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References

Bartelheim 1996

Martin Bartelheim & Elke Niederschlag, *Bronzezeitliche Zinngewinnung im Erzgebirge?* Archäologie aktuell im Freistaat Sachsen **4** (1996), 61–66.

Berger 1980

Walter Berger, *Zur Charakterisierung des Brandverhaltens von Werkstoffen*. VFDB-Zeitschrift **1980**, ii, 45–47.

Moderne Chemiewerkstoffe sind im Gegensatz zu Naturstoffen meist chemisch sehr einheitlich aufgebaut. Entsprechend sind dann auch Verdampfung und Zersetzung auf enge Temperaturbereiche beschränkt. Die große Gefahr liegt nun darin, daß bei einer empirischen Prüfung ein solcher Temperaturbereich nicht erreicht wird und der Prüfbefund entsprechend günstig ausfällt. Wird dann im tatsächlichen Brandgeschehen der kritische Temperaturbereich überschritten, so kann es zu plötzlicher Verdampfung oder Zersetzung mit explosionsartiger Verbrennung und Bildung von gefährlichen Stichflammen kommen, die das Brandgeschehen außerordentlich stark beschleunigen und die Löscharbeiten und -mannschaften entsprechend gefährden.

Die mit empirischen Prüfmethoden erhaltenen Befunde und Gutachten über das Brandverhalten von Werkstoffen wurden bei tatsächlichen Großbränden bisher regelmäßig widerlegt. Und in unzähligen Gebäuden und anderen Objekten wurden aufgrund der Prüfbefunde falsche Materialien verwendet, die das Brandrisiko erhöhen.

Nicht brennbar ist ein Werkstoff nur dann, wenn er keine Bestandteile enthält, die exotherm mit Sauerstoff reagieren können. Begriffe wie "schwer entflammbar", "feuerhemmend", "selbstverlöschend" etc. gelten immer nur für begrenzte Temperaturbereiche, sie sind für die Charakterisierung des Brandverhaltens von Werkstoffen irreführend und sollten deshalb vermieden oder nur in Verbindung mit Temperaturangaben gebraucht werden.

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.

Chernykh 1994

Eugéne N. Chernykh, *L'ancienne production miniere et métallurgique et les catastrophes écologiques anthropogenes*, *Introduction au probleme*. Trabajos de Prehistoria **51** (1994), ii, 55–68.

Chernykh 1998

Evgenij N. Chernykh, *Ancient mining and metallurgy in Eastern Europe*, *Ecological problems*. 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), 129–133.

According to the practice of the 18th and 19th centuries for smelting and refinement of a ton of copper (of merchandise quality), it was necessary to burn for charcoal from 300 to 500 cubic metres of the best wood – the pine or the birch (Chernykh 1994). This calculation does not include the charcoal necessary for the metalworking (for example, alloying or making finished goods). The wood needed for mining as such (timbering, staircases and so on), and for constructing various devices, which needed the best timbers, is not included either.

Calculations exist which demonstrate, that in the territory of South Urals one hectare of forested area could produce up to 250–270 cubic metres of satisfactory wood for burning it into charcoal (under condition of continuous tree-felling). Consequently, smelting and chemical refining of a ton of copper demanded in fact 1,5–2 hectares of good-quality forest for tree-felling. The process of re-establishment of conditional forest lasts up to 60 years for a birch and up to 80 years for a pine. But very often the reforestation did not take place at all: conditional forests were replaced by unconditional ones, which could not be used for producing charcoal.

Clark 2007

Gregory Clark, *A Farewell to Alms*, *A brief economic history of the world*. Princeton Economic History of the Western World (Princeton 2007).

Why are some parts of the world so rich and others so poor? Why did the Industrial Revolution—and the unprecedented economic growth that came with it—occur in eighteenth-century England, and not at some other time, or in some other place? Why didn't industrialization make the whole world rich—and why did it make large parts of the world even poorer? In A Farewell to Alms, Gregory

Clark tackles these profound questions and suggests a new and provocative way in which culture—not exploitation, geography, or resources—explains the wealth, and the poverty, of nations.

Countering the prevailing theory that the Industrial Revolution was sparked by the sudden development of stable political, legal, and economic institutions in seventeenth-century Europe, Clark shows that such institutions existed long before industrialization. He argues instead that these institutions gradually led to deep cultural changes by encouraging people to abandon hunter-gatherer instincts—violence, impatience, and economy of effort—and adopt economic habits—hard work, rationality, and education.

The problem, Clark says, is that only societies that have long histories of settlement and security seem to develop the cultural characteristics and effective workforces that enable economic growth. For the many societies that have not enjoyed long periods of stability, industrialization has not been a blessing. Clark also dissects the notion, championed by Jared Diamond in Guns, Germs, and Steel, that natural endowments such as geography account for differences in the wealth of nations.

A brilliant and sobering challenge to the idea that poor societies can be economically developed through outside intervention, A Farewell to Alms may change the way global economic history is understood.

Cottrell 1955

Fred Cottrell, *Energy & Society*, *The relation between energy, social change, and economic development.* (Bloomington ²2009).

When first published in 1955, this book was among the first interpretive treatments of the connection between a society's energy conditions and evolution of its culture. The book begins with a basic discussion of the earliest forms of energy uses and evolves through a discussion of how the evolution of alternative energy converters has impacted the growth of civilization. Dr. Cottrell takes us from food gathering societies up through the beginning of the industrial revolution into the age of nuclear power. With each step of change, he discusses how society has changed and the impact these changes have had on economic, moral and social issues. Today, more than any time in history, the questions of energy sources, energy conversion, energy uses and energy distribution are among the greatest challenges faced by civilization. In this book, Dr. Cottrell does not give you answers or predictions but takes you through the thought processes necessary to overcome the multible barriers we face in moving into the future.

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.* Der Anschnitt, Beiheft 9 (Bochum 1999), 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.

Gordon 1992

Robert B. Gordon & David J. Killick, *The Metallurgy of the American Bloomery Process.* Archeomaterials **6** (1992), 141–167.

During the nineteenth century, Americans in New Jersey and the Adirondack region of New York brought the ancient bloomery process for the direct reduction of iron to a high state of technological development. Using this process, they were able to make iron as good as the best Swedish grades. Rich magnetite ore was used; low fuel consumption was achieved by preheating the air blast, and labor productivity was maximized by ore preparation and hearth design that speeded the reduction process. Magnetite grains were reduced to particles of sponge iron in the upper part of the hearth, fell with liquid slag, and agglomerated on rims of iron formed around pieces of charcoal to nucleate the bloom. The hearth was manipulated to form a pool of liquid slag on top of the bloom that served as a trap for descending sponge-iron particles. The iron in the bloom was often partially carburized by entrapped charcoal particles. Although dismissed by some historians as "primitive," the American bloomery process was a sophisticated adaptation of an ancient technology to local resources and economic conditions and was capable of producing grades of iron for special applications not easily made in other ways.

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.

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).

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Killick 1996

David Killick, *On Claims For "Advanced" Ironworking Technology in Precolonial Africa*. In: Peter R. Schmidt (Hrsg.), *The Culture and Technology of African Iron Production*. (Gainesville 1996), 247–266.

The central argument in both of these hypotheses is that African iron-smelting techniques differed significantly from those employed elsewhere in the Old World. This review has shown that this thesis is mistaken in the case of "direct steel production" in Africa and dubious at best in the claim for preheated blast. The case for an African direct steel process is negated by the fact that steel blooms have been reported from many other areas of the Old World and by historical and experimental evidence that the steel can be produced at will in most bloomery furnaces. The argument for preheated blast is severely weakened by evidence from experimental bloomery smelting in Europe that shows that comparable temperatures are attainable in furnaces that cannot possibly have employed preheated blast.

Even if both of these hypotheses are rejected, ample evidence remains of change in African bloomery iron smelting over the two and a half millennia of the African Iron Age. African ironworkers adapted the bloomery process to a wider variety of ores and invented a greater range of furnace designs than did bloomery ironworkers elsewhere in the Old World (Killick 1991b). There is therefore no lack of invention in African iron smelting; what requires explanation is the lack of growth in productivity of African iron technology over this span of time, during which the productivity of iron smelting in Europe grew by a factor of one thousand. Where specialist iron industries did emerge in later African history, as at Bassar, Togo (de Barros 1986), or on the Ndop Plain of Cameroon (Fowler 1990), increased productivity was obtained by changes in the social organization of production, not by technological innovations that greatly increased the amount of iron produced in a furnace in a given time. One of the tasks that lies ahead is to identify the reasons for the lack of growth in productivity in smelting technology. Were the barriers to increasing productivity social, or environmental, or both?

direct steel

Kunst 2001

Michael Kunst, *Die Kupferzeit der Iberischen Halbinsel*. In: Blech (Hrsg.), *Denkmäler der Frühzeit*. Hispania Antiqua (Mainz 2001), 67–100.

Leusch 2015

Verena Leusch, Barbara Armbruster, Ernst Pernicka & Vladimir Slavčev, *On the Invention of Gold Metallurgy, The Gold Objects from the Varna I Cemetery (Bulgaria)—Technological Consequence and Inventive Creativity.* Cambridge Archaeological Journal **25** (2015), 353–376.

This paper discusses the invention of gold metallurgy within the Southeast European Chalcolithic on the basis of newly investigated gold objects from the Varna I cemetery (4550–4450 cal. bc). Comprehensive analyses, including preceding gold finds, shed new light not only on the technical expertise of the so far earliest known fine metalworkers, but also on the general context and potential prerequisites in which the invention of gold metallurgymay be embedded. Here, these structural trajectories as well as the unprecedented inventions connected to this early gold working will be highlighted in order to contextualize the apparently sudden appearance and rapid development of this new craft.

van der Merwe 1980

Nikolaas Johannes van der Merwe, *Production of high carbon steel in the African Iron Age, The direct steel process.* In: R. E. Leakey & B. A. Ogot (Hrsg.), *Proceedings of the 8th Panafrican Congress of Prehistory and Quaternary Studies, Nairobi, September 1977.* (Nairobi 1980), 331–334.

The questions which arise naturally from the evidence presented are whether the direct steel process was invented and used in Africa exclusively, and when the invention took place. Regarding origins, no examples of direct steel materials are known from outside Africa. A possible example from Roman Britain (Bell 1912) shows variable microstructures and high-carbon areas in an iron bloom, but it would seem to be the result of welding together several pieces of bloom in a crucible, in the course of which carburization occurred in the welds. It is still possible, of course, that the direct steel method had a wider distribution than currently recognized, but no evidence for it exists at the moment. The antiquity of the direct steel process in Africa can only be guessed. The archaeological examples (admittedly few) date from the Later Iron Age and cover an area from Ethiopia to South Africa. Ethnographic examples are known from West Africa, Tanzania and Rhodesia. Both natural draught and forced draught furnaces are involved. The possibility that the method dates from the Early Iron Age cannot be excluded, although there is no evidence for it. It can be hypothesized with somewhat higher probability, on technological grounds, that the large, natural-draught furnaces of West and Central Africa were invented as a specialized adaptation to the direct steel process. These high-temperature furnaces date from the Late Iron Age, but this does not necessarily imply invention of the direct steel process during the second millenium AD. The answers to these questions will, no doubt, emerge as a result of metallographic and/or chemical investigations of iron specimens. For now, it will suffice to conclude that African metallurgists invented the only direct method for the production of steel known in metallurgical history.

Morris 2015

Ian Morris, *Foragers, farmers, and fossil fuels, How human values evolve.* University Center for Human Values Series (Princeton 2015).

Most people in the world today think democracy and gender equality are good, and that violence and wealth inequality are bad. But most people who lived during

the 10,000 years before the nineteenth century thought just the opposite. Drawing on archaeology, anthropology, biology, and history, Ian Morris, author of the best-selling Why the West Rules—for Now, explains why. The result is a compelling new argument about the evolution of human values, one that has far-reaching implications for how we understand the past—and for what might happen next.

Fundamental long-term changes in values, Morris argues, are driven by the most basic force of all: energy. Humans have found three main ways to get the energy they need—from foraging, farming, and fossil fuels. Each energy source sets strict limits on what kinds of societies can succeed, and each kind of society rewards specific values. In tiny forager bands, people who value equality but are ready to settle problems violently do better than those who aren't; in large farming societies, people who value hierarchy and are less willing to use violence do best; and in huge fossil-fuel societies, the pendulum has swung back toward equality but even further away from violence.

But if our fossil-fuel world favors democratic, open societies, the ongoing revolution in energy capture means that our most cherished values are very likely to turn out—at some point fairly soon—not to be useful any more.

Originating as the Tanner Lectures delivered at Princeton University, the book includes challenging responses by novelist Margaret Atwood, philosopher Christine Korsgaard, classicist Richard Seaford, and historian of China Jonathan Spence.

Moshage 1960

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

Muhly 1973

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** (1973), 111–122.

Park 2015

Jang-Sik Park & Susanne Reichert, *Technological tradition of the Mongol Empire as inferred from bloomery and cast iron objects excavated in Karakorum.* Journal of Archaeological Science **53** (2015), 49–60.

Iron objects from Karakorum, the former capital of the Mongol Empire, were metallographically examined. Most were forged out of bloomery iron, particularly those requiring superior functional properties. By contrast, approximately one third were made from cast iron, with carbon levels approximating either cast iron or ultrahigh carbon steel. The carbon concentration of the bloomery products was controlled either by a carburization treatment directed at the functional parts or by the welding of a pre-carburized steel plate to a low carbon body. By comparison, cast iron-based steelmaking was achieved by subjecting pieces of solid cast iron to a combined thermal and mechanical treatment aimed at accelerating decarburization. Some anonymous cast objects were circulated as a feedstock for this unique process, naturally taking the form of thin plates. Also, the cast products examined were contaminated with substantial amounts of sulfur and silicon, suggesting that they originated from liquid iron smelted at relatively high temperatures using fossil fuel instead of charcoal. Given these findings, it can be concluded that the Mongol Empire took advantage of an effective multi-faceted iron tradition, which combined bloomery-based and cast iron-based iron technologies. It is important to note, however, that the former still remained the key technological tradition dominating the local contemporary iron industry.

Keywords: Mongol Empire | Karakorum | Iron tradition | Bloomery iron | Cast iron | Steelmaking

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.

Rovira 1999

Salvador Rovira, *Una propuesta metodológica para el estudio de la metalurgia prehistórica, El caso de Gorny en la región de Kargaly (Orenburg, Rusia).* Trabajos de Prehistoria **56** (1999), ii, 85–113.

A Methodological Proposal to Study the Prehistorical Metallurgy: The Case of Gorny in the Kargaly Region (Orenburg, Russia)

Archaeological field-work realised at the site ofGorny (occupied from 1700 to 1400 BC) has furnished an important collection of materials related to metallurgical activities (ores, slags, by-products and copper objects). These have been analyzed by a variety of instrumental techniques (scanning electron microscopy, X-ray fluorescence spectroscopy and metallography). The results show that metallurgy was a primitive one that worked oxidised copper ores by a non-slagging smelting process. Cast objects were finished by cold hammering and, on some occasions, annealing.

A replication of the prehistoric technology has been achieved by means of on-site smelting experiments. Thus, economic variables such as the efficiency of copper recovery and charcoal consumption have been evaluated and, using them, theoretical models of copper production and its behavioural impact have been constructed.

Keywords: Metallurgy | Slags | Ores | Copper Bronze Age | Srubnaya Culture | Russia | Smelting experiments

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.

Rovira 2009

Salvador Rovira, Ignacio Montero-Ruiz & Martina Renzi, *Experimental co-smelting to copper-tin alloys.* In: Tobias L. Kienlin & Ben Roberts (Hrsg.), *Metals and Societies, Studies in honour of Barbara S. Ottaway.* Universitätsforschungen zur prähistorischen Archäologie 169 (Bonn 2009), 407–414.

Many aspects of prehistoric technologies for copper-tin alloy production are so far unknown to us and require further investigation. In particular, there is a shortage of archaeological slags that strongly contrasts with the frequent discovery of bronze objects. In this article we will briefly review the most important archaeological evidence concerning tin, as well as describe a successful experiment carried out to obtain bronze through a process of co-smelting copper and tin ores. We will also show the most relevant analytical data obtained during a lab study of the materials coming from this experiment. As we can gather from recent archaeometallurgical research, the technology that has been employed in the experiment is quite close to the one that a prehistoric metallurgist could have used. Thus, co-smelting is a process that we have to consider when talking about early bronze production.

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 Vorhaben – 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 co-smelting 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.