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References

ALIMOV 1998

Kamildžan Alimov et al., *Prähistorischer Zinnbergbau in Mittelasien, Vorbericht der Kampagne 1997.* Eurasia Antiqua **4** (1998), 137–199.

Kamildžan Alimov, Taškent, Nikolaus Boroffka, Berlin, Mira Bubnova, Dušanbe, Jurij Burjakov, Samarkand, Jan Ciemy, Bochum, Jussuf Jakubov, Dušanbe, Joachim Lutz, Hermann Parzinger, Berlin, Ernst Pernicka, Freiberg, Viktor Radililovskij, Dušanbe, Vladimir Ruzanov, Timur Širinov, Samarkand, Dimitri Staršinin, Dušanbe und Gerd Weisgerber, Bochum

ANTHONY 2009

David W. Anthony, *The Sintashta Genesis, The Roles of Climate Change, Warfare, and Long-Distance Trade.* In: BRYAN K. HANKS & KATHERYN M. LINDUFF (Hrsg.), *Social Complexity in Prehistoric Eurasia, Monuments, Metals and Mobility.* (Cambridge 2009), 47–73. .

Recent studies by Di Cosmo (1999, 2002) and Vehik (2002) have emphasized the transformational political effects of intertribal warfare in arid grasslands on two continents. Intensified warfare in both places encouraged greater political complexity, hierarchy, and elite-centered, distance-trading activities. This chapter argues that intensified warfare and long-distance trade played powerful roles in the origins of the Sintashta culture. Sintashta is defined by a group of fortified settlements and cemeteries dated about 2100–1800 bce (calibrated) in the northern Eurasian steppe between the upper Ural and upper Tobol rivers southeast of the Ural Mountains. Outside the settlements were cemeteries that yielded whole-horse sacrifices, chariots, and many weapons. Inside the settlements, almost every excavated house yielded copper slag and remains of furnaces or intensely burned hearths. The metal was copper or arsenical bronze, usually in alloys of 1–2.5 % arsenic. Pieces of crucibles were placed in two graves at Krivoe Ozero (Vinogradov 2003: 172), and broken casting molds were recovered from the Arkaim settlement. An estimated 6,000 tons of quartzitic rock bearing 2–3 % copper was mined from the single documented mining site of Vorovskaya Yama east of the upper Ural River (Grigoriev 2002: 84; Zaikov, Zdanovich, and Yuminov 1995). The surprising evidence for metallurgical production inside every excavated structure suggests that the Sintashta settlements were the focus of intense metalworking activities, although the scale and organization of metal production is not well understood either within or between them (see Hanks, Chapter 9 in this volume).

BARTELHEIM 1997

Martin Bartelheim, *Aunjetitz und El Argar, Neue Überlegungen zu einer alten Frage.* In: CORNELIA BECKER, MARIE-LUISE DUNKELMANN, CAROLA METZNER-NEBELSICK, HEIDI PETER-RÖCHER, MANFRED ROEDER & BIBA TERŽAN (Hrsg.), *Χρόνος, Beiträge zur Prähistorischen Archäologie zwischen Nord- und Südosteuropa, Festschrift für Bernhard Hänsel.* Studia honoraria 1 (Espelkamp 1997), 275–285.

Zusammenfassend betrachtet, scheint es sich, wie vor allem im Falle der Keramik zu beobachten, bei den skizzierten Analogien eher um einen über weite Räume hinweg wirkenden Zeitgeschmack zu handeln, als um das Produkt einer direkten Beeinflussung einer Region durch die andere. Die Aunjetitzer Kultur und die El Argar-Kultur präsentieren sich als zwei hochentwickelte Regionen mit starker Ausstrahlung innerhalb eines weiterreichenden kulturellen Spannungsfelds mit ähnlichen Tendenzen in puncto Gestaltungswille ihres mobilen Inventars und der technischen Entwicklung. Ob den beiden Kulturzentren ihre Nähe zu Lagerstätten von vermutlich in jenen Zeiten begehrten Metallen wie Kupfer und, im Falle der Aunjetitzer Kultur, auch Zinn dabei zu diesem Aufschwung verhalf, ist denkbar, aber momentan kaum eindeutig zu verifizieren. Im Gegensatz zur El Argar-Kultur bleibt die extensive Nutzung der metallischen Rohstoffe um die Aunjetitzer Kultur herum (Harz, Thüringer Wald, Erzgebirge, Riesengebirge und Westböhmen) noch zu beweisen.

Es wird also offensichtlich, daß es gute Argumente für eine unabhängige Entstehung beider Kulturen aus lokalen Wurzeln heraus gibt. Dennoch sind verbindende Elemente nicht zu übersehen, die auf eine gemeinsame Vorgängerkultur und auch ähnliche zeitgleiche überregionale Tendenzen in der Kulturentwicklung zurückzuführen sind. Die verblüffenden Analogien in der Keramik sind nach heutigem Kenntnisstand allerdings mit hoher Wahrscheinlichkeit Produkt eines Zufalls.

Boroffka 2002

Nikolaus Boroffka, Jan Cierny, Joachim Lutz, Hermann Parzinger, Ernst Pernicka & Gerd Weisgerber, *Bronze Age Tin from Central Asia: Preliminary Notes.* In: Katie Boyle, Colin Renfrew & Marsha Levine (Hrsg.), *Ancient interactions: east and west in Eurasia.* (Cambridge 2002), 135–159.

One of the most important results of the project is the first proof of Bronze Age tin mining and processing in Central Asia, which owing to the very considerable size of the deposits is of potential importance far beyond this limited region. This is obvious from the fact that even the small seasonal settlement in Karnab-Sichkonchi shows evidence of long-distance contacts.

A second, perhaps not so spectacular result is the observation that the Andronovo culture is so tightly associated with mining and metallurgy that its characterization as a culture of purely pastoral nomads should probably be revised. They (or their products) repeatedly appear in direct contact with the highly urbanized sedentary civilizations of the Margiana or Bactria (e. g. Vinogradova 1994; Avanessova 1997), often as metallurgists of quite developed capabilities. In the northern steppes their mining and metallurgical activities of considerable scale have long been known (Kuzmina 1991; Kadyrbaev & Kurmankulov 1992; Avanessova 1996; Parzinger in press, all with further literature). During our recent research in Uzbekistan and Tajikistan all investigated mining sites have again been associated with Andronovo, even though settlements of other, so-called sedentary cultures were present in the surroundings as well (Isakov 1981; 1991; Lyonnet 1996). While the pastoral component in the economy of the Andronovo tribes, based on settlement structures and zooarchaeological data, can hardly be contested the idea of pure nomadism does not seem to fit with the extensive mining and metallurgical activities or the long-distance contacts of these same tribes. The fact that the campsite levels in Karnab repeatedly show the same internal organization also indicates a stable social structure. The Bronze Age Andronovo society was probably much more complex and had much more intense long-distance connections than is observable at present based largely on funerary finds.

BRENTJES 1971

Burchard Brentjes, *Ein elamitischer Streufund aus Soch, Fergana (Usbekistan).* Iran **9** (1971), 155.

Sie stammen aus Nippur, Fara, Chafadschi (P1. Ia) und anderen Orten Mesopotamiensle und Indiens, doch verweist bereits Poradais auf die Wahrscheinlichkeit eines Imports dieser Steatitarbeiten aus Elam. Es ist wie die mesopotamischen Funde in die Mitte des 3. Jahrtausends vor Chr. zu datieren.

BUCHWALD 2005

Vagn Fabritius Buchwald, *Iron and steel in ancient times.* Historisk-filosofiske Skrifter 29 (Copenhagen 2005).

The history of iron and steel is presented from the earliest known examples until 1200 A.D., when new methods of production were introduced. In an introductory chapter the utility of meteoritic iron for tools and weapons is discussed, and it is shown how the three iron types, meteoritic, telluric and man-made iron may be distinguished. The competition between copper, bronze and iron in the Mediterranean area is followed, and the transition from Bronze Age to Iron Age explained. Early centres of iron production, such as Elba, are examined in some detail. In a chronological development, the Etruscan, Roman and Celtic handling of ores and metal is examined, and the success of Noric steel explained. The North European scene is explored, with emphasis on Norway, Sweden and Denmark, and it is shown that there were two steel-producing centres in Scandinavia, Valdres in the Iron Age and Viking Age, and Småland in early mediaeval times. The material has been examined from a metallurgical standpoint. The metal phases are analysed and tested for their hardness, and it is shown that ancient iron was usually a complex alloy of three elements, iron, carbon and phosphorus, the last one being an important component. The manufactured objects, whether nails, horseshoes or tools, were extremely heterogeneous, in the structure as well as in the hardness and the slag inclusions, but it is shown that there is a logical, metallurgical harmony between the heterogeneous zones. The furnace slags have been characterized by their morphology and composition, and the slag inclusions have been analysed in great detail and used to discriminate between artefacts of Danish origin and those of foreign origin. It turns out that a significant fraction of Danish Viking Age and early mediaeval artefacts have been imported from Norway, Scania and Halland. The special world of metallurgy is elucidated with discussions of furnace technology, forging, hardening, hammer-and pattern-welding. The war booty sacrifices, which are rich in pattern-welded swords, are treated with examples from Vimose, Nydarh and Illerup Ådal.

CIERNY 2003

Jan Cierny & Gerd Weisgerber, *Bronze Age Tin Mines in Central Asia.* In: ALESSANDRA GIUMLIA-MAIR & FULVIA LO SCHIAVO (Hrsg.), *Le probleme de l'etain a l'origine de la metallurgie – The Problem of Early Tin, Acts of the XlVth UISPP Congress, University of Liege, Belgium, 2–8 September 2001.* BAR International Series 1199 (Oxford 2003), 23–31.

After a general introduction to the problem of the provenience of Near Eastern tin in the Bronze Age 2nd millennium B.C., tin mines and mining techniques are described for Uzbekistan and Tajikistan. The enormous amount of tin produced by the Andronovo people could also have been for export.

Cierny 2005

Jan Cierny, Thomas Stöllner & Gerd Weisgerber, *Zinn in und aus Mittelasien*. In: Ünsal Yalçin, Cemal Pulak & Rainer Slotta (Hrsg.), *Das Schiff von Uluburun, Welthandel vor 3000 Jahren, Katalog der Ausstellung des Deutschen Bergbau-Museums Bochum vom 15. Juli 2005 bis 16. Juli 2006*. (Bochum 2005), 431–448.

Das Besondere der Lagerstätte von Muschiston ist aber, dass das Zinnerz mit Kupfererzen vermengt ist. Da dieses sich durch Verwitterung und Oxidation grün und gelb verfärbt hat, sind und waren beide Erze im Quarz nicht zu übersehen.

Es ist nur schwer vorstellbar, wie in der Bronzezeit Zinnund Kupfererze getrennt worden sein sollen; daher wird es wohl so gewesen sein, dass beide Erze zusammen verhüttet wurden. Dann wäre das Kupfer lagerstättenbedingt mit dem gleichfalls im Erz enthaltenen Zinn im Schmelzofen bei der Verhüttung legiert worden. Die Kupfer-Zinn-Legierung Bronze wäre dann unter Umständen zufällig entdeckt worden. Diesen alternativen Ansatz zur Entdeckung der Bronze im 3. Jt. v. Chr. hatte bis dahin noch niemand ins Gespräch gebracht, da das Mischerz von Muschiston sowohl sehr selten als auch nirgends sonst Lagerstätten bildend vorkommt. Bei Schmelzversuchen mit dem “Bronzeerz” von Muschiston an der Bergakademie Freiberg wurde in der Tat eine Bronze erschmolzen. Kam die Kenntnis der Bronze tatsächlich aus den tadschikischen Bergen? Zur Beantwortung dieser Frage muss noch viel archäologische Grundlagenforschung geleistet werden.

Cleuziou 1982

Serge Cleuziou & Thierry Berthoud, *Early Tin in the Near East, A reassessment in the light of new evidence from western Afghanistan*. Expedition **25** (1982), i, 14–19.

Expedition25.1-014-Figures.pdf

There are two possible routes from Afghanistan to Mesopotamia. One crosses the northern part of the Iranian plateau, along the Elburz Mountains, then through passes in the Zagros descends to Babylonia and Assyria. In the 1st millennium it was one of the principal supply routes of eastern goods to Assyria. In the 2nd millennium the tin that Assur exported to Anatolia might have followed this route. Along it are found such sites as Tepe Sialk (where the use of tin is attested in the 4th millennium), Tepe Giyan and Tepe Hissar, where other finds (such as lapis lazuli at Hissar) implicate them in long-distance commerce in the 3rd millennium.

The second route is by sea, along the Arabian coast of the Gulf, perhaps also going by land through southern Iran. It was at the time of Gudea of Lagash (2150-2111 B.C.) and earlier the great supply route of eastern commodities to southern Mesopotamia. It is by this route that the copper of Makkan came, copper which analysis has shown to have originated in the peninsula of Oman. It also brought the products of Meluhha, including lapis lazuli, carnelian, copper, ivory and various woods. Nothing, however, suggests the passage of tin through this area. For example, there is little tin in the artifacts recovered at Qala’at al Bahrain, dating between 2300 and 1800 B.C.

Craddock 1993

Paul T. Craddock, *A short review of the evidence for Bronze Age mining in the British Isles*. In: Heiko Steuer & Ulrich Zimmermann (Hrsg.), *Montanarchäologie in Europa, Int. Koll. „Frühe Erzgewinnung und Verhüttung in Europa“ in Freiburg i. Br. vom 4. bis*

7. Oktober 1990. Archäologie und Geschichte 4 (Sigmaringen 1993), 37–56.

Craddock 1999

Paul T. Craddock:, *Paradigms of metallurgical innovation in prehistoric Europe.* In: Andreas Hauptmann, Ernst Pernicka, Thilo Rehren & Unsal Yalgin (Hrsg.), *The Beginnings of Metallurgy, Proceedings of the International Conference „The Beginnings of Metallurgy", Bochum 1995.* Veröffentlichungen aus dem Deutschen Bergbau-Museum 84 (Bochum 1999) [Der Anschnitt, Beiheft 9], 175–192.

Cramer 1995

Clayton E. Cramer, *What Caused The Iron Age? unveröffentlichter Seminarvortrag, December 10, 1995.* (Sonoma 1995). <http://www.claytoncramer.com/unpublished/Iron2.pdf> (2012-11-17).

Whether the underlying cause was a tin shortage, or a copper shortage, it is easy to understand why Eastern Mediterranean societies first turned to iron as a cheaper, less effective alternative to bronze. After the discovery of carburization and quenching, steel was both cheaper and more effective than bronze.

Egypt had its own sources of copper ore in the Sinai, but still bought heavily from Cyprus. While tin ore deposits are now mined in the Eastern Desert of Egypt, "it is doubtful whether these deposits were known or worked in antiquity." Nonetheless, because of Egypt's much more southerly location relative to the other Eastern Mediterranean nations, the tin exports from Iran to the Eastern Mediterranean disrupted by invasion around 1200 BC might have continued to Egypt without interference. With adequate supplies of bronze, Egypt would have had much less reason to experiment with the inferior metal iron — and thus, less opportunity to discover steel.

In seeking explanations for technological change, it is tempting to see such change as the logical expression of chance discovery. Perhaps this is a seductive idea to twentieth century people because so many of the significant discoveries of modern times were lucky accidents: penicillin, nitroglycerin, and X-rays, to name a few. But modern Western society encourages and rewards innovation, and most people regard innovation as a generally positive influence on their lives. Modern Western society accepts that the only constant is change. It is no surprise that twentieth century man assumed, until recently, that a chance technological discovery was the proximate cause of the Iron Age.

Throughout most of human history, societies have changed very slowly, regarding change with suspicion. Such societies would have taken the dramatic change from bronze to iron only under the most pressing need. From the available evidence, this pressing need was a critical bronze shortage. A sudden disruption of the political structures that made possible long-range trade in tin apparently induced this shortage.

Dayton 1971

J. E. Dayton, *The problem of tin in the Ancient World.* World Archaeology **3** (1971), 49–70.

WorldArchaeology03-049-Comment.pdf, WorldArchaeology03-049-Reply.pdf

Tin ores are shown to be absent, and indeed unlikely to exist in the region of the Caucasus specifically and the Near East in general. Possible sources of tin are reviewed, and the most probable ores to have been exploited in the ancient Near East are considered to have been those of central Europe. It is argued that the metal was imported in the form of bronze, and that the Akkadian word annaku refers to this alloy. This trade was carried out by way of the Danube and eastern Anatolia.

Dayton 1973

J. E. Dayton, *The problem of tin in the Ancient World: a reply to Dr Muhly and Dr Wertime.* World Archaeology **5** (1973), 123–125.

Dayton 2003

John E. Dayton, *The problem of tin in the ancient world, (Part 2).* In: Alessandra Giumlia-Mair & Fulvia Lo Schiavo (Hrsg.), *Le probleme de l'etain a l'origine de la metallurgie – The Problem of Early Tin, Acts of the XlVth UISPP Congress, University of Liege, Belgium, 2–8 September 2001.* BAR International Series 1199 (Oxford 2003), 165–170.

The sources of the tin used to make the bronzes of the Bronze Age has been a matter of much speculation since the writer's paper of 1971. Obvious and well-known tin deposits in Europe (Cornwall, Spain and Bohemia have been ignored by Middle Eastern archaeologists in a frantic search for an eastern source. (The idea that bronze and technology could have spread from Barbarian Europe being anathema to the belief in the superiority of the not so very 'Fertile Crescent'). Minute traces of tin at the ppm level have been hailed as the source of all Bronze Age bronze, e.g. at Kestel in Anatolia, and traces in eastern Iran and Afghanistan.

Recent lead isotope analysis of ancient tin ingots (Begemann et all 999) has shown that some tin in Phoenician times was coming from Central Africa, and the area known to the Ancient Egyptians as "The Land of Punt." This has confirmed the ignored work of Brill et a] (1974) who analysed lead from 12th Dynasty tombs and of the writer (1971, 1978, and 1986) who analysed lead ores from the area.

During Caspers 1994

Elisabeth C. L. During Caspers, *Further Evidence for 'Central Asian' Materials from the Arabian Gulf.* Journal of the Economic and Social History of the Orient **37** (1994), 33–53.

The coasts of Arabia bordering on the Arabian Gulf, the Gulf of Oman and the Arabian Sea were natural stopping off places for traffic from the ancient Near East and South Asia; consequently, the region received cultural impulses from both quarters throughout the last three millennia B.C. down to historical times. It is, therefore, not surprising that the Murghabo-Bactrian culture, generated by surprisingly wealthy farming societies of high artistic and technical knowledge living in northwest Afghanistan, southern Uzbekistan (ancient Bactria) and the Murghabo river delta in southeastern Turkmenia (ancient Margiana) whose impact is evinced from ancient Mesopotamia in the west to the Indus Valley Civilization in the east') has also made its influence felt both culturally and/or in a mercantile sense, along the southern shores of the Arabian Gulf and in the Arabian Peninsula. Calibrated C-14 datings and cross references to comparable materials from datable cultural complexes in neighbouring areas gives this Central Asian culture a floreat in the later half of the third and the first centuries of the second millennium B.C.

During Caspers 1995

Elisabeth C. L. During Caspers, *Local MBAC materials in the Arabian Gulf and their manufacturers.* Proceedings of the Seminar for Arabian Studies **26** (1995), 47–64.

Garner 2015

Jennifer Garner, *Bronze Age tin mines in central Asia.* In: Andreas Hauptmann & Diana Modarressi-Tehrani (Hrsg.), *Archaeometallurgy in Europe III*, *Proceedings of the 3rd International Conference Deutsches Bergbau-Museum Bochum June 29 – July 1, 2011.* Der Anschnitt, Beiheft 26 (Bochum 2015), 135–143.

Since the oldest known artifacts of tin bronze appeared in Mesopotamia and ancient Orient, more and more questions arose about the origin of this alloy, particularly since neither copper nor tin deposits are present in Mesopotamia. Due to this fact some researchers belief that the source of the metal, especially tin, is located in Central Asia. In Central Asia are large copper and tin deposits with traces of mining, dating to the middle and Late Bronze age (2nd millennium BC). Tin production during the Early Bronze Age is also likely, since the first tin-bronze artefacts appeared within the Sejma-Turbino circle during the End of 3rd millennium BC. The Zeravshan valley posses large tin deposits and a part of the later Silk Road leads through the valley connecting the eastern with the western regions. Several different tin mining districts in the Zeravshan valley were excavated: in Karnab and Lapas, situated between Samarkand and Bokhara; Èangali near Kattakurgan; Mushiston, which is not far away from Pendjikent and the famous settlement of Sarazm. The Mining took place in open cast trench mines, which followed the veins into an unknown depth or, like in Mushiston, in an underground mine, which old galleries and chambers formed a huge labyrinth. Ceramic typology and radiocarbon dates date the mines in Karnab, Lapas and Changali to the middle 2nd millennium BC (Andronovo-Tazabagjab culture). Only Mushiston started at the end of the 3rd millennium BC and stopped in the late Bronze Age.

Horne 1982

Lee Horne, *Fuel For The Metal Worker*, *The Role of Charcoal and Charcoal Production in Ancient Metallurgy.* Expedition **25** (1982), i, 6–13.

Expedition25.1-006-Figures.pdf

If this estimate of 20 to 1 for a charcoal to copper ratio is accurate (and there are only a few studies to substantiate it), then by all accounts iron uses much less charcoal for extraction than copper does. This may come as a surprise in view of our picture of the environmentally destructive consequences of the coming of iron. Nonetheless, a variety of ethnographic and experimental reports indicate that iron requires no more than 10 kg of charcoal for each kg of iron produced, counting in both smelting and forging. The reasons for this difference lie in the production technologies of the two metals. It is true that iron has a higher melting temperature than copper and needs a more reducing atmosphere. We saw, however, that iron is smelted below its melting temperature. Furthermore, copper slag, unlike iron slag, must remain melted during the process in order for the melted copper to pass through and sink to the bottom of the kiln. In these ways copper extraction appears to be the more fuel intensive of the two.

Kavtaradze 2004

Giorgi L. Kavtaradze, *The Chonology of the Caucasus during the Early Metal Age: Observations from Central Trans-Caucasus.* In: Antonio Sagona (Hrsg.), *A view from the highlands, Archaeological studies in honour of Charles Burney.* Ancient Near Eastern Studies Supplement 12 (Herent 2004), 539–556.

Under the weight of a revised chronological framework, we are led to a reassessment of a number of cultural-historical, ethno-genetic and social-economical events. In so doing the interrelationships between the ancient Near Eastern and east European societies appears in rather different light.

Kienlin 2004

Tobias L. Kienlin, *Zur Metallographie urgeschichtlicher Artefakte: Ergebnisse einer Untersuchung an Kupfer- und Bronzebeilen des nordalpinen Raumes.* In: P. Portella (Hrsg.), *Fortschritte in der Metallographie, Vortragstexte der 37. Metallographie-Tagung, 17.–l9. September 2003 in Berlin.* Sonderbände der Praktischen Metallographie 35 (Frankfurt 2004), 3–10.

Ausgehend von einer Gruppe spätneolithisch-kupferzeitlicher Beile zeigt sich, wie zunächst die Verwendung nebenelementreicher Fahlerzmetalle, später diejenige der Zinnbronze zu besseren mechanischen Eigenschaften der in Frage stehenden Beile führte und damit der Attraktivität des Werkstoffs Metall den Weg bereitete. Die Anwendung metallographischer Verfahren erlaubt eine differenzierte Betrachtung dieses Prozesses, und hervorzuheben sind nochmals die sehr unterschiedlichen Gefügeausprägungen der Beile des Typs Salez. Es zeigt sich eine recht kompetente Anpassung der Vorgehensweise an den jeweiligen Nebenelementgehalt, vor allem aber auch die Problematik der Abhängigkeit von einem Werkstoff, auf dessen Zusammensetzung man nur beschränkt Einfluss nehmen konnte. Erst die Zinnbronze erlaubte hier eine Stabilisierung auf hohem Niveau, indem der Gehalt des für eine Kaltverfestigung ausschlaggebenden Legierungselements beherrschbar wurde. Damit einher geht zugleich eine Vereinheitlichung der Schmiedetechnik, die auf überregional sich durchsetzende Vorgehensweisen und Erwartungshaltungen an die Qualität entsprechender Beile schließen läßt.

Kienlin 2005

Tobias L. Kienlin, *Frühbronzezeitliche Vollgriffdolche und Randleistenbeile, Zu Herstellungstechnik, Zusammensetzung und Materialwahrnehmung.* Archäologisches Korrespondenzblatt **35** (2005), 175–190.

Early bronze age metal hilted daggers and flanged axes: production techniques, composition and recognition of materials

The recent analysis of Early Bronze Age metal hilted daggers by S. Schwenzer (2004) has improved our knowledge substantially. To understand the development of early metallurgy, metal analyses are of great importance; in this way Schwenzer has proved that a refined handling of the alloying constituent tin took place. However, his research on the reasons for using tin bronze is influenced by the wish to show that bronze metal hilted daggers came from Italy or the Alpine region. It also makes assumptions about the properties of the copper types and alloys which have to be examined in greater detail. A metallographical analysis of Early Bronze Age flanged axes from the area north of the Alps has been undertaken to investigate the use of various copper types and tin bronze. This analysis of flanged axes – supported by experimental archaeology – provides significant clues about

the recognition and choice of material which also have some significance for the production of metal hilted daggers.

Mit der Neubearbeitung der frühbronzezeitlichen Vollgriffdolche durch St. Schwenzer (2004) hat deren Kenntnis wichtige Fortschritte erfahren. Für die Frage nach dem Entwicklungsstand der frühen Metallurgie sind dabei vor allem die Metallanalysen von Interesse, anhand derer Schwenzer einen differenzierten Umgang mit dem Legierungselement Zinn nachweisen kann. Seine Ausführungen zu den Gründen der Verwendung der Zinnbronze sind jedoch von dem Anliegen beeinflusst, die Vollgriffdolche aus dem italischen oder alpinen Raum abzuleiten. Sie gehen zugleich einher mit Annahmen zu den Materialeigenschaften der in Frage stehenden Kupfersorten bzw. -legierungen, die einer eingehenderen Betrachtung bedürfen. Ausgehend von einer metallographischen Untersuchung frühbronzezeitlicher Randleistenbeile des nordalpinen Raums soll der Verwendung unterschiedlicher Kupfersorten und der Zinnbronze in der Frühbronzezeit nachgegangen werden. Aus der Zusammenschau mit experimentellen Arbeiten ergeben sich dabei Anhaltspunkte über die Materialwahrnehmung und -auswahl auch bei der Herstellung der Vollgriffdolche.

Kienlin 2010
Tobias L. Kienlin, *Traditions and Transformations: Approaches to Eneolithic (Copper Age) and Bronze Age Metalworking and Society in Eastern Central Europe and the Carpathian Basin*. BAR International Series 2184 (Oxford 2010).

Krause 1998
Rüdiger Krause, *Zur Entwicklung der frühbronzezeitlichen Metallurgie nördlich der Alpen*. In: Bernhard Hänsel (Hrsg.), *Mensch und Umwelt in der Bronzezeit Europas – Man and Environment in European Bronze Age, Abschlußtagung: Die Bronzezeit, das erste goldene Zeitalter Europas, Berlin, 17.–19. März 1997*. (Kiel 1998), 163–192.

Kupferinstitut 2004a
Deutsches Kupferinstitut, *Kupfer-Zinn- und Kupfer-Zinn-Zink-Gusslegierungen (Zinnbronzen)*. (Düsseldorf 2004). <http://www.kupfer-institut.de/front_frame/pdf/Infodruck%20i.%2025_12_2004.pdf> (2012-11-10).

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Julius Moshage, *Energie bewegt die Welt*, *Das große Buch der Naturkräfte.* (1960).

MUHLY 1973A
J. D. Muhly, *Tin Trade Routes of the Bronze Age.* American Scientist **61** (1973), 404–413.
New evidence and new techniques aid in the study of metal sources of the ancient world.

MUHLY 1973B
J. D. Muhly & T. A. Wertime, *Evidence for the sources and use of tin during the Bronze Age of the Near East: a reply to J. E. Dayton.* World Archaeology **5** (1973b), 111–122.

MUHLY 1985
James D. Muhly, *Sources of Tin and the Beginnings of Bronze Metallurgy.* American Journal of Archaeology **89** (1985), 275–291.
Recent discoveries of Bronze Age tin ingots and tin artifacts, together with new geological evidence on tin deposits in Europe, the Mediterranean and Western Asia, provide the opportunity to survey the evidence for possible sources of tin and the first use of bronze in the eastern Mediterranean and in Western Asia. Afghanistan now emerges as the most promising eastern source of tin, with western sources most likely located in southern England and Brittany. Central European tin sources still provide serious problems within the context of the nature of Bronze Age mining technology and the type of cassiterite being utilized at that time.

PARZINGER 2001
Hermann Parzinger & Nikolaus Boroffka, *Woher stammt das Zinn der Bronzezeit in Mittelasien?* Archäologie in Deutschland **2001**, iii, 12–17.
Bald hundert Jahre ist bekannt, dass Metallfunde aus Vorder-und Zentralasien seit Mitte des 3. Jt. v. Chr. immer häufiger aus Bronze bestehen, einer Legierung aus Kupfer und Zinn. Für die Kupfergewinnung kommen zahlreiche Lagerstätten zwischen Altaj im Osten und Karpatenbogen im Westen sowie zwischen Ural im Norden und Oman im Süden infrage, doch die Herkunft des Zinns ist bis heute ungeklärt.

PERNICKA 1998
Ernst Pernicka, *Die Ausbreitung der Zinnbronze im 3. Jahrtausend.* In: BERNHARD HÄNSEL (Hrsg.), *Mensch und Umwelt in der Bronzezeit Europas – Man and Environment in European Bronze Age, Abschlußtagung: Die Bronzezeit, das erste goldene Zeitalter Europas, Berlin, 17.–19. März 1997.* (Kiel 1998), 135–147.

PRIMAS 2002
M. Primas, *Early tin bronze in Central and Southern Europe.* In: MARTIN BARTELHEIM, ERNST PERNICKA & RÜDIGER KRAUSE (Hrsg.), *Die Anfänge der Metallurgie in der Alten Welt,*

Euroseminar Freiberg/Sachsen, November 1990. Forschungen zur Archäomatrie 1 (Rahden/Westf. 2002), 303–314.

The present article deals with the shift from copper to tin bronze and reviews analyses from different regions in the southern part of Europe. Lead isotope analysis suggests a foreign provenance for early tin bronze. The widespread adoption of tin bronze technology between 2200-1800 cal. BC did not produce a uniform pattern. Regional preferences indicate variation in social organisation. Beads of metallic tin will be discussed as probable indicators of interregional networks of exchange.

Keywords: Central And Southern Europe, Early Bronze Age, Tin Bronze, Tin Beads, Social Organisation.

Пугаченкова 1965

Г. А. Пугаченкова & Л. И. Ремпель, История искусств Узбекистана, С древнейших времен до середины девятнадцатого века. (Москва 1965).

G. A. Pugachenkova & L. I. Rempel, Geschichte der Künste Usbekistans, Von den ältesten Zeiten bis zur Mitte des neunzehnten Jahrhunderts.

Radivojević 2013

Miljana Radivojević, Thilo Rehren, Julka Kuzmanović-Cvetković, Marija Jovanović & J. Peter Northover, *Tainted ores and the rise of tin bronzes in Eurasia, c. 6500 years ago.* Antiquity **87** (2013), 1030–1045.

Antiquity087-1030-Supplement.pdf

The earliest tin bronze artefacts in Eurasia are generally believed to have appeared in the Near East in the early third millennium BC. Here we present tin bronze artefacts that occur far from the Near East, and in a significantly earlier period. Excavations at Plocnik, a Vinca culture site in Serbia, recovered a piece of tin bronze foil from an occupation layer dated to the mid fifth millennium BC. The discovery prompted a reassessment of 14 insufficiently contextualised early tin bronze artefacts from the Balkans. They too were found to derive from the smelting of copper-tin ores. These tin bronzes extend the record of bronze making by c. 1500 years, and challenge the conventional narrative of Eurasian metallurgical development.

Keywords: Eurasia, Serbia, Bulgaria, Pločnik, Belovode, fifth millennium BC, Vinča culture, copper, tin, bronze, metallurgy, compositional analysis

Radivojević 2014

Miljana Radivojević, Thilo Rehren, Julka Kuzmanović-Cvetković & Marija Jovanović, *Why are there tin bronzes in the 5th millennium bc Balkans?* In: Selena Vitezović & Dragana Antonović (Hrsg.), *Archaeotechnology, Studying technology from prehistory to the Middle Ages.* (Belgrade 2014), 235–256.

The appearance of the earliest tin bronze artefacts is traditionally linked to the copper-tin alloying practice in the 3rd millennium BC Near Eastern Bronze Age settlements. Advocates of this model argue that tin for alloying may have come from deposits located in central Asia or southwest Iran; however, finding evidence for tin bronze production remains a challenge for archaeologists. Here we present apiece of tin bronze foil discovered in the Vinca culture site of Pločnik in Serbia, and securely dated to c. 4650 BC, which makes it the earliest known tin bronze artefact anywhere in the world. Compositional analysis links it to smelting a complex copper-tin ore, such as chalcopyrite intergrown with stannite and/or fahlerz, while metallographic analysis indicate its intentional production and understanding of material properties of the newly acquired metal. These results initiated a reassessment of the fourteen previously discovered and analysed artefacts of similar compositional pattern as the Pločnik foil. The rise of tin bronze metallurgy in the Balkans is also discussed in the light of the concurrent appearance of other colourful metal objects in this region.

Keywords: tin bronze, Vinca culture, Pločnik, Balkans, Chalcolithic

Rovira 2002

Salvador Rovira, *Early slags and smelting by-products of copper metallurgy in Spain.* In: Martin Bartelheim, Ernst Pernicka & Rüdiger Krause (Hrsg.), *Die Anfänge der Metallurgie in der Alten Welt*, *Euroseminar Freiberg/Sachsen, November 1990.* Forschungen zur Archäomatrie 1 (Rahden/Westf. 2002), 83–98.

Many aspects of prehistoric metallurgy in Spain are well known through the research programs carried out over the last years, but early copper smelting slags are almost unknown. This paper deals with the composition and structure of Chalcolithic slags determined by SEM facilities. The slags are products of a smelting process implemented in ceramic reducing crucibles (basins and trays). Other smelting debris such as copper prills, ores and slagged sherds belonging to those reducing implements are also taken into account.

Keywords: Copper Slags, Copper Ores, Copper Smelting, Prills, Composition, Reducing Crucibles, Sem Analysis, Chalcolithic, Bronze Age, Spain.

Rovira 2003

Salvador Rovira & Ignacio Montero, *Natural Tin-Bronze Alloy in Iberian Peninsula Metallurgy: Potentiality and reality.* In: Alessandra Giumlia-Mair & Fulvia Lo Schiavo (Hrsg.), *Le probleme de l'etain a l'origine de la metallurgie – The Problem of Early Tin*, *Acts of the XlVth UISPP Congress, University of Liege, Belgium, 2–8 September 2001.* BAR International Series 1199 (Oxford 2003), 15–22.

The Iberian Peninsula is a rich area in tin resources, but they are not homogeneously distributed. Tin resources are concentrated in the western and northwestern regions. It is not unusual to find copper-tin ores in those areas where tin resources are scarcer. So, in the eastern Pyrenees, the central ranges (Sierra de Guadarrama and Mounts of Toledo), Sierra Morena or in the Murcia region mixed copper-tin ores have been found. Some of these ores were used by prehistoric metallurgists as has been determined by the analyses of metallurgical debris from Bronze Age sites (Bauma del Serrat del Pont, Villaviciosa de Odon, Gravera Puente Viejo, Llanete de los Moros). A general discussion about natural tin alloy in the early metallurgy of the Iberian Peninsula based on the analytical study of some archaeological samples using XRF, SEM and metallography is carried out.

Ruzanov 1999

Vladimir Ruzanov, *Zum frühen Auftreten der Zinnbronze in Mittelasien.* In: Andreas Hauptmann, Ernst Pernicka, Thilo Rehren & Unsal Yalgin (Hrsg.), *The Beginnings of Metallurgy*, *Proceedings of the International Conference „The Beginnings of Metallurgy“, Bochum 1995.* Veröffentlichungen aus dem Deutschen Bergbau-Museum 84 (Bochum 1999) [Der Anschnitt, Beiheft 9], 103–105.

Shalev 1999

Sariel Shalev, *Recasting the Nahal Mishmar Hoard: Experimental archaeology and metallurgy.* In: Andreas Hauptmann, Ernst Pernicka, Thilo Rehren & Unsal Yalgin (Hrsg.), *The Beginnings of Metallurgy*, *Proceedings of the International Conference „The Beginnings of Metallurgy", Bochum 1995.* Veröffentlichungen aus dem Deutschen Bergbau-Museum 84 (Bochum 1999) [Der Anschnitt, Beiheft 9], 295–300.

Simon 1993

Klaus Simon, *Zum ältesten Erzbergbau in Ostthüringen und Sachsen, Argumente und Hypothesen.* In: Heiko Steuer & Ulrich Zimmermann (Hrsg.), *Montanarchäologie in Europa*, *Int. Koll. „Frühe Erzgewinnung und Verhüttung in Europa" in Freiburg i. Br. vom 4. bis 7. Oktober 1990.* Archäologie und Geschichte 4 (Sigmaringen 1993), 89–104.

Unumstößliche Beweise für örtlichen Erzbergbau aus urgeschichtlicher Zeit stehen auch in Ostthüringen und Sachsen nach wie vor aus. Ein Großteil des benötigten Metalls dürfte – sei es als Rohstoff (Barren, Schrott), sei es als Fertigprodukt – zweifellos aus den klassischen Bergbauregionen des Südens sowie aus anderen Gegenden nach Mitteldeutschland gelangt sein. Indes erhärten neue Recherchen zunehmend die traditionelle Vorstellung von einer wesentlich bodenständig mitbestimmten Kupfer- und Bronzemetallurgie bereits während des älteren Metallzeitalters. Gestützt auf zahlreiche Erzvorkommen, wie sie die meisten Nachbargebiete vermissen lassen, bildete der mitteldeutsche und böhmische Raum offenbar eine eigene paläometallurgische Provinz. Gegenüber den karpatischen und alpinen Zentren merklich verzögert, fiel die Blüte des frühen Bergbaus nördlich der Mittelgebirgsschwelle allerdings anscheinend erst in die jüngere Bronze- und ältere Eisenzeit.

Maßgeblich für die Nutzung der nach heutigen Kriterien oft kaum bauwürdigen Lagerstätten war nicht ihre Ausdehnung, sondern ihre Zugänglichkeit (Nähe, Aufschluß). Günstige Zusammensetzung und ausreichende Ergiebigkeit der Erze im Ausgehenden können – bei aller Unterschiedlichkeit der Erzparagenese – allgemein vorausgesetzt werden. Einen besonderen Anreiz dürfte die Nachbarschaft von Kupfer- und Zinnerzen im Erzgebirge und im Vogtland geboten haben. Im engeren Rahmen deutet sich ein zeitliches Gefalle in der Nutzung der Vorkommen von den Altsiedelgebieten, deren Ressourcen bereits in der älteren Bronzezeit erschlossen (und erschöpft?) worden sind, entlang überregionaler Verkehrsbahnen in die Randzonen der Gebirge an. Als Bezugsorte kommen wiederholt nahegelegene Höhensiedlungen in Betracht, deren metallurgische Spezialisierung auch archäologisch faßbar ist. Dem etablierten Bergbau mit ortsfester Besiedlung gingen im Vogtland anscheinend Jahrhunderte sporadischer, am ehesten saisonaler Erzgewinnung voraus. Mit derartigen Betriebsformen, die kaum Spuren hinterlassen haben, ist vielleicht auch hinsichtlich der ausgedehnten Seifenzinnlagerstätten in den Hochlagen des Erzgebirges zu rechnen, wofür erste archäologische Argumente angeführt werden können. Die Ausbeutung der mitteldeutschen Buntmetallerze verfiel in der älteren Eisenzeit; unter anderen Voraussetzungen wurde sie erst im Mittelalter wieder aufgenommen. Die auf mancherlei Indizien und Deduktionen gegründeten Hypothesen bedürfen nun der Bestätigung und Vertiefung durch gezielte archäometallurgische Forschungen, wie sie neuerdings auch im Räume der deutschen Mittelgebirge mit Erfolg betrieben werden. Ansatzpunkte für derlei Vor-haben – teilweise schon vor Jahrzehnten gewonnen, jedoch bisher kaum beachtet – bieten sich im Hinblick auf die frühe Bronzemetallurgie gerade im sächsischen Erzgebirge und seinem weiten Umfeld in Hülle und Fülle.

Spindler 1971

Konrad Spindler, *Zur Herstellung der Zinnbronze in der frühen Metallurgie Europas.* Acta Praehistorica et Archaeologica **2** (1971), 199–253.

Bei der Diskussion der einzelnen Bearbeitungsräume haben sich zahlreiche Anhaltspunkte in Hinblick auf das Aufkommen und die Ausbreitung der Bronzetechnik ergeben, die es erlauben, ein Bild der Entwicklung der Zinnmetallurgie in Europa von den Anfängen bis an das Ende der Mittelbronzezeit zu zeichnen.

Es stellte sich heraus, daß man verschiedene Kupfer- resp. Bronzesorten anhand ihres Zinngehaltes unterscheiden kann:

1. Reines, zinnloses Kupfer.

2. Spuren von Zinn im Kupfer. Es gibt Kupfersorten, die gewisse Verunreinigungen mit Zinn aufweisen. Dabei handelt es sich ganz offenbar um Zinn, daß entweder aus dem Erz bestimmter Kupfersorten selbst stammt oder das durch Zuschläge in die Schmelze oder beim Legieren mit anderen Metallen, wie zum Beispiel Arsen, eingeschleppt wurde. Diese Gehalte konnten bei der Analyse meist nur mit SSpur"bestimmt werden und übersteigen in der Regel nicht den Wert 0,0641 %. Nur in wenigen Fällen wurden Verunreinigungen mit Zinn bis 0,126 % nachgewiesen, darüber kaum noch; ausnahmsweise wurde einmal der Wert 2,6 % festgestellt, der die höchste Verunreinigungsquote der Nitraer Arsenbronzen darstellt.

3. Bronzen. Beabsichtigt hergestellte Bronzen enthalten üblicherweise mehr als 2 % Zinn. Ich habe diese Legierungen in drei Klassen mit Gehalten von 2,01 bis 4,00 %, 4,01 bis 7,95 % und 8 und mehr Prozent eingeteilt. Die Beliebtheit dieser drei Legierungsklassen ist je nach dem Stand der Metallurgie und der Nähe zu den europäischen Zinnerzlagerstätten in den verschiedenen bronzeführenden Kulturen unterschiedlich.

4. Herablegierte Bronzen. Schwachlegierte Bronzen weisen Werte zwischen 0,126 und 4,00 % Sn auf. Solche Legierungen erscheinen meist bei Kulturen, die Zinnbronze zu verwenden beginnen. Vermutlich wurden von benachbarten Kulturen echte Bronzen eingehandelt und mit unlegiertem Kupfer gemischt, um soweit wie möglich die veredelnde Wirkung der Zinnbeigabe auszunützen. Bei bronzeführenden Kulturen können gelegentlich die "KupferBarren aus herablegierter Bronze bestehen. Wir erklärten solch Gehalte mit der Verwendung von Altmetall bei der Kupfererzverhüttung.

Tylecote 1991

R. F. Tylecote, *Early copper base alloys; natural or man-made.* In: Jean-Pierre Mohen & Christiane Éluère (Hrsg.), *Découverte du métal.* Millénaires 2 (Paris 1991), 213–221.

The purer native coppers are very malleable in the cold state and as expected the arsenical native coppers work harden at a higher rate.

Additions of 9 % As and 10 % Sn to molten native coppers give good castable alloys. Tin can be added to pure copper either as stannite or as cassiterite ; the former seems to be more efficient but les common.

Coppers with 2 % As or less are probably made from oxide copper ores with As as an impurity. Those with more than 4 % are almost certainly made by cosmelting copper and arsenic-containming minerals to molten copper.

In view of its tin resources it is not surprising that NW Europe made bronzes at the start of the EBA, while the Near East had to make do with Cu-As alloys until trade was able to rectify the situation.

Wainwright 1943

G. A. Wainwright, *Egyptian bronze-making.* Antiquity **17** (1943), 96–98.

This picture of the early 14th century B.C. shows the manufacture of bronze by the advanced method of mixing the metals themselves. It also shows that this step had been taken during the 200 years between 1580 and 1370 B.C. After this it only remained to learn the right proportions of the two metals in order to obtain the best results.

Weisgerber 1991

Gerd Weisgerber, *Die Suche nach dem altsumerischen Kupferland Makan.* Das Altertum **37** (1991), 76–90.

Yalçin 2005

Ünsal Yalçın, *Das Schiff von Uluburun, Welthandel vor 3000 Jahren, Führer durch die Ausstellung des Deutschen Bergbau-Museums Bochum vom 16. Oktober 2005 bis 16. Juli 2006.* (Bochum 2005).

Yener 2015

K. Aslıhan Yener et al., *New tin mines and production sites near Kültepe in Turkey, A third-millennium BC highland production model.* Antiquity **89** (2015), 596–612.

K. Aslıhan Yener, Fikri Kulakoğlu, Evren Yazgan, Ryoichi Kontani, Yuichi S. Hayakawa, Joseph W. Lehner, Gonca Dardeniz, Güzel Öztürk, Michael Johnson, Ergun Kaptan & Abdullah Hacar

An unexpected new source of tin was recently located at Hisarcik, in the foothills of the Mount Erciyes volcano in the Kayseri Plain, close to the Bronze Age town of Kültepe, ancient Kanesh and home to a colony of Assyrian traders. Volcanoes in Turkey have always been associated with obsidian sources but were not known to be a major source of heavy metals, much less tin. X-ray fluorescence analyses of the Hisarcik ores revealed the presence of minerals suitable for the production of complex copper alloys, and sufficient tin and arsenic content to produce tin-bronze. These findings revise our understanding of bronze production in Anatolia in the third millennium BC and demand a re-evaluation of Assyrian trade routes and the position of the Early Bronze Age societies of Anatolia within that network.

Keywords: Kültepe Kanesh | Bolkardağ | Kestel | Anatolia | Bronze Age | pXRF | tin | trade | networks

Zwicker 1991

U. Zwicker, *Natural copper-arsenic alloy and smelted arsenic bronzes in early metal production.* In: Jean-Pierre Mohen & Christiane Éluère (Hrsg.), *Découverte du métal.* Millénaires 2 (Paris 1991), 331–340.

There are not many dated slag and crucible samples from smelting processes which contain arsenic bronze, whilst many objects exist which consist of arsenic bronze. As the amount of slag produced from the smelting of oxide ore is very small and often in the form of powder there are not many pieces of slag left from these early smelting processes. From the few investigations done on samples of slag and on fragments of crucibles which contain droplets of arsenic bronze and therefore show that arsenic bronze was smelted or melted one can suppose that

the arsenic content of the objects cast from these crucibles varied to a high degree. This would be in good agreement with the variation of the arsenic content in most ores containing arsenic and also with the fact that in early hoards there is often a great variation of the arsenic content in the same type of objects. Even in the 2 kg of ore which was excavated from the neolithic settlement of Norsun Tepe more than 25 km from the nearest ore body almost pure copper could be produced from some ore particles as well as an alloy containing more than 10 % As. Probably it was well known in the early times of metallurgy that the castability of copper could be improved by the addition of arsenic in the form of pure arsenic or by the addition of ores or of speiss containing arsenic. As these additives were probably introduced into the copper in the form of powder they may have been lost by corrosion processes or were not detected during the excavation of early smelting places. This can be seen from the three layered ingot with matte on the top, speiss in the middle and copper alloy on the bottom, where the speiss showed the highest corrosion and oxidation rate during its more than 3,000 years contact with humid earth. As many smelting and alloying processes may have been used during the beginning of metallurgy it needs many careful excavations and investigations to discover the first production of arsenic bronze.