bologni v depoju San Francesco, v depojih Poggio Berni, Chiuse di Frontone, Marsia in Manciano ter na obrobju panonske nižine v hrvaških depojih Miljana, Kapelna in Ivanec Bistranski skupaj s kolesastimi obeski in v avstrijskem depoju Mahrers-dorf.[9] So predmet pogostih obravnav, ki večinoma zanemarjajo podrobno obravnavo njihovih oblik, te pa ne predstavljajo tako homogene skupine, kot se zdi na prvi pogled (npr. Bietti Sestieri 1997, 387-390). Njihovo natančno tipološko razvrstitev otežuje predvsem dejstvo, da so večinoma razlomljeni, kar velja tudi za ingote s Kanalskega Vrha. Med kanalskimi ingoti smo posebno pozornost namenili ingotom bikoničnega tipa s trapeznim presekom, ki imajo na sredini namesto luknje reliefno izbočeno površino, ki spominja na pečat, ali pa je gladka (*sl. 15*). Njim podobne je najti tudi v depojih Veliki Otok, Dragomelj in Madriolo (Borgna 1992, t. 5: 26; 13: 26) in so značilni za zaho-dni del slovenskega



Sl. 15: Bikonični ingoti, značilne značilni oblike za zahodnoslovenski in venetsko-furlanski prostor. 1 Kanalski Vrh, 2 Dragomelj.
Fig. 15: Biconical ingots of typical shape for western Slovenia and Veneto-Friuli region. 1 Kanalski Vrh, 2 Dragomelj.

[9] Razprostranjenost bikoničnih ingotov je povzeta po Žbona-Trkman, Bavdek 1996, 71, sl. 6 z dopolnitvami po Casagrande et al. 1993, 269 op. 36, 270 op. 39).

in venetsko-furlanskega prostora (Trampuž Orel et al. 1996, 180). Analizirani primerki iz Kanalskega Vrha, Velikega Otoka in Dragomlja sodijo po kemijski sestavi v 6. skupino kanalskih ingotov, vlitih iz kovine, katere izvor vidimo v kompleksni rudi.

Naše razpoznavanje izvornih rud je seveda hipotetično, potrebne bi bile primerjalne analize ingotov in rudišč (analize Pb izotopov in spektralne analize rud), da bi domneve strokovno preverili. Tu jih bomo vendarle upoštevali, ker nudijo pripravno osnovo za iskanje izvora naših ingotov. Na to je prvi opozoril Czajlik (et al. 1999) v metalografski študiji pogač z najdišča Celldömölk-Saghegy, predvsem iz depoja II. Ugotovil je, da njihova sestava kaže rudno formacijo iz petih elementov (Cu-Ni-Co-Bi-Ag), značilno za omejeno število evropskih rudišč, med katerimi so najbližja v Avstriji in na Slovaškem, ni pa jih v Karpatski kotlini in ne na Balkanu. Omenjeno kompleksno rudo domneva tudi v ingotih s Kanalskega Vrha in Velikega Otoka. Kot so naše raziskave tudi dokazale, izvira špajza v omenjenih ingotih iz taljenja prav takšnih kompleksnih bakrovih rud vrste Fahlerz. Ležišča baritovo-kobaltovo-nikljevo-srebrovo-bizmutovih rudnih žil, ki jih uvrščajo tudi v *Skutterudit* - skupino, se v Evropi omenjajo predvsem na Saškem in v Turingiji (Erzgebirge) - Schneeberg, Annaberg, Marienberg, Saalfeld, Rammelsberg ter v Češkem rudogorju - Jáchymov, in v avstrijskih Nizkih Turah - Mitterberg in Schladming, medtem ko jih na področju Jugovzhodnih Alp glede na dosedaj objavljene podatke ni (Schröcke, Weiner 1981, 278 s; Drovenik 1984, 146 ss). Za naše ingote so najzanimivejša najbližja ležišča v avstrijskih Alpah, čeprav ne želimo zanemariti dejstva, da edini ingoti s speiss-sestavo, ki so bili do sedaj znani in analizirani in so tudi po obliki podobni kanalskim, izvirajo iz Guschaua (območje Saalfelda), torej z bolj oddaljene Saške.

Vzhodne Alpe, katerih del so Nizke Ture, vsebujejo veliko večino vseh avstrijskih mineralnih ležišč. Njihove zaloge, še posebej bakra, kot tudi zgodovina rudarjenja so predmet številnih raziskav, med katerimi zavzemajo posebno mesto arheološke in arheometalurške raziskave. Ležišča bakra so zlasti številna na geološkem območju t. i. *Grauwacken Zone* (*sl. 13*), metalogenetske enote, ki se razprostira med severnimi Apnenimi Alpami in južnimi Centralnimi Alpami kot več sto kilometrov dolg, ozek pas - od doline Inna pri Schwazu na zahodu pa skoraj do madžarske meje na vzhodu (Wallach 1993, 15 ss). Skoncentrirana so na več območjih, od katerih so za nas posebej zanimiva tista, kjer se omenjajo kompleksne rude. Dve sta v zahodnem delu Grauwacken Zone, na Salzburškem, eno pa v vzhodnem delu, na Štajerskem. Prvo je območje Mitterberga, kjer so med najbolj razširjenimi rudne žile halkopirita s tetraedritom, omenjajo pa se tudi Ni-Co-Sb arzenidi (Holzer 1986, 22). Tu je tudi temeljito raziskano in dokazano rudarjenje skozi vso bronasto dobo (Günther et al. 1994). Drugo je ob-močje Schladminga, natančneje orudeni predel Tur južno od mesta, posebej ležišče Zinkwand-Vöttern-Giglach, kjer se nahaja nikljevo-kobaltova ruda z arzenopiritom, nikljevimi in kobaltovimi arzenidi, löllingitom, bizmutovimi minerali in halkopiritom (Prochaska 1993, 12). Z istega območja poročajo tudi o galenitno- tetraedritno-stibnitni rudi z različno vsebnostjo srebra (Holzer 1986, 32). Brez dvoma je z arheometalurškega stališča najpomembnejše tretje območje - Liezen. Tukaj so namreč sodobne raziskave sledov rudarjenja in taljenja bakrove rude ter arheološka izkopavanja v širši okolici rek Palten in Liesing prispevale pomembne dokaze o rudarjenju kompleksnih rud v pozni bronasti dobi. Analize bakrove rude iz rudišč Bärndorf in Büschendorf, kakor tudi analize žlindre, kamna in "črnega bakra" iz poznobronastodobnega talilnega prostora "Versunkene Kirche" v okrožju Trieben, so pokazale, da so tam že tedaj kopali, sortirali, pražili in talili kompleks-ne rude (pirit, halkopirit in tenantit z zelo nizko vsebnostjo srebra, kobaltovimi minerali, arzenopiritom). Dokaz so koncentracije niklja in kobalta, odkrite v žlindri. Namreč pri taljenju, katerega produkt je bil "črn baker", je prišlo do izločanja niklja in kobalta iz rude v žlindro in *speiss*. Zato je za žlindre iz doline Paltental značilna skoncentrirana vsebnost obeh nečistoč, še posebej pa kobalta, kar naj bi bila razlikovalna lastnost rud liezenškega območja od mitterberških, v katerih dominira nikelj. Raziskave so tudi tukaj potrdile dosedanje izkušnje, da so rudo kopali, pražili in talili na rudiščih; ker tam niso našli polizdelkov, razen redkih analiziranih primerkov, domnevajo, da so bakrove pogače transportirali v druga metalurška središča, verjetno v naselbinah, kjer so baker rafinirali, izdelovali zlitine in vlivali ingote (Prochaska, Presslinger 1989; Presslinger, Eibner 1993).

Drugo rudno območje, ki tudi leži razmeroma blizu Kanalskega Vrha, in je po mineraloški pestrosti prav tako eno izmed najbogatejših v Evropi in največje na italskem polotoku, je Toskana, nekdanja Etrurija (*sl. 13*). Njena odločilna vloga v razvoju villanovske kulture in oblikovanju prvih mestnih državic, ki je temeljila tudi na naravnih danostih same pokrajine, predvsem na rudnem bogastvu, je bila pred časom temeljito analizirana. Spremembe v naselbinskem sistemu, ki kažejo na določene politične povezave manj-ših skupnosti znotraj Etrurije, neposredni trgovski stiki s sosednjimi pokrajinami na jugu (Lazio, Campania), z vzhodno jadransko obalo, s severom padske nižine, Venetom, Furlanijo in zahodno Slovenijo ter vzpostavitev trgovine z oddaljenimi predeli Alp že na koncu mlajše bronaste in v začetku starejše železne dobe (Ha B1), postavljajo Etrurijo na prvo mesto med tedanjimi italskimi skupnostmi (Bietti Sestieri 1997, 380 ss). Tudi tu se od bakrovih rud omenjata halkopi-rit in s srebrom bogat tetraedrit pa kositer, svinec, živo srebro in predvsem železo.[10] Kljub izčrpni arheološki evidenci naselbin na območju toskanskih rudišč, ki naj bi bile povezane z rudarjenjem že od začetka mlajše bronaste dobe (Bd D), pa so podatki zaradi pomanjkanja tovrstnih sistematičnih raziskav prazgodovinskih najdišč precej skopi (Giardino 1995, 116 ss). Izvorno področje poznejše etruščanske civilizacije in izjemne metalurške tradicije se po raziskanosti rudnih nahajališč in sledov najstarejšega rudarjenja žal še vedno ne more primerjati s podobnimi avstrij-skimi raziskavami v Vzhodnih Alpah.

Ne glede na to več dejstev govori v prid možno-sti, da je izvor kompleksne rude, iz katere izvira ko-vina kanalskih ingotov, v avstrijskih rudiščih. Eno je geografska lega Kanalskega Vrha, ki ga od rudišč v Nizkih Turah oddeljuje le 250 kilometrov, od sredine Toskane pa več kot 400 kilometrov današnjih lokalnih cest, in drugo specifična ruda. Ingote z dominantnim nikljem je mogoče povezati z rudo z območja Mitterberga, tiste z visokim nikljem in kobaltom pa z rudo z območja Schladminga ali območja Liezen-Paltental. Tovrstna ruda se za Toskano ne omenja. Kovina iz kompleksnih rud se nahaja tudi v drugih depojih zahodne Slovenije, tako v vseh ingotih Velikega Otoka, v nekaterih pogačah ter surovcih iz Dragomlja (*sl. 16*) in v bikoničnem ingotu iz furlanskega depoja Porpetto (*sl. 17*).[11] Ker so iz takšne kovine vliti tudi ingoti posebne oblike, značilne za zahodno Slovenijo in furlansko-venetski prostor, je upravičeno pričakovanje, da se enaka kovina nahaja tudi v depoju Madriolo in drugih venetsko-furlanskih depojih s podobnimi ingoti, ki pa žal niso analizirani.

Ingoti iz kanalskega depoja ne dokazujejo le izkoriščanja in predelovanja sulfidne bakrove rude z visoko vsebnostjo arzena in antimona, torej tetraedrita s tenantitom oz. Fahlerza; dokazujejo tudi izkoriščanje kompleksne rude, torej Fahlerza z nikljevimi in kobaltovimi arzenidi, in poznavanje ter ločevanje posameznih faz taljenja. Rezultat tega je bila izjemno trda, toda krhka kovina srebrno-svetlečega videza. Dejstvo, da so iz nje vlivali ingote, pomeni, da so špajzo, nasprotno poznejšim pojmovanjem, cenili in jo uporabljali. Ostaja le vprašanje, zakaj so jo potrebovali, kajti kljub veliki trdoti zaradi svoje krhkosti ni bila primerna za uporabne predmete. Morda leži odgovor v predmetih s Kanalskega Vrha. Značilno kovino kanalskih ingotov - tistih z nenavadno visokimi vrednostmi arzena, antimona in niklja, včasih tudi kobalta, bi lahko videli v skupini kolesastih obeskov in v sekirah (*sl. 6:* 1-9, 19, 20 in *sl. 7*). Ker so omenjene vrednosti precej nižje kot v ingotih, sklepamo, da so bile zlitine "razredčene" z drugačnim bakrom z nizkimi nečistočami. Opazovanje odrezane površine štirih metalografsko preiskanih ingotov iz Velikega Otoka in Kanalskega Vrha je pokazalo, da je ostala po preteku nekaj mesecev svetleče srebrne barve samo površina tistega ingota, ki je bila spolirana, potem ko je bil vzorec odrezan (ingot P 6584 s Kanalskega Vrha); ostale površine so potemnele.[12] Morda je bila tudi to ena od ugodnih, antikorozijskih lastnosti nenavadne, svetle, v poznejših obdobjih sicer "odpadne" kovine, ki so jo livarji v območju Caput Adriae uporabljali pri izdelavi bakrovih zlitin s kositrom, da so prihranili pri uporabi dragocenega kositra.

Pravilnosti teh domnev ni lahko dokazati, vsekakor pa je potrebno dopolniti in kritično ovrednotiti pred časom objavljeno drugačno mnenje o vrsti in uporabi kovine v kanalskih ingotih (Northover 1998b, 118 s). Avtor jih primerja z ingoti precej mlajšega železnodobnega depoja Arbedo iz Ticina, opredeljenega v 6.- 4. st. pr. n. š. (Schindler 1998). Obojne šteje med ternarne zlitine bakra z arzenom in antimonom in meni, da oboji niso bili neposredno uporabljeni za izdelavo katerihkoli pre-dmetov. Mnenje opira predvsem na rezultate analiz arbedskih ingotov, ki kažejo povišane vrednosti arzena, antimona, niklja in srebra, vendar teh kovin takorekoč ni mogoče zaslediti v predmetih tega depoja (Northover 1998a, 290). Predvsem je treba opozoriti, da je primerjava obojih ingotov nenatančna, zato deloma tudi zavajajoča. Kot podobni so navedeni polizdelki iz časovno in tehnološko različnih obdobij in iz različnih faz predelave kovine. Večino ingotov iz arbedskega depoja namreč predstavljajo surovci (Schindler 1998, 169) - torej deli pogač, ki so v metalurškem procesu primaren polizdelek, med tem ko so v kanalskem depoju v večini ingoti, torej v kalup vliti sekundarni izdelki. Tudi vzorec nečistoč, ki smo ga natančno analizirali pri kanalskih ingotih, ni tako zelo podoben arbedskemu. Pri posebej omenjenih arbe-dskih ingotih s povišanimi vrednostmi nečistoč (le 21 ana-liziranih primerkov), so vrednosti samega arzena in antimona primerljive s kanalskimi, medtem ko so vre-dnosti niklja večinoma tako nizke, da komaj dosegajo tiste v kanalskih predmetih (npr. št. 3756, 3770, 3755 itd.); kobalt, ki je pomembna značilnost mnogih kanalskih ingotov, je v arbedskih le na ravni

[10] Markoe 1992-1993, 16 ss, posebej op. 23, 24, 27 z dodatno geološko literaturo; Craddock 1986, 214 ss.

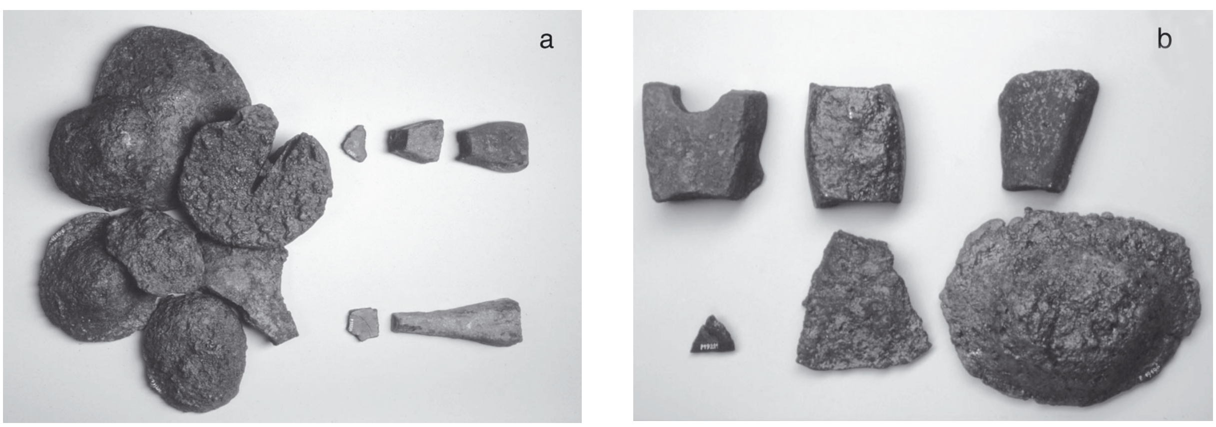
[11] Še neobjavljene analize depojev Dragomelj in Porpetto je leta 1997 izvršil David Heath; sodelavcu Petru Turku se zahvaljujem za dovoljenje, da sem lahko uporabila dragomeljsko gradivo pred skupno objavo. Gradivo iz Porpetta je povzeto po Borgna, Turk 1998, 363, sl. 1).

[12] Za odvzem metalografskih vzorcev ingotov iz Velikega Otoka se najlepše zahvaljujem dr. Spomenki Kobe, Laboratorij za keramiko, Inštitut Jožef Stefan.

sledov.[13] Torej vzorci nečistoč, ki so se v naši obravnavi izkazali za pomembne pri opredelitvi tipa kovine v ingotih, morda pa tudi za izvor, v obeh depojih niso tako zelo podobni. Predvsem je pomembno, da sestava kovine v nekate-rih kanalskih predmetih kaže, da so takšne ingote v nasprotju z arbedskim depojem uporabljali za vlivanje predmetov. Metalografske analize kanalskih ingotov so tudi jasno definirale prej zelo ohlapno opredelitev njihove kovine kot ternarne zlitine, katere izvor naj bi bile rude tipa Fahlerz (Northover 1998b, 118). Zdaj vemo, da to ni zlitina, ampak trdna raztopina, ki nastane pri taljenju večelementne rudne formacije in so jo namerno izločili pri procesu pridobivanja bakra iz kompleksnih rud (Paulin et al. 1999; idem 2000). Avstrijske raziskave takih rud in produktov taljenja so tudi dokazale, da se povišane koncentracije kobalta in/ali niklja izločajo prav v žlindri in špajzi teh rud.

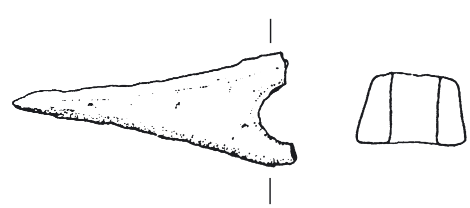
ZAKLJUČEK

V delavnicah na območju Caput Adriae se je na začetku 1. tisočletja uporabljala posebna kovina, ki je izvirala iz rud v rudiščih Nizkih Tur. Bila je svetleča in trda, podobna kositru, vendar se kljub temu zaradi izredne krhkosti ni mogla meriti z njim; zato ni bila primerna za uporabne predmete. Pač pa so iz nje vlivali neuporabne predmete simbolnega pomena (sekire) in take, ki so zahtevali srebrnosvetleč videz (kolesasti obeski). Ta kovina potrjuje domnevo, da je bilo območje Furlanije in zahodne Slovenije povezano z izkoriščanjem rudišč v Vzhodnih Alpah (Bietti Sestieri 1997, 390), pri čemer mislim na avstrijske Vzhodne Alpe. Uporabe bližjih morebitnih bakrovih rudišč te vrste v Jugovzhodnih Alpah, ki naj bi prišla v poštev zaradi velike koncentracije bikoničnih ingotov v bližini (Borgna, Turk 1998, 352, op. 18), seveda ni mogoče izključiti. Žal pa je tudi



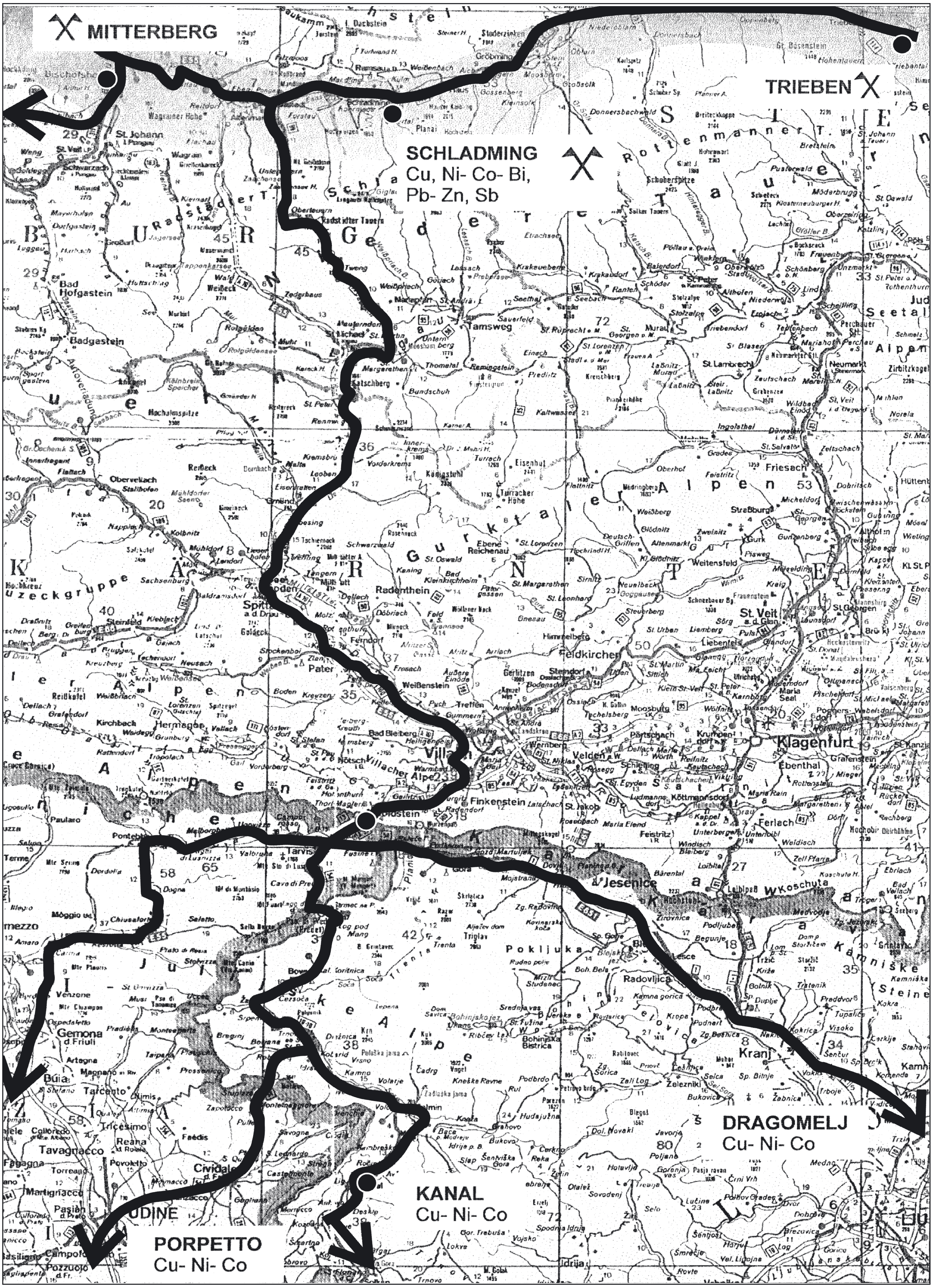
Sl. 16: Dragomelj. Izbor ingotov in pogač, katerih kovina kaže na izvor iz kompleksnih rud. a) z Ni- arzenidi; b) z Ni- in Co- arzenidi (foto Tomaž Lauko).
Fig. 16: Dragomelj. The cast ingots and plano-convex ingots which metal content indicates the polimetallic ore origine. a) Fahlore with Ni-arsenides; b) Fahlore with Ni- and Co-arsenides (photo: T. Lauko).

	%											
	Cu	Sn	Pb	As	Ni	Sb	Co	Bi	Fe	Mn	Ag	Zn
PR (5) 232519	83.4	*0.05*	*7.06*	*1.57*	*2.59*	*1.69*	*1.11*	< d.l.	*2.29*	< d.l.	*0.09*	*0.13*



Sl. 17: Porpetto. ICP-AES analiza bikoničnega ingota z značilno visokim nikljem in kobaltom (risba ingota po Borgna, Turk 1998, 363, sl. 1; analiza D. Heath 1996, neobj.)
Fig. 17: Porpetto. ICP-AES analysis of the biconical ingot with typically increased Ni- and Co- content (a drawing after Borgna, Turk 1998, 363, Fig. 1; analysed by D. Heath 1996, unpublished).

[13] Prim. Northover 1998a, 290, 306



Sl. 18: Smeri tovornih poti in kontaktov med Caput Adriae in rudišči v Vzhodnih Alpah (Nizke Ture) na začetku 1. tisočletja pr. n. š.
Fig. 18: Directions of trade-routes and contacts between the Caput Adriae region and the ore deposits in the Eastern Alps (the Niedere Tauern) at the beginning of 1st millenium BC.

ni mogoče potrditi glede na dostopne podatke v domači literaturi, dokler ne bodo spektralne analize slovenskih rudišč bolj popolne. V našem primeru analize dokazujejo, da je potekalo tovorjenje kovine od rudišč do delavnic tudi na več sto kilometrov dolgi razdalji, če je bilo to potrebno. Tovorili niso samo ingotov ampak tudi pogače, kot dokazuje dragomeljski depo. Ker tedaj še ni bilo cest, je najverjetneje, da so tovorili z živalmi. Iz zgodovine tovorništva je znano, da je ena žival - konj ali osel - nesla tudi do 150 kg težak tovor (Wenninger 1995, 406). Torej bi en konj z lahkoto nosil cel dragomeljski depo z 80,805 kg teže, kaj šele mnogo lažji depo iz Porpetta z 27,270 kg ali pa samo njegovo najtežjo pogačo z 11,250 kg. Zato tudi ni mogoče zlahka pritrditi sklepu, da naj bi takih polizdelkov zaradi večkrat izjemnih tež nekaterih primerkov, kot je omenjena pogača ali pa oxhide ingoti, ne tovorili iz bližine rudišč, ampak da naj bi nastali v lokalnih metalurških delavnicah (Borgna, Turk 1998, 352).

Poti, ki so povezovale vzhodnoalpske doline z Jadranskim morjem in po katerih se je odvijalo tovorjenje kovine in izdelkov, so bile zelo verjetno predhodnice rimskih in srednjeveških tovorniških poti, ki so tekle bolj ali manj nespremenjeno do uvedbe železnice v 19. stoletju. Od dveh najpomembnejših srednjeveških poti, ki sta vodili z juga proti severu čez Koroško, je takoimenovana "spodnja" tekla od Furlanije (Humin), čez Kanalsko dolino, Trbiž, Beljak, Spittal, čez prelaze Katschberg in Radstäter Tauern do Salzburškega in naprej proti Češki že vsaj od 13. stoletja dalje (Wenninger 1995, 405 ss). Mogoče je sklepati, da je v tej smeri vodila tudi ena izmed povezav mitterberških in schladminških rudišč z Jadranom, in sicer tista, ki je vodila naravnost do furlanskih metalurških središč (*sl. 18*). Druga, ki se je verjetno od te ločila že v Trbižu, pa je šla čez prelaz Predel, skozi vas Strmec, pri Bovcu vstopila v dolino Soče in se nadaljevala proti Kobaridu, kot je to omenjeno v beneških dokumentih iz 14. stoletja, ko je bil ta del poti pomemben za trgovino med Koroško, Tolminsko in Furlanijo (Gestrin 1965, 211). Od Kobarida navzdol je verjetno vodila proti Tržaškemu zalivu v smeri, kot je omenjena za novozgrajeno cesto konec 16. stoletja. Vojne Habsburžanov z Benečani so namreč narekovale izboljšavo prometne povezave notranjeavstrijskih dežel z morjem, ki je tekla po avstrijskem ozemlju, da so se tako izognili beneškemu (Rajšp 1994, 46 ss). Potek tega dela poti je dokumentiran tudi z mitnicami v Kobaridu, Volčah pri Tolminu in v Kanalu. Arheološko je soška pot dokumentirana posredno, z različnimi najdbami. Nedvomno je bil v pozni bronasti dobi uporabljan prelaz Predel (Teržan 1996, 256), posamezne bronastodobne najdbe od kovinskih do keramičnih so razporejene vzdolž cele poti,[14] med najvažnejšimi pa so gotovo hiša iz pozne bronaste dobe na Mostu na Soči in depoji Grgar, Kanalski Vrh in Šempeter. Zaradi lege kanalskega depoja na robu planote nad Avščkom in drugih bližnjih arheoloških najdišč je mogoče, da se je tovorna pot v pozni bronasti dobi od Mosta na Soči navzdol vila po robu Banjšic in ne po poznejši habsburški soški cesti. Pomen "soške" smeri pri povezavi notranjealpskih dolin s Tržaškim zalivom utemeljuje pred leti odkrita naselbina Sermin pri Kopru, ki je morda igrala pomembno posredniško vlogo v trgovini in prometu med severnim Jadranom in jugovzhodnoalpskim zaledjem. Podobno vlogo v posredovanju kovin in izdelkov, vendar v tretji smeri, je morda imela tudi naselbina Dragomelj (*sl. 18*). Ležala je na trgovsko-tovorni povezavi, ki se je odcepila od glavne se-verno-južne smeri pri Trbižu proti vzhodu; od tam je vodila čez Podkoren in vzdolž Save čez radovljiško in kranjsko ravan naprej proti jugovzhodu, čez Dragomelj in nato morda po Savi tja do severozahodne Hrvatske, kakor nakazujejo bikonični ingoti in nekateri drugi posamični predmeti v tamkajšnjih depojih Miljana, Ivanec Bistranski in Kapelna (Vinski-Gasparini 1973).

Zahvale

Rada bi se zahvalila kolegici Betki Žbona-Trkman, kustosinji Goriškega muzeja v Novi Gorici, ki nama je širokogrudno dala na voljo depo s Kanalskega Vrha za vsestranske raziskave, in dr. Urši Opara-Krašovec, raziskovalki Kemijskega inštituta v Ljubljani, ki je pomagala pri računalniški obdelavi rezultatov. Najina največja zahvala pa velja prof. dr. Bibi Teržan in prof. dr. Borisu Orlu za nenehno spremljanje in svetovanje pri najinem raziskovalnem delu.

BÁNDI, G. in M. FEKETE 1977-1978, Újabb bronzkincs Velem-Szentviden. - *Savaria. A Vas Megyei Múzeumok Értesitője*, 11-12, 101-133.

BIETTI SESTIERI, A. M. 1997, Italy in Europe in the Early Iron Age. - *Proc. Prehist. Soc.* 63, 371-402.

BORGNA, E. 1992, *Il ripostiglio di Madriolo presso Cividale e i pani a piccone del Friuli-Venezia Giulia*. - Studi e ricerche di protostoria mediterranea 1, Roma.

BORGNA, E. in P. TURK 1998, Metal exchange and the circulation of bronze objects between Central Italy and the Caput Adriae (XI-VIIIth BC): implications for the community organisation. - V: *Proceedings of the XIII Congress* (Forlì 1996) 4, 351-364, Forlì.

CASAGRANDE, A., G. L. GARAGNANI, E. LANDI, E. PELLEGRINI in P. SPINEDI 1993, Indagini analitico-strutturali su reperti metallici di età Protostorica dell'Italia continentale: Dati e considerazioni preliminari su un programma di ricerca pilota. - *St. Etr.* 58, 255-272.

COLES, J. M. in A. F. HARDING 1979, *The Bronze Age in Europe*. - London .

[14] Svoljšak 1988-1989; Šinkovec 1996, 160, sl. 19.

COURTOIS, J.-C. 1976, Complément pour l' étude du Bronze final et du Premier Age du Fer dans les Alpes Centrales Françaises. - V: A. Bocquet (ed.), *Les ages des métaux dans les Alpes.* IXe congrès de l' Union internationale des sciences préhistoriques et protohistoriques (Nice 1976), 73-92, Nice.

CRADDOCK, P. T. 1995, *Early metal mining and production*. - Edinburgh.

CRADDOCK, P. T. 1986, The Metallurgy and Composition of Etruscan Bronze. - *St. Etr.* 52, 211-271.

CZAJLIK, Z., F. MOLNAR in K. G. SÓLYMOS 1999, On the origin of Late Bronze Age semi-products found at Celldömölk-Sághegy according to electron-mikroprobe (EPMA) studies. - *Communicationes Archaeologicae Hungariae* 1999, 35-46.

DROVENIK, M. 1984, *Nahajališča mineralnih surovin*. - Ljubljana.

FRIGERIO, G. 1981, Interpretazione delle vicende di Capiago Intimiano nel contesto della preistoria e protostoria del territorio comasco. - V: E. Bianchi in G. Frigerio, *L'Età Preromana,* Storia di Capiago Intimano 1, 81-147, Como.

GESTRIN, F. 1965, *Trgovina slovenskega zaledja s primorskimi mesti od 13. do konca 16. stoletja*. - Dela 1. razr. SAZU 15/4.

GIARDINO, C. 1995, *The West Mediterranean between the 14th and 8th Centuries B.C.* - BAR Int. Ser. 612.

GÜNTHER, W., C. EIBNER, A. LIPPERT in W. PAAR 1994, *5000 Jahre Kupferbergbau am Hochkönig - Bischofshofen*. - Salzburg.

HEATH, D. J., N. TRAMPUŽ OREL in A. PAULIN (unpublished), Ingots, ingots of speiss and ingots of unusual composition in the Late Bronze Age.

HEATH, D. J., N. TRAMPUŽ OREL, A. PAULIN in Z. MILIĆ 2000, Wheel-shaped pendants: evidence of a Late Bronze Age metal workshop in the Caput Adriae. - V: A. Giumlia-Mair (ed.), *Ancient Metallurgy between Oriental Alps and Pannonian Plain,* Quaderni dell'Associazione Nazionale per Aquileia 8, 53-70.

HOLZER, H. F. 1986, Austria. - V: F. W. Dunning in A. M. Evans (eds), *Mineral deposits of Europe* 3. *Central Europe,* 15-40, London.

JAFFÈ, F. C. 1986, Switzerland. - V: F. W. Dunning in A. M. Evans (eds), *Mineral deposits of Europe* 3. *Central Europe,* 41-54, London.

KASSIANIDOU, V. 1998, Was silver actually recovered from speiss in antiquity? - V: T. Rehren, A. Hauptmann in J. D. Muhly (eds), *Metallurgica antiqua - in Honour of Hans-Gert Bachmann and Robert Maddin,* Der Anschnitt 8, 69-76, Bochum.

MARÉCHAL, J. R. 1985, Methods of ore roasting and the furnaces used. - V: M. J. Hughes (ed.), *Furnaces and Smelting Technology in Antiquity,* British Museum Occasional Paper 48, 29-41.

MARKOE, G. E. 1992-1993, In pursuit of silver: Phoenicians in Central Italy. - *Hamburger Beitr. Arch.* 19-20, 11-31.

MEEKS, N. 1993, Surface characterization of tinned bronze, high-tin bronze, tinned iron and arsenical bronze. - V: S. La Niece in P. T. Craddock (eds), *Metal Plating and Patination*, 247-275, London.

MORDANT, C., D. MORDANT in J.-Y. PRAMPART 1976, *Le dépôt de bronze de Villethierry (Yonne).* - 9e supplément à Gallia préhistoire.

MÜLLER, A. 1991, L' Âge du Bronze dans les Hautes-Alpes. - V: *Archéologie dans les Hautes-Alpes,* 103-131, Musée départemental de Gap.

NORTHOVER, P. 1998a, Analysis of copper alloy metalwork. - V: M. Schindler, *Der Depotfund von Arbedo TI und die Bronzedepotfunde des Alpenvorraumes vom 6. bis zum Beginn des 4. Jh. v.Chr.*, Antiqua 30, 289-316.

NORTHOVER, P. 1998b, Exotic alloys in antiquity. - V: T. Rehren, A. Hauptmann in J. D. Muhly (eds), *Metallurgica Antiqua - In Honour of Hans-Gert Bachmann and Robert Maddin,* Der Anschnitt 8, 113-121, Bochum.

OTTO, H. in W. WITTER 1952, *Handbuch der ältesten vorgeschichtlichen Metallurgie in Mitteleuropa.* - Leipzig.

PAULIN, A., S. SPAIĆ, S. SPRUK, J. D. HEATH in N. TRAMPUŽ OREL 1999, Speiss from the Late Bronze Age. - *Erzmetall* 52/11, 615-622.

PAULIN, A., S. SPAIĆ, D. J. HEATH in N. TRAMPUŽ OREL 2000, Analysis of Late Bronze Age Speiss. - *Bulletin of the Metals Museum* 32, 29-41.

PERNICKA, E. 1995, Gewinnung und Verbreitung der Metalle in prähistorischer Zeit. - *Jb. Röm. Germ. Zentmus.* 37, 21-129.

PERONI, R. (ed.) 1961, *Ripostigli delle età dei metalli* 1. *Ripostigli del Massicio della Tolfa.* - Inv. Arch. Italia 1, I 1-I 3.

PRESSLINGER, H. in C. EIBNER 1993, Prähistorische Kupfererzbergbau und die Verhüttung der Erze. - V: H. Presslinger in H.-J. Köstler (eds), *Bergbau und Hüttenwesen im Bezirk Liezen (Steiermark).* - Kleine Schriften 24, 25-36, Trautenfels.

PRIMAS, M. 1984, Bronzezeitlicher Schmuck aus Zinn. - *Helv. Arch.* 57-60/2, 33-42.

PRIMAS, M. 1985, Tin objects in Bronze Age Europe. - V: M. Liverani, A. Palmieri in R. Peroni (eds), *Studi di paletnologia in onore di Salvatore M. Puglisi,* 555-562, Roma.

PROCHASKA, W. 1993, Geologie und Lagerstätten des Bezierkes Liezen. - V: H. Presslinger in H.-J. Köstler (eds), *Bergbau und Hüttenwesen im Bezirk Liezen (Steiermark),* Kleine Schriften 24, 7-14, Trautenfels.

PROCHASKA, W. in H. PRESSLINGER 1989, Palten-Liesing-Tal: Kupfererze und prähistorische Laufschlacken. Aufschlussreiche geochemische Untersuchungen. - *Da schau her* 4 , 9-14.

RAJŠP, V. 1994, Obsoška cesta v prometni politiki Avstrijske države. - *Kronika* 42, 46-51.

RYCHNER , V. in N. KLÄNTSCHI 1995, *Arsenic, nickel et antimoine. Une approche de la metallurgie du Bronze moyen et final en Suisse par l'analyse spectrometrique* 1, 2. - Cahiers d' archéologie romande 63.

SCHINDLER, M. P. 1998, *Der Depotfund von Arbedo TI und die Bronzedepotfunde des Alpenvorraumes vom 6. bis zum Beginn des 4. Jh. v.Chr.*. - Antiqua 30.

SCHRÖCKE, H. in K.-L. WEINER 1981, *Mineralogie - Ein Lehrbuch auf systematische Grundlage.* - Berlin, New York.

SNOJ, D. 1992, Sermin. - *Var. spom.* 34, 91-106.

STARE, F. 1975, *Dobova*. - Pos. muz. Brež. 2.

SVOLJŠAK, D. 1988-1989, Posočje v bronasti dobi. - *Arh. vest.* 39-40, 367-386.

ŠINKOVEC, I. 1996, Posamezne kovinske najdbe bakrene in bronaste dobe. - V: B. Teržan (ed.), *Depojske in posamezne najdbe bakrene in bronaste dobe na Slovenskem* 2, Kat. in monogr. 30, 125-163.

TERŽAN, B. (ed.) 1995-1996, *Depojske in posamezne kovinske najdbe bakrene in bronaste dobe na Slovenskem* 1, 2, Kat. in monogr. 29, 30.

TERŽAN, B. 1996, Sklepna beseda. - V: B. Teržan (ed.), *Depojske in posamezne najdbe bakrene in bronaste dobe na Slovenskem* 2, Kat. in monogr. 30, 243-258.

TRAMPUŽ OREL, N., D. J. HEATH in V. HUDNIK 1996, Spektrometrične raziskave depojskih najdb pozne bronaste dobe. - V: B. Teržan, *Depojske in posamezne najdbe bakrene in bronaste dobe na Slovenskem* 2, Kat. in monogr. 30, 165-242.

TRAMPUŽ OREL, N., HEATH, D. J. in V. HUDNIK 1998, Chemical analysis of Slovenian bronzes from the Late Bronze Age. - V: C. Mordant, M. Pernot in V. Rychner (eds), *L' Atelier du bronzier en Europe du XXe au VIIIe siècle avant notre ère. Actes du colloque international "Bronze '96" Neuchâtel et Dijon, 1996* 1. *Les Analyses de composition du métal : leur apport à l'archéologie de l' Âge du Bronze,* 223-237, Paris.

TYLECOTE, R. F. 1987, *The Early History of Metallurgy in Europe.* - London.

VINSKI-GASPARINI, K. 1973, *Kultura polja sa žarama u sjevernoj Hrvatskoj.* - Monografije 1, Zadar.

WALLACH, G. 1993, Montanarchäologische Bodendenkmale. - V: H. Presslinger in H. J. Köstler (eds), *Bergbau und Hüttenwesen im Bezirk Liezen (Steiermark).* - Kleine Schriften 24, 15-24, Trautenfels.

WENNINGER, M. J. 1995, Handel, Verkehr und Transportwesen. - V: F. W. Leitner (ed.), *Grubenhunt und Ofensau. Vom Reichtum der Erde* 2. *Beiträge zum Kärntner Landesausstellung,* 405-415, Klagenfurt.

ŽBONA-TRKMAN, B. in A. BAVDEK 1996, Depojski najdbi s Kanalskega Vrha. - V: B. Teržan (ed.), *Depojske in posamezne kovinske najdbe bakrene in bronaste dobe na Slovenskem* 2, Kat. in monogr. 30, 31-71.

The Kanalski Vrh hoard - a case study of the metallurgical knowledge and metals at the beginning of the 1st millennium BC

Translation

INTRODUCTION

The uncovering of trade contacts and transportation routes in the prehistoric periods is based on studies of the typologies and distribution of artifacts, and on the hypothesized models of their spread and exchange, which are also dependent on the type and reasons for deposition (Coles, Harding 1979). The comparison of written sources from historical periods is a welcome addition, as are comparisons of data from other fields, such as ethnology, geography, and economic history. Often the decisive elements are results of research in natural science, by which we primarily mean research into the composition of materials. Spectral analysis of the chemical composition and metallographic analysis of prehistoric metals from Slovenia offer much information supplementing our knowledge about the composition of artifacts of copper and copper alloys, and our conception of metallurgical knowledge at the end of the Late Bronze Age. If these results are carefully related to the corresponding archaeological data and selected archaeological conclusions, it is possible to form a cultural-historical image of a given region from an economic point of view. In this specific case, a series of hypotheses have been opened - about the choice of ore deposits and transportation routes, about the role of metallurgical centers and foundry workshops, about metallurgical knowledge and its exclusivity. This would, in fact, be the aim of our archaeometrical research: - not merely hundreds of analyses, but also a comparative, synthetic analysis and presentation of archaeological and chemical results. The present study represents such an attempt.

The Kanalski Vrh hoard was recently published in entirety, analyzed chemically, and interpreted in detail (in: Teržan (ed.) 1995, Pl. 95-118, and 1996, 31 ff., 165 ff.). It is actually composed of two units that were found at different but nearby locations, although they are treated as one in the above study. This double nature did not seem important in that case, which does not mean that it is not significant in a study of the reasons for the deposition. The hoard contains numerous objects - axes, decorative sheet metal, torcs, wheel-shaped pendants, circlets, tubes, and an admirable quantity of semi-finished products and some raw material - 50.450 kg of broken ingots, one entire plano-convex ingot and several plano-convex ingot fragments. In terms of the material, it is well dated to the beginning of the 1st millennium BC, i.e. the transitional HaA2/HaB1 period (Žbona-Trkman, Bavdek 1996, 64), while in terms of composition it is classified among the large hoards of horizon III (Turk 1996, 112 ff.) in the region between Friuli and Transdanubia, a new feature of which was the great amount of mostly fragmentary, biconical ingots cast in a mould.

THE ARCHAEOLOGICAL AND CHEMICAL CHARACTERISTICS OF THE ARTIFACTS

The observation of the exterior features and characteristics of the artifacts and the study of their distribution led to interesting data, summarized here on the basis of the original publication (Žbona-Trkman, Bavdek 1996). Immediately after the discovery of the hoard, great attention was drawn by the shiny silver-gray surfaces of most of the wheel-shaped pendants and circlets, strongly distinguished from the dark green color of the remaining artifacts, because of which it was thought that two different alloys were in question[1]. Comparisons of the form, size, and weight of the pendants and circlets has shown the use of the same mould for the casting of several objects. The find of a mould for circlets, identical to that from the Kanalski Vrh hoard, at the settlement of Sermin near Koper, and moulds for winged axes with an emphasized interface from the handle to the blade, as at the Kanalski Vrh hoard, and which are characteristic for the broader region along the northern and eastern Adriatic coasts, the same in Sermin and in the hoard from Šempeter, have indicated the possibility that such objects were produced by workshops in the Caput Adriae region.

Great attention was drawn by the ingots, both in terms of the large quantity and their shape. This kind of semi-finished product was so to speak unknown in Slovenia, with the exception of the ingots from Veliki Otok, which had not until then exhibited any true connection with the otherwise rich finds of raw copper in the form of plano-convex ingots from the earlier Ha A hoards. The biconical ingots, as well as the pendants, torcs, and decorative sheet metal connected the Kanalski Vrh hoard with similar finds, primarily from the Italic and western Alpine regions, and less with the Carpathian basin.

Through chemical analysis (using the ICP-AES method), the mentioned observations were further confirmed and supplemented (Trampuž Orel et al. 1996). They disclosed the use of the same kind of copper in the production of alloys and the identical batches for pendants, axes and torcs, which indicated the products of the same foundry workshop, buried even before they entered circulation. The reason for the unusually shiny surface of the jewellery was also shown - a relatively high content of tin (above 10%). The analyses also uncovered greatly elevated values for lead, particularly in the ingots, thus confirming the widespread opinion that copper alloys with lead (even to 27%) were in use in the eastern Mediterranean and in Europe at the transition to the 1st millennium BC, when the use of lead greatly increased (Pernicka 1995, 54, Fig. 16). As the artifacts in this hoard, as well

[1] In the conservation report of the Regional Museum in Nova Gorica for 1990, Jana Šubic Prislan noticed that the "lengthy cleaning of the majority of objects was rewarded by uncovering of a flawless, smooth surface, covered with a healthy green-brown patina ..." and that among the pendants and circlets were artifacts "with a gray and gray-yellow patina".

as certain other specimens from the southeastern Alpine region with a very high content of lead, are typologically connected to material from the Italic area, or at least with the region to the west of Slovenia, the hypothesis was suggested that the new technology - the use of lead in producing a copper alloy - began to spread in Slovenia at the Ha A2/Ha B1 transition through a mediating role by the Italic peninsula.

Wheel-shaped pendants

The typological and chemical characteristics will be discussed of the objects from Kanalski Vrh that best define the significance of this find in the framework of the Caput Adriae, as well as in the broader region of the Eastern Alps and central Italy. As was already mentioned, after discovery of the hoard attention was drawn by the unusual pale and shiny surface of the wheel-shaped pendants and circlets, and a special study was devoted to these objects (Heath et al. 2000). Among the published artifacts, 35 pendants (of 43) and 56 circlets (of 62) have a shiny surface. At first it seemed that the cause was the more than 10% content of tin, although this did not take into account those objects that have a similar concentration of tin but nonetheless are covered with a green patina. A more detailed inspection of the pendants revealed that sections on the upper and lower sides were covered with a dark gray layer (*Fig. 1*). Analysis of the surface of one of the pendants (P 6348) with x-ray fluorescence (XRF) showed that the concentration of tin in the dark section was almost three times greater than on the other, lighter surfaces and in the interior of the artifact (*Fig. 2*). The comparison of a microscopic photo of this section with the photo of a tin coated Roman mirror (Meeks 1993, 258, Fig. 21: 11) has indicated the possibility that the pendants from Kanalski Vrh could have been tinned (*Fig. 3*). The technique of tinning and other procedures for producing bronze objects with a surface of silver appearance that were resistant to corrosion have already been researched in detail (Meeks 1993). The silvery appearance could also be achieved with an alloy containing a relatively low amount of tin (around 14%), if the surface of the artifact was then tinned - molten tin being applied to the heated surface, which then also acted as an anti-corrosion protection. A second possibility was an alloy with a high tin (19-27%), where the surface of the artifact had to be polished. The alloys of the pendants as well as the circlets from Kanalski Vrh contained only 10-20% tin, most often 12-13%, which places them among low-tin bronzes. Thus it can be concluded that in most cases the silvery appearance was the result of tinning, although for final proof metallographic analyses will be necessary (SEM, EDX).

Attention was also drawn by the frequent groupings of identical alloys. So as to get an overview of the relation of alloy to form, we classified the pendants according to the number and form of spokes into seven groups (*Fig. 4*). Pendants of type 1 with eight spokes proved to be most suitable for a combined archaeological-chemical study. They are the most numerous, of a silver-shiny appearance, and with traces of tinning (with exception of the pendant no. 17, which was covered with a green patina). Their shape is totally uniform, symmetrical and elegant, which indicates the same model and identical mould. Their chemical composition was - surprisingly - varied (*Fig. 5*). At first glance, groups of pendants from identical alloys are evident (as indicated by the very similar values for tin, lead, and impurities), which represent individually prepared batches or "loads" - meaning the quantity of alloy prepared for casting in moulds. It is possible to distinguish four, perhaps even five batches that differ in amounts of tin and lead and more or less pure copper. At first glance, the greatest quantity of identical alloys is in the first group of pendants from nos. 1-9 (batch 1), which exhibit highly similar amounts of tin, lead, and impurities (Sn 10.5 -12.3%, Pb 1-2% and approx. impurity values: Sb 0.9%, Ni 0.9%, As 1%, Co 0.2%). Quantities of lead less than 3% probably refer to the nature contents of copper ore (Rychner 1990, 210), and thus such compositions are defined as a binary alloy of copper and tin. The copper used has a relatively high proportion of impurities if we compare it with that from Slovenian Ha A artifacts, where more than half of the objects have only 0.2-0.5% antimony and nickel and less than 0.7% arsenic (Trampuž Orel et al. 1998a, 229 ff. and Fig. 7). The next group of pendants, nos. 10-14, have somewhat higher tin values (Sn 12.6-15.6%) and very high lead contents (Pb 14-16%); the copper used had less impurities than that of batch 1. For their production, a ternary copper alloy was prepared with tin and lead, perhaps even in two batches (batch 2, batch 3). A similar alloy was used for pendants 15-16 (batch 4), only with much less lead (Pb 6%). The least rich alloy was used for pendant no. 17 (batch 5), which contained very little tin (Sn 3.5%) and almost no lead (Pb 1.7%), but once again copper with higher impurity rates, especially of antimony (Sb 3.31%) and arsenic (As 1.28%) - this pendant is green. Pendants 18 and 19 unfortunately were not analyzed.

Several pendants of type 2 with six spokes were also cast in identical moulds (*Fig. 4:* 19-25). Of these seven, four had a shiny appearance (21, 23-25), and the remaining three were green (19, 20, 22). Analysis (*Fig. 6*) shows that the pendants no. 19 and 20 were not made of an alloy (Sn only 0.2 - 1.1%); they were cast from a copper with very high impurities (As 4%, Ni 2%, Sb 4%), which perhaps naturally contained lead ore (Pb 2.99 %) - significant data to which we will return when discussing the ingots. The remaining pendants are of a bronze - binary alloy with tin (Sn 9.7 - 18.2%). They differ greatly in terms of production from the type 1 pendants. They are less elegant, of gently asymmetrical shape, with various thickenings of the spokes and rim, indicating a poorer quality mould that was more quickly deformed after repeated use, and perhaps a lower quality alloy (a lack of sufficient quantities of lead). The three pendants of type 3 with five spokes were made from the same mould (*Fig. 4:* 26 and two pendants that were not analyzed). All have a green patina, the alloy was a low-tin bronze (Sn 3.6%) with somewhat increased lead (Pb 6.4%). The remaining pendants of types 4 - 7 (*Fig. 4:* 27-33) have individual shapes and all have a surface with a silvery appearance. A copper with less impurities was used for them containing quite a lot of tin (Sn 9.9-16.7%), while lead was not added, other than a small quantity (Pb 4.3%) in pendant 28.

From the described characteristics of the alloys and forms, it is possible to draw a conclusion about the production procedures for several types of pendants. The elegant pendants with eight spokes of type 1 were produced according to an excellent original model and in high quality moulds - for the first nine pendants most likely several entirely identical moulds connected to one another. The production of the model points to a skilled and pedantic craftsman, as all of the products have a symmetrical, elegant form. The casts were free from faults, which also indicates a high quality alloy - thus meaning a metalsmith with great knowledge and experience. The casting would have taken place gradually, as he produced several batches. He probably had available ingots from at least two types of copper - one type with a natural lead content (Pb 1-2%) and high impurities and another type with deliberately added lead (Pb 6-16%). Tin was probably added in the form of bronze alloys rich in tin (Sn 10-17%). Evidently he skillfully chose and measured the composition of individual batches, as the pendants of this series, despite fairly major variants in the lead content do not exhibit any difference in the exterior appearance, and even differences in weight are relatively minor. At the end of the process, the pendants were dipped into molten tin, so as to achieve a silver-shiny appearance. Pendants with six and five spokes of type 2 and 3 are lesser quality casts. The products exhibit mistakes that could have resulted from less exactly made models or poorer quality moulds, and perhaps also the "wrong" alloy (among them are at least three that have not preserved their shiny surface).

Axes and torcs

Uniform alloys and identical batches have also been established for other objects from Kanalski Vrh (*Fig. 7*). The same batch was prepared for axes P 6492 and 6493. All the axes have exceptionally little tin (Sn<2%) and lead at the level of natural occurrence (Pb< 3%). The copper, however, contains relatively high amounts of arsenic, antimony, and nickel (As 1.1-1.2%, Sb 1.85-2.01%, Ni 0.8-0.9%), similarly to the pendants of type 1 with eight spokes. Because of their low level of tin, the axes were not suitable for use.

The torcs also exhibit identical and similar alloys and the same casting batches (*Fig. 7*). One batch was used to cast torcs P 6495 and 6496, and from another, torcs P 6497, 6501, and 6500. In this manner metallurgical analysis has contradicted archaeological classification - the torc with threaded circlets P 6501 was assigned typologically as the product of another workshop[2], while its composition shows that it was cast at the same time as the other two torcs, thus in the same workshop. In contrast to the axes, the torcs were cast from a harder bronze with a fairly high quantity of tin (Sn 7%), and with no lead added to the alloy. The copper exhibits small values for impurities (As 0.3-0.5%, Sb 0.4-0.5%, Ni 0.3-0.5%), like that of the axes and pendants of type 1.

Ingots

The ingots from Kanalski Vrh are classified among biconical types (pick-ingots, pane a piccone), whose common characteristic of biconical form is more or less similar to the classic examples of double axes from Cyprus and Sardinia from the 12th-11th centuries BC. Analysis of these ingots has drawn attention because of the unusually high quantity of lead and impurities. They were first classified as a binary alloy of copper with lead, while the impurities were attributed to the use of copper ore of the Fahlore type (Trampuž Orel et al. 1996, 194, 202 ff.). Both could also be traced in the metals of the early Ha B period elsewhere in Europe[3]. The term "Fahlore", that will be used here, represents an extensive group of complex sulfides, with the most important minerals being tetrahedrite and tennantite, but it can also contain mixed crystals of both minerals with considerable amounts of Zn, Fe, Ni, Co, Mn, and other elements (polymetallic ores). The ores of the Fahlore group are very widespread, appearing as additions at Pb-Zn ore sites, and are frequently silver bearers in galenite. Well-known Fahlore sites in Europe include Schwaz and Brixlegg in the Tyrol (Austria), and Grimentz at Val d'Annivier in Switzerland (Schröcke, Weiner 1981, 169 ff.; Jaffé 1986, 47).

The concentrations of Co (up to 8%) and Ni (up to 19%) in the Kanalski Vrh ingots seem too high to be the result of smelting Fahlore with the usual composition. Comparisons with ingots from Guschau (*Fig. 8a*) in Saxony (Otto, Witter 1952, 44; Tylecote 1987, 199 ff.) and with scrap material from the smelting site at Lascours in southern France from the 2nd-1st cent. BC (Maréchal 1985) has drawn our attention to the possibility that the metal in Kanalski Vrh ingots could be what is known as speiss (*Fig. 8b*). This is a a complex hard solution of arsenides - compounds of arsenic with copper, nickel, cobalt, and iron, created as a by-product of smelting the iron-rich Fahlore with a sufficiently large concentration of arsenic and/or antimony (Craddock 1995, 290). Speiss is formed next to matte as a separate layer of silver colour, and it is removed similarly as is slag. When cooled, it is hard because of the high amounts of arsenic and antimony, and thus also brittle and unsuitable for the production of usable objects. In metallurgy, speiss is considered an unwelcome product retaining precious metals, which can only be processed with difficulties. Despite this, silver was produced from speiss in the 19th century. Speiss has also been found at archaeological sites, although mostly as the discarded by-product of smelting lead-ores in antiquity (Monte Romero, Rio Tinto). Speiss in the shape of ingots, i.e. as a semi-finished product, has so far been found only in the hoard from Guschau (most likely from the LBA), if we exclude the mining site of Palaia Kavala in northern Greece, where the arguments for semi-products seem weak (it is probably scrap material), and the archaeological dating of the finds seems uncertain (Kassianidou 1998, 70 ff.).

So as to prove that speiss was also a component of the Kanalski Vrh ingots, metallographic analysis was undertaken of ingot P 6584 and ingots P 6632, 6563, and 6541 (*Fig. 9a* and *9b*). The analysis of the first ingot, which is highly reminiscent in form of the ingots from Guschau, with optical and electronic microscopes (EDX), confirmed that this ingot was made of pure speiss, which was extracted, as was also the case with matte, during the first smelting of a complex ore (primary speiss). The small quantity of matte in the sample indicates that matte and speiss were formed alongside during the smelting of the ore, and the ingots were then cast from the speiss. Measurements of the hardness of the specimen could be compared with those of steel (Paulin et al. 1999). Differential thermal analyses (DTA) of the next three ingots uncovered new smelting products - speiss, which resulted from the oxidic smelting of the primary speiss and a slag (Paulin et al. 2000). Comparative analyses of three ingots from Veliki Otok (*Fig. 9c*), whose chemical composition also indicates a speiss origin, have confirmed our discoveries (Northover, unpublished).

The analyses of ingots from Kanalski Vrh can be divided into several groups even at first glance[4]. They differ in the type and quantity of impurities (As, Ni, Sb, and Co) and in the combinations of copper with lead or without, and exceptionally with tin. Evidently several groups contain relatively pure copper, and the others contain copper with very high concentrations of impurities - occasionally only arsenic and antimony, and most often arsenic, antimony, nickel, and cobalt (*Fig. 10*)[5]. Thus group 1 consists of 6 ingots of copper with very low impurities (aver. values: As 0.10%, Sb 0.06%, Ni 0.03%, Co 0.02%) and with high amounts of lead (aver. value: Pb 36.6%). Group 2 consists of 22 ingots of copper with high impurity levels (aver. values: As 5.64%, Sb 6.54%, Ni 6.17%, Co 2.49%) but without lead (aver. value Pb 0.26%). In group 3 are only 3 ingots of copper with high levels of impurities and lead (aver. value: Pb 31.95%), and low tin (aver. value: Sn 2.18%). Group 4 contains 10 ingots of copper with high levels of arsenic and antimony and very low levels of nickel and cobalt (aver. values: As 4.53%, Sb 6.83% and Ni 0.03%, Co 0.02%), and without lead (aver. value: Pb 0.15%). Group 5 contains 8 ingots with similar impurity pattern, but high lead content (aver. value: Pb 36.06%). The largest group 6 contains 104 ingots of copper with similarly high values of impurities as in group 2 and 3, although - in contrast to these - with added lead (aver. value: Pb 28.17%) and without tin.

If we consider the elemental composition of the ingots from Kanalski Vrh, and particularly the impurities, in the light of the chemical formulas of the ores, the groups listed could exhibit connections with the mines from which the metals of these ingots might perhaps have originated (*Fig. 11*). For ingot group 1, where copper and lead were the predominant elements with almost no traces of impurities (Cu:Pb 1:1 or even 1:2), this could be *chalkopyrite* ($Cu_2Fe_2S_4$), with added *galena* (PbS), and perhaps even occa sionally with *sphalerite* Zn(Fe)S. In group 2 of the ingots, with almost two-thirds of copper and one third consisting of very high

[2] Cf. Žbona-Trkman, Bavdek 1996, 62 and Pl. 163:2,8.

[3] Rychner, Kläntschi 1995, 86 f.

[4] Groups of ingots were determined according to the impurity pattern in the analyses published by Trampuž Orel et al. 1996, 227-230.

[5] Data in *Fig. 10* are taken from analyses of the selected ingots (104 pcs.) which chemical pattern corresponds to individual groups of ingots.

impurities (arsenic, antimony, nickel, and cobalt), a *polymetallic ore* could be seen, i.e. tetrahedrite with tennantite $(Cu, Fe)_{12} (Sb, As)_4 S_{13}$ together with *nickel* and *cobalt arsenides*. Group 3, which is the smallest (3 ingots), consisted of a *polymetallic ore* with additions of galena and tin. The group 4 and 5 ingots consist of pure *Fahlore* (i.e. tetrahedrite with tennantite) with or without added *galena*. Group 6, the largest, again exhibits a *polymetallic* origine - *tetrahedrite* with *tennantite, nickel* and *cobalt arsenides*, and with added *galena*. *Fig. 12* shows certain characteristic representatives of group 1 ingots of copper and lead (flat ingots), and from groups 2 and 6, of polymetallic ore (biconical ingots with or without hole in the center, premonetary forms, etc.).

DISCUSSION

It is known that wheel-shaped pendants cannot be classified to a limited time frame, as they were in use for several centuries, and their forms are quite varied[6]. If we limit ourselves to those most similar to the examples from Kanalski Vrh, the sites of discovery form an arc extending along the Alps (*Fig. 13*), from the French Central Alps and their foothills in the west (the hoards of Beaurière, Loubière, and Villethierry), through the northern section of the Swiss highland plateau (in the settlements along Lake Neuchâtel: Auvenier, Estavayer, and in Montlingenberg south of Lake Boden), to the southeastern Alps and the Caput Adriae, i.e. the surrounding of the Trieste Bay (the hoard of Kanalski Vrh, the settlement of Frattesina-Fratta Polesine), extending to the south into central Italy (Tolfa, Costa del Marano), and coming to an end in the east in the Pannonian plain (in the hoards of Ivanec Bistranski and Velem Szent Vid)[7]. It is interesting that this arc also encompasses the finds of torcs with threaded circlets, as well of ingots of the biconical type.

Although similar types can be found among the collected pendants, such as pendants with six spokes or double-cross pendants, a superficial comparison shows that among them there are no so-to-speak identical products, as they were evidently produced by numerous local workshops. Nonetheless, they are related by the shiny surface of the metal from which many examples were cast. So far Primas has already drawn attention to the significance of prehistoric products of pure tin; she has also noted objects from a "white metal" (a copper alloy with more than 10% tin, occasionally enriched with lead), which would have served as a replacement for tin. The recognition and production of such an alloy would be restrected to persons with a special knowledge of properties and working of metal. As there were objects of a symbolic value and votive meaning such as wheel-pendants particularly often cast from "white metal", Primas supposes that this indicates a certain "proto-alchemic" knowledge, spread in Bronze Age Europe (Primas 1985, 559 f.). The analysis of the composition and manufacture of the pendants from Kanalski Vrh (primarily those with eight spokes) entirely confirmed Primas' conclusions concerning the necessary special and exclusive metallurgical knowledge. They additionally revealed a new metallurgical skill in the Late Bronze Age - tinning. Proof of the tinning of low-tin bronzes in Europe is scarce (Meeks 1993, 248 ff.) and refers mostly to the Hallstatt, La Tène (fibulae, bracelets, coins), Hellenistic and early Roman periods (mirrors). The pendants and perhaps also the circlets from Kanalski Vrh were among the first finds of this type to be recognized from the Late Bronze Age. There might exist more examples, although it is difficult to identify them among the published material because of the often incomplete descriptions of the surface and the minimal numbers of analyzed specimens. From the Swiss pendants from Zürich - Wollishofen and Hitzkirch which were cast from a high-tin bronze enriched with lead (Primas 1984), it can be just presumed that the metalworkers also polished the surfaces of the artifacts, and thus successfully protected them from corrosion[8]. Such a process is reported in the Villethierry hoard, where pendants of high-tin bronze (Sn 20-25%) exhibit a polished surface (Mordant, Prampart 1976). The craftsmaster who cast the pendants with eight spokes from Kanalski Vrh economized his use of tin with a low-tin bronze, achieving the same final effect with tinning. The pendants from Kanalski Vrh are among the most attractive of this type, apparently the master products of an excellent workshop in the Caput Adriae region. Its model workshops can be sought in Italy, in the nearby technologically developed craftsmen centres of the Po plain in 11th/10th cent. BC. This hypothesis is also supported by the finds of moulds - for ring-pendants from Sermin near Koper and for wheel-pendants in Freghera-Cermenate near Como (*Fig. 14*).

The torcs exhibit a similarly elegant style and quality of production. Their exterior appearance, because of the precise execution and the detailed incised decoration, approaches that of the phalerae from this hoard, and relates them to similar products in regions of France, Switzerland, and the southern Tyrol (Žbona-Trkman, Bavdek 1996, 61, Fig. 4). In addition to one example from the cemetery at Dobova (Stare 1975, t. 41: 5) in the southeastern Alps (Slovenia), very similar torcs with threaded circlets (*Fig. 13*) were found in the opposite western section of the Alps, in two hoards of the French Central Alps - at Loubière and Réallon (Müller 1991, 117-118, 121). The chemical composition of Kanalski Vrh torcs supports their scarce occurence in Slovenia. The low impurity copper used distinguishes them from the copper with higher impurities, discovered in the Kanalski Vrh winged axes which are the typical product of the western Slovenia and the Veneto-Friuli region (Žbona-Trkman, Bavdek 1996, 59 ff., Fig. 3; Bietti Sestieri 1997, 390). If we consider their alloy, rich in tin, which is in contrast to the tradition of economical use of tin in the southeastern Alpine and Carpathian region, we might presume that the torcs were the product of another workshop and were perhaps also intended for other, more distant areas.

The distribution of biconical ingots also corresponds to the Alps, and supplements that of the wheel-shaped pendants and torcs (*Fig. 13*). They are found in the hoards of the northern French Alps (Goncelin, Albertville, Thénesol), in the hoard of Larnaud on the Saône together with wheel-shaped pendants, in the Swiss hoards of Schiers and Filisur, in the western Slovenian hoards of Kanalski Vrh (together with wheel-shaped pendants and torcs), Veliki Otok, and Dragomelj, in the Friulian hoards of Madriolo, Purgessimo, Nimis, Redipuglia, Porpetto, in the Po plain hoards of Montagnana and Frattesina-Fratta Polesine together with wheel-shaped pendants, in central Italy in Bologna, in the hoard of San Francesco, in the hoards of Poggio Berni, Chiuse di Frontone, Marsia, and Manciano, and on the edges of the Pannonian Plain in the Croatian hoards of Miljana, Kapelna and Ivanec Bistranski together with wheel-shaped pendants, and in the Austrian hoard of Mahrersdorf[9]. The biconical ingots have

---

[6] Žbona-Trkman, Bavdek 1996, 63, with references for wheel-shaped pendants.

[7] The distribution of wheel-shaped pendants was taken from Žbona-Trkman, Bavdek 1996, 70, fig. 5, with additions of Beaurière (Courtois 1976, 85, Fig. 7: 12,14.), Loubière and Larnaud (Müller 1991, 121-122), Villethierry (Mordant, Prampart 1976, 169 ff.), Coste del Marano (Peroni 1961, I 1(6) 32.), Velem Szent Vid (Bándi, Fekete 1977-1978, 120-122, Fig. 20-22). I would like to thank Peter Turk for additional references.

[8] The data about an usually high concentartion of tin and lead in the cited artifacts must be taken with precaution, as the analytical method is not mentioned in the article, and only approximate values are cited for both elements - Sn ca. 60%, Pb ca. 30%.

[9] The distribution of biconical ingots is taken from Žbona-Trkman, Bavdek 1996, 71, Fig. 6, with additions acc. to Casagrande et al. 1993, 269 n. 36, 270 n. 39.

often been studied, but mostly without detailed classification of their form, so that they do not in fact represent such a homogenous group as it may seem at first glance (e.g. Bietti Sestieri 1997, 387-390). An accurate typological classification is primarily hindered by the fact that most are broken, which also applies to the ingots from Kanalski Vrh. Particular attention was paid among these to the biconical types with a trapezoidal section (hammer-shaped), which often have a relief surface like a stamp in place of a hole in the centre, or the surface is smooth (*Fig. 15*). Similar specimens are also found in the hoards of Veliki Otok, Dragomelj, and Madriolo (Borgna 1992, Pl. 5: 26; 13: 26), and are characteristic for the western part of Slovenia, and also the Veneto-Friuli region (Trampuž Orel et al. 1996, 180). The analyzed examples from Kanalski Vrh, Veliki Otok, and Dragomelj belong, according to chemical composition, to group 6 of the Kanalski Vrh ingots, cast from a metal whose source can be seen in a polymetallic ore.

Our identification of the original ore source is certainly hypothetical, and comparative analyses of the ingots and ore sources (analysis of Pb isotopes and spectral analysis of the ore), would be necessary to confirm these suggestions. They nonetheless offer a basis for seeking the source of the Kanalski Vrh ingots. This was first noted by Czajlik (et al. 1999), in the metallographic study of plano-convex ingots from the site of Celldömölk-Saghegy, mostly from hoard II. He established that their composition indicated an ore formed from five elements (Cu-Ni-Co-Bi-Ag), characteristic for a limited number of European ore sources, the closest (to western Hungary) being in Austria and Slovakia, as they are lacking in the Carpathian basin and the Balkans. He considered that this kind of ore was also used for Kanalski Vrh and Veliki Otok ingots. As our research has also shown, the speiss in the mentioned ingots was derived from smelting exactly the same polymetallic ores of the Fahlore type as mentioned by Czajlik. Deposits of barite-cobalt-nickel-silver-bismuth ore veins, classified also as the Skutterudit -group, are mentioned in Europe mostly in Saxony, Thuringia (Erzgebirge) - Schneeberg, Annaberg, Marienberg, Saalfeld, Rammelsberg, and in the Czech ore mountains - Jáchymov, in the. Eastern Alps (Austrian Niederer Tauern) - Mitterberg and Schladming, while seemingly, on the basis of published data, they are missing in the southeastern Alps (Schröcke, Weiner 1981, 278 f.; Drovenik 1984, 146 ff.). The most interesting sources for the Kanalski Vrh ingots are the nearest deposits in the Austrian Alps, although we should not disregard the fact that the only known and analyzed ingots with a speiss composition and a similar form to ours come from Guschau (Saalfeld region) - from the more distant region of Saxony in southeastern Germany.

The Eastern Alps, part of which are the Niedere Tauern, contain the vast majority of all Austrian mineral deposits. These deposits, particularly of copper, have been, along with the history of mining, the subject of extensive research, also archaeological and archaeometallurgical. Copper deposits are especially numerous in the geological sector called the Grauwacken Zone (*Fig. 13*), metallogenic unit extending between the northern Calcareous Alps and the southern Central Alps in a more than several hundreds km long, but narrow belt - from the Inn valley near Schwaz in the west almost to the Hungarian border in the east (Wallach 1993, 15 ff.). They are concentrated in several regions, the most interesting for us being those with polymetallic ores. Two are located in the western part of the Grauwacken Zone, in the Salzburg region, and one in the eastern part in Styria. The first is the Mitterberg district in the Salzburg region, where the most widely distributed ore veins are of chalcopyrite with tetrahedrite, while Ni-Co-Sb arsenides are also mentioned (Holzer 1986, 22). Mining throughout the entire Bronze Age has been proven and well researched (Günther et al. 1994). The second district is to the south of Schladming, specifically the Zinkwand-Vöttern-Giglach deposit of Ni-Co ore with arsenopyrite, Ni- and Co- arsenides, löllingite, bismuth minerals, and chalcopyrite (Prochaska 1993, 12). The same region also contains a galenite-tetrahedrite-stibnite ore with various silver concentrations (Holzer 1986, 32). From the archaeometallurgic standpoint, the most important region is Liezen. Modern investigation into the mining and smelting of copper ore, and archaeological excavations in the broad vicinity of the Palten and Liesing rivers has contributed important knowledge about the exploitations of polymetallic ores in the Late Bronze Age. The analysis of copper ore from the mining sites of Bärndorf and Büschendorf, together with analyses of slag, matte, and "black copper" from the Late Bronze Age smelting site of "Versunkene Kirche" in the Trieben district, have proven the extraction, sorting, roasting, and smelting of polymetallic ores (pyrite, chalcopyrite, and tennantite with very low concentrations of silver, cobalt minerals, and arsenopyrite). The proof is the concentrations of nickel and cobalt found in the slag. During the smelting process leading to the production of "black copper", the nickel and cobalt were extracted from the ore into the slag and speiss. Thus the slag from the Paltental valley contains characteristic concentrated values of both impurities, and particularly cobalt. This is also the main characteristic distinguishing the Liezen ores from those of Mitterberg, where nickel is predominant. The research here has also confirmed previous conclusions that the ore was extracted, roasted, and smelted at the deposit itself or nearby. As no semi-finished products were found there, other than the rare analyzed examples, it is considered that the copper plano-convex ingots were transported to other metallurgical centres, probably to settlements, where the copper was refined, alloyed, and cast into ingots (Prochaska, Presslinger 1989; Presslinger, Eibner 1993).

Another ore deposit region, also located relatively near Kanalski Vrh, and in terms of mineralogical variety one of the richest in Europe, and the largest in the Italian peninsula is Tuscany, the former Etruria (*Fig. 13*). Its decisive role in the development of the Villanova Culture and the formation of the first city states, which was also based on the natural features of the region, and primarily the ore supplies, has already been analyzed in detail. Changes in the settlement system, which indicate certain political connections between smaller communities within Etruria, the direct trade contacts with the neighbouring provinces to the south (Lazio, Campania), with the eastern Adriatic coast, to the north with the Po valley, Veneto, Friuli, and western Slovenia, and the establishment of exchange with distant sections of the Alps as early as the end of the Late Bronze Age and the beginning of the Early Iron Age (HaB 1), place Etruria in first place among the Italic groups of the time (Bietti Sestieri 1997, 380 ff.). Of copper ores in this region, chalcopyrite is mentioned, along with silver-rich tetrahedrite, as well as tin, leads, mercury, and iron[10]. Despite exhaustive archaeological evidence from settlements in the territory of the Tuscan ore deposits, which have been reported to be connected to mining from the beginning of the Late Bronze Age (Br D), the data is quite scarce because of the lack of systematic research into the prehistoric sites (Giardino 1995, 116 ff.). The source region of the later Etruscan civilization with the exceptional metallurgical tradition unfortunately still cannot be compared to similar Austrian researches in the Eastern Alps as regards the investigation of ore deposits and traces of the earliest mining.

Even without reference to this, several facts speak in favour of the possibility that the sources of the polymetallic ores from which the metals of the Kanalski Vrh ingots were extracted were Austrian mines. One is the geographic position of Kanalski Vrh, which is only 250 km from the mines in the Niedere Tauern, while more than 400 km of present-day local roads divide it from central Tuscany. Another fact is the specific characteristics of the ore. Ingots with predominant nickel can be related to ore from the Mitterberg region, and those with high nickel and cobalt concentration to ore

[10] Markoe 1992-1993, 16ff., esp. n. 23, 24, 27 with additional geological references; Craddock 1986, 214 ff.

from the Schladming or Liezen-Paltental regions. Such ores are not mentioned for Tuscany. Metals from polymetallic ores are also found in other hoards from western Slovenia, such as in all the ingots from Veliki Otok, in several plano-convex ingots and fragments from Dragomelj (*Fig. 16*), and in the biconical ingots from the Friulian hoard of Porpetto (*Fig. 17*)[11]. As such metal was also used to cast ingots of special form, characteristic for western Slovenia and the Friulian-Venetan region, the expectation is justified that such metals would also be found in the hoard of Madriolo and other Venetan-Friulian hoards with similar ingots, which unfortunately have not been analyzed..

The ingots from the Kanalski Vrh hoard do not prove merely the exploitation and processing of sulfide copper ore with high concentrations of arsenic and antimony, thus tetrahedrite with tennanite or Fahlores; they also prove the exploitation of polymetallic ores, thus Fahlores with nickel and cobalt arsenides, and the recognition and separation of individual phases of smelting. The result of this was an exceptionally hard but brittle metal of silvery-shiny appearance. The fact that ingots were cast from it means that speiss, in contrast to later attitudes, was appreciated and utilized. The question remains as to why they used it, when despite its great hardness it was unsuitably brittle for objects of everyday use. The answer may lie in the artifacts from Kanalski Vrh. The characteristic metal of the ingots from this site - those with unusually high values for arsenic, antimony, and nickel, and occasionally also cobalt, can be seen in the group of wheel-shaped pendants and in the axes (*Fig. 6:* 1-9, 19, 20 and *Fig. 7*). As the mentioned concentrations are considerably lower than in the ingots, it can be concluded that the alloys were "diluted" with another copper with low impurities. Observation of the sampled (cut off) surfaces of the four metallographically analyzed ingots from Veliki Otok and Kanalski Vrh showed that after several months the shiny silver colour remained only on that surface which was polished after sampling (ingot P 6584 from Kanalski Vrh); the remaining surfaces became darkened[12]. Perhaps this was also one of the positive, anticorrosive qua-lities of the unusual, silvery in later periods even "rejected" metal that the smiths in the Caput Adriae region used in the production of a copper alloy with tin, so as to economize in the use of valuable tin.

It is not easy to prove accurately the above hypothesis but nevertheless it is necessary to supplement and critically evaluate the recently published contradictory opinions about the type and use of metals in the Kanalski Vrh ingots (Northover 1998b, 118 f.). The author compared them to ingots of the considerably later Iron Age hoard of Arbedo from Ticino, classified to the 6th-4th centuries BC (Schindler 1998). Northover counted both among ternary alloys of copper with arsenic and antimony, and considered that neither was directly used for the production of any objects whatsoever. This opinion was based primarily on the results of the analysis of the Arbedo ingots, which contain increased concentrations of arsenic, antimony, nickel, and silver, although these metals can hardly be traced in the artifacts of this hoard (Northover 1998a, 290). It should first be noted that the comparison of both types of ingots is inaccurate, and thus at the very least somewhat misleading. Semi-finished products from chronologically and technologically different periods, and from various phases of metal working, were cited as similar. Most of the ingots from the Arbedo hoard are fragments of plano-convex ingots (Schindler 1998, 169), thus a primary semi-finished product in the metallurgical process, while most of those from the Kanalski Vrh hoard are cast ingots, thus secondary products cast in a mould. The impurity pattern, exactly analyzed for the Kanalski Vrh ingots, is not very similar to that from the Arbedo hoard. For the specifically mentioned Arbedo ingots with increased concentrations of impurities (21 samples analyzed), only the values for arsenic and antimony are comparable to those from Kanalski Vrh, while the values for nickel are mostly so low that they barely reach those from the Kanalski Vrh artifacts (e.g. nos. 3756, 3770, 3755, etc.); cobalt, which is an important characteristic of many of the Kanalski Vrh ingots, is only at the level of a trace element for the Arbedo examples[13]. Thus the impurity pattern, which in our study proved to be important in classifying the type of metal in the ingots, and perhaps also its source, is hardly very similar in both hoards. It is particularly important that the composition of the metal in several Kanalski Vrh objects indicates that such ingots, in contrast to the Arbedo hoard, were used for casting artifacts (see also Heath et al. 2000). Metallographic analysis of the Kanalski Vrh ingots has clearly defined a formerly too lax classification of the metal as a ternary alloy of the Fahlore type (Northover 1998b, 118). Now it is clear that this is not an alloy, but instead a solid solution created during the smelting of multi-elemental ore formations, and that it was deliberately separated during the process of acquiring copper from polymetallic ore (Paulin et al. 1999; idem 2000). The Austrian investigations of such ores and smelting products have also proven that the elevated concentrations of cobalt and/or nickel were eliminated directly into the slag and speiss of these ores.

CONCLUSION

The workshops of the Caput Adriae region at the beginning of the 1st millennium BC utilized a special metal originating from the ores of the Niedere Tauern mines. It was shiny and hard, similar to tin, but owing to its exceptional brittleness it could not compete with tin; thus it was not suitable for objects of everyday use. Nonetheless it was used for casting objects of symbolic significance (axes), and those that required a silvery-shiny appearance (wheel-shaped pendants). This metal, mostly appearing as speiss, confirms the hypothesis that the region of Friuli and western Slovenia were involved in the exploitation of ore sources in the Eastern Alps (Bietti Sestieri 1997, 390). The above statement has to be defined more accurate in geographical sense: the ore source were the Austrian Eastern Alps. The use of possibly closer copper mines of this type in the southeastern Alpine region, which was recently suggested because of the large concentration of biconical ingots in the vicinity (Borgna, Turk 1998, 352, n. 18), can not be excluded. Unfortunately, this also cannot be confirmed given the currently available geological data; we must wait until the spectral analyses of Slovenian ore deposits are more complete. In this particular case, the analysis revealed that metal was transported from the relatively distant mines to the workshops (over several hundred kilometers), if this was necessary. In addition to cast ingots, plano-convex ingots were also transported, as is proven by the Dragomelj hoard. As there was no road network then, it is most likely that they used pack animals. It is known from the history of transport that one pack animal - a horse or donkey - could carry up to 150 kg in freight (Wenninger 1995, 406). Thus a single horse could easily carry the entire Dragomelj hoard weighing 80.805 kg, not to mention the much lighter hoard from Porpetto with 27.27 kg, or even its heaviest plano-convex ingot of 11.25 kg. Thus it is also not possible to confirm easily the suggestion that semi-products were not.transported from the vicinity of ore deposits because of the often exceptional weight of some examples, the mentioned plano-convex ingot or ox-hide ingots, but rather that they would have been produced in local metallurgical workshops (Borgna, Turk 1998, 352).

---

[11] The as yet unpublished analyses of the Dragomelj and Porpetto hoards were performed in 1997 by David Heath; I thank Peter Turk for allowing me to use the material from Dragomelj prior to the publication. The material from Porpetto was taken from Borgna, Turk 1998, 363, Fig. 1).

[12] I am very grateful to Dr. Spomenka Kobe, Laboratory for ceramics, Institute Josef Stefan Ljubljana, for taking metallographic samples from the Veliki Otok ingots.

[13] Cf. Northover 1998a, 290, 306.

The routes connecting the eastern Alpine valleys with the Adriatic Sea, along which the transportation of metals and products would have taken place, were very likely the forerunners of the Roman and medieval transport routes, which continued in use in more or less unchanged form to the introduction of the railway in the 19th century. Of the two most important medieval routes that ran from south to north through Carinthia, what is known as the "Low Road" led from Friuli (Gemona), through the Valcanale/Kanal valley, Tarvisio/Trbiž, Villach/Beljak, Spittal, and over the passes of Katschberg and the Radstäter Tauern to the Salzburg region, and further towards the Bohemian region from at least the 13th century onwards (Wenninger 1995, 405 ff.). It is possible to conclude that one of the connections between the Mitterberg and Schladming ore deposits and the Adriatic led in this direction directly to the Friulian metallurgical centres (*Fig. 18*). A second route, which probably branched off in Tarvisio/Trbiž, crossed at the Predel pass, and through the village of Strmec, entered the Soča River valley at Bovec and continued to Kobarid, as was mentioned in Venetian documents from the 14th century, when this part of the route was important for trade between Carinthia, the Tolmin region, and Friuli (Gestrin 1965, 211). From Kobarid onwards to the Bay of Trieste, the route probably led in the direction mentioned for a newly built road at the end of the 16th century. The wars of the Habsburgs with the Venetians dictated the improvement of the transport connections between the interior of the Austrian state and the sea, which ran through Austrian controlled land so as to avoid that of the Venetians (Rajšp 1994, 46 ff.). The course of this route is also documented by toll-houses at Kobarid, Volče near Tolmin, and Kanal. The Soča route is documented indirectly by various archaeological finds. The Predel pass was definitely in use in the Late Bronze Age (Teržan 1996, 256), and individual Bronze Age finds, from metal to pottery, are located along the entire route[14], the most important among them being the Late Bronze Age houses at Most na Soči (Sta Lucia) and the hoards of Grgar, Kanalski Vrh, and Šempeter. It is possible, because of the location of the Kanalski Vrh hoard on the edge of the plateau above Avšček and other nearby archaeological finds, that the pack-horse route in the Late Bronze Age from Most na Soči downstream winded along the edge of Banjšice and did not follow the course of the later Habsburg Soča valley road. The importance of the "Soča" direction in connecting the inner Alpine valleys with the Bay of Trieste is substantiated by the recently excavated settlement of Sermin near Koper, which perhaps played a significant mediating role in trade and transport between the northern Adriatic and the southeastern Alpine hinterland. A similar mediating role in the trade in metal and metal products, although in a third direction, may have been held by the settlement of Dragomelj (near Ljubljana). It lay on the trade and transport connection that branched off from the main north-south route at Tarvisio/Trbiž towards the east. From there the route led through Podkoren and along the Sava River, through the Radovljica and Kranj plains on towards the southeast, passed the Dragomelj settlement, continued again along the Sava, all the way to the western end of the Pannonian plain - to northwestern Croatia, as is shown by the biconical ingots and certain other individual objects in the hoards of Miljana, Ivanec Bistranski, and Kapelna (Vinski-Gasparini 1973).

Acknowledgements

We would like to express our thanks to colleagues Betka Žbona-Trkman, curator of the Regional Museum in Nova Gorica, for kindly providing the Kanalski Vrh hoard for study and various analyses, and to Dr. Urša Opara-Krašovec (Institute of Chemistry Ljubljana) for computer assistance. At last but not at least we are very grateful to Prof. Biba Teržan and Prof. Boris Orel for continual following and advising our research work.

Neva Trampuž Orel
Narodni muzej Slovenije
Prešernova 20
SI-1000 Ljubljana

David John Heath
Narodni muzej Slovenije
Prešernova 20
SI-1000 Ljubljana

[14] Svoljšak 1988-1989; Šinkovec 1996, 160, fig. 19.