

# The copper axe blade of Zug-Riedmatt (Canton of Zug, Switzerland) – a key to chronology and metallurgy in the second half of the fourth millennium BC

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**Abstract** - The copper axe blade discovered in the pile dwelling site of Zug-Riedmatt is one of the few Neolithic copper axe blades in Europe that can be dated with certainty. The blade's form and its metal composition suggest that it is connected both to the south – more specifically to Copper Age cultures in northern Italy and southern Tuscany – and to the copper axe of the famous ice mummy of Tisenjoch (called 'the Iceman' or 'Ötzi'). We were able to confirm this connection to the south by measuring the lead isotope composition of the blade, which traces the blade's origin to Southern Tuscany. Due to these links to the south, the copper axe blade of Zug-Riedmatt can be described as a key to understanding Neolithic metallurgy north of the Alps in the second half of the fourth millennium BC. As the classification of the blade will have far-reaching consequences in regard to chronology and cultural history, we have decided to make the results of our analyses available as quickly as possible – even if this means that for now we can only discuss some basic results and assumptions about the blade's context.

**Key words** – archaeology; Circum-Alpine region; chalcolithic; pile dwelling; copper axe; metallurgy; lead isotopes; LA-ICP-MS; MC-ICP-MS; Horgen; Remedello; Rinaldone; Tuscany; Iceman

**Titel** - Die Kupferbeilklinge von Zug-Riedmatt, Kanton Zug, Schweiz – ein Schlüsselfund zu Chronologie und Metallurgie der zweiten Hälfte des 4. Jahrtausends v. Chr.

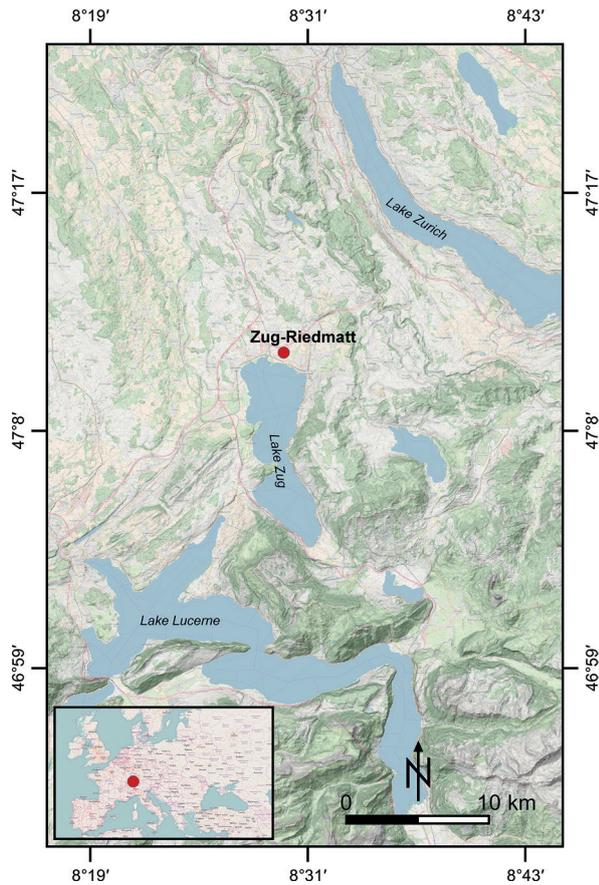
**Zusammenfassung** - Die Kupferbeilklinge aus der Pfahlbaufundstelle von Zug-Riedmatt ist eine der ganz wenigen sicher datierten jungsteinzeitlichen Kupferbeilklingen Europas. Ihre Form und Metallzusammensetzung zeigen klare Verbindungen nach Süden, zum Bereich der kupferzeitlichen Kulturerscheinungen Norditaliens und der südlichen Toskana, sowie zum Kupferbeil der bekannten Eismumie vom Tisenjoch (Ötzi). Dieser Bezug nach Süden wurde nun durch eine Bleisotopenanalyse vollumfänglich bestätigt, die eine Herkunft des Kupfers aus der südlichen Toskana festlegt. Die Zuger Kupferbeilklinge ist deshalb ein Schlüsselfund für das Verständnis der Kupfermetallurgie während der zweiten Hälfte des 4. vorchristlichen Jahrtausends nördlich der Alpen. Da die chronologischen und kulturgeschichtlichen Konsequenzen dieses Fundes weitreichend sind, sollen die Resultate der Analysen möglichst rasch zur Verfügung gestellt werden, auch wenn ihr Kontext hier erst ansatzweise diskutiert werden kann.

**Schlüsselwörter** – Archäologie; zirkumalpiner Raum; Chalkolithikum; Kupferzeit; Pfahlbau; Kupferaxt; Metallurgie; Bleisotopen; LA-ICP-MS; MC-ICP-MS; Horgen; Remedello; Rinaldone; Toskana; Ötzi

## Find Context and Dating

The copper axe blade was found in 2008 during the excavation of the pile dwelling site Zug-Riedmatt (HUBER & SCHAEREN, 2009, 128–130, 137; GROSS ET AL., 2017). Conventionally, the archaeological material of this multi-phased site would be attributed to the 'Horgen' archaeological assemblage. Today, the findspot is at about 800m distance from the shore of Lake Zug (fig. 1) and is covered by limnic and delta sediments, which are about 5m thick. Due to the sediments' thickness, a caisson had to be installed, and only 64m<sup>2</sup> of the former settlement site could be excavated (fig. 2). As the organic remains were exceptionally well-preserved, only a fraction of the entire site area was excavated, and the scientific samples taken were thorough and dense (fig. 3). It has been decided to add the site Zug-Riedmatt to the UNESCO world heritage site *Prehistoric Pile Dwellings around the Alps* (SCG UNESCO PALAFITTES, 2015). Furthermore, Zug-Riedmatt, as well as the site Zürich-Opéra, has been chosen as basis for the

project *Formation and Taphonomy of Archaeological Wetland Deposits: Two Transdisciplinary Case Studies and Their Impact on Lakeshore Archaeology funded by the SNSF* (SNSF, 2014). Due to the site's location on the lake shore at the margins of the Lorze river delta, some specific features and conditions shaped life in the settlement. The site was far from fertile land. Thus, it is no surprise that the site, or at least the known section thereof, was characterised by hunting and fishing remains during the first phase of occupation (stratigraphic Units 3–5; fig. 4). In the subsequent phases of occupation (from Unit 6 onwards), husbandry became more and more important (BILLERBECK-BRASCHLER, 2016; BILLERBECK ET AL., 2014). Furthermore, the site is located at the northern end of the lake and, therefore, at the gateway for the shortest land route from the Saint Gotthard Pass to Lake Zurich, which may indicate that the trans-Alpine transport and trade network was of particular importance for the settlers. This assumption is supported by the presence of non-local raw materials, such as serpentinite, nephrite, and rock crystal (quartz). These raw materials



**Fig. 1** Localisation of the Zug-Riedmatt site (red dot) between the Alps and the Swiss plateau (mapping: Amt für Denkmalpflege und Archäologie Zug, J. Reinhard, based on OSM and SRTM data).

most likely stem from the Gotthard region and are found in various semi-finished products, completed objects, and in production waste.

The axe blade was found within the settlement's stratigraphic sequence in the border area of two deposits (see **fig. 4**, Units 5 and 6). According to the excavator, Benedikt Lüdin, the blade had not been disturbed and was lying slightly tilted. The scratch marks caused by his trowel and the blade's patina support his observations. During post-excavation stratigraphic analysis, the find was allocated to Unit 5. Results from transdisciplinary investigations in relation to pollen (ISMAIL-MEYER ET AL., in prep.), botanic macro remains (STEINER, 2017), and micromorphology (ISMAIL-MEYER ET AL., submitted) indicate that during the sedimentation process of Unit 5 the influence of water on the find's location increased steadily. Hence, it is possible that the site was abandoned for a while towards the end of Unit 5's sedimentation. By contrast, it can be assumed that the period during which the overlying

Unit 6 formed was dominated by pronounced terrestrial and aerobic conditions. It can, therefore, be concluded that in the time after the blade had sunk into the sediment, the surface area where sedimentation occurred was at least seasonally above the mean water level (STEINER, 2017, 197–228). In accordance with this we can assume that the following occurred: processing waste from fishing and debris from the hearth was repeatedly deposited (GROSS & HUBER, in prep.), after which the axe blade sunk into the ground, which was only covered by shallow water. Had it been lost by accident, it would have been easy to recover the blade even at a later point. There are no indications for any fire disasters in the excavated area. Furthermore, at the time of sedimentation, the blade was not damaged in any way, nor was it fitted into a haft. Therefore, the blade was neither disposed of nor accidentally lost in its entirety. Moreover, due to the blade's precious raw material, it is unlikely that the blade is ordinary residential waste. Thus, we assume that the blade was deliberately deposited in the shallow water as a sacrifice.

In many cases, it is possible to date remains from wetland settlements in the foothills of the Alps to the exact year thanks to dendrochronology. However, at Lake Zug the situation for dendrochronology is often less ideal; oak was rarely used for construction in this region. Instead, mainly wood from the riparian forests nearby was used. Due to the constantly wet condition, the wood from these forests tend to show less extreme signs of growth. Therefore, the tree ring sequences in this area do not properly display pointer years, which makes dendrochronological dating difficult. Furthermore, the riparian forests from where timber was procured were actively managed by large scale coppicing practices. These regularly recurrent disturbances in growth make dendrochronological dating impossible for now (HUBER & SCHAEREN, 2009, 114). For this reason, and at least for now, the settlement remains of Zug-Riedmatt had to be dated using radiocarbon dating and by typological comparison with sites that have been dendrochronologically dated. The typological dating is mainly based on the different types of antler sleeves and their frequencies (BILLERBECK-BRASCHLER, 2016, chapter 6) as well as on the formal and stylistic aspects of the ceramic finds. On this basis, we can date the settlement deposits of Zug-Riedmatt to somewhere in the time between 3250 and 3100 BC. For the radiocarbon dating, 16 samples (HAJDAS, 2017a; 2017b) from the stratigraphic sequence of Zug-Riedmatt were evaluated (**fig. 5**). The values from all samples were consistent and

confirmed the archaeological dating. However, as expected, the run of the calibration curve in the considered timespan, with its three pronounced parallel and consecutive wiggles, makes it difficult to narrow down the calibrated data for Zug-Riedmatt. For this reason, there are three possible time periods to which the archaeological context of the axe blade of Zug-Riedmatt might relate: from around 3300, around 3175, or around 3100 calBC – all of which are equally possible. The same is the case for the radiocarbon dating of the axe of the Iceman of Tisenjoch ('Ötzi') (ROM ET AL., 1999), as well as for the dating of other comparable axe blade find complexes in Italy (see fig. 5). The raw radiocarbon data from the few dated find complexes containing similar flanged copper axe blades correlate to such an extent that it is easily possible that these complexes are contemporaneous. However, not even the minutely detailed stratigraphic data sequences of Zug-Riedmatt can tell us to which of the three possible time periods



Fig. 2 View into the excavation caisson a few days before the axe blade was found, the arrow indicates the findspot (photo: Amt für Denkmalpflege und Archäologie Zug, R. Glauser).

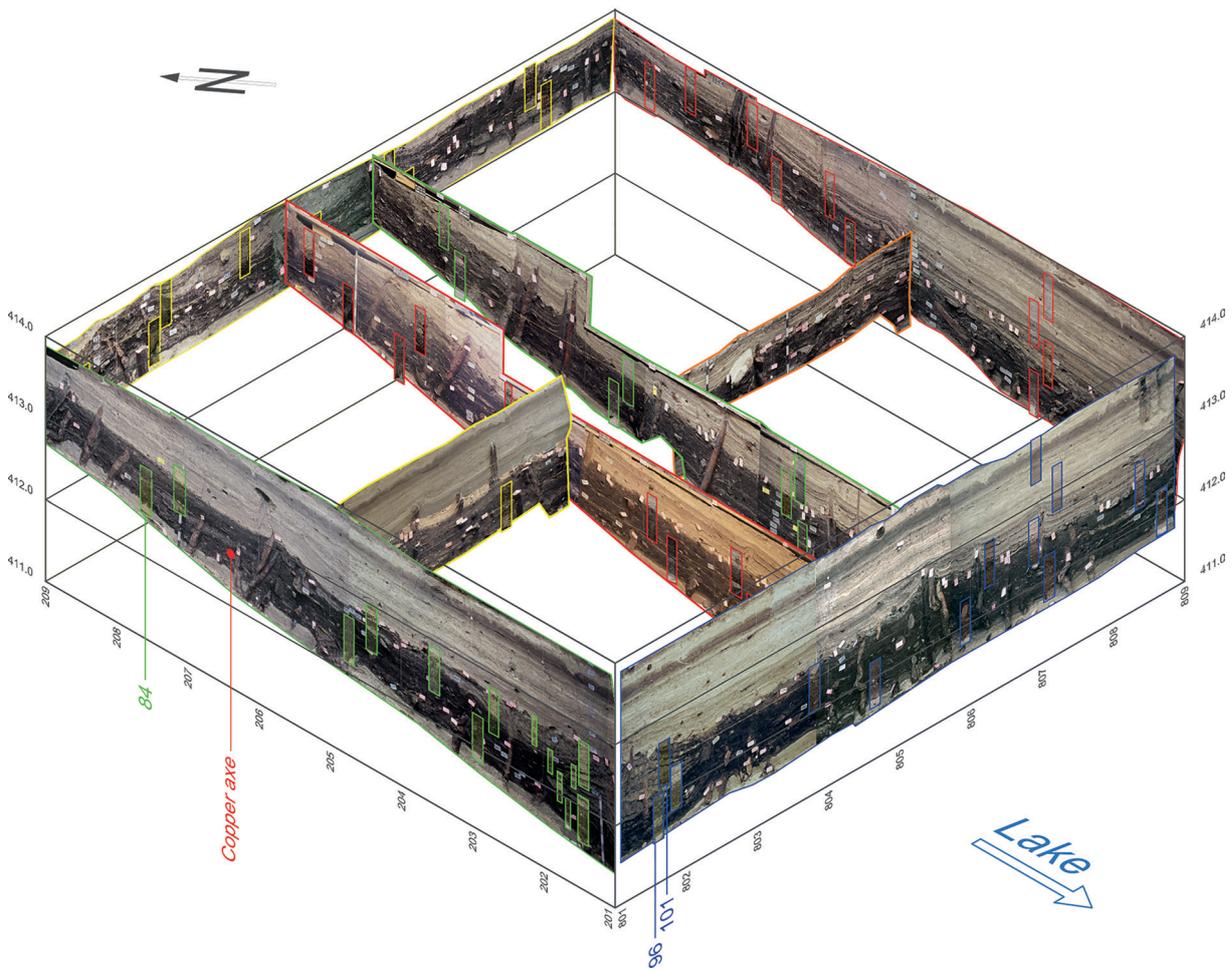
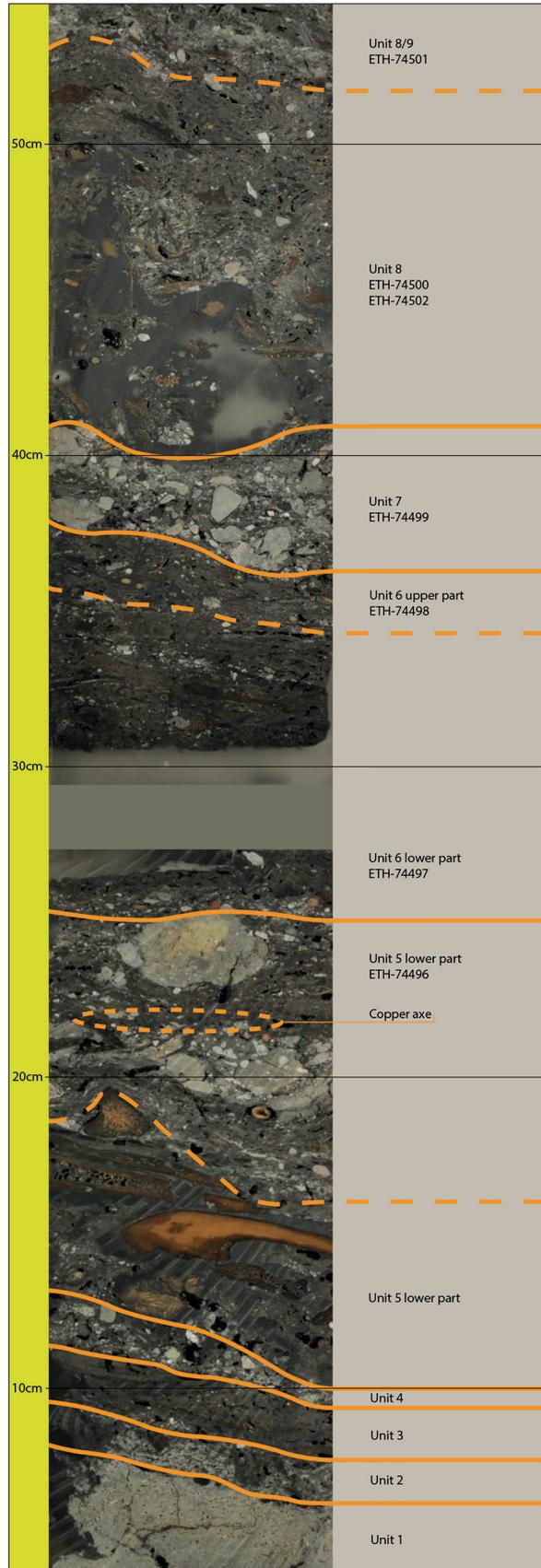


Fig. 3 Isometric view of the profiles and profile columns of Zug-Riedmatt and the axe blade's location (graphics: Amt für Denkmalpflege und Archäologie Zug, S. Hlavová).



the site really belongs. Due to the comparison with ceramics and antler sleeves from other dendrochronologically dated find complexes (e. g. Zurich-Opéra, Zurich-Mozartstrasse, Zurich-KanSan Seefeld; see JOCHUM ZIMMERMANN, 2016; SCHIBLER, 1997; WEBER, 2016), we prefer the time around 3175 calBC. In contrast, Bayesian estimation prefers the one around 3300 calBC. Either way, we can be sure that the axe blade stems from before 3000 calBC; however, most current approaches date certain cultural phenomena connected to such blades such as Remedello daggers, halberds, and anthropomorphic stele to after this time (DE MARINIS & PEDROTTI, 1997; PEDROTTI, 1995).<sup>1</sup>

### Description of the Copper Axe Blade of Zug-Riedmatt and Comparisons

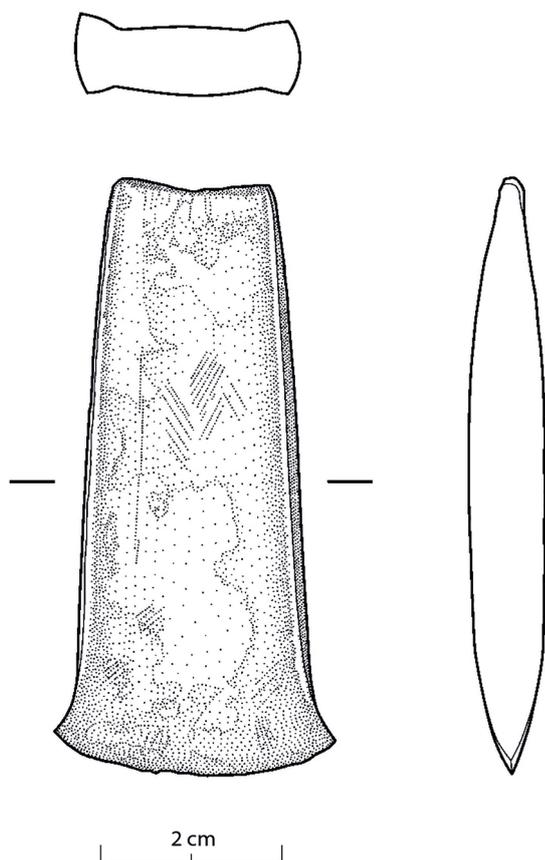
The copper axe blade of Zug-Riedmatt is preserved in its entirety and – apart from a few scratches originating from its excavation – undamaged (fig. 6). The blade is small and delicate with almost straight and narrow sides. In the longitudinal section, the blade is somewhat lentiform. The small butt shows a slight notch. Remarkable are the faint but regular and distinct flanges raised by peening (for a summary on this type of axe see KLIMSCHA, 2010). It can be assumed that the blade sank into the sediment without its haft. Had there been a haft, it would have been conserved as the general conservation in these layers was ideal and as the blade remained beneath the water level. It is not possible to tell whether the blade had ever been hafted, since corrosion of the original surface has removed possible signs of grinding, polishing, or hafting. Nevertheless, the signs of processing show that the blade was ready to use when it was deposited. The entirety of the surface corrosion is due to pitting. Pitting corrosion occurs under anaerobic conditions with a pH value of below six and low carbonate values; as was the case in the anaerobic milieu covered by water in which the blade sedimented. In the further course of the sedimentation, the conditions became slightly more aerobic. The already corroded blade then oxidised on the top as can be seen from its dark brown *Pfahlbaupatina* (pile

**Fig. 4** Polished section of profile column 84; location of the samples used for radiocarbon dating (sample number), and the stratigraphic location of the copper axe blade as well as the reference to the related units (pictures polished sections: K. Ismail-Meier, IPNA Basel).

The copper axe blade of Zug-Riedmatt (Canton of Zug, Switzerland)

Lab No.	Site	Sample No.	Material	Unit	<sup>14</sup> C-Age	±1σ	calBC 1σ (Oxcal 4.3.2)
ETH-78824	Zug-Riedmatt	ZGRI 101.24	moss, fir needles	Unit 14	4485	35	3332-3262; 3254-3214; 3186-3156; 3127-3098
ETH-78823	Zug-Riedmatt	ZGRI 101.23	hazel nut	Unit 13	4482	27	3329-3262; 3254-3216; 3181-3158; 3124-3098
ETH-78822	Zug-Riedmatt	ZGRI 101.22	hazel nut	Unit 11/12	4439	26	3307-3304; 3264-3240; 3104-3021
ETH-78821	Zug-Riedmatt	ZGRI 101.20-21	hazel nut	Unit 10	4450	26	3316-3293; 3288-3274; 3266-3237; 3110-3081; 3069-3026
ETH-78820	Zug-Riedmatt	ZGRI 101.14-16	hazel nut	Unit 9	4498	26	3334-3264; 3240-3212; 3190-3153; 3136-3105
ETH-74501	Zug-Riedmatt	1680-ZGRI 84.54-56	hazelnut	Unit 8/9	4467	24	3326-3231; 3224-3220; 3174-3160; 3119-3092
ETH-74502	Zug-Riedmatt	1680-ZGRI 84.43-54.2	axe shaft ( <i>Quercus</i> sp.), core	Unit 8	4429	24	3262-3254; 3098-3020
ETH-74500	Zug-Riedmatt	1680-ZGRI 84.43-54.1	hazel nut	Unit 8	4488	24	3330-3264; 3246-3215; 3184-3157; 3125-3101
ETH-74499	Zug-Riedmatt	1680-ZGRI 84.38-43	<i>Prunus spinosa</i> kernel	Unit 7	4473	23	3326-3231; 3224-3220; 3174-3161; 3118-3095
ETH-74498	Zug-Riedmatt	1680-ZGRI 84.35-38	hazel nut	Unit 6	4470	23	3326-3231; 3224-3220; 3174-3160; 3118-3093
ETH-74497	Zug-Riedmatt	1680-ZGRI 84.25-35	hazelnut	Unit 6	4475	23	3326-3230; 3224-3220; 3174-3161; 3118-3096
ETH-74496	Zug-Riedmatt	1680-ZGRI 84.20-25	hazel nut	Unit 5	4513	23	3344-3322; 3272-3269; 3234-3171; 3163-3116
ETH-78819	Zug-Riedmatt	ZGRI 96.8	apple pericarp	Unit 4	4477	26	3327-3218; 3176-3160; 3120-3096
ETH-78818	Zug-Riedmatt	ZGRI 96.7	hazel nut	Unit 3	4583	26	3486-3473; 3372-3341
ETH-78817	Zug-Riedmatt	ZGRI 96.3	moss, fir needles	Unit 2	4546	27	3361-3331; 3214-3186; 3156-3126
ETH-78816	Zug-Riedmatt	ZGRI- 96.2	moss	Unit 1	4515	35	3346-3320; 3272-3266; 3236-3170; 3164-3114
GifA-93041	Tisenjoch	B-91/36	ax shaft ( <i>Taxus baccata</i> )	axe	4500	70	3344-3262; 3250-3099
GifA-94370	Tisenjoch	B-91/36	ax shaft ( <i>Taxus baccata</i> )	axe	4450	70	3331-3214; 3186-3156; 3128-3018
GifA-93040	Tisenjoch	B-91/36	ax shaft ( <i>Taxus baccata</i> )	axe	4440	60	3328-3218; 3178-3159; 3122-3011; 2948-2944
ETH-12182	Remedello Sotto		human bone	grave 106	4485	60	3338-3208; 3194-3148; 3142-3094
ETH-12189	Remedello Sotto		human bone	grave 34	4400	70	3264-3240; 3104-2911
LTL-12526	Ischia di Castro, Ponte San Pietro-Chiusa Ermini	6442	human bone, <i>tibia dextra</i>	grave I, ind.1	4550	45	3366-3322; 3234-3171; 3162-3116
LTL-12527	Ischia di Castro, Ponte San Pietro-Chiusa Ermini	6445	human bone, <i>tibia sinistra</i>	grave I, ind.4	4424	45	3264-3241; 3104-3001; 2992-2928

Fig. 5 Data basis and calibrated values of the radiocarbon data series of Zug-Riedmatt, of the axe of Tisenjoch (ROM ET AL., 1999, 186), comparable data from the necropolis of Remedello (DE MARINIS & PEDROTTI, 1997, 288) and from the hypogeum 1 of Ponte San Pietro-Chiusa Ermini near Ischia di Castro (NEGRONI CATACCHIO ET AL., 2014, 98) (compilation: Amt für Denkmalpflege und Archäologie Zug, E. Gross & G. Schaeren).



**Fig. 6** Drawing and photo of the copper axe blade of Zug-Riedmatt. Find complex no. 1680-1053.1; position no. 333. Maximal length: 6.5 cm; maximal width: 2.7 cm; width of the blade: 2.7 cm; width of the butt: 1.8 cm; maximal thickness: 0.8 cm; weight before taking the samples: 76.04 g (weight of the samples: 0.0262 g). Date of find: 22.10.2008; global co-ordinate: 47.18244/8.49106 (WGS84); MAMSL: 412.64.) (drawing: Amt für Denkmalpflege und Archäologie Zug, E. Kläui; photo: Amt für Denkmalpflege und Archäologie Zug, R. Eichenberger).

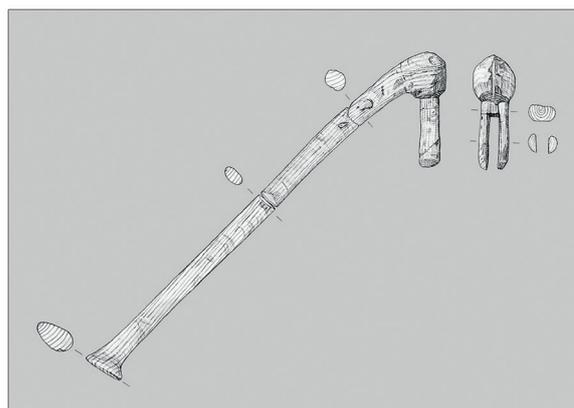
dwelling patina). However, this patina is missing in places where loam was clinging to the blade. As a result, the corroded copper red surface is still visible there today. Pitting corrosion has affected the blade's surface to such depth that the processing marks have become visible as layer- and fissure-like structures reminiscent of damascened objects. These marks show that casting defects were hammered out during peening. The processing and hammer marks at the borders show that the flanges were beaten out of a cast. This made it possible to forge the form of a flat axe during the process of peening. In other words, the flanges were lacking in the initial workpiece and also in any potential mould (SPERL, 1992; EGG & GOEDECKER-CIOLEK, 2009, 120–123). They could therefore be seen as simply a relic from the manufacturing technique of peening sideways with a hammer; however, it is likely that they were also appreciated due to their stabilising effects, which impede the blade from swerving from the forked mounting of the haft. The cutting edge with the corners protruding slightly was also attained through peening. The little that is known about how such copper blades were hafted is based on only one single conserved haft – that of the Iceman's copper axe (fig. 7, bottom). This blade was fixed with pitch in the forked mounting of a knee-shaped haft (*Knieholm*). The joint was then stabilised by wrapping a stripe of hide around it. Normally, this type of knee-shaped haft was produced from segments of oak trunks with one, preferably right-angled, branch. In rare cases beech trunks were used as well; the only known yew haft is the one of Tisenjoch. The branch would have been forked and

served to wedge the blade. The branch's diameter corresponds to the width of the blade. Many such knee-shaped hafts with forked mounting and semi-finished knee-shaped hafts were found during the excavation of Zug-Riedmatt (fig. 7, top and middle). This type of haft was also used in the same way as a shaft for larger rectangular blades made out of solid rock, bones, or antlers (GROSS & SCHIBLER, 1995, 166–167).

Formally the axe blade of Zug-Riedmatt is almost exactly the same as the axe blade found in grave 62 of Remedello Sotto (fig. 8.2) (DE MARINIS & PEDROTTI, 1997, 271–272; DE MARINIS, 2013, 329, fig. 25, middle; SCHILZ, 1995, 47–49). Many other axe blades found in the necropolis of Remedello Sotto, the axe blade of Tisenjoch (fig. 8.1) (SPERL, 1992; EGG & GOEDECKER-CIOLEK, 2009, 120–123), the blades from Ischia di Castro-Ponte San Pietro<sup>2</sup>, as well as several other axe blades further north (Zürich-Kleiner Hafner, Portalban, Vinelz: fig. 8.3)<sup>3</sup> and south (Lagolo, Bellinzona-Castel Grande)<sup>4</sup> of the Alps show a preference for little weight and gracility. Thus, formally similar blades were found in lakeside dwellings north of the Alps as well as on the Alpine divide (Tisenjoch/Hauslabjoch), in the valleys south of the Alps, in the Po valley and in the Colline Metallifere. The distribution pattern of blades of this form suggests that the blades originate from the Colline Metallifere.

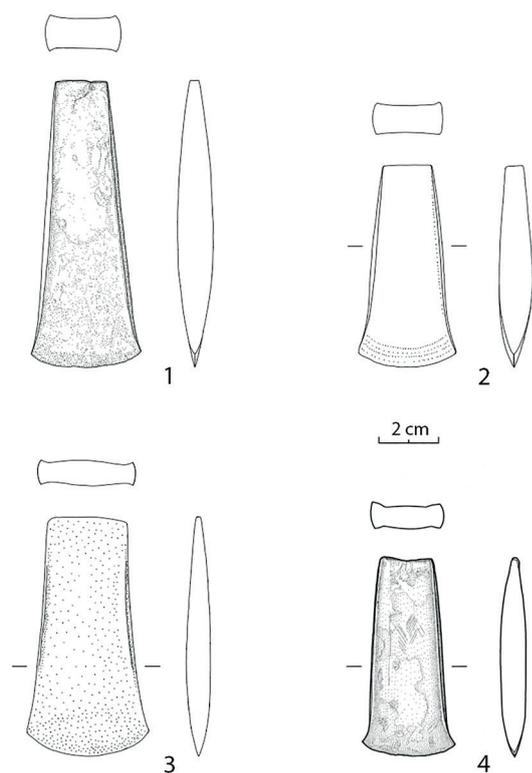
### Metal Analyses<sup>5</sup>

The copper axe blade of Zug-Riedmatt is noteworthy for two reasons. First, the blade is one of the few datable copper objects from the last quarter of the 4<sup>th</sup> millennium BC found in the Swiss Plateau.<sup>6</sup> Second, axe blades with flanges have only rarely been attested for the Neolithic. These peculiarities give rise to the question of whether the axe blade of Zug-Riedmatt should be seen as the product of a minor local, but still elusive, metallurgical practice, or as an import from a different cultural-geographical context. To be able to answer this question, it is necessary to characterise the blade's material more thoroughly and, if possible, to determine the place of origin of the blade and its raw material (STRAHM, 1994). A chemical analysis of the axe blade of Zug-Riedmatt was conducted by Dr Markus Wälle from the ETH Zurich, Department of Earth Sciences using LA-ICP-MS (WÖRLE, 2012). This method of analysis (laser ablation) is minimally invasive. Very small sample quantities – invisible to the naked eye and only a few nanograms in mass – are evaporated using



**Fig. 7** Top: Knee-shaped haft with a forked mounting from the excavation of Zug-Riedmatt (length 60 cm). (drawing: Amt für Denkmalpflege und Archäologie Zug, S. Nüssli Bouzid); middle: reconstruction of the copper axe blade of Zug-Riedmatt (length 66 cm) with haft by J. Weiss (photo: Amt für Denkmalpflege und Archäologie Zug, R. Eichenberger); bottom: reconstruction of the Iceman's axe (length 66 cm) by W. Hein (photo: A. Franzkowiak).

a laser beam, with the vapours then measured. The analysis showed that the blade was made out of relatively pure copper with a detectable concentration of arsenic (0.5 %) and silver (0.081 %) (fig. 9). The only other metal for which a noteworthy concentration could be detected was bismuth



**Fig. 8** A selection of flanged copper axe blades from north and south of the Alps (scale 1:3): 1: Tisenjoch/Hauslabjoch (EGG & SPINDLER, 2009); 2: Remedello Sotto, grave 62 (DE MARINIS, 2013); 3: Zurich-Kleiner Hafner (SUTER, 1987); 4: Zug-Riedmatt (graphic: Amt für Denkmalpflege und Archäologie Zug, S. Pungitore).

(0.021 %). The analysis does not only provide us with the composition of the object; it also yields information about the ores and the smelting techniques that were used. Therefore, it can be expected that the metal composition is characteristic for a certain time frame and/or for a certain region.

In **fig. 9** the analysis results for various flanged axe blades from the region between the Swiss Plateau and Etruria are compared with the results for Zug-Riedmatt. Some flanged axe blades (the Tisenjoch axe blade, the axe blades from the necropolis of Remedello, one axe blade from Bologna and one from Arezzo) also show higher concentrations of arsenic, silver and bismuth – just like the axe blade of Zug-Riedmatt. This similarity, along with the fact that a group of three blades also resemble one another in form (namely the axe blade of Zug-Riedmatt, the Tisenjoch axe blade and the axe blade from Remedello Sotto, grave 62), suggest that this group might be related in regard to place of origin, workmanship, and dating. Nevertheless, the heterogeneity of trace element concentrations

when all axe blades are considered indicates that the other axes with a similar form (though not included in the above-mentioned group of three) might be of several different places of origin, workmanship, and dating. For example, some of the axes display far higher concentrations of antimony than the group of three. All other specimens are generally without any arsenic, or include concentrations of other characteristic trace elements, which distinguishes them from the above group. Thus, both the distribution map of flanged axe blades and the metal compositions indicate that the axe blade of Zug-Riedmatt might derive from Italy. Therefore, another question arises: how does the blade compare to the copper of Neolithic flat axes (GROSS & SCHAEREN, 2013)? These flat axes from older times were made using very pure copper (e. g. both axe blades of Zurich-Wollishofen; see CEVEY ET AL., 2006, plate 1, A-1233, A-1234, tab. 1.) or pure copper with a higher concentration of arsenic (compare to the values of the axe blades of Zurich-Bauschanze, Zurich-Rathaus, Dietikon, or Wetzikon-Robenhausen; see CEVEY ET AL., 2006, plate 1, A-1003.11, A-2243, A-2273, A-469.1). This so-called arsenical copper has been termed “Mondsee-Kupfer” (“Mondsee Copper”; MATUSCHIK, 1998, 243–244) and is seen as characteristic for late Neolithic metallurgy north of the Alps between 3900 and 3500 BC. Some recently analysed examples of such flat axes from the region around Lake Zurich are listed at the bottom of **fig. 9**. This group contains some compositions that are strikingly similar to the Zug-Riedmatt/Tisenjoch/Remedello/Etruria group mentioned above – for example the axe blades of Zurich-Rathaus and Wetzikon-Robenhausen which also display slightly higher silver and bismuth concentrations. Our data contradict the former assignment of the blades of Zug-Riedmatt and Tisenjoch to the context of ‘Mondsee-Copper’ with its morphological traditions oriented to the east. Furthermore, if the blades of Zug-Riedmatt and Tisenjoch do not belong to the so-called ‘Mondsee-Copper Group’, this raises the question whether other objects were also wrongly assigned to this group. In turn, this casts a shadow of doubt on the homogeneity of the ‘Mondsee-Copper group’ as a whole. In order to establish where the axe blade of Zug-Riedmatt stems from, a lead isotope analysis of the axe blade of Zug-Riedmatt was conducted.

Lead isotope analyses enable us to determine the origin of a metal object (VILLA, 2016). All rocks on the Earth’s crust contain radioactive uranium, which slowly decays. This leads to an increase in the lead isotopes  $^{206}\text{Pb}$  and  $^{207}\text{Pb}$  (FAURE, 1977,

The copper axe blade of Zug-Riedmatt (Canton of Zug, Switzerland)

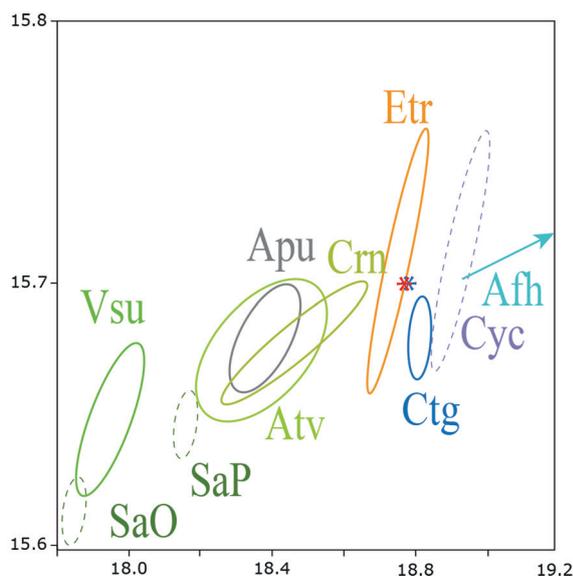
Site	Fe	Co	Ni	Zn	As	Se	Ag	Sn	Sb	Te	Au	Pb	Bi
CH-Zug-Riedmatt (ZG)	<0,02	<0,0002	0,0079	<0,0015	0,5	<0,015	0,081	<0,0025	0,0014	<0,004	<0,0001	0,0016	0,021
I-Tisenjoch (Alto Adige)	0,0204	<0,0001	0,0202	0,00298	0,436	0,0066	0,0956	0,000545	0,00186	0,00068	0,000508	0,0023	0,0177
I-Remedello Sotto (Brescia), grave 62			0,01		0,62		0,08	tr.					0,02
I-Remedello Sotto (Brescia), grave 102			tr.		0,4		0,13						tr.
I-Remedello Sotto (Brescia), grave 4			0,07		0,8		0,05					tr.	tr.
I-Remedello Sotto (Brescia), grave 78			tr.		tr.		0,1					tr.	tr.
I-Bologna, Borgo Panigale (Bologna)			0,1		0,3		0,03		tr.			tr.	
I-Prov. Arezzo	0,08	0	0,001	0	0,17		0,06	0	0		0	0	0,01
CH-Zürich-Kleiner Hafner (ZH), A-52701	0,01193	0,00008	0,02226	0,00078	0,00000	0,00368	0,00498	0,00030	0,00009		0,00006	0,00004	0,00001
CH-Vinelz (BE)	0	0	0,17	0	0		0,01	0	0		0	0	0,001
CH-Portalban (FR)	0	0	0,5	0	0		0,04	0	0		0	0	0
CH-St-Prex (VD)	0,37	0	0,005	0,29	0,039		0	0	0,18		0,005	0,098	0,012
CH-Fully (VS)	0	0	0,058	0,5	0,53		0,046	0	0,42		0,008	0,041	0,005
CH-Genève-Station gaz (GE)	0,38	0,033	0,001	0	0		2,2	0	1,5		0,005	0,008	0,014
CH-Genève-Pierres du Niton (GE)	0	0,016	0,001	0,96	0,76		0,05	0	0,87		0,018	0	0
I-Prov. Brescia	0	0	0,56	0	0		0,01	0	0		0	0	0
I-Bologna-Borgo Panigale (Bologna)	0,08	0	0,07	0	0,08		0,02	0	0,02		0	0	0,012
I-Prov. Firenze	0,09	0	0,001	0	0,01		0,06	0	0,25		0	0	0,001
I-Montespèrtoli (Firenze), hoard	0	0	0,001	0	0		0,06	0	0		0	0	0,001
I-Fucecchio (Firenze)	0	0	0,04	0	0		0,19	0	0		0	0	0,001
I-Prov. Firenze or Pistoia	0,06	0	0,001	0	0,005		0	0	0,007		0	0	0
I-Prov. Firenze or Pistoia	0,03	0	0,01	0	1,7		0,06	0,3	0		0	0	0,005
I-Prov. Firenze or Pistoia	0,05	0	0,001	0	0,03		0,52	0	0,85		0	0	0
I-Prov. Siena	0	0	0,001	0	0		0,12	0	0,07		0	0	0
I-Sarteano (Siena), grave	0,08	0	0,04	0	0,06		0,02	0	0,19		0	0	0
I-Castelluccio la Foce (Siena)	0,23	0	0,001	0	0,07		0,06	0	0,04		0	0	0,01
I-Pienza Ospedaletto (Siena)	0	0	0,001	0	0,34		0,02	0	0,39		0	0	0
I-Guardistallo-Acqua Prateri (Pisa), grave	0	0	0,001	0	0,05		0,02	0,01	0,03		0	0,15	0,01
I-Pomarance (Pisa)	0	0	0,001	0	0,28		0,23	0	0,22		0	0	0
I-Grosseto (Grosseto)	0	0	0,04	0	1,7		0,44	0	2,7		0	0	0,4
I-Ischia di Castro-Ponte San Pietro (Viterbo), grave 15	0	0	0,01	0	0,28		0,17	0	0,51		0	0,01	0
I-Ischia di Castro-Ponte San Pietro (Viterbo), grave 14	0	0	0,001	0	0,11		0,22	0	0,35		0	0	0
CH-Wetzikon Robenhausen (ZH), A-469.1	0,02583	0,00017	0,01798	0,00270	0,20320	0,01401	0,09284	0,00047	0,00263	0,00166	0,00028	0,04350	0,01634
CH-Zürich-Wollishofen, Haumesser (ZH), A-1233	0,00613	0,00004	0,03232	0,00134	0,00029	0,01099	0,00802	0,00156	0,00048	0,00141	0,00006	0,00333	0,00038
CH-Zürich-Wollishofen, Haumesser (ZH), A-1234	0,00000	0,00010	0,02604	0,00369	0,00000	0,00547	0,02107	0,00013	0,00020	0,00000	0,00029	0,00049	0,00003
CH-Zürich-Bauschanze (ZH), A-1003.11	0,01770	0,00002	0,01660	0,00664	0,53200	0,00163	0,03174	0,00134	0,01690	0,00127	0,00063	0,01393	0,00168
CH-Zürich-Rathaus (ZH), A-2243	0,00096	0,00007	0,00161	0,00025	0,33737	n.b.	0,07137	0,00000	0,12040	n.b.	0,00027	0,00254	0,01953
CH-Dietikon (ZH), A-2273	0,00309	0,00006	0,00433	0,00059	0,27239	n.b.	0,02895	0,00003	0,02201	n.b.	0,00030	0,00137	0,00132

**Fig. 9** Results of the trace-element analysis of the axe blades given in percent by weight. Upper part: results of the trace-element analysis of Zug-Riedmatt and all metallurgically similar flanged copper axes from the late 4<sup>th</sup> to 3<sup>rd</sup> millennium BC; middle: flanged axes displaying different traits; bottom part: flat axes from a chronological horizon, presumed to be before 3500 calBC. "tr." small traces detected. (graphic: Amt für Denkmalpflege und Archäologie Zug, E. Gross & G. Schaeren; data basis: Stuttgarter Datenbank and S. van Willigen, SNM Zurich; measurement values for the Tisenjoch axe blade: ARTIOLI ET AL., 2017, 5 table 1).

199–202). However, not all rocks are of the same age, nor did they all originally contain the same concentration of uranium. In other words, the Earth's crust consists of rocks which regionally differ in their concentration of <sup>206</sup>Pb and <sup>207</sup>Pb. When ore deposits are formed, some elements are redistributed according to geochemical regularities. Sulfur reacts with about a dozen metals (e. g. Zinc, copper) and forms sulfide. In certain ground

waters, the sulfides' solubility initially increases, and then suddenly decreases: this creates concentrated sediments of metal sulfides. Lead (Pb) dissolves with copper (Cu) and then precipitates in sulfides. By contrast, uranium always remains excluded from the sulfides because of geochemical reasons. Due to this, the isotopic composition of the Pb in the sulfides does not change any more. Neither <sup>206</sup>Pb nor <sup>207</sup>Pb can accumulate. Another

lead isotope,  $^{204}\text{Pb}$ , is not formed through radioactive decay and has remained constant since the beginning of the solar system. Therefore, the ratios of  $^{206}\text{Pb}/^{204}\text{Pb}$  and  $^{207}\text{Pb}/^{204}\text{Pb}$  isotopes in ore minerals are frozen in the state in which they were when the ore mineralisation occurred. Hence, ore deposits which formed at different times can be distinguished from one another because of their Pb isotope composition: rocks from different regions have acquired different so-called 'fingerprints' (ARTIOLI ET AL., 2016). Throughout the entire Mediterranean, where early innovative centres of European and near Eastern metallurgy are situated, the range of variation in these Pb-isotopic compositions is about 5 %. This may sound like a very small variation; however, it is more than a thousand times more than the deviations in value that can be detected through isotope analyses. The areas in which ore was mined and worked in to metal in the 4<sup>th</sup> and the 3<sup>rd</sup> millennium BC are displayed in **fig. 10**: The Pb isotope measurements for the axe of Zug-Riedmatt is marked by a red star ( $^{206}\text{Pb}/^{204}\text{Pb} = 18.7642 \pm 14$ ,  $^{207}\text{Pb}/^{204}\text{Pb}$

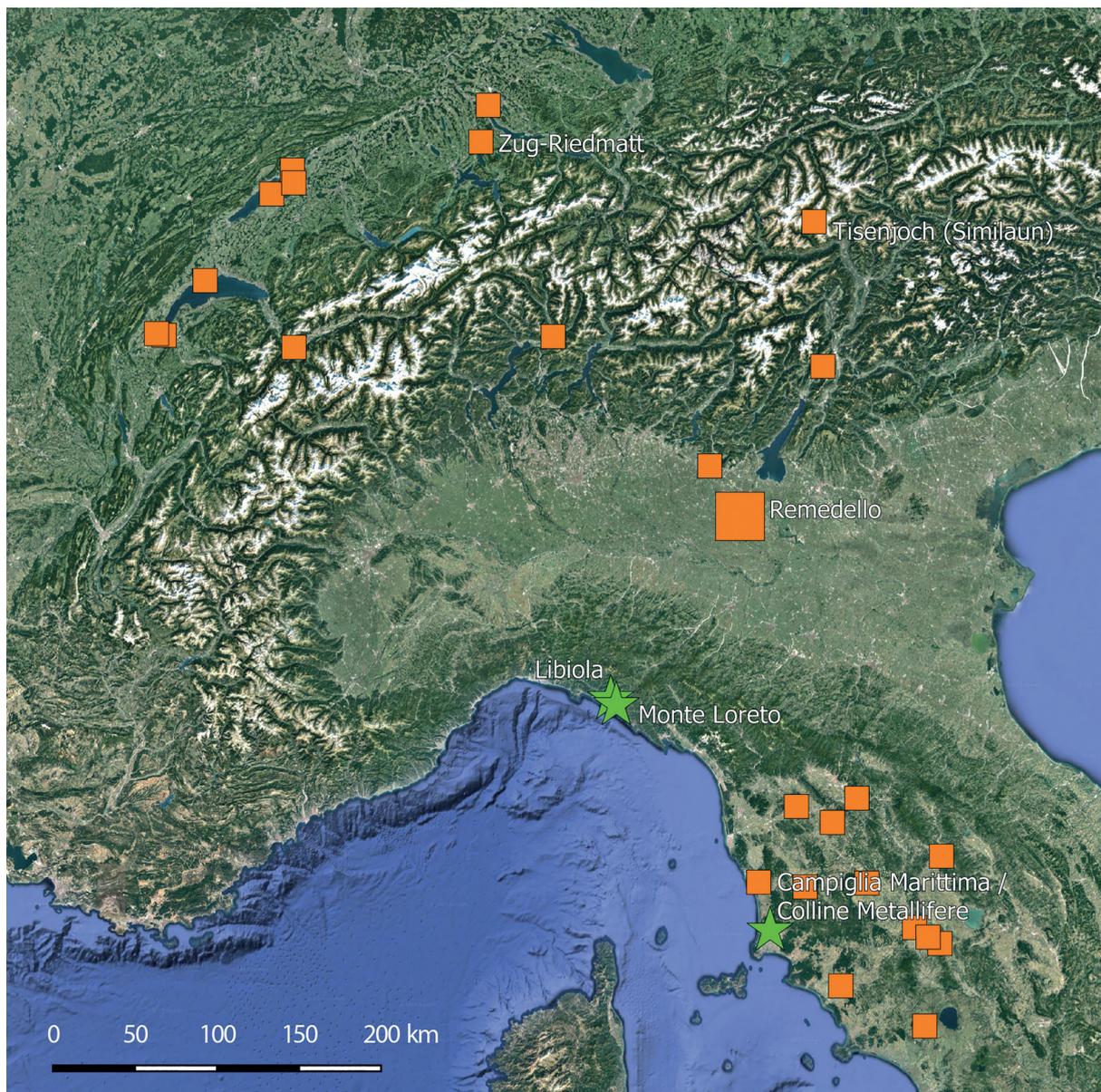


**Fig. 10** Boxplot diagram of the lead isotope ratios of the examined ore deposits with the plotted values for the copper axe blades of Zug-Riedmatt (red star) and of Tisenjoch/Hauslabjoch (blue star). The x-axis corresponds to the ratio of  $^{206}\text{Pb}/^{204}\text{Pb}$  isotopes, the y-axis to the  $^{207}\text{Pb}/^{204}\text{Pb}$  ratio. The elliptical areas with different colours show the different 'fingerprints': Sardinia (SaO, SaP); the south-east coast of the Iberian Peninsula (Ctg); the southern slopes of the Alps (VsU, Atv, Crn); northern and southern Tuscany (Apu, Etr); the Aegean (Cyc). Cyprus is not on the map as the ores there have a lower  $^{207}\text{Pb}/^{204}\text{Pb}$  ratio than can be plotted here. The  $^{206}\text{Pb}/^{204}\text{Pb}$  ratio in the Inn valley (Afh) is too high to be included in the diagram (diagram: I. M. Villa, Institute for Geological Sciences, University of Bern; measurement values for the Tisenjoch axe blade of Tisenjoch: ARTIOLI ET AL., 2017, 5 table 1).

$= 15.6986 \pm 12$ ,  $^{208}\text{Pb}/^{204}\text{Pb} = 39.0125 \pm 45$ ; with uncertainties of 2 sigma on the last decimal places. Analyses by MC-ICP-MS by I. M. Villa). This corresponds perfectly to the data given for southern Tuscany (Campiglia Marittima, Colline Metallifere). Theoretically, it would also be conceivable that ores from Almería/Cabo de Gata/Cartagena (Carthago Nova) in Andalusia are possible; however, there are several arguments against this. Firstly, as far as we know, the southeastern Iberian ores were not smelted to win copper. Secondly, the Pb isotope compositions of the Iberian ores do not correspond exactly to the Tuscan ones. Thirdly, the route of transportation would be far longer than for Tuscan copper. So far, copper mining in the Colline Metallifere is only documented from the Middle Bronze Age onwards. As it is certain that at the Ligurian coast copper was mined from the second half of the 4<sup>th</sup> millennium BC onwards, we can expect that if a similar prospection was done in Tuscany as in Liguria (MAGGI & PEARCE, 2005), it would show that copper was mined there around this time as well. A first piece of proof from San Carlo, Livorno has recently been published by ARTIOLI ET AL. (2017, 14). Furthermore, the Copper Age remains in Tuscany and especially the fact that southern Tuscany is the main area of distribution for copper axe blades with slight flanges are a clear confirmation of the supposed origin (see **fig. 11**). Moreover, the hypogeum from Ischia-di Castro Ponte-San Pietro (NEGRONI CATACCHIO ET AL., 2014, 98), which includes a slightly flanged copper axe blade, shows radiocarbon data consistent with the data of Zug-Riedmatt and Tisenjoch, and is situated in the vicinity of a copper-mine that was used in historic times.

## Implications

The blade of Zug-Riedmatt is one of the early flanged copper axe blades, which can occasionally be found in the Swiss Plateau but are more frequent in northern and central Italy. The closest formal matches are the axe blades of Tisenjoch/Hauslabjoch and the one of grave 62 from Remedello Sotto. These three axe blades appear even more identical in regard to the chemical composition of the metals used. It can, therefore, be assumed that in relation to dating, place of origin, and metallurgic craftsmanship all three of them belong to the Tyrrhenian-Ligurian copper metallurgy of the second half of the 4<sup>th</sup> millennium BC (DOLFINI, 2015; DOLFINI & GIARDINO, 2015). Further-



**Fig. 11** Distribution map of flanged copper axe blades (orange squares, larger squares indicate several blades at the same place) and copper mines (green stars). The two mines from the Ligurian coast provided radiocarbon dates from the second half of the 4<sup>th</sup> millennium calBC. However, these mines show different lead isotope ratios than the axe blade of Zug-Riedmatt. The star indicating the copper mine of Campiglia Marittima stands for the numerous other copper mines of the Colline Metallifere, which is the main area of distribution for blades of this shape. The lead isotope composition of these mines corresponds to that of the axe blade of Zug-Riedmatt (mapping: Amt für Denkmalpflege und Archäologie Zug, E. Gross & D. Jecker, based on Google Maps data).

more, isotope analyses suggest that at least the copper ore used for two of these axe blades (the ones of Tisenjoch/Hauslabjoch (ARTIOLI ET AL., 2017) and Zug-Riedmatt) stems from southern Etruria. No isotope analyses have yet been conducted for the axe blades of Remedello Sotto and for other Italian and Swiss axe blades with weak flanges. Therefore, it is highly probable that the axe blade of Zug-Riedmatt was imported from southern Etruria (fig. 11).

This result puts an unexpected light on the topic of Neolithic metallurgy in the Swiss Plateau and its development during the 4<sup>th</sup> millennium BC. The production of copper objects in the regions between Lake Constance and Lake Zurich begins around 3800 BC and continues until around 3500 BC. For the time after this only few copper objects and crucibles have been found north of the Alps. For this reason, academia had assumed that by 3500 BC the easily accessible high quality copper deposits had

dried up and that until about 2600 BC the Neolithic culture was characterised by the near absence of copper or even an 'animosity' towards the material. According to this view, the few known objects were simply recycled scrap metal made in accordance with tradition (SCHICKLER, 1968; STRAHM, 1994, 33; GROSS & SCHAEREN, 2013).

However, the copper axe blade of Zug-Riedmatt with its link to metallurgical traditions south of the Alps demonstrates that copper metallurgy at the end of the 4<sup>th</sup> millennium BC on the Swiss plateau is not to be understood as a very humble end-of-range model of the earlier metallurgy (3800-3500 BC) north of the Alps. In fact, this metallurgy is a new kind derived from the hot-spots of metallurgical innovation in the regions of the Tyrrhenian-Ligurian coast. This contradicts the theory proposed in ARTIOLI ET AL. (2017, 9-11), in which the Alps are depicted as "a neat cultural barrier separating distinct metal circuits". The as yet unpublished isotopic analyses of the copper finds from Lake Biel confirm our theory that Italian ores played a major role in lake-side dwellings north of the Alpine divide (LÖFFLER, in press). The copper axe blade of Zug-Riedmatt accentuates a multitude of contemporaneous cultural bonds to the south, which seemed to be unconnected and had been underestimated until now (RÖDER & GROSS, 2007, 230-236). Furthermore, it challenges the evolutionistic and one-track perceptions of a time that marks a watershed in early metallurgy.

## Notes

<sup>1</sup> This particularly affects the dating of grave 62 of Remedello Sotto as well as the necropolis' main chronological clusters of tombs (DE MARINIS & PEDROTTI, 1997; DE MARINIS, 1997), the dating of Remedello daggers with copper blades, and the dating of representations thereof on anthropomorphic stelae. This will have consequences on the traditional dating of Copper Age phenomena south of the Alps, e.g. 'Remedello' and 'Rinaldone' - however, these consequences will need to be addressed fully in an article of its own.

<sup>2</sup> Chiusa d'Ermini, hypogeum 1: Negroni Catacchio et al., 2014, 95, fig. 8.4; Aspesi, 2012, 36, fig. 3; Pianizza: Rittatore, 1951, 5.

<sup>3</sup> Zürich-Kleiner Hafner: SUTER, 1987, 143, plate 91.2; FASNACHT, 1995, fig. 106.10; CEVEY ET AL., 2006, plate 5, A-52701; Portalban: ABELS, 1972, 85, plate 44, 613; Vinelz: FASNACHT, 1995, fig. 107.2.

<sup>4</sup> Lagolo: PEDROTTI, 1995, 65-66, fig. 26; Bellinzona-Castel Grande: DE MARINIS, 2013, 331, fig. 27.1.

<sup>5</sup> We were only informed about the publication of the metallurgical research of the Tisenjoch axe (ARTIOLI ET AL., 2017) after the article was already finished. For this reason, all we could do was to add the results of the analysis of the Tisenjoch axe and some additional remarks.

<sup>6</sup> Copper objects and crucibles which have been dated with certainty to the time-frame 3500 -3000 calBC in Switzerland: copper awls from Arbon-Bleiche 3: LEUZINGER, 2002; LEUZINGER, 1997, 52, fig. 3.6-8; copper awls from Feldmeilen-Vorderfeld, layer III: CEVEY ET AL., 2006, plate 5, A-55794; A-55795; crucibles from Zürich-Mozartstrasse, layer 3, und Zürich-Kansan Seefeld, Horgen layers: FASNACHT, 1989, fig. 1 und 2.

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