5. COPPER AND BRONZE: THE FAR-REACHING CONSEQUENCES OF METALLURGY

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Abstract: Historians and archaeologists have long viewed the discovery of the metals and the invention of metallurgy as a revolutionary step in the history of humanity. But metallurgy was more than a technical revolution; its invention in the Bronze Age was primarily a social revolution. This chapter introduces the technological innovations associated with smelting and casting, and the economic and social problems that came with the development of metallurgy. At the same time, the chapter highlights the role of trade and its connection to the rise of metallurgical, proto-industrial centers. The ensuing social and political complexity, disparities, and military conflict are a direct result of that connection and of the competition for resources inherent for metallurgy. Finally, the chapter points to the rise of a class of specialists in society, forerunners to modern engineers.

We can make tools, jewelry, toys, kitchenware, furniture, and almost any other item from metal. Useful though metals are, however, they are sometimes less than perfect for the jobs we need them to do. That is why most of the "metals" we use are not actually metals at all but alloys—metals combined with other substances to make them stronger, harder, lighter, or better in some other ways. Copper is good in some ways, but bronze is far better. Choosing copper as topic for this chapter is actually a way to introduce not the discovery of metals, but the invention of metallurgy. Understanding the social implications of introducing those new materials—alloys—is crucial for the engineers of the future, who will find ways of using and improving existing materials, or will come up with new ones. This chapter will therefore explore the consequences of metallurgy from a social and political perspective.

1. *The revolutionary role of metals and alloys*

The revolutionary aspect of discovering the properties of metals and, especially, alloys, has long been recognized. However, the idea that even the (pre)history of humanity could be divided into "ages" on the basis of the materials out of which humans made their tools and weapons is relatively new. It goes back to a Danish archaeologist named Christian Jürgensen Thomsen (1788-1865; Fig. 1).[1] He studied Greek and Latin in Paris, and was very fond of the Roman poet Lucretius (99-55 B.C.), the author of a philosophical poem entitled *De rerum natura* (On the Nature of Things). In that poem, Lucretius describes how the first tools that humans used were "hands, and nails, and teeth, and stones and branches torn from trees," before they discovered bronze and iron. With bronze, men "tilled the soil" and "roused the waves of war," before "the sword of iron came forth," and, as they despised "bronze sickle's curving blade," they began to "cleave the earth " with iron.[2] Inspired by Lucretius, Thomsen invented the so-called Three-Age System still used in prehistoric archaeology. That we still refer to one of those chronological divisions as Bronze Age underscores the significance of metallurgy for the history of humanity.

It is easy to overstate the importance of discovering metals and alloys. However, the invention and practice of metallurgy were not the most important developments, as Lucretius and Thomsen thought. On one hand, metallurgy remained in some parts of the world a secondary activity without any substantial cultural and social impact. On the other hand, the same techniques were used both in societies with low level of organization and in complex societies such as those in Mesopotamia and Egypt.

Figure 1. Christian Jürgensen Thomsen, the "inventor" of the Three-Age system, in which bronze and iron represent the "Metal Ages," the most advanced stages in the development of human technology. (Source: https://en.wikipedia.org/wiki/Christian_J%C3%BCrgensen_Thomsen#/media/File:Christian_J%C3%BCrgensen_Thomsen.jpg)

2. *Metallurgy and innovation*

Metallurgy consists of a series of complicated operations, from finding and extracting the ore to smelting and processing. Using metals considerably shortened the time necessary for the production of tools or weapons, and allowed for the mass production of identical or, at least, similar artifacts. However, a key component of metallurgy is mastering a great number of physical and chemical reactions and processes, as well as the precise sequence of operation and its timing, the *chaîne opératoire* mentioned in a different context in Chapter 3. That is why initially metals were used, the extraction and processing of which did not require too much of an intellectual and technological effort. There is a Bronze Age *before* the Iron Age, as Thomsen put it, because iron metallurgy is much more complicated and involves a lot more knowledge than bronze metallurgy.

In certain parts of the world, for various reasons the knowledge was lost at some moment in time and the technology for producing bronze had to be reintroduced at a later time. People with metalworking knowledge must have therefore moved around for metallurgy to spread. One way for that to happen involved specialists moving into new territories, thus gradually spreading their knowledge. Another was to have people learning the trade in one place, under the direction of specialists, and then moving to new territories or returning to their own communities with the skills to produce metal objects. Either way, the demand for copper preceded the actual movement of specialists or apprentices. However, both in the Far East (northeastern Thailand and China) and in the New World (Mexico, Peru), copper and bronze metallurgy was invented independently, without any contacts with the centers in the Near East and the Mediterranean region.

In short, metallurgy implies a long process of learning and professional specialization. Unlike pottery, for example, metallurgy cannot be done "on the side," at least not when the goal is to produce a large number of similar artifacts. In other words, someone involved, for example, in agriculture on a regular basis cannot do some metallurgy during his or her spare time. The learning process is long and complicated, and that requires time and dedication. That is the main reason for which metallurgy cannot spread as a diffusion of ideas from person to person, for metal working needs to be taught by a specialist to another person. Metallurgy implies not only the existence of specialists, but also a complex process of learning, which sets it apart from other technologies, the spread of which was simply based on diffusion.

3. *Copper and smelting*

Copper was fashioned into artifacts as early as the 7th millennium B.C. Some of the earliest artifacts—tubular beads and other dress accessories—are from Çatal Hüyük in Turkey (ca. 6,500 B.C.), the archaeological site most prominently featured in Chapter 2. There are good reasons to believe that the copper in those artifacts, much like those excavated at Ali Kosh (eastern Iran), was extracted from ore. A copper axe was found with the mummified body of a man who died in the Austrian Alps ca. 3,300-3,200 B.C. "Ötzi," as this extraordinary mummy came to be known, was a hunter, but possibly also a shaman, in which case the axe was not necessarily a tool, but an object used in rituals.[3] The earliest use of metal, therefore, had no economic role, as most metal artifacts were either dress accessories or objects of ritual use. Such artifacts were sometimes collected and deposited in the earliest hoards known to history, but none of them shows wear traces, a clear indication that their function was not utilitarian, but ritual. In other words, those artifacts were produced for storing a matter (metal) perceived to be rare and, therefore, precious.

Why would metal be regarded as rare and precious? The first worked copper was the native variety that was dug out at the surface (Fig. 2). Native copper (copper in its pure state, without impurities) is still available in such regions of the world as Australia, France, China, Namibia, and Iran, where it appears in the form of distorted masses or extremely distorted crystals. Native copper does not have impurities, so it can be worked out by hammering. The copper artifacts from Çatal Hüyük were hammered. However, repeated cold treatment can make copper implements brittle. Applying heat renders copper less brittle, an operation known as annealing, which initially served for the fashioning of durable cutting edges.

Figure 2. Native copper from Ray mine (Arizona). Copper sometimes appears as isometric cubic and octahedral crystals, but more often as irregular masses and fracture fillings. The specimen in the picture is only 5.25 cm long. (Source: https://upload.wikimedia.org/wikipedia/commons/thumb/9/91/Copper-21991.jpg/240px-Copper-21991.jpg)

The presence of impurities in the copper increases the durability and malleability of the metal. One of the most frequent impurities is arsenic, which is present in such ores as arsenopyrite, enargite, and especially tennantite. The latter seems to have been the basis for obtaining arsenical bronze through the ore reduction by means of roasting. As arsenic sublimes upon heating at atmospheric pressure, it was thus possible to obtain copper mixed with impurities without very complicated technologies. Indeed, some of the halberds (a particular kind of weapon combining a spear with a battle-axe) that archaeologists discovered in England and Ireland are made of copper mixed with large amounts of arsenic, and have rivets of pure (and therefore more malleable) metal. When the primary copper ores that contain arsenic are roasted, they turn into copper arsenate (olivenite). Further reduction of the copper arsenate by charcoal yields a copper-arsenic alloy (bronze). During roasting, however, a very large quantity (over 50 percent) of arsenic is lost as As_2O_3. Roasting may well be a relatively simple technology, but the production of copper-arsenic alloys is quite inefficient.

Copper ores are of two kinds: oxidized (malachite) and sulfide ores (peacock ore or fahlerz). The distribution of both kinds on the surface of the planet is very uneven. There are no sulfide ores in the Near East, one of the oldest centers for bronze metallurgy. On the other hand, the earliest evidence of copper mining refers to copper silicates and malachite. In order to extract copper from malachite, one needs to separate the metal from impurities or other elements. This was possible only through smelting, which thus gained an enormous importance in early metallurgy.

Key concepts: smelting

A form of extractive metallurgy, smelting is based on the idea of bringing the ore to a temperature sufficiently high for melting the metal. A reducing agent decomposes the ore, thus separating the other elements as gases or slag and leaving the metal base behind. The reducing agent most commonly used in the past was charcoal. The reducing environment consisted of an air-starved furnace, in which the incomplete combustion forced the oxygen atoms out of the raw metal. Copper smelting involves high temperatures and a reducing environment, two conditions that characterize pottery kilns. It is therefore possible that the process was discovered during experiments with firing pottery. In other words, playing with “cooking” copper ore, early potters may have discovered smelting, and in the process became the earliest metallurgists.

Smelting can be done either in a crucible or in a furnace—a single or multiple bowl-like feature over which a clay superstructure was built to contain the ore and the charcoal.

ACTIVITY: Watch a video explaining smelting in a pit:
https://www.youtube.com/watch?v=8uHc4Hirexc

Smelting in furnace first appeared in the Near East, specifically in the lands now within Israel and the Sinai Peninsula (Egypt) during the 5th millennium B.C. Probably the most famous of the earliest smelting sites is Timna, where the earliest evidence of smelting in furnace has been radiocarbon-dated to 4460-4240 B.C.[4] Smelting at Timna released impurities either as gas (CO_2) or as slag (primarily iron), which was tapped off, while the copper sank to the bottom of the furnace, where it was collected in the form of plane-convex ingots. In the Mediterranean region, however, pure copper was formed into ingots of a special form—the so-called "oxhide ingots"—probably in order to be transported at long distance (fig. 3).

Figure 3. Oxhide ingot from Zakros (Crete), now in the Heraklion Archaeological Museum (Greece). How would you explain the shape of this ingot? Can you think of any practical reasons for the long sides being curved? (Source: https://upload.wikimedia.org/wikipedia/commons/0/02/Copper_Ingot_Crete.jpg)

The earliest such ingots have been found in Hazor (northern Israel) and dated between the 17th and the 16th century B.C. Lead isotope analysis revealed that the copper in those ingots actually came from Cyprus, which implies regular and quite intensive commercial contacts between the Mediterranean island and northern Israel.[5] However, oxhide ingots appear as far to the north and to the northwest as Bulgaria and Germany, and they also appear in Egyptian wall paintings.[6] The trade connections made possible by the need to procure good copper for metallurgy seems therefore to have extended very far in a relatively short period of time.

4. *Metallurgy, alloys, and trade*

Because pure copper is soft, the idea of adding other minerals may have come from the production of copper-arsenic alloys. The addition of other metals is useful, because it reduces the temperature at which copper melts, while at the same time increasing the hardness of the finished metal. Copper melts at 1981° F, which implies the use of an enclosed furnace and of forced draught. By adding only 10 percent tin to the alloy (bronze), the temperature drops at 1832 ° F, which still requires a furnace, but not forced draught. On the Brinell scale of hardness, the value of pure copper varies between 50 (for cast copper) and 110 (for copper worked by means of cold treatment). The addition of 10 percent tin increases the hardness to a value ranging from 70 (cast) to 230 (when the copper is fully cold-worked). Beginning with the 16th century B.C., therefore, alloys produced in Transcaucasia mixed tin with copper, as demonstrated by the metallographic analysis of artifacts found in Stepanakart (Azerbaijan), Sengavit (Armenia), and Mekegni (Daghestan). The metallographic analysis showed that the particular choice of ingredients for the alloy was not just a matter of available materials, but also a component of careful planning, since specific artifacts required specific alloys.

Tin came from tin ore (tinstone or cassiterite), which has an even more uneven distribution on planet Earth. Tin for prehistoric bronzes came from Sardinia, Brittany (France), Cornwall (England), Iran, or Bohemia. There is no tin in the Near East or the Eastern Mediterranean, despite the fact that some of the earliest centers of metallurgy were located there. No surprise, therefore, that by 800 B.C. tin appears in lists of commodities as a precious metal, along with such luxuries as gold, silver, iron, elephant hides, ivory, and purple-died cloth.[7] The rarity of tin, as well its importance for some of the hardest and most durable copper-alloys explain why the development of metallurgy encouraged the development of long-distance exchanges and of trade. There was long-distance trade already in the Neolithic, whether with lithic materials (such as obsidian, mentioned in chapter 3) or with amber. However, both the density and the intensity of commercial exchanges increased considerably during the Bronze Age, which led to the establishment of "fixed routes" along which goods were moved from northern to southern Europe, and from there to the Near East and beyond. The exchange of goods encouraged the exchange of ideas, technologies, and ornamental patterns. Bronze-Age human communities, at least in the Old World, were much more inter-connected than ever before. Moreover, the exceptional position of some communities, either close to raw materials or strategically positioned at the crossroads of important trade routes, led to unprecedented levels of economic prosperity, as well as aggression. For example, with no tin resources in the vicinity, the archaeological sites attributed to the

Únětice culture in Central Europe (2300-1600 B.C.) have produced an abundance of bronze artifacts, some of which are ingots, an indication that bronze moved up and down along the trade routes from the Baltic to the Aegean Seas in both raw and manufactured form. Moreover, Únětice sites have also produced evidence of contacts with the British Isles, the main source of the tin that went into the alloy produced on sites in Europe and the Near East (Fig. 4).

Figure 4. The Nebra Sky Disk, a bronze disc of about 30 cm in diameter with representations of the moon, the sun, and the stars. The disc was found in 1999 in Saxony Anhalt, Germany, and is attributed to the Únětice culture (Early Bronze Age, ca. 1600 BC). The analysis of trace elements by x-ray fluorescence has revealed that the copper in the alloy originated in Austria and the gold in Transylvania. The tin may well have come from Cornwall. The Nebra Sky Disk is therefore a unique illustration of the astronomical knowledge of the prehistoric inhabitants of Central Europe, as well as an excellent example of the connections between bronze metallurgy and trade. (Source: https://upload.wikimedia.org/wikipedia/commons/7/7b/Nebra_Scheibe.jpg)

While copper and tin moved in one direction, other goods came from the opposite direction (Fig. 5). For example, originating from the southern coast of the Baltic Sea, amber is found on many sites in the Near East and Transcaucasia in the form of beads, pendants, or even cups.[8] Many gold artifacts found on Mycenaean sites in Greece are made of metal from Transylvania, while the silver axes from hoards discovered in Romania have a decoration most typical for Mycenaean weapons.[9]

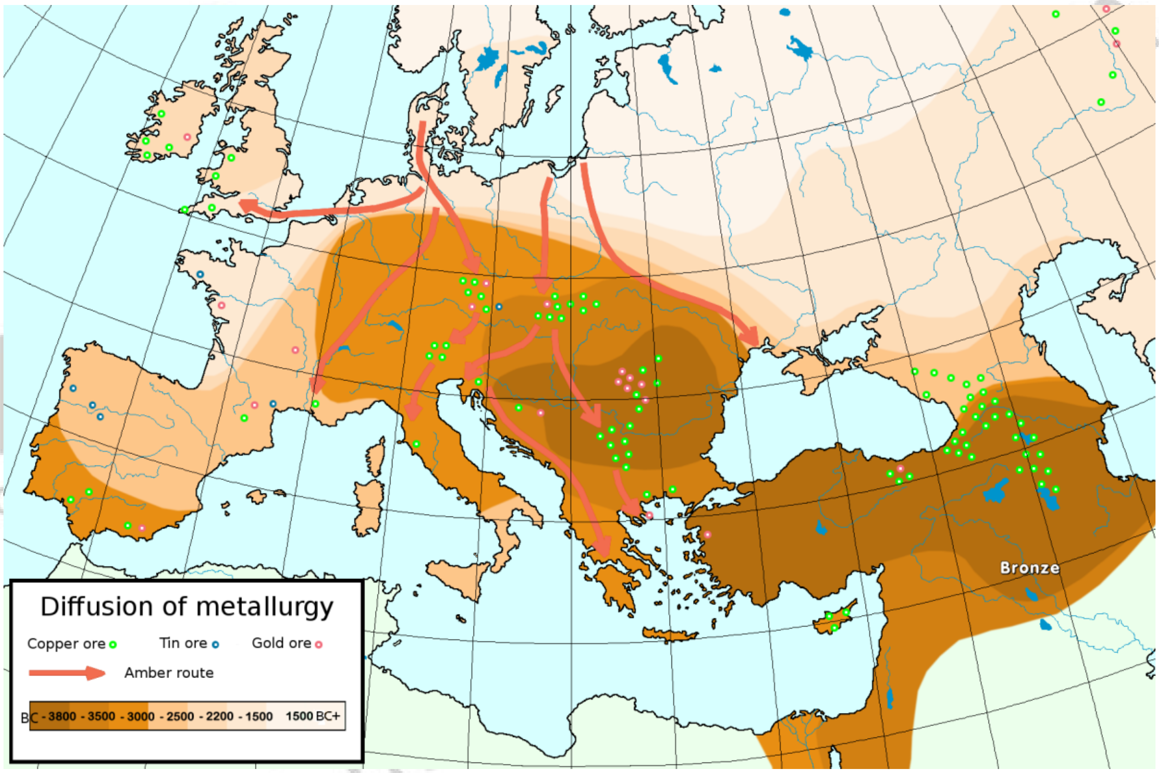

Figure 5. The connection between the diffusion of the bronze metallurgy and the development of trade routes is evidence on this map showing the diffusion of metallurgy from 3800 to 1500 B.C. (Source: https://upload.wikimedia.org/wikipedia/commons/f/fb/Metallurgical_diffusion.png)

In the Mediterranean region, long-distance trade is also documented by means of copper and tin ingots from some of the earliest shipwrecks that underwater archaeologists have discovered. A ship went down before 1300 B.C. at Uluburun, off the south coast of Turkey, together with a cargo of copper and tin, as well as other rare goods, such as cedar and ebony wood, terebinth resin, elephant tusks, tortoise shells, and ostrich eggshells. There were no less than 354 oxhide ingots on the ship, some of which were marked by incision, most likely upon receipt or export, and probably as a warranty of their quality for export.[10] The lead isotope analysis of oxhide copper ingots found in Sardinia—an island with clear evidence of copper smelting in the Bronze Age—showed that they had originated in Cyprus.[11] The invention of metallurgy thus put a high premium on metals and spurred the development of long-distance trade in response to a high demand in the emerging centers of metallurgical production.

4. Metallurgy and social-political complexity

The movement of metals in the form of ingots along the long-distance trade routes led to the rise of metallurgical centers in regions otherwise devoid of any local resources. Some of the most intriguing sites with abundant evidence of bronze metallurgy appear in areas with no copper or tin ores. For example, Hacınebi, in southeastern Turkey was a proto-industrial center specializing in the purification and casting of copper coming from the area farther to the north. The end products were then exported to the southern area of the Near East to be further processed there into local bronzes on the basis of imported tin. The excavations carried out in Hacınebi provided evidence for every aspect and each step of the smelting process, including slags, fragments of slag-accreted crucibles, clay molds, and smelting furnaces. There is even a fragment of tuyere (a tube through which air is blown into a furnace), the shape of which indicates that it was used at the end of a reed blowpipe, and not for actual bellows. In order for a temperature of 2192 °F to be maintained inside a furnace with an internal diameter of 25 cm, no less than three adults had to blow continuously into pipes such as that for which the Hacınebi tuyere may have been used. In other words, smelting was a labor-intensive operation and clearly required craft specialization.[12]

In fact, the archaeological evidence suggests that smelting was developed far beyond cottage production and involved the existence of specialized workshops. The scanning electron microscope examination of a slag-accreted crucible from Hacınebi has shown that sulfide ores were utilized for smelting. The copper ores in question came from at least 200 km (124 miles) to the northwest from the site. Metallurgy at Hacınebi required organization and planning, special trade deals with the northern neighbors to ensure a constant supply of ore, and with various neighbors to the south, to whom the copper produced on the site was then exported. Moreover, sites similar to Hacınebi were often fortified, and probably inhabited primarily by smelters who were brought there from somewhere else. This strongly suggests that proto-industrial centers such as Hacınebi could not have existed without some form of political organization guaranteeing the stability of the trade routes and the safety and security of the specialists residing within their walls. Elsewhere, fortified settlements seem to have operated as power centers. For example, Early Bronze Age Lerna (Greece) had a double ring of defense walls with gates and towers. Inside the fortification, there was a palace or administrative center in a central building that archaeologists called the “House of Tiles” (Fig. 6). Many proto-industrial centers were also power centers. The invention of metallurgy triggered a whole set of transformations in society, some of them with far-reaching consequences for such things as labor division and the rise of early states.

Figure 6. Lerna, stairs to the upper floor in the House of Tiles, which probably served as an administrative center inside the fortified site built there in the Early Bronze Age. (Source: https://upload.wikimedia.org/wikipedia/commons/c/c4/Lerna1.JPG)

There were also significant changes in the geopolitics of the Bronze Age. Our knowledge of Bronze-Age tools and weapons is primarily based on deposits (hoards, or caches of objects buried for safe-keeping). Some of the largest hoards have been found in Hungary and Transylvania (western and central Romania). Both regions lack tin, but throughout the Bronze Age witnessed the rise of some complex societies clearly geared towards war and conquest. By developing contacts with other societies located at a long distance (for example, Mycenae, in Greece), Bronze-Age communities in central Europe were able to procure the raw materials necessary for bronze metallurgy. They were also borrowing from the outside techniques for the metallurgy of both gold and silver, of which they had more abundant resources. As a matter of fact, the development of metallurgy in the Bronze Age involved not only copper, but also gold and silver, as well as lead.

With a relatively low melting point at 621 °F, lead is the easiest metal to process. It was first employed for making rivets to be used for repairing broken vessels, such as found at Phylakopi on the island of Melos and Chalandriani on the island of Syros, both in the Aegean. Lead ingots discovered on both sites indicate a local production of lead, as well as trade with lead in the same form and probably along the same routes as those used for copper and tin. Lead, instead of tin, was in fact used for a substitution alloy employed in the production of shaft-hole axes such as found in Belgium and Scandinavia. By contrast, the earliest artifacts made of gold—ring- or disc-shaped pendants—appear in the the 5th millennium B.C. on sites attributed to the Gumelniţa and Tiszapolgár cultures of Southeastern and East Central Europe, respectively (Fig. 7). The jewelry and pole decorations from the "Royal Tombs" at Alaca Hüyük (Turkey) are among the earliest silver artifacts known and have been dated to the 3rd millennium B.C. Clearly, the consequences of the invention of metallurgy most visible in the archaeological record involve the symbolic representation of power.

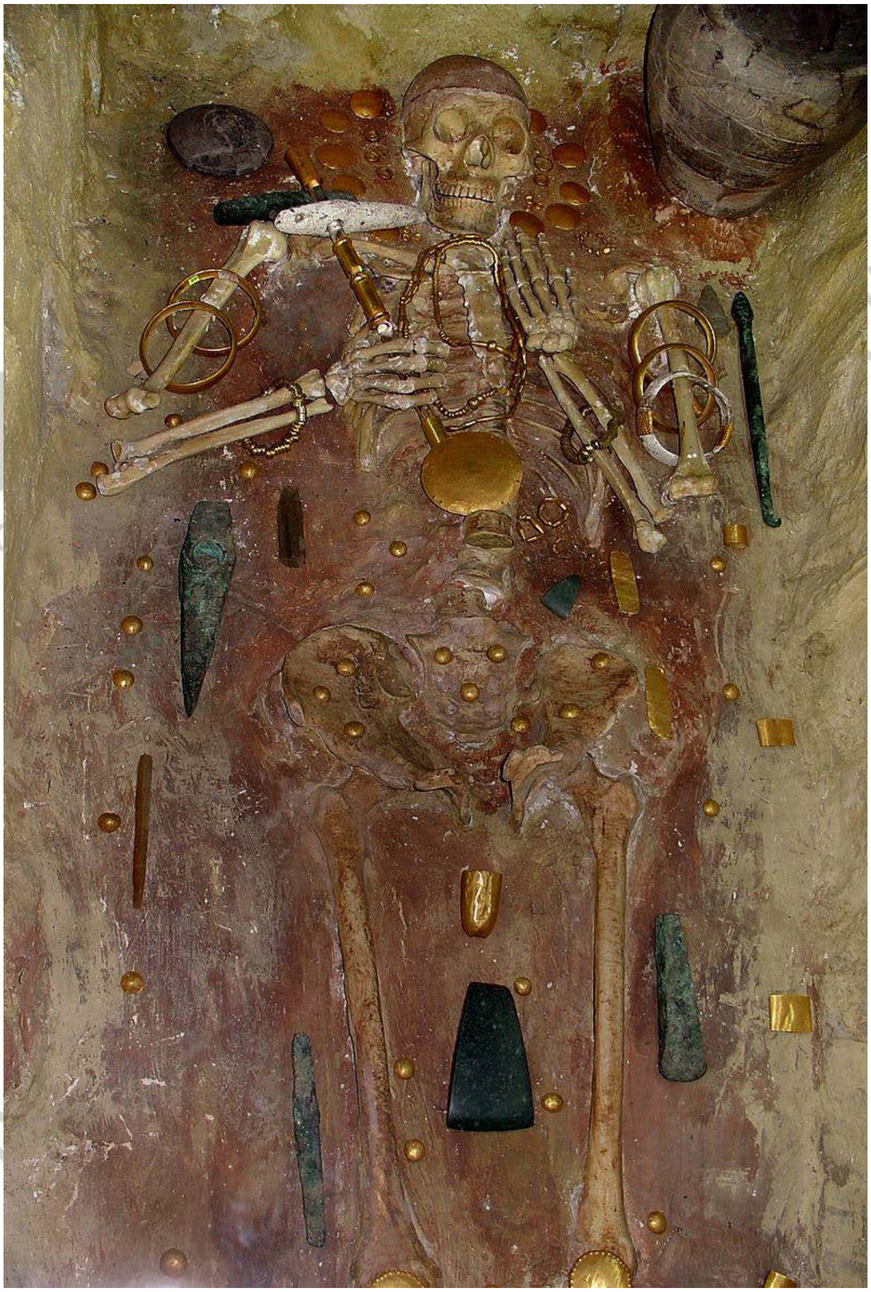

Figure 7. A high-status male burial from Varna (Bulgaria), dated to the 5th millennium B.C. The grave goods include both bronze (axes, but also spear heads), and gold artifacts (bracelets, beads, a scepter and a pectoral disc). Note the abundance of semi-spherical gold mounts probably adorning the shroud

that covered the body. (Source: https://upload.wikimedia.org/wikipedia/commons/9/9b/Or_de_Varna_-_N%C3%A9cropole.jpg)

5. The use of metallurgy: bronze artifacts

Unlike gold and silver, bronze was initially used for the production of daggers, axes, and swords. Throughout the Bronze Age, tools continued to be made out of stone. Only later did iron metallurgy put an end to the use of stone as raw material for tools. The first implements made of copper were daggers, probably for ritual, and not practical use. Such daggers have been found in Beycesultan and Alaca Hüyük, both in Turkey. The earliest axes were flat or adze-like (e.g., palstave), much like the axe found with Ötzi's mummy. Those were not very efficient tools, and some may have had only a special, probably ritual function. By contrast, the earliest functional axes were shaft-hole specimens discovered on sites of the Tiszapolgár and Gumelniţa cultures. Saws (first documented archaeologically at Los Millares, in Spain) and sickles appeared later, around 3000 B.C. and 1500 B.C., respectively. Except for harvesting tools such as sickles, there were no agricultural implements: the plowshare is an Iron-, not Bronze-Age invention.

The most impressive artifacts of the Bronze Age are the weapons. The dagger appears to be a Near Eastern, the sword a European invention. Bronze Age swords were made by casting, after which the edges were hammered. This type of weapon originated in the region around, and especially north of the Black Sea, probably as a further development of the dagger. The technology to produce blades is first documented archaeologically in the Aegean, where both copper-tin and copper-arsenic alloys were used to produce swords, ca. 1700 B.C. They were of course longer than daggers, with blades in excess of 100 cm. A great diversity of swords existed in the Middle Bronze Age (1500-1400 B.C.), some of which originated in the Mediterranean (Mycenaean Greece), others in the northwest (Ireland). One of the most important weapon types of the Bronze Age, and the longest-lasting sword of prehistory is the so-called Naue II type (named so after a German archaeologist who first described such swords in the late 19th century). Such swords produced in Europe were highly valued in the Near East, but were quickly replaced after 1200 B.C. with iron blades. While iron blades were also produced there, it was in China that bronze swords remained in use the longest, the latest being produced during the Han dynasty (3rd century B.C.-3rd century AD). An equally European origin may be attributed to the battle-axe, which makes its appearance around 1500 B.C., followed after two centuries or so by helmets, shields, and armor (Fig. 8).[13]

Figure 8. Bronze-Age helmets from Viksø, Denmark, now in the National Museum in Copenhagen. Each helmet is made up of two halves joined by riveting. The horns are riveted by means of fixed circular fixings. Despite popular misconceptions, those were not helmets used in actual fighting (and definitely not by Vikings, who came only 2,500 years later!), but most likely ceremonial helmets for various religious rituals. (Source: https://upload.wikimedia.org/wikipedia/commons/d/d4/Bronze_Age_Helmets,_Nationalmuseet_Copenhagen.jpg)

6. *Mold and "lost-wax" casting*

This relatively rapid development of artifact form and complexity would not have been possible without the parallel development of mold technology. Casting could be done in open one-piece molds carved onto the sides of stone blocks (sometimes even into the native rock). Molds composed of two identical halves were made first of stone, then of clay.

ACTIVITY: Watch a video about the casting a replica of a Bronze-Age axe in a soapstone mold: http://www.youtube.com/watch?v=yt0XJz3Sf_0

For intricate forms, or for producing parts of larger objects, a new technique was invented ca. 3000 B.C.—the "lost wax." The object to be cast was first modeled in wax around a small clay core. The wax "model" was then enclosed in clay and baked, a process during which the molten wax escaped through orifices purposefully left in the clay. By such means, a cavity appeared inside, which the molten metal could now fill. The artisan then plugged the "clay package." The baked clay was broken after the metal was set, and the cast object was removed.

Key concepts: "lost wax" casting

The "lost wax" technique allows for the casting of objects with complicated shapes. The details of that shape are initially rendered in wax, after which the negative space created by melting the wax is filled with molten bronze (1600° F). This technique also allows for the casting of larger objects, including bronze statues, several components of which could be cast in a sequence of "lost wax"-casting events. During the Renaissance (late 15th century A.D.), the indirect lost-wax technique was developed, which made it possible to make copies of statues. The surface of the statue was divided mentally into different parts, and covered in clay placed over the designated segmented areas, much like a jigsaw puzzle around a 3D. When the pieces hardened, the statue was removed, and the pieces reassembled and securely bound together. The empty space was filled with molten wax to create what is known as an "intermodel." After the latter was freed from the piece mold, wax rods (sprues) were attached perpendicular to the surface of the intermodel to serve as the vents for the evacuation of air and gasses during the casting process. Another layer of clay was placed over the intermodel and the whole structure was baked to melt the wax. The resulting mold was then filled with molten metal, as in the traditional "lost-wax" technique.

One of the first free-standing bronze statues since Antiquity, Donatello's *David* (1440s), now at the Bargello Museum in Florence, was cast in this manner. Bronze casting, however, is used not only by artists, but also to preserve original works of art. Leonardo da Vinci's horse (known as *Gran Cavallo*), for example, was part of an equestrian statue of the duke of Milan, Ludovico il Moro (1494-1499), but the artist never managed to finish the work. The statue was meant to be the largest equestrian monument in the world. Based on Leonardo's sketches, two full-size bronze casts were produced in 1998, one of which is now in Milan, the other in Grand Rapids. The indirect lost-wax technique led to a proliferation of copies, which in turn prompted the adoption of prohibitive laws. For example, in 1956, a French law limited the number of copies of each Rodin sculpture to 12—8 to be purchased by anyone, and 4 to be in the exclusive possession of cultural institutions.

The range of forms to be produced by various casting techniques increased enormously throughout the Bronze Age. Perhaps more importantly, the practice of using the same master object for the production of clay molds allowed for the production of sets of identical end products in bronze. Some forging may have followed the casting, in order to produce sharp edges (as in the case of swords and axes, but not always for sickles), thin blades (of daggers), or to bend items to required shape. For the production of such dress accessories as torcs (neck ornaments), bracelets, or composite rings, wiredrawing was practiced by pulling red-hot metal through draw bars. Thin sheet was produced by hammering metal bars onto an anvil. Both wiredrawing and thin sheet hammering were techniques employed primarily in gold and silver metallurgy. Another technique invented during the Bronze Age for the decoration of objects made of thin gold or silver sheet is the so-called *au repoussé*. With this technique, bosses, dots, rosettes and other motifs were produced by pushing the metal sheet into wooden forms. The technological innovations accompanying the invention of metallurgy thus created a vast field of artisanal expertise, and made room for a conceptual distinction between craft and art and between artisan and artist.

6. *The social implications of metallurgy*

Much evidence for Bronze Age metallurgy comes from the analysis of hoards, which are collections of weapons and tools—some in whole form, others broken—that were deposited in locations from which they were never retrieved for a wide variety of reasons. There are also hoards of gold artifacts, with a large array of spectacular objects, such as the bracelets, diadems, and gorgets from Villena in southern Spain (Fig. 9). Besides being an illustration of the parallel development of bronze and gold

Figure 9. The hoard of gold artifacts found in Villena (Spain). The hoard includes of 59 objects and weighs 10 kg, of which 9 consist of 23.5 –carat gold. The hoard dates from the late Bronze or early Iron Age, ca. 1000 B.C.. (Source: https://upload.wikimedia.org/wikipedia/commons/7/7a/Tesoro_de_Villena.jpg)

metallurgy—often with comparable techniques—the hoards testify to the concern with accumulating (and storing) wealth, which must have been a direct consequence of the social transformations triggered by the introduction of metallurgy. One of the most famous golden objects of the European Bronze Age, for example, is the mask found in 1876 in a cylindrical shaft grave inside the fortified settlement at Mycenae in southern Greece (Fig. 10). The mortuary use of this gold mask is not unique. In fact many gold and bronze objects (especially weapons) were deposited in graves. The northwest European equivalent of the rich burials in Mycenae is a number of large, circular barrows that appear in the Middle Bronze Age on sites of the Wessex culture in England. Early Bronze-Age barrows in Transcaucasia were often for individuals of high status, buried with a large collection of artifacts, including chariots with wooden wheels.

Figure 10. The gold death-mask from shaft grave V, grave circle A, in Mycenae. The mask was discovered in 1876 by Heinrich Schliemann, who believed the grave to have been that of Agamemnon. However, the mask is most likely from the second half of the 16th century B.C. and thus at least 200 hundred years older than the historical character believed to have been the model for the king of Mycenae known from the Homeric poems. (Source: https://upload.wikimedia.org/wikipedia/commons/c/c8/MaskOfAgamemnon.jpg)

In the eyes of many, the complicated technological procedures involved in smelting and casting must have turned the full-time specialists in bronze metallurgy into individuals with extraordinary powers. The civilizing hero of Greek mythology, Prometheus, was a metallurgist providing "divine knowledge" to humanity. In ancient Roman religion, Vulcan (the god from whose name the English word "volcano" ultimately derives) was said to have stared for hours at the fire, before discovering that, when making the fire hotter with bellows, certain stones sweated silver or gold. He later fashioned thrones for all gods of the Roman mythology. Thor, one of the main gods of the Norse mythology, is known for his hammer (Mjölnir), which was custom-made by the dwarves of Nidavellir, the quintessential blacksmiths of the North. Both in Antiquity and in traditional societies (such as those in East Africa, for example), smelters enjoyed a much more prestigious status than smiths.[14] The civilizing dimension of metallurgy was thus associated more often to smelting copper ore in a furnace than to casting object in molds. Part of the explanation for that may be that while the latter is a fairly clear process of turning molten metal into objects, the former looks more like magic as it turns "stones" into metal ingots.

7. Conclusion

Alloys are stronger and harder than their main metals, less malleable and ductile. The invention of metallurgy during the Bronze Age, which was primarily geared towards the production of alloys, had several crucial consequences. On a technological level, a series of new skills became at the same time necessary and commonplace. Such skills required long-term learning processes and apprenticeship, which transformed a group of people in society into specialists, and set apart their social position, both in lifetime and in death. A good parallel to that is the way in which nuclear energy is put to use in the modern world. It is simply not sufficient to create an infrastructure; a number of highly trained specialists are required as well. The modern use of nuclear technology offers another parallel to the early bronze metallurgy, perhaps not accidentally. The “civilian” use of that technology is often accompanied by its high premium placed for its military applications.

From an economic point of view, even though bronze was not used for the production of tools as much as iron would be during the Iron Age, raw materials (copper, tin, lead in the form of ingots) and finished products (weapons or tools made of bronze) became abundantly available. The early history of metallurgy also reveals the connections between technology and the rise and development of trade routes. Not only does knowledge still spread along trade routes, but there are still very good examples of industrial power-houses developing in regions of the world devoid of resources, much like in the Early Bronze Age. Perhaps more important from the point of view of this course is the fact that the introduction of metallurgy had social implications far beyond setting apart a class of specialists. The new artifact types made possible by metallurgy introduced the possibility of new scales of value and new ways to demonstrate social divisions. Accumulating objects made of bronze, gold, and silver was not only a way to store wealth. It was also a new way to set a group of people apart from the others, not as specialists, but socially distinct by means of economic privilege, in short, an elite. The social disparities created by the adoption of new technologies and their use for the display of power symbols and social status, such as illustrated by the archaeology of the Bronze Age, are still a matter of great concern in the 21st century. Future engineers have much to learn from the lessons of the past. The introduction of bronze—a new technology—called for an unprecedented development of long-distance trade. Mastering the new technology required time- and energy-consuming training of a class of specialists, which, for the first time in history, came to play a special role in society clearly marked ideologically by their association with magic. Metallurgy also opened new paths for the development of warfare and the symbolic representation of power. Similarly, we should expect any new materials to change the trade patterns around the globe, to create new social categories and inequality, and to have consequences in fields of human activity for which that may not have been designed in the first place.

Discussion questions:

1. During the Bronze Age, objects of bronze, gold, and silver produced by means of complicating techniques were hoarded as valuables. What counted more for their being regarded as such—the intrinsic value of the metal, or the labor involved in producing them? Explain your answer.
2. Silicon has a much wider distribution on the planet than either copper or tin, for it is the second most abundant element of the Earth's crust. However, there is currently a high demand on silicon primarily because of its use in the building materials (such as Portland cement), semiconductor industry, and solar panels. Can you think of anything similar to Hacınebi, the Únětice culture, or Uluburun that resulted from the worldwide trade with silicon, and the associated industries?
3. Are there any groups of specialists in 21st-century societies around the globe that are remotely similar to the smelters of the Bronze Age? If so, in what ways?

Glossary:

Alloy: a mixture of metals

Annealing: a heat treatment of the metal that alters its properties to increase ductility and reduce hardness

Ingot: a piece of metal cast into a shape suitable for further processing

Metallurgy: the technology of metals

Native copper: copper in its pure form

Proto-industrial center: prehistoric sites (often fortified) specializing in copper smelting and bronze casting

Smelting: a process by which a metal is obtained from ore through heating beyond the melting point in the presence either of oxidizing (air) or reducing agents (charcoal, coke).

Suggested readings:

Hanks, Bryan K. and Katheryn M. Linduff, eds., *Social Complexities in Prehistoric Eurasia. Monuments, Metals, and Mobility*. Cambridge/New York: Cambridge University Press, 2009.

Mei, Jianjun, and Thilo Rehren, eds., *Metallurgy and Civilisation. Eurasia and Beyond. Proceedings of the 6th International Conference on the Beginnings of the Use of Metals and Alloys (BUMA VI).* London: Archetype, 2009.

Pare, C. F. E., ed. *Metals Make the World Go Round. The Supply and Circulation of Metals in Bronze-Age Europe. Proceedings of a Conference Held at the University of Birmingham in June 1997*. Oxford: Oxbow, 2000.

Weeks, Lloyd R. *Early Metallurgy of the Persian Gulf. Technology, Trade, and the Bronze Age World*. Leiden/Boston: Brill, 2004.

Yener, K. Aslihan. *The Domestication of Metals. The Rise of Complex Metal Industries in Anatolia*. Leiden/Boston: Brill, 2000.

NOTES

[1] Bo Gräslund, "The background to C. J. Thomsen's Three Age System," in *Towards a History of Archaeology*, edited by Glyn Daniel (London: Thames & Hudson, 1981), pp. 45-50.

[2] Lucretius, *De rerum natura* V 1282-1292; English translation by Ronald Melville (Oxford: Oxford University Press, 1997), p. 173.

[3] Michel Carrier, "Ötzi: the mummy from the cold," *Arts and Cultures* 5 (2004), 47-59.

[4] Beno Rothenberg and Tim C. Shaw, "Chalcolithic and Early Bronze Age IV copper mining and smelting in the Timna Valley (Israel): excavations 1984 and 1990," in *Ancient Mining and Metallurgy in Southeast Europe. International Symposium, Donji Milanovac, May 20-26, 1990*, edited by Petar Petrović and Sladana Đurdekanović (Belgrade/Bor: Archaeological Institute/Museum of Mining and Metallurgy, 1995), pp. 281-294.

[5] Noël H. Gale, "Copper oxhide ingots and lead isotope provenancing," in *Metallurgy: Understanding How, Learning Why. Studies in Honor of James D. Muhly*, edited by Philip P. Betancourt and Susan C. Ferrence (Philadelphia: INSTAP Academic Press, 2011), pp. 213-220.

[6] Anthony Harding, "Oxhide ingots in the European north?" *Antiquity* 89 (2015), no. 343, 213-223.

[7] James D. Muhly, "Sources of tin and the beginnings of bronze metallurgy," *American Journal of Archaeology* 89 (1985), no. 2, 275-291.

[8] Anna J. Mukherjee *et al*., "The Qatna lion: scientific confirmation of Baltic amber in late Bronze Age Syria," *Antiquity* 82 (2008), 49-59.

[9] Anthony Harding, "Trade and exchange," in *The Oxford Handbook of the European Bronze Age*, edited by Harry Fokkens and Anthony Harding (Oxford: Oxford University Press, 2013), pp. 370-381, here 377.

[10] Andreas Hauptmann, Robert Maddin, and Michael Prange, "On the structure and composition of copper and tin ingots excavated from the shipwreck at Uluburun," *Bulletin of the American Schools of Oriental Research* 328 (2002), 1-30.

[11] Noël H. Gale, "Copper oxhide ingots: their origin and their places in the Bronze Age metal trade in the Mediterranean," in *Bronze Age Trade in the Mediterrranean. Papers Presented at the Conference Held at Rewley House, Oxford, in December 1989*, edited by Noël H. Gale (Jonsered: Paul Åströms förlag, 1991), pp. 197-239.

[12] Hadi Özbal, Annemie Adriaens, and Bryan Earl, "Hacınebi metal production and exchange," *Paléorient* 25 (1999), no. 1, 57-65.

[13] Marianne Mödlinger, "European Bronze-Age cuirasses. Aspects of chronology, typology, manufacture, and usage," *Jahrbuch des Römisch-Germanischen Zentralmuseums*, 59 (2012), 1-49.

[14] Duncan Miller, "Smelter and smith: Iron-Age metal fabrication technology in southern Africa," *Journal of Archaeological Science* 29 (2002), no. 10, 1083-1131.