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Input Shortages and the Lack of Sustainability of Bronze Production by the Únětice

Abstract

After a long period of prosperity, the Únětice (2300-1600 BC) – a central European Early Bronze Age culture –collapsed without obvious reason. Thus, the academic literature has favored multiple explanations but without providing much evidence of the latter. Our aim is to provide an empirically grounded explanation consistent with the features of this culture. We claim that the 1600 BC collapse could be the result of simultaneous shortages of two main inputs of the bronze production process, namely tin and fuel. Periodical tin shortages are possible because Únětician were using tin alluvial deposits. Moreover, the production of bronze requires huge quantities of wood and charcoal used as fuel, leading to deforestation. Evidence of deforestation around 1600 BC is provided.

Keywords: Únětice culture, Central Europe, collapse, Early Bronze Age, stream tin, metalworking, deforestation, fuel.

JEL Classification: N53, O1, Q32, Q4, Q53

Input Shortages and the Lack of Sustainability of Bronze Production by the Únětice

1. Introduction

Únětice (2300-1600 BC) is a well-known Central European culture of the Early Bronze Age (EBA) (Harding, 2000; Szeverény, 2004). The most widely used periodisation of Únětice culture consists of six phases (Moucha, 1963). The first four phases – proto, early, middle and pre-classical – form the early Únětice culture and the "classical and post-classical" the late. Únětician were present over a large area of Central Europe (Müller, 2012, p. 258), spanning from East Germany to South Poland – between the Harz mountains and the Warta river - and centered on the current German-Czech border, and therefore experienced considerable differences in local environmental and related conditions. The pattern of settlement closely follows natural geographical features, with northern and southern branches of the culture that can be roughly distinguished. They are separated from each other (by the highlands of the Thuringian forest, Erzgebirge and Sudeten mountains) and this created smaller settlement regions that to some extent develop on independent lines. It evolved from the Bell Beaker culture and originated in the territories of contemporary Bohemia. Ten local sub-groups can be distinguished in its classical phase.[1] Despite such diversity, all sub-groups shared some common features and it is thus possible to talk about a "culture". The latter is characterized by graves (flat graves and barrows, including the so-called "princely graves"), burials and funerary practice[2] (which are also indicative of great socio-economic inequality), potteries, settlements (especially fortified settlements). However its main feature is that Únětice people were the first bronze metalworkers in central Europe (Roberts et al., 2009). Numerous metal items – especially those made of bronze – have been found in graves, hoards and settlements, inside the Únětician territory (Jaeger et al., 2015) and also far beyond it, e.g. in Scandinavia.

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[1] Bohemia, Moravia, Slovakia (following the Nitra group), lower Austria, central Germany, lower Saxony, lower Lusatia, Silesia, greater Poland and Galicia.

[2] Burial rite displays strong uniformity; deceased were buried always in north-south alignment, with head facing east, and the body was lying in a "crouched" position.

An astonishing feature of this culture is its rapid evolution and its decline in a short period of time, resulting in its total disappearance. After 1600 BC, the Únětice culture seems simply to have vanished. The latter remains a mysterious collapse for which various – and complementary – explanations have been proposed in the academic literature. As for other social collapses of the past, most explanations are related to cultural factors (Drews, 1993) and their possible negative impact on the environment (Diamond, 2005).

Several Non-Exclusive Explanations of the Únětician Collapse

Some are related to the transformations of the Únětician socio-economic structure implied by the development of bronze production. For Svizzero (2015), the collapse can be the result of an economic crisis known in modern economic analysis as the "Dutch Disease", a term that broadly refers to the harmful consequences of large increases in a country's income, which in the present case should be the consequence of the boom in the bronze production sector. For Tisdell and Svizzero (2015), the collapse was most likely calamitous because as a result of its bronze production, Únětice's population was able to increase considerably and the elite were able to develop a lavish lifestyle. Neither of these could be maintained once the mining of tin became much less productive. It should be however noted that there are no evidence that the Únětice were significantly dependent on imported food supplies (obtained for instance in exchange of bronze items) to sustain their standard of living. Thus depopulation in this context was not the result of food shortages due to collapse in their long distance trade.

Changed trade routes are also a possible explanation of the collapse of the Únětice (De Navarro, 1925; Ekholm, 1980; Czebreszuk, 2007; Ernée, 2012; Jaeger and Gniezno, 2012).

Other explanations highlight the role of the environment as a cause and/or a marker of the collapse. For Tisdell and Svizzero (2016) the collapse is mainly due to human-induced deterioration in ecosystems since immigration in Únětice territory and population growth led to unsustainable agricultural development. Several publications (Bátora et al., 2012; Kneisel, 2012; Müller, 2012) have pointed to important correlations between the social collapse and environmental damages.

The Impacts of Bronze Production

In the present paper, we want to underpin the role of bronze production *per se* in the social collapse. First, bronze production affects the environment because the sources of the metals used can be exhausted after a while (Bouzek et al., 1989; Cathro, 2005) or become increasingly scarce.

Second, metalworking activities impact the regional vegetation in various ways. Local and regional agriculture is intensified in response to subsistence needs of the miners and ecosystems are therefore under pressure (Tisdell and Svizzero, 2016). There is a high demand for wood for different purposes (construction, mining), and especially for fuel (charcoal) required by the smelting process. This leads to deforestation, soil erosion and finally collapse, as exemplified, for instance, by consequences of the prehistoric exploitation of copper on the island of Cyprus (Constantinou, 1992). By the time the Bronze Age was well under way, wood was being consumed on a scale that could not possibly be sustained on a long-term basis. Indeed, mining, smelting, metal-working, ship-building, pottery-making, construction industries and the exploitation of salt brine all created massive demand for wood for fuel, and wood was used for almost all domestic fuel.

2. Bronze Production, the Hallmark of Únětice Culture

The Únětice culture is distinguished by its characteristic metal objects including ingots torcs, flat axes, flat triangular daggers, bracelets with spiral-ends, disk and paddled headed pins and curl rings which are distributed over a wide area of central Europe and beyond (Jaeger et al., 2015). Since bronze production is the hallmark of Únětice, the demise of the latter could be due to some problems associated with the sustainability of bronze production. Such production requires labour, metallurgical knowledge as well as access to metals ores and fuel. Let us turn to some of these requirements (metallurgical knowledge, copper sources) in order to assess what kind of troubles Únětician people might have encountered. The other requirements or inputs of the bronze production are considered in the subsequent sections, i.e. tin sources (sections 3 and 4) and fuel (sections 5 and 6).

Metallurgical Knowledge

Únětician people obtained knowledge about metallurgy either by cultural diffusion and/or by migration. Indeed they are located at the convergence of the two streams of migration and cultural influences. One was from southeast Europe (Carpathians and the Balkans), where the earliest artefacts made of native copper and copper minerals are known from the Early to the

Middle Neolithic (Kienlin, 2013, p. 416) and where the beginnings of the Bronze Age was around 3000 BC. The other influence was from western Europe, namely the Bell beaker which was initiated in Iberia (Merkl, 2010). Indeed, the re-emergence of metallurgy in Central Europe is linked to various regional groups of the Corded Ware and Bell Beaker cultures that were later replaced by Únětice.

Copper Sources

Bronze is an alloy obtained by the small addition of any various metals (arsenic, tin,…) to copper. Copper ores are present in the Erzgebirge and this favors the assumption of the exploitation of local ores in the Early Bronze Age. However there seems to be "*no evidence for prehistoric mining in the Erzgebirge, but the Rammelsberg deposit in the Harz Mountains might have supplied some of the copper,*" (Niederschlag et al., 2003, p. 61). Lutz and Pernicka (2013, p. 125) have confirmed such result in their study of the prehistoric copper sources of the Eastern Alps. Indeed, they have found an excellent match between all objects of the Nebra hoard and the Sky Disk of Nebra and trace elements (lead isotope ratios) in ores and prehistoric slags from the Mitterberg district.

This is not a surprising result. Indeed, even for copper objects found in Central Europe and dating from the late Neolithic-Eneolithic, copper smelting has never been unequivocally documented, even though in southeastern Europe this was the period of a flourishing copper metallurgy, with copper mining attested to at Rudna Glava in Serbia and at Ai Bunar in Bulgaria (Höppner et al., 2005). However, the Harz mountains are located on the northwestern border of the territory associated with the Únětice culture, while the Erzgebirge mountains are centrally located in this territory (Niederschlag et al., 2003, Fig.1, p. 63). In other words, copper ores used by Únětician were imported but not on a long distance. Unworked copper (e.g. ingots) may have been imported by some Únětice settlements for which the importers exchanged amber, knitted goods and even finished bronzes.

3. Academic Debates about Tin and Bronze and their Implications for Únětice

As for any major innovation able to provide a 'revolution' (e.g. the cultivation of crops and animal domestication), bronze production is at the center of debates among scholars. These debates – which have been fostered by the recent progress of archeo-metallurgy - are mainly about the introduction and the spread of bronze production. Concerning the former, until recently it was widely agreed that the earliest tin bronze artefacts in Eurasia had appeared in the Near East in the early third millennium BC. However, recent excavations in Serbia (at Vinca culture site) extend the record of bronze-making by 1500 years, and challenge the conventional narrative of Eurasian metallurgical development (Radivojevic et al., 2013). Concerning the latter, the spread of bronze making, two main theories are present: the diffusionist theory (which assumes the existence of a single homeland for metallurgy, usually located in lowland regions of the Near East) and the localizationist theory (which assumes that the emergence of metallurgy in various locations is the simple continuation of the working of native copper). This matter is still being debated in the academic literature, as exemplified by Thornton et al. (2010) rebuttal of Amzallag's publication (2009) about the distinctive role of crucible and furnace.

Two of the numerous debates pertaining to bronze production are particularly relevant in order to understand the fate of the Únětice culture. Let us turn to each of these two debates.

The Origin of Tin Ores: Imported vs Local?

Since the production of bronze requires tin and tin deposits are very rare compared to copper, tin was a strategic raw material of the Bronze Age. Therefore, there is a long tradition of debates in the academic literature about the geographical origins of tin. Indeed, while bronze first appeared in the Near East (from Mesopotamia to Egypt), this region (which consists of plains) has no (obvious and major) source of tin. Thereby, the prevailing thought was that Afghanistan or central Asia were the only sources available to the ancient Near East even during the earlier formative third millennium BC. It is only during the late 1980s that excavations and archaeo-metallurgical investigations yielded the solution of a major enigma puzzling scholars for decades: tin mines were present in the central Taurus mountains (Yener et al., 1989). Thus, a tin supply was located in a non-exotic location, Turkey, where the earliest tin bronzes exist. Moreover this result also suggests that multiple tin sources could have been exploited in the Near East (even though their exploitation has left no or little archaeological evidence). It seems likely to us that a similar scenario is possible about tin sources in central Europe.

Indeed, there are opposing views about the sources of tin used in central Europe during the EBA (and onwards). Before we turn to these views, it is important to note that tin occurs in both primary deposits (which occur mainly within igneous intrusive rocks, such as granite) and secondary deposits or placers (which derive from the weathering and erosion of primary deposits). Cassiterite[3] is noteworthy in that its high specific gravity of 7.1 is comparable to that of metallic iron, and also because its hardness is comparable to that of quartz, so that it is highly resistant to abrasion and tends to concentrate in gravels and alluvial deposits (Darling, 2002, p 58). Some scholars consider that the tin deposits of the Erzgebirge were of a hard rock type, resulting not in the formation of alluvial or placer cassiterite but in seams of cassiterite buried in granite rock deep beneath the surface of the earth and thus not accessible to a BA prospector. Therefore, and according to this view, as expressed by Mulhy (1985, p 290), "*the history of Saxo-bohemian tin was a history of hard rock mining (…) to go back not earlier than the twelfth century A.C.*" Others, such as Dayton (1971), consider that the existence of alluvial tin was possible in central Europe and even that the streams of northern Bohemia may have carried them far from central Europe (e.g. to southeast Europe-Serbia; Durman, 1997). Despite the use of up-to-date investigation methods – such as the isotopic analysis of ores and metal objects – this debate is still present in the academic literature. On the one hand, and even though tin ores are present in the Erzgebirge, and as quoted by Earle et al. (2015), "*There are also tin ores in Central Europe in the Erzgebirge, but so far no evidence of BA exploitation exists (Haustein et al., 2010)*". Therefore, although they produced bronze items, the Únětician people did not develop tin mining during the EBA. On the other hand, however, they had access to local tin. As stated by Bouzek et al. (1989, p. 203) "…*many small sources of metals, both tin and copper, were exploited, the former metal by washing from the river and creek beds. Though these sources were more modest than the British and Spanish tin supply, they seem to have served the Bohemian and Saxon Bronze Age cultures well"*. A "solution" to this debate seems to have been provided by Childe's cautious comment (1929, p. 5), as quoted by Clark (1966, p. 195) who considered that tin in central Europe was "*not plentiful nor easily worked, but the weathered surfaces may once have contained alluvial 'pipes'now exhausted*".In other words, tin was not mined but most likely won from alluvial stream deposits carrying tin-oxide minerals (Niederschlag et al., 2003; Kienlin, 2013, p. 419). Indeed, cassiterite is easier to find than arsenic because it is durable, dense and hard. This may also help to explain the shift from arsenical copper to tin bronze. Cassiterite concentrates in stream channels (alluvial (placer) deposits) can be found with a gold pan (Cathro, 2005). Due to its much easier minability in prehistoric times, the use of this secondary deposit type was more common than mining on primary cassiterite veins (Haustein et al., 2010, p. 826).

[3] Cassiterite (SnO_2) is the more important tin ore, a naturally occurring oxide mineral which typically contains about 78,8% of tin.

The Development of Bronze Production: a Linear and Gradual Process?

When we talk about bronze, we usually - and implicitly - refer to tin bronze. However bronze can be produced with copper using alloys other than tin. Here again there are two different views about the development of bronze production according to the metal alloyed with copper. Until recently, it was commonly believed that the bronze production process was – from a chronological point of view – linear and gradual. Such "evolutionist" view implicitly refers to the relative chronology of the EBA introduced by Paul Reinecke (1924). In the latter, the subdivision of the EBA into two phases, A1 and A2, was explained with the growing ability to manage the new bronze technology. Almost all further chronological discussion has kept the view of a gradual development of the technology from bone and boar tusk pins to the first hammered metal objects consisting mostly of copper with hardly any tin in A1 up to perfectly alloyed bronze with 90% of copper and 10% of tin and refined casting techniques in A2. According to this view, the first bronze produced in virtually all Europe was an alloy of copper and arsenic. This seems to be logical since arsenic minerals are much more abundant than tin minerals. Furthermore, arsenic and copper minerals commonly occur together in sulphide deposits, and both weather to greenish oxide and carbonate minerals that can be difficult to distinguish (Cathro, 2005). It should be noted that ores of these metals other than tin (arsenic, antimony, zinc…) were present in Central Europe. Consequently, before 1800 BC Úněticians were not dependent on imports to get these metals. The gradual shift to tin bronze[4]-a copper alloy containing around 8 to 12% tin - was likely to occur because tin bronze has better "qualities" than bronze made from alloys with metals other than tin. In addition and due to arsenic toxic fumes, numerous smiths were dying when they produced arsenical copper.

According to Kienlin (2013, p. 420-421), in central Europe (Únětice), the move to tin bronze was a gradual process that only came to an end well into the second millennium B.C. (around 1800/1700 B.C.). So, from 2300 to 1800/1700 B.C., it is likely that Únětice people caste various alloys of copper with metals other than tin (arsenical copper, then fahlore copper). Therefore, and according to this evolutionist vision, it is only from 1800 BC that Únětician people would have used tin to make bronze.

[4] According to Merkl (2010, p. 20, footnote 4), "It has not been clarified whether there is a specific threshold marking the difference between naturally tin-bearing copper and copper deliberately alloyed by tin – so-called tin-bronze. Whilst before around 2000 BC copper artefacts generally do not contain more than around 4% tin, afterward copper artefacts contain significantly more than 4% tin."

However, such linear and gradual view has been recently challenged by authors who consider that there is no transition between the two EBA sub-periods, A1 and A2, but a complete overlap between the type objects of the two phases (Stockhammer et al., 2015). In other words, it is inaccurate to assume - as was done previously - that the watershed of Únětician bronze production was 1800 BC, with no tin bronze before that date and tin bronze after. This new view reinforces our conclusion since it implies that tin (i.e. placer tin) was used before 1800 BC and therefore its exhaustion is more likely to have occurred during the Únětician era.

4. Evidence and Consequences of Tin Crises

The above mentioned academic debates about tin and bronze lead us to highlight two conclusions. First, even though there is no archaeological record of mining during the central European BA, it is very likely that Únětician people were using local tin –and not imported – since they were able to exploit tin alluvial deposits of the central European mountains. Second, the traditional phases EBA1 and EBA2 do not represent a relevant chronological sequence in central Europe. Therefore, it is likely that Únětician people were producing various types of bronze from 2300 BC and onwards (i.e. long before the classical phase), including tin-bronze.

Both conclusions allow us to draw inferences about the demise of the Únětice culture. First, the mining of placer tin did not leave any trace of prehistoric activity in this region. Although Niederschlag et al. (2003, p. 96) consider such explanation as an "*unsatisfactory postulate*", it seems to us a reasonable conclusion if one accepts the idea that ancient placer mines could have been obliterated by subsequent mining (Cathro, 2005) or alluvial wash. Second, placer tin might have been exhausted "rapidly", i.e. after few centuries. This explanation is supported, for instance, by the words of Hoover and Hoover (1912[1950], footnote on p. 412), "*…we see no reason why alluvial tin may not have existed within easy reach and have become exhausted. How quickly such a source of metal supply can be forgotten and no evidence remain, is indicated by the seldom remembered alluvial gold supply from (Wicklow) Ireland.*"

Recycling, Cheating, Robbery and Hoarding: The Logical Consequences of Tin Crisis

Although we have until now talked about tin exhaustion, the complete exhaustion of tin sources is not a necessary condition for a tin crisis to occur. Indeed, a tin crisis may result of tin shortage – as an essential input of bronze production – i.e. of an excess of tin demand over its supply. What could be the logical consequences of such shortage? Let us turn to an analysis of human behavior on both sides of the bronze market.

On the supply-side, bronze producers may adopt one of the two following strategies. First they try to maintain the production of a high-quality tin bronze (i.e. with an 8-12% tin content). For such purpose, the only option[5] is to recycle[6] bronze items. Únětice is also well known to have re-smelted bronze products. Some of the hoards belonged to those who collected scrap metal for re-smelting. Such practice might be explained by the growing scarcity of metals – and especially of placer tin – as long as the demand of bronze products increased. The second strategy consists in the production of low-quality bronze products. Metallurgists begin doping metal, meaning they add minimal quantities of tin, or turn to natural copper only, simply they are cheating.

On the demand side, bronze objects were probably too expensive and therefore out of reach for commoners, i.e. they were restricted to the elite. When tin becomes scarcer, the price of bronze objects increased. As a result, some people would be tempted to obtain bronze items by illegal means such as robbery. Such robbery may be of graves (since Únětician were often buried with bronze artefacts) or houses containing bronze objects. Facing such threat, the owners of bronze objects would be motivated to secure their wealth and hoarding[7] is the logical outcome of such behavior.

For the elite, even though the price of bronze products increases as a result of the tin crisis, they however still want to own high-quality bronze products because the latter are the symbol of their social status. Únětician halberds, for instance - as associated with tribal elites and power - are always made according to higher standards. One solution for the elite could be therefore to extract – as a tax in kind or tribute[8] - an additional surplus consisting of bronze products in order to recycle them. Once again and in reaction to this 'legal collection' organized by the elite, some people may be tempted to hide the bronzes they own, providing another motive for the hoarding behavior.

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5 There is however another option – i.e. to import tin – that we explore further in the paper.

6 As documented by Karageorghis and Kassianidou (1999) for the Late Bronze Age in Cyprus.

7 Of course hoards are of various kinds (personal, collective) and hoarding is consistent with various purposes (votive hoard, founder hoard, trader hoard…); see for instance Childe (1930, Ch. 2). Thus, we simply highlight here what could be one of these purposes.

8 Even though we do not know how the Únětician elite managed to get their hands on an economic surplus.

Tin Crisis and the Fate of Únětice

Haustein et al. (2010, p. 830) have demonstrated that *"the tin-isotope ratio of the 'Himmelsscheibe von Nebra' will be presented: the value fits well with the bulk of investigated tin ores from Cornwall"*. Since this result has been published, one may infer that all tin used in Únětice was imported from Cornwall, which of course is not a relevant conclusion given, notably, the very long distance between Cornwall and Central Europe. However, Haustein et al. (2010) conclusion may reinforce our demonstration. Indeed, it is possible that, when Únětician people were confronted to placer tin shortages, they imported small quantities of tin from abroad. In other words, and as a complement of the suppliers' behaviors presented in the previous sub-section, imports are also a solution to overcoming a tin shortage.

Another important feature of the Nebra sky disk is that it was buried[9] around 1600 BC (Haustein et al., 2010, p. 830), i.e. at the period during which the Únětice started to vanish. In other words, the collapse of the Únětice culture could be (as least partly) the result of a tin crisis occurring around 1600 BC.

5. Fuel Used in the Metalworking Process

Ore Extraction and the Demand for Wood

Unlike tin or gold, copper does not occur in concentrated form in secondary drift or alluvial deposits. Thus, copper ore exploitation in prehistory was only possible in hard rock and was primarily accomplished by fire-setting which necessitated large amounts of burning wood. Wood could be used for the roasting process and for the mining technique of fire-setting, in which fire was used as a method to break up ore-bearing rock into manageable pieces. One way to quantify the potential demand for fuel wood is to run archaeological experiments. There are two main groups of factors that affect rock exploitation. First, factors that describe the morphology of the rock, e.g., chemical and mineral composition of the rock, grain size, thermal expansion ratio and internal structure. Second, factors that relate to the fire-setting application, e.g. characteristics of the fuel wood (green or seasoned wood, size, round or split wood, water content, and species), temperature, archaeological experience in the fire-setting technique, ventilation and construction of the wood stack.

[9] Its manufacture date remains however uncertain.

However, and assuming various rock-to-wood weight ratios, it seems that the demand of wood for fire-setting activities was limited and could be met by exploiting only local forests without the unsustainable harvesting of wood (see e.g. Pichler et al., 2013).

The Smelting Process and the Compulsory Use of Charcoal

While wood could be used for the roasting process[10] and for the mining, the smelting process of copper ores[11]required the use of charcoal as a fuel since no other fuel commonly used in ancient times would burn hot enough to smelt copper. Indeed, wood burns at a lower temperature than charcoal (it has half of charcoal's caloric value) so charcoal was a more efficient fuel for metallurgical activities and was necessary for the smelting process since separating the copper from the gangue was possible only by smelting, using furnaces that were able to reach at least 1,089 °C.

Charcoal production requires a significant expenditure of labor and wood. The latter needs to be cut and dried for up to several months, then used to construct a charcoal stack. Hardwoods were preferred for metallurgical uses because they contain more carbon and are stronger and more durable. Only about 10-20% of the wood used in a charcoal stack becomes charcoal, and large amounts of charcoal is required to make a significant amount of copper using ancient techniques (Craddock, 1995). In fact, different and subsequent ratios have to be considered in order to approximate the deforestation impact of the production of a given weight of metal. These ratios are: surface of forest/number of trees; number of trees/volume or weight of wood; weight of dried wood/weight of charcoal; weight of charcoal/weight of ores smelted; weight of ores smelted/weight of metal produced. Given the large number of these ratios on the one hand, and the large number of factors influencing these ratios on the other hand, the deforestation impact of bronze production can only be roughly approximated. While for mining, Pichler et al. (2013) derived a generalised rock-to-wood weight ratio with a range of approximately 0.7 to 1, according to Craddock (1995, p. 193) the smelting process required 122 kg of charcoal for 1 kg of copper. Since charcoal is about 10 to 20% of the dried wood used for its production, it is certain that forests were severely and negatively impacted by the procurement of the fuel needed for the smelting process. Suitable fuel supplies may even have been locally exhausted after few decades.

In addition to the previous conclusion, we have to remind ourselves that the Únětice were the first bronze-producers in central Europe. In other words, these people did not have a precise knowledge of the various factors influencing the smelting process, such as the measure of the

[10] Roasting consisted of calcinating the ore by lighting fires on ore collected in piles in open areas.
[11] Since cassiterite, the dominant tin ore, melts at only 600 degrees Celsius.

temperature into the furnace, the chemical composition of ores, the involuntary presence of fluxes (…). Puziewicz et al. (2015) provide XRF analysis of Únětice culture ornaments. They confirm the chemical variation of their composition and their typically dendritic metal microstructure which suggests rather poor control of the smelting and solidification process (compared to bronze artefacts of the subsequent Urnfield culture). In other words, Úněticians who were learning how to produce bronze alloys through a trial-and-error process, were probably consuming much more fuel than modern archaeological experiments of the ancient smelting process suggest.

6. Deforestation and Shortages of Suitable Fuel

Fuel procurement and use in metallurgical activities would obviously have a major environmental impact on metal-producing regions, including deforestation, soil erosion, and the destruction of habitats for many plant and animal species.

Metal Production and Deforestation

Such long-term damage[12] to the natural environment is, for instance, clearly documented for the island of Cyprus.[13] Constantinou (1992) estimates that the island of Cyprus must have been deforested up to sixteen times in a 3,500 year period in order to produce the charcoal required to make the estimated four million tons of ancient slag known on the island. Similarly it is suspected that the decline of Çatal Höyük (6500 BC; modern Turkey) – where metalworking was marginal - is probably related to deforestation since the almost universal use of pottery and pottery kilns, plaster and terrazzo, would have had a significant negative impact on local woods and forests. The great silver mines of Laurion, near Athens, seem to have encountered the same difficulty. Wertime (1982) estimated on the basis of 3500 tons of silver and 1.4 million tons of lead production for classical Athens over perhaps 300 years, that the Laurion mines had consumed 1 million tons of charcoal and 2.5 million acres of forest. More generally, the role of deforestation as a contributor to social collapse is even more likely to have occurred in the Levant[14] and the drier Mediterranean countries than in Central Europe.

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[12] It was also reinforced by grazing, particularly by goats.

[13] The name ‘copper’ for the metal in all Western European languages is derived from the Latin *aes cyprium* which means "Cypriot copper."

[14] In the Epic of Gilgamesh, the earliest epic poetry that has survived, Gilgamesh (a Sumerian, king of Uruk around 2700-2500 BC) and his companion go off to cut down a cedar forest, braving the wrath of the forest god Humbaba, who has been entrusted with forest conservation. This led to the loss of Gilgamesh's immortality which may be a literary reflection of the realization that Sumeria could not be sustained owing to deforestation and the shortage of wood.

In the former areas, forests were less dense than in Europe and mining led to an irreversible change in the vegetation and landscape.

The Multiple Causes of Deforestation

Of course deforestation occurred before the production of metals, i.e. from the Neolithic period onwards. Usually the landscape was opened by (fire) clearance to establish space for agriculture and livestock farming. By using pollen analysis, when a major alteration of the vegetation occurs, trees values decrease dramatically whilst grasses (*Poaceae*), pasture, and cultural indicators, as well as the values of local microcharcoal, begin to rise. This pattern in the pollen diagram shows a more open landscape and reflects large-scale forest clearance. In addition the Neolithic package also contains pottery, which is another user of pyrotechnology and thus another contributor to deforestation. Salt production is also clearly documented in Central Europe since the Early Neolithic and the most common procedure of salt winning was brine evaporation, which also requires large quantities of wood for the boiling pans (Saile, 2012). In addition to these multiple causes, the deforestation process was reinforced by the production of metal, indirectly through the establishment of the farmstead which reflected the expansion of settlement activities in the mining area, and directly, as previously explained, through the use of wood and charcoal as fuel sources of the metal along the *chaîne opératoire*. It is thus likely that in the vicinity of ore mining beech trees were probably felled over a wide area because fire from beech charcoal was needed to work metals.

Deforestation and the Fate of Únětice

For the Únětice, deforestation around 1600 BC is attested by the distribution of the pollen profiles (Kneisel, 2012, p. 227; Müller, 2012). It is therefore quite likely that the bronze production declined because the fuel costs had risen to the point where this production had become uneconomic. Reduced availability of supplies of suitable fuel for extracting tin and copper from gangue and so on near the source of mining ores may have eventually resulted in short supply of tin and copper. This would have impeded economic production. When fuel became scarce in the vicinity of mining areas, 'virgin' tin and copper ores would have had to be transported to places where fuel was available or fuel would have to be carted to the area of mining of the ores. This would have added considerably to costs.

Besides deforestation, the production of bronze has also impacted the environment throughout heavy metal emissions, which originate from ore extraction and particularly from smelting activities. Indeed, the activity of mining and refining metals, especially as it was performed by ancient prehistoric cultures, would tend to put significant amounts of undesirable heavy metals, especially arsenic, into the environment. As exemplified, for instance, by the decline of Etruscan civilization, heavy metals poisoning in areas of metallurgical activity was responsible for or contribute to the abandonment of these sites (Harrison et al., 2010).

For the Únětice, it is thus very likely that people were contaminated by metal pollution. Indeed, evidence shows metal technology in the settlements, where furnaces have also been found in the habitation area. This suggests heavy metal contamination as an additional stimulus to the noted phenomenon of the peaceful abandonment of settlements at the turn of the EBA to the MBA.

However, heavy metal pollution cannot be considered as a major cause of the Únětice collapse. Indeed, although ore-processing procedures release metals (e.g., lead, copper, arsenic, antimony) into the environment, their presence in Bohemian forest lakes during the BA is not significant (Vesely, 2000). Moreover, the Tumulus culture (Hügelgräberkultur) dominated Central Europe during the Middle Bronze Age (1600-1200 BC) and was the descendant of the Únětice culture. In other words, the hiatus between these two cultures – i.e. the lack of archaeological records such as settlements, potteries (…) - is only about 100 to 200 years. It is therefore too short to be the result of heavy metal pollution which usually has longer negative impacts on the environment. However it fits well with the negative impacts of deforestation since after 50-80 years a deforested region can be naturally reforested given the continental climate of central Europe.

7. Conclusion

After 700 years of existence, the Únětice culture suddenly disappeared. Such an event is intriguing for two reasons. First, the Únětice experienced considerable economic prosperity. Indeed, their economy was mainly based on the Neolithic package typical of central Europe, i.e. by a diversified agriculture - including the cultivation of several cereals and pulses - and animal husbandry - mainly cattle and pigs. Moreover, the Únětice had a pottery industry and were involved in a long-distance trade network, from Northern to Southern Europe, in which mainly luxury goods (e.g. amber, furs, gold...) were exchanged. More than anything, the Únětice were the first bronze producers of central Europe, an activity providing wealth and power to its elite as well as labor for some of its population.

Second, and despite this, this culture suddenly disappeared without obvious reasons. Indeed, no archaeological evidence has been found which are consistent with some of the usual explanations of social collapses, such as war, disease or natural disaster. Moreover, a few decades after its disappearance, new cultures - the Tumulus culture on the west and the Trzciniec culture on the east - appeared in the region formerly occupied by Únětice.

These two reasons have led us to favor an endogenous explanation of the Únětician collapse. We have demonstrated that bronze production, the hallmark of Únětice as well as its source of power, was also its weakness. This is so because in order to produce bronze Únětician people were using placer tin which has been rapidly exhausted. Furthermore, the production of bronze required huge quantities of wood and charcoal which led, after a few centuries, to the deforestation of much of the Únětician area. Unsustainable use of these natural resources (as inputs in the bronze production) may have led to the collapse of the Únětice culture. This together with falling agricultural productivity, not easily reversed, (Tisdell and Svizzero, 2016) may well have been a major contributor to the abandonment of Únětice settlements.

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References

Amzallag, N. (2009), 'From metallurgy to Bronze Age civilizations: the synthetic theory', *American Journal of Archaeology*,**113,** 497-519.

Bátora, J., A. Behrens, J. Gresky, M. Ivanova, K. Rassmann, P. Tóth and K. Winkelmann (2012), 'The rise and decline of the Early Bronze age settlement Fidvár near Vráble, Slovakia', in J. Kneisel, W. Kirleis, M. Dal Corso, N. Taylor and V. Tiedtke (eds.), *Collapse or Continuity? Environment and Development of Bronze Age Human Landscapes,* Vol. 1, Bonn: Verlag Dr Rudolf Habelt GmbH, pp. 111-129.

Bouzek, J., D. Koutecky and K. Simon (1989), 'Tin and prehistoric mining in the Erzgebirge (Ore Mountains): some new evidence', *Oxford Journal of Archaeology*,**8,** 203-212. doi: 10.1111/j.1468-0092.1989.tb00200.x

Cathro, R.J. (2005), 'Tin deposits and the early history of Bronze', *CIM Magazine/bulletin* 1088 [Online] **98**. Available at http://www.aditnow.co.uk/documents/personal-album-272/tin-deposits-and-the-early-history-of-bronze.pdf [Accessed 25 October, 2016].

Childe, V.G. (1929), *The Danube in Prehistory,* Oxford: Clarendon Press.

Childe, V.G. (1930), *The Bronze Age,* New York: Biblio and Tannen.

Clark, J.G.D. (1966), *Prehistoric Europe: The Economic Basis,* Stanford, CA: Stanford University Press.

Constantinou, G. (1992), 'Ancient copper mining in Cyprus', in A. Marangou and K. Psillides (eds.), *Cyprus, Copper, and the Sea,* Nicosia: Government of Cyprus, pp. 43-76.

Craddock, P.T. (1995), *Early Metal Mining and Production,* Washington, DC: Smithsonian Institution Press.

Czebreszuk, J. (2007), 'Amber between the Baltic and the Aegean in the third and second millennia BC (an outline of major issues) ', *Aegaeum Liege,***27,** 363-370.

Darling, A.S. (2002), 'Non-ferrous metals', in I. McNeil (ed.), *An Encyclopedia of the History of Technology,* Routledge, pp. 47-145.

Dayton, J.E. (1971), 'The problem of tin in the ancient world', *World Archaeology,***3,** 49-71.

De Navarro, J.M. (1925), 'Prehistoric routes between Northern Europe and Italy defined by the amber trade', *The Geographical Journal,***66**(6)**,** 481-503.

Diamond, J.M. (2005), *Collapse: How Societies Choose to Fail or Succeed,* New York: Viking Press.

Drews, R. (1993), *The End of the Bronze Age: Changes in Warfare and the Catastrophe ca. 1200 B.C.,* , Princeton, NJ: Princeton University Press.

Durman, A. (1997), 'Tin in southeastern Europe?', *Opvscula Archaeologica,***21,** 7-14.

Earle, T., J. Ling, C. Uhnér, Z. Stos-Gale and L. Melheim (2015), 'The political economy and metal trade in Bronze Age Europe: understanding regional variability in terms of comparative advantages and articulations', *European Journal of Archaeology,***18**(4)**,** 633-657. doi: 10.1179/1461957115y.0000000008.

Ekholm, K. (1980), 'On the limitations of civilization: the structure and dynamics of global systems', *Dialectical Anthropology,***5**(2)**,** 155-166. doi: 10.1007/bf00246769.

Ernée, M. (2012), 'Bernstein in der böhmischen Aunjetitz-Kultur – zu den Anfängen der Bernsteinstrasse', *PAMÁTKY ARCHEOLOGICKÉ* **CIII,** 71-172.

Harding, A.F. (2000), *European Societies in the Bronze Age,* Cambridge: Cambridge University Press.

Harrison, A.P., I. Cattani and J.M. Turfa (2010), 'Metallurgy, environmental pollution and the decline of Etruscan civilisation', *Environmental Science and Pollution Research,***17**(1)**,** 165-180. doi: 10.1007/s11356-009-0141-5.

Haustein, M., C. Gillis and E. Pernicka (2010), 'Tin Isotopy - a new method for solving old questions', *Archaeometry,***52**(5)**,** 816-832. doi: 10.1111/j.1475-4754.2010.00515.x.

Hoover, H.C. and L.H. Hoover (1912[1950]), 'De Re Metallica', *Mining Magazine,* New York: Dover Publications Inc English translation of Georgious Agricola from the latin edition in 1556.

Höppner, B., M. Bartelheim, M. Huijsmans, R. Krauss, K.P. Martinek, E. Pernicka and R. Schwab (2005), 'Prehistoric copper production in the Inn Valley (Austria) and the earliest copper in Central Europe', *Archaeometry,***47**(2)**,** 293-315. doi: 10.1111/j.1475-4754.2005.00203.x.

Jaeger, M., J. Czebreszuk, J. Müller and J. Kneisel (2015), 'Metal finds', in J. Czebreszuk, J. Müller, M. Jaeger and J. Kneisel (eds.), *Bruszczewo IV. Natural Resources and Economic Activities of the Bronze Age People*, Bonn: Verlag Dr. Rudolf Habelt GmbH pp. 227-234.

Jaeger, M. and P. Gniezno (2012), 'Kościan group of Únetice culture and fortified settlement in Bruszczewo. Their role in micro- and macro-regional exchange', in M. Jaeger, J. Czebreszuk and K.P. Fischl (eds.), *Enclosed Space - Open Society, Contact and Exchange in the Context of Bronze Age Fortified Settlements in Central Europe,* Poznań-Bonn: SAO/SPEŚ 9, pp. 167-176.

Karageorghis, V. and V. Kassianidou (1999), 'Metalworking and Recycling in Late Bronze Age Cyprus – the Evidence from Kition', *Oxford Journal of Archaeology*, **18**(2)**,** 171-188. doi: 10.1111/1468-0092.00078.

Kienlin, T.L. (2013), 'Copper and bronze: Bronze Age metalworking in context', in H. Fokkens and A. Harding (eds.), *The Oxford Handbook of the European Bronze Age,* Oxford: Oxford University Press, pp. 414-436.

Kneisel, J. (2012), 'The problem of the middle Bronze Age inception in Northeast Europe or: Did the Únětice society collapse?', in J. Kneisel, W. Kirleis, M.D. Corso, N. Taylor and V. Tiedtke (eds.), *Collapse or Continuity? Environment and Development of Bronze Age Human Landscapes*, Vol. 1, Bonn: Verlag Dr. Rudolf Habelt GmbH, pp. 209-234.

Lutz, J. and E. Pernicka (2013), 'Prehistoric copper from the Eastern Alps', *Open Journal of Archaeometry,***1**(25)**,** 122-126. doi: http://dx.doi.org/10.4081/arc.2013.e25.

Merkl, M.B. (2010), 'Bell Beaker metallurgy and the emergence of fahlore-copper use in Central Europe', *Interdisciplinaria Archaeologica* **1,** 19-27.

Moucha, V. (1963), 'Die periodisierung der Úněticer kultur in Böhmen', *Sborník Československé společnosti archeologické* **3,** 9-60.

Muhly, J.D. (1985), 'Sources of tin and the beginnings of bronze metallurgy', *American Journal of Archaeology,***89**(2)**,** 275-291. doi: 10.2307/504330.

Müller, J. (2012), 'Changes in the Bronze Age: social economical and/or ecological causes?', in J. Kneisel, W. Kirleis, M.D. Corso, N. Taylor and V. Tiedtke (eds.), *Collapse or Continuity? Environment and Development of Bronze Age Human Landscapes,* Vol. 1, Bonn: Verlag Dr. Rudolf Habelt GmbH, pp. 257-266.

Niederschlag, E., E. Pernicka, T. Seifert and M. Bartelheim (2003), 'The determination of lead isotope ratios by multiple collector Icp-Ms: a case study of early Bronze Age artefacts and their possible relation With ore deposits of the Erzgebirge', *Archaeometry,***45**(1)**,** 61-100. doi: 10.1111/1475-4754.00097.

Pichler, T., K. Nicolussi, G. Goldenberg, K. Hanke, K. Kovács and A. Thurner (2013), 'Charcoal from a prehistoric copper mine in the Austrian Alps: dendrochronological and dendrological data, demand for wood and forest utilisation', *Journal of Archaeological Science,***40**(2)**,** 992-1002. doi: 10.1016/j.jas.2012.09.008.

Puziewicz, J., J. Baron, T. Ntaflos and B. Miazga (2015), 'The composition and microstructural variation of the Bronze Age metal ornaments from Lower Silesia (South-West Poland): chemical analytical and archaeological aspects', *Archaeometry,***57**(4)**,** 653-676. doi: 10.1111/arcm.12104.

Radivojevic, M., T. Rehren, J. Kuzmanovic-Cvetkovic, M. Jovanovic and J. Northover (2013), 'Tainted ores and the rise of tin bronzes in Eurasia, c. 6500 years ago', *Antiquity,***87,** 1030-1045. doi: 10.1017/S0003598X0004984X.

Reinecke, P. (1924), 'Zur chronologischen Gliederung der süddeutschen Bronzezeit', *Germania,***8,** 43-44.

Roberts, B.W., C.P. Thornton and V.C. Pigott (2009), 'Development of metallurgy in Eurasia', *Antiquity,***83,** 112-122.

Saile, T. (2012), 'Salt in the Neolithic of Central Europe: production and distribution', in V. Nikolov and K. Bacvarov (eds.), *Salz und Gold: die Rolle des Salzes im prähistorischen Europa / Salt and Gold: The Role of Salt in Prehistoric Europe,* Provadia, Bulgaria: Provadia & Veliko Tarnovo (Proceedings of the International Symposium (Humboldt-Kolleg) available at http://www.uniregensburg.de/philosophie-kunst-geschichte-gesellschaft/vor-und-fruehgeschichte/medien/saile_2012.pdf). pp. 225-238.

Stockhammer, P.W., K. Massy, C. Knipper, R. Friedrich, B. Kromer, S. Lindauer, J. Radosavljević, F. Wittenborn and J. Krause (2015), 'Rewriting the Central European Early Bronze Age Chronology: Evidence from Large-Scale Radiocarbon Dating', *PLoS ONE*,**10**(10)**,** e0139705. doi: 10.1371/journal.pone.0139705.

Svizzero, S. (2015), 'The collapse of the Únětice culture: economic explanation based on the 'Dutch Disease', *Czech Journal of Social Sciences, Business and Economics*,**4**(3)**,** 6-18.

Szeverény, V. (2004), 'The early and middle Bronze Ages in Central Europe', in P. Bogucki and P.J. Crabtree (eds.), *Ancient Europe; 8000 B.C. - 1000 A.D. Encyclopaedia of the Barbarian World*, Vol. 2, New York: Charles Scribners & Sons, pp. 20-30

Thornton, C.P., J.M. Golden, D.J. Killick, V.C. Pigott, T.C. Rehren and B.W. Roberts (2010), 'A chalcolithic error: rebuttal to Amzallag 2009', *American Journal of Archaeology*,**114**(2)**,** 305-15.

Tisdell, C.A. and S. Svizzero (2015). The collapse of some ancient economies due to unsustainable mining development (a draft), *Economic Theory, Applications and Issues*, Working paper No. 72. Brisbane: School of Economics, The University of Queensland.

Tisdell, C.A. and S. Svizzero (2016). The economic development and decline of Únětice. A case of ecologically unsustainable economic growth? Initial thoughts, *Economics, Ecology and the Environment*, Working Paper No. 201. Brisbane: School of Economics, The University of Queensland.

Vesely, J. (2000), 'The history of metal pollution recorded in sediments of Bohemian forest lakes: since the Bronze age to the present', *Czech Geological Survey*,**4,** 147-166.

Wertime, T.A. (1982), 'Cypriot metallurgy against the backdrop of Mediterranean Pyrotechnology: energy reconsidered', in J.D. Muhly, R. Maddin and V. Karageorghis (eds.), *Early Metallurgy in Cyprus, 4000-500 B.C.*, Nicosia, Cyprus: Department of Antiquities, pp. 351-62.

Yener, K.A., H. Özbal, E. Kaptan, A.N. Pehlİvan and M. Goodway (1989), 'Kestel: An early Bronze Age source of tin ore in the Taurus mountains, Turkey', *Science*,**244**(4901)**,** 200.

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