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Titelbild

Alacahöyük gehört zu den wichtigsten prähistorischen Städten in Anatolien. Besonders berühmt sind die frühbronzezeitlichen Fürstengräber mit ihren zahlreichen Grabbeigaben aus Gold, Silber und Bronze, darunter die frühesten Eisenfunde Anatoliens. Zum Grabinventar zählten auch zahlreiche bronzene Sonnenstandarten und Tierfiguren. Im Vordergrund ist eine dieser Sonnenstandarten zu sehen. Sie dient heute als Symbol des Kultur- und Tourismusministeriums der Türkei.

Im Hintergrund ist eine schroffe Landschaft bei Derekutuğun, Kreis Bayat, Provinz Çorum zu sehen. In Derekutuğun wurde seit dem 5. Jt. v. Chr. gediegenes Kupfer bergmännisch gewonnen. Im Vordergrund ist eine der prähistorischen Strecken abgebildet. Fotos stammen von Herausgeber.

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Deutsches Bergbau-Museum Bochum
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Telefon (02 34) 58 77 112/124
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Inhaltsverzeichnis

Tobias L. Kienlin

Aspects of the Development of Casting and Forging Techniques from the Copper Age to the Early Bronze Age of Eastern Central Europe and the Carpathian Basin

In this paper metallographic evidence is used to outline the development of methods of casting and forging in the Copper and Early Bronze Ages of southeast and central Europe. Unlike studies concentrating on the provenance of copper the focus is on the state of knowledge of prehistoric metalworkers and their technological choices (cf. Kienlin 2008; 2010). Microstructural data of Copper Age shafthole axes and flat axes as well as of Early Bronze Age flanged axes is presented and general characteristics of casting and working the axes are established. Despite similarities and tradition in overall approach two horizons of Copper Age metallurgical knowledge and practice can be distinguished. The reasons for the differences observed in casting technique and forging are discussed. In a long-term perspective the emergence of a metallurgical tradition can be discerned leading up into the Early Bronze Age.

Jászladány type axes, the first group of copper implements examined, form the most numerous sub-group or type among the Copper Age *zweischneidige Äxte* (Schubert 1965) or rather more fittingly *kreuzschneidige Äxte* whose one arm is in the form of an axe while the other one is set at a right angle to form an adze-like implement (fig. 1). Jászladány type shafthole axes have a wide distribution throughout large parts of southeastern Europe. Axe-adzes of this type were uncovered in a number of cemeteries belonging to the Bodrogkeresztúr culture. By their occurrence in graves of this group they are firmly linked to the Middle Copper Age in Hungarian terminology (*Hochkupferzeit*; Patay 1984) with possible beginnings in the Early Copper Age Tiszapolgár culture.

Of roughly the same date, our metallurgical horizon 1, there is a group of flat axes, rather slim and lengthy, of almost rectangular to wedge-shaped outline (fig. 1). There is substantial variation in details of size, cross-section (symmetrical vs. asymmetrical) and outline, especially of the neck and cutting edge (cf. Novotná 1970; Mayer 1977; Patay 1984; Říhovský 1992). Among the axes sampled there are such of Szakálhát, Stollhof, Stollhof-Hartberg and Split type (or variant) and related forms. By their occurence in graves and hoards alongside other types of copper implements this group of axes, too, belongs to the time of the Bodrogkeresztúr culture and contemporaneous groups in adjacent areas such as Jordanów/Jordansmühl and Brešć-Kujawski. In absolute terms we are talking about the late 5th and early 4th millennium for Tiszapolgár and Bodrogkeresztúr as well as neighbouring Neolithic groups from the north-

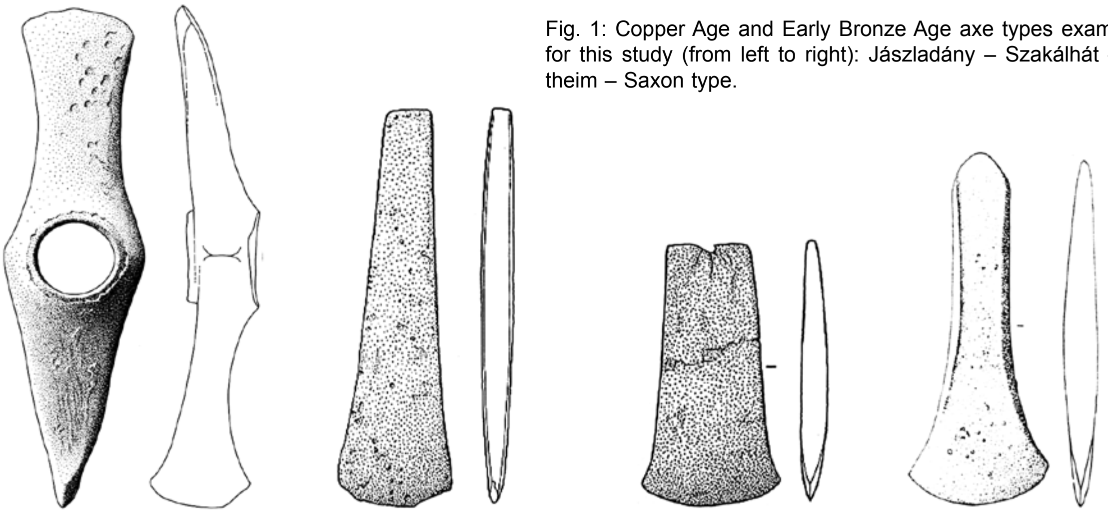


Fig. 1: Copper Age and Early Bronze Age axe types examined for this study (from left to right): Jászladány – Szakálhát – Altheim – Saxon type.

alpine region of central Europe (Dobeš 1989; Parzinger 1992; Parzinger 1993; Raczky 1995; Magnusson Staaf 1996; Matuschik 1996; Matuschik 1997; Klassen 2000).

By contrast Altheim, Vrádište and Vinča type axes, our metallurgical horizon 2, tend to be shorter, of a more sturdy shape and have a slightly trapezoidal to rectangular outline (fig. 1). Their cutting edge is slightly curved, their neck is straight and their cross-section is symmetrical, less often asymmetrical (Vinča). A number of Altheim axes was recovered from the lakeside settlements of Mondsee and Attersee in Austria. The Altheim and Mondsee cultures belong to the Late Neolithic (*Jungneolithikum*) of the northalpine region (Lüning 1996). Their beginnings are synchronized with Hunyadi-halom and proto-Boleráz around 3800 B.C. After 3600 B.C. their development continues parallel to (early Baden-) Boleráz into the second half of the 4th millennium. Younger evidence for the use of Altheim and Vinča type axes comes from (late Baden-) Kostolac and Vučedol. The final Copper Age Vučedol sequence succeeding Kostolac is dated by Maran (1998) to about 3000 to 2500 B.C. when Early Bronze Age groups such as Makó make their appearance.

Finally, Saxon type flanged axes take us into the Early Bronze Age (fig. 1). They are named after their suspected place of origin in the area of the Únětice culture, but are found across broad areas of eastern central Europe. Flanged axes of this type and related forms were made from different types of copper – among them *fahlore* copper and tin bronze. They mark the beginning the "metallurgical" Early Bronze Age proper. By the reference to the different raw materials used, however, we touch upon questions of the chronological relationship of Saxonian type axes with other Early Bronze Age axe forms such as the Salez and Neyruz types (Abels 1972; Krause 1988). For on the one hand all of these axes are seen as roughly contemporaneous in Bronze Age A1 after 2200 B.C. On the other hand it is thought possible, that due to their lack of tin the Salez type axes might represent an earlier stage of development. In this case, at least the tin alloyed axes of the Neyruz and Saxonian types are taken to be younger than the Salez ones and belong to the second half of the Early Bronze Age (A2). Alternatively, even all of the Neyruz and Saxonian type axes are dated to Bronze Age A2 (Hafner 1995; Bartelheim 1998).

Casting: Cores and Open Moulds?

Drawing on different aspects of the evidence available both open moulds and (closed) bi-valve moulds have been suggested for the axes in question. The early date – of the shafthole axes – and „primitive" form – of the flat axes – are taken to imply the use of open moulds. Oxide inclusions and heavy forging are thought to support this assumption and indeed there is a limited number of mould finds which seem to prove this line of argument (e.g. Mayer 1977; Patay 1984; Budd 1991; Magnusson Staaf 1996). On the other hand, the number of moulds known is very small. It is hardly sufficient to establish a casting technique commonly used. Other authors, therefore, focus on the precision of the axes' outline and their cross-section which are thought to imply the use of bivalve moulds. Still others doubt that casting in open moulds is practicable and would have given satisfactory results at all (e.g. Sangmeister & Strahm 1973; Dobeš 1989).

The evidence is ambiguous (see also N. Boroffka in print) and even metallographic examinations do not provide a definite solution to this problem. Still it is possible on this basis to comment on some previous suggestions (cf. Kienlin, Bischoff & Opielka 2006). In a by now classic paper it was shown that the shaft-hole of Copper Age tools was cast around a core and the earlier hypothesis discarded that this feature was produced by drilling (Renfrew 1969; cf. Coghlan 1961; Patay *et al.* 1963). Metallographic data was used to demonstrate that intense forging was involved in bringing these artefacts into their final shapes and the same type of eutectic copper oxide was documented that was found in many of our horizon 1 artefacts (Charles 1969; see below). With regard to this new data we would disagree on the earlier conclusion that shaping was done by cold-work followed by annealing and surface finish. There is no reason to transform the object into a soft condition just to finish the surface and we certainly do not find any evidence for "further [i.e. final] cold work on an anvil" (Charles 1969: 42; see below). Irrespective of whether hot-work or cold-work was applied, however, there remains the question of the kind of mould used and the role of forging in shaping these artefacts.

Charles (1969) suggested that a rough shape was produced in an open cored mould and much deformation was required to achieve the final form. In particular both the axe arm and the adze arm had to be broadened and the latter had to receive its characteristic bending. A concentration of oxides at the "upper" surface (in the casting mould) which – presumably – was left uncovered during casting certainly is a strong argument in favour of this view – although there is variation and this feature reportedly was less marked in the axe-adze examined (Charles 1969). Given that after casting the complete upper side of the axe should have been flat, most likely rather porous and covered by an oxide layer, one would expect that the necessary working affected the cutting edge of the adze arm rather strongly. Clearly, a larger number than the six axes examined so far would be desirable to support this view, but we never found clustering of oxide inclusions along the surface. It is unlikely that the oxides in their observed form and distribution are consistent with open mould casting. Forging of the adze arm's cutting edge is not systematically different from that of the axe arm. While there are samples in which the oxides are quite heavily deformed into parallel layers this is not the case in all the Jászladány axes examined. In the latter case the amount of deformation was certainly not sufficient, if the surface was initially flat. The same observation was made on flat axes of horizons 1 and 2 previously supposed to have been cast in open moulds (Kienlin, Bischoff & Opielka 2006; Kienlin 2007).

According to Charles (1969: 42) "solidification would not proceed until the mould had been filled and the fire had died down or had been dispersed". In the light of experimental work the opposite is likely: In contact with air, the temperature drops fast, solidification is rapid and gas adsorption is high. The problem would be to obtain a complete filling of the mould, especially when the copper is allowed to run into it from an above fire as Charles suggested. The latter proposal is quite inconceivable but any attempt at casting (from a crucible) into an open mould of this size would result in problems to get the mould completely filled. Not only would the concentration of oxide inclusions increase but also the porosity caused by either vapour or hydrogen. The microstructures of the Jászladány axes examined clearly show that this was not the case. By contrast, any kind of cover would allow for solidification to take place more slowly and improve the filling of the mould. With only a little imagination this approach would suggest the addition of important features to the mould and not rely on heavy forging to give an axe's arms their final shape.

Renfrew (1969) argued for an autonomous development of the metallurgy of the southeast European Copper Age. Certainly he cannot be accused of taking a „primitivist" stance underestimating the inventiveness of European metalworkers. Still there is an evolutionary undertone to his discussion and it might be due to this particular perspective that the use of some kind of closed moulds was not taken into consideration. Given that cores were known to produce the shaft-hole one might ask instead why large parts of the surface should have remained uncovered and – more importantly – why both arms should have been cast in one plane. This approach would have multiplied the amount of work required to prepare the as-cast object for use, especially the massive deformation necessary to bend the adze arm into its final position.

There is no evidence beyond dispute for the use of open moulds in the production of Jászladány type axes (see above) and we should bear in mind that such Middle Copper Age implements by no means represent the beginnings of metallurgy in the area in question. The situation is somewhat unclear for our horizon 1 but latest by horizon 2 there is unequivocal evidence of closed moulds: A shrinkhole in the neck of an Altheim type axe clearly shows that casting took place in an uprising closed mould (Mayer 1977: 55 no. 141). Given that with the end of the Middle Copper Age the interest in massive shaft-hole tools was in decline one might ask why this innovation should occur in the context of the ongoing production of rather simple forms such as flat axes. By the Early Bronze Age metallographic analysis and increased porosity in the neck of the axes shown by X-rays demonstrate that for all axe types casting took place in an upright standing mould (Kienlin 2008).

Working: Horizons 1 and 2 of Copper Age Metallurgy

Cold-Work and Hardness: Copper Age Horizon 2 and Early Bronze Age

With regard to temperatures required for recrystallization, duration and practicability, one would expect forging to involve the following steps: cold-working the as-cast object – annealing – final cold-hammering (cf. Scott 1991). This procedure has a twofold aim: Even when casting in a closed mould some degree of deformation is required to finish the as-cast object. Feeders and casting seams need to be removed and a smooth surface be achieved, which is done by hammering and subsequent polishing. If a stronger deformation is required, e.g. for shaping an axe's blade or neck, this may necessitate more than one annealing process. Final cold-working, on the other hand, increases hardness and adds to the strength and durability of a weapon or tool.

It is this process we encounter with the axes of horizon 2 (fig. 2). At least some of these were cast in closed bivalve moulds and most could be finished with a rather limited total reduction in thickness (see above). Some deformation was required, however, to give the axe its final shape and outline. This was done in one, rarely several cycles of cold-work and annealing. Metalworkers in horizon 2 did not recognize the differential work hardening of pure copper and arsenical copper (cf. Budd 1991). But final cold-work often was stronger than the deformation achieved in the previous step and this certainly implies they were actively interested in the hardness of their axes. In addition, good knowledge of the raw material used can be assumed. For there is some clustering in the 20-40 % deformation range beyond which the increase in hardness achieved by smithing levels off (see experimental data published by Lechtman 1996). The conspicuous absence of significantly higher rates of deformation reflects the empirically gained knowledge of a *point of diminishing returns* for working the most commonly used copper during the later Copper Age with its typically limited arsenic contents (cf. Kienlin, Bischoff & Opielka 2006). The increase in hardness to

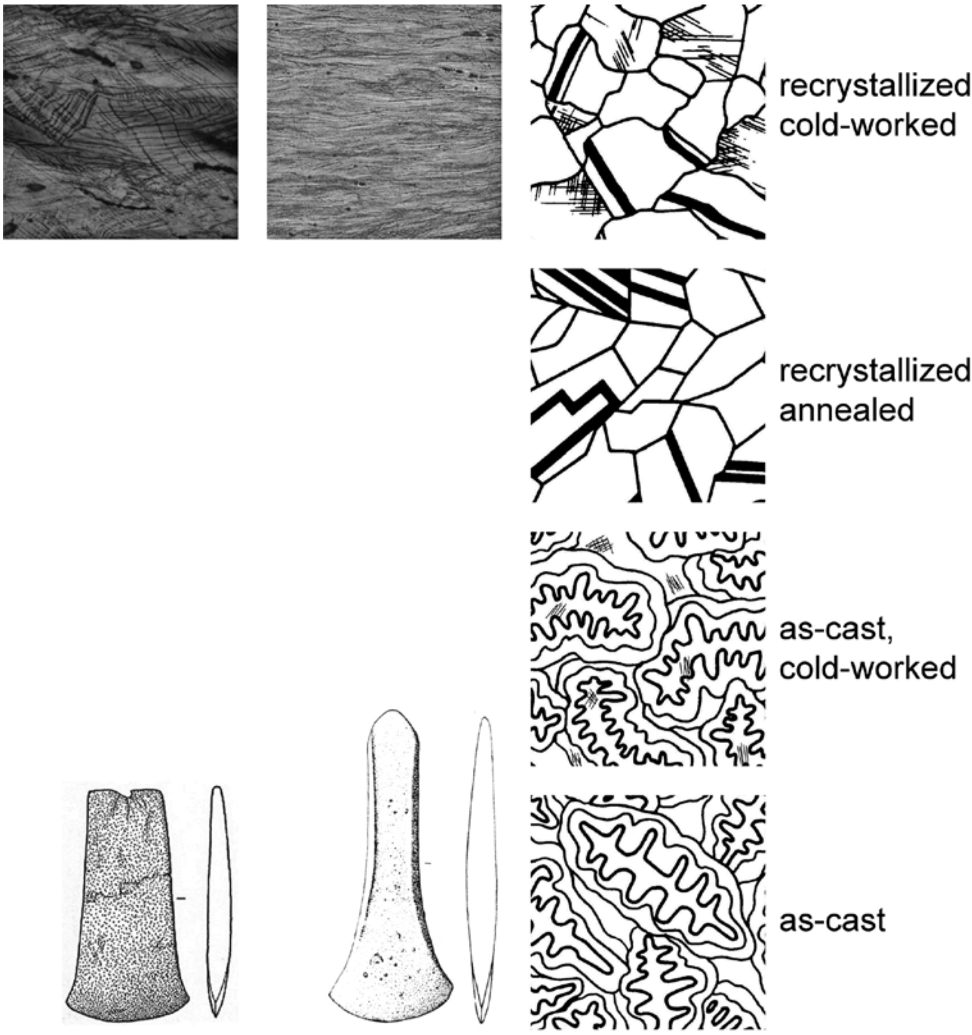


Fig. 2: *Chaîne opératoire* for Copper Age horizon 2 and Early Bronze Age axes.

100–150 HV achieved remains much below that of Early Bronze Age axes consisting of *fahlore* copper or tin bronze. Yet the tradition and overall procedure established in the working of horizon 2 axes can be traced right up to the Early Bronze Age, when a two-step working of Saxon type flanged axes is the rule (fig. 2). Initially, the improvement of mechanical properties was limited yet it may have substantially added to the durability of such implements as our horizon 2 axes (cf. Kienlin & Ottaway 1998). Subsequently, profiting from the new *fahlore* type copper and tin bronze, during the EBA a considerable increase in hardness was achieved by a rather strong final cold-work (e.g. Kienlin 2006).

Hot-Work and Shape: Copper Age Horizon 1

Against this background of a long-standing tradition of working copper and copper alloys both the Jászladány type axe-adzes and the flat axes from horizon 1 show some distinct deviations (fig. 3). Unlike the somewhat younger horizon 2 axes they show a fully recrystallized microstructure without any traces of deliberate cold-working in the final step. What little deformation there is in the microstructures such as some slightly deformed annealing twins close to the surface is indicative of other production steps, namely surface finish, or use. Deformed oxide inclusions and numerous annealing twins, on the other hand, show that a deformation took place. The procedure encountered is best interpreted as an intense hot-working with continuous re-heating during a forging process of some duration. Most of the deformation required to finish these axes was achieved while they were heated up with little or no further deformation upon cooling. In line with the younger material from central and southeastern Europe the working of horizon 1 axes involved the application of heat. They stand in the same broad tradition because, for example, the early metalwork of the Iberian peninsula – operating largely on the basis of cold-working as-cast objects – shows that the practice (or knowledge) of annealing or hot-work cannot be taken for granted (Rovira Llorens & Gómez Ramos 2003). Instead these are technological choices taken by metalworkers operating within a specific cultural tradition. Unlike the younger Altheim and Vinča axes, however, as well as subsequent Bronze Age practice no attempt was made to improve the mechanical properties by cold-working.

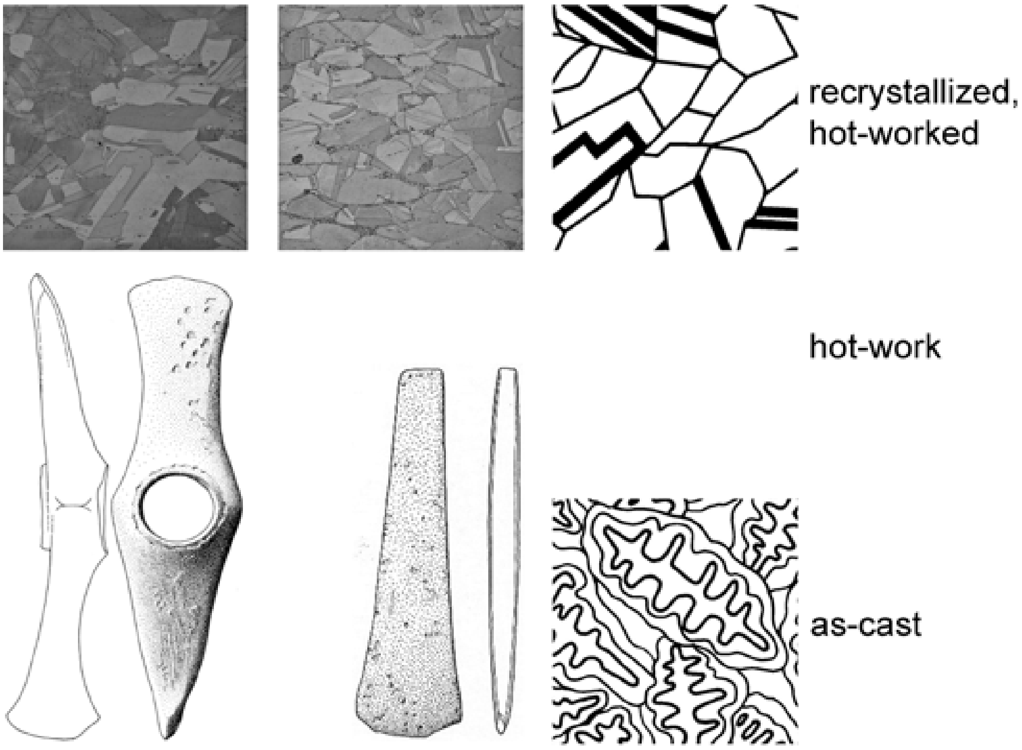


Fig. 3: *Chaîne opératoire* for Copper Age horizon 1 axes.

Hot-Work, Cold-Work and Oxides: Reasons of the Differences between Horizons 1 and 2

Based on these differences in the approach to forging there are two horizons of Copper Age metallurgy: Horizon 1 with recrystallized, hot-worked microstructures, typically without final cold-work – comprising Jászladány type axe-adzes as well as flat axes of Szakálhát, Stollhof, Stollhof-Hartberg and Split types. Horizon 2 with artefacts cold-worked for shape and surface finish, annealed and cold-worked for hardness – comprising flat axes of Altheim, Vrádište and Vinča types.

There may be problems with the modern notion of hardness being „desirable“ for weapons and tools. Yet the apparent stability of the horizon 2 cyclical approach to forging with a final cold-work far into the Bronze Age entitles us to ask for the reasons of this difference in approach. To this aim we have to turn back to the casting technique and the influence of oxide inclusions on the working of horizon 1 axes.

In a majority of horizon 1 axes oxides take the form of a network consisting of the ($Cu+Cu_2O$)-eutectic (cf. Schumann 1991) which upon forging often was deformed into distinct layers (fig. 4). In the as-cast microstructure this oxide network covered the boundaries of the original casting grains. Upon recrystallization the oxide layers restricted the formation of new grains. This is why they are frequently seen running along grain boundaries even after annealing. They may also be found, however, incorporated upon growth into newly formed grains of the recrystallized microstructure.

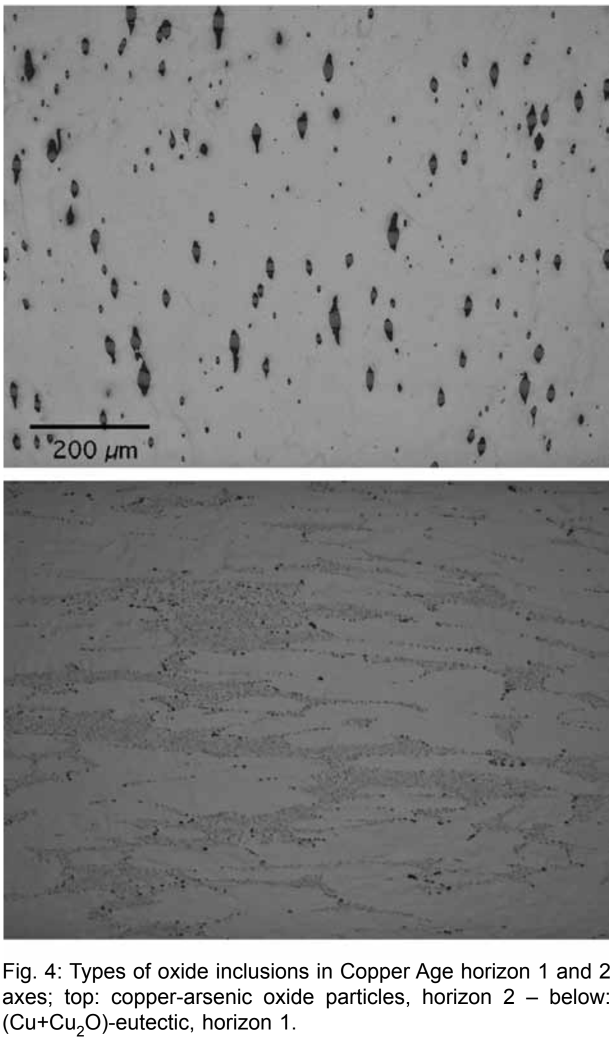
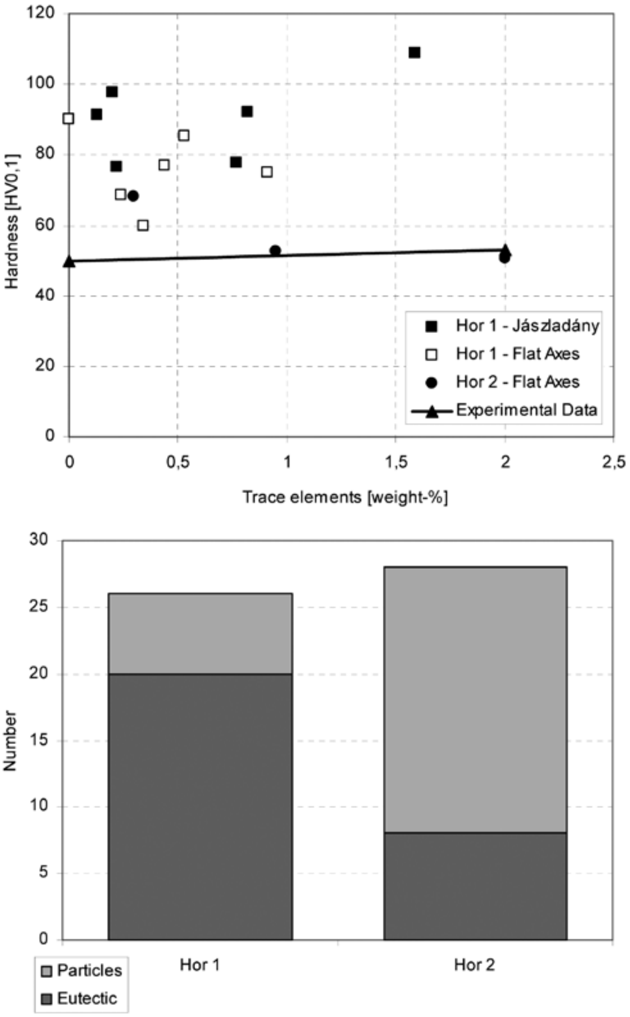


Fig. 4: Types of oxide inclusions in Copper Age horizon 1 and 2 axes; top: copper-arsenic oxide particles, horizon 2 – below: ($Cu+Cu_2O$)-eutectic, horizon 1.

Younger axes of horizon 2, on the other hand, rarely show this feature. Instead, most of them contain distinct particles consisting of mixed copper-arsenic oxides which are seldom found in horizon 1 axes (fig. 4). Thus, without being restricted to either horizon 1 or 2 both oxide types show a clear correlation with older and younger axes respectively (fig. 5).

It is supposed that the presence of the ($Cu+Cu_2O$)-eutectic along grain boundaries makes the metal brittle while particles of mixed copper-arsenic oxides may be plastically deformed (Northover 1989). The latter is certainly true as there are many horizon 2 axes with this feature (Kienlin 2007). Less clear is the effect of the ($Cu+Cu_2O$)-eutectic on workability: In modern practice the ($Cu+Cu_2O$)-eutectic is thought to deteriorate mechanical properties and it is recommended to restrict oxygen pick-up upon casting. However, in principle both hot- and cold-working copper containing the ($Cu+Cu_2O$)-eutectic is possible (Schumann 1991). This certainly applies to the forging of our prehistoric axes as well. Overall reduction in thickness is limited and it is likely that a rather high amount of the ($Cu+Cu_2O$)-eutectic was tolerable without causing problems. Some horizon 1 flat axes show a high reduction in thickness with the oxides heavily deformed into parallel layers indicating that the ($Cu+Cu_2O$)-eutectic did not cause intolerable brittleness. Some kind of working was possible and there is evidence that either hot-working or cold-working could be practiced: Hot-working is the rule in horizon 1 (see above), but among the few horizon 2 axes with this oxide type there are pieces with substantial cold-work. Obviously, it was possible to cold-work axes with the ($Cu+Cu_2O$)-eutectic oxide type.

Fig. 5: Top: influence of the ($Cu+Cu_2O$)-eutectic on the hardness of Copper Age horizon 1 and 2 axes without cold-work (experimental data after Lechtman 1996) – below: frequency of oxide types in horizon 1 and 2 axes.



It is unlikely, therefore, that the ($Cu+Cu_2O$)-eutectic prevented cold-work and necessitated hot-work. Yet there is another reason why its presence might have encouraged an emphasis on easy shaping at high temperatures (fig. 5). The hardness of pure undeformed copper is around 50 HV and solid solution hardening up to about 2 % arsenic is minimal (Lechtman 1996). By comparison, axes with the ($Cu+Cu_2O$)-eutectic oxide type – recrystallized and without final cold work – are harder, sometimes considerably so. The presence of this kind of oxide inclusions, which are hard and brittle, increases the hardness of the whole object to values well above what can be expected from a microstructure with little or no signs of final cold-work. Forging in horizon 1 was carried out at high temperatures to make up for reduced deformability. But for the same reason – the additional hardness the ($Cu+Cu_2O$)-eutectic provided – durability of the axes was felt to be sufficient. “Deficencies” in casting (high amount of [$Cu+Cu_2O$]-eutectic) discouraged attempts at optimizing hardness by way of forging technique (cold-working). The presence of the ($Cu+Cu_2O$)-eutectic provided an alternative mechanism to improve performance by – unconsciously – benefiting from actual “shortcomings” in casting technique.

Casting and Compositional „Determinism“

With an average of 2.97 % flat axes of horizon 1 tend to contain a distinctly higher amount of oxide inclusions than those of horizon 2 (1,83 % of sample area). Since in horizon 2 the older *Reinkupfer* is gradually replaced by low percentage arsenical copper the question arises if composition has got a role to play in the changes observed. From figure 6, however, it becomes obvious that arsenic is not the only reason for this decline in oxide frequeny (contra Charles 1967). In both horizon 1 and 2 there is no apparent relation between trace element content and the frequency of oxide inclusions. It follows that it is not the absolute amount of arsenic present (i.e. the copper chosen) which reduces oxide inclusions but the handling of the molten copper prior to and during casting (e.g. use of a charcoal layer to cover the crucible). It is in this respect that there is a difference between both horizons, for horizon 2 axes tend to contain less oxide inclusions irrespective of composition. Quite obviously the handling of the casting process was different and probably more advanced than with the earlier axes of horizon 1.

Similarly, at first glance one gets the impression that the (Cu+Cu_2O)-eutectic is more likely to occur in axes with low trace element contents. Yet there are exceptions to this rule with trace element contents up to around 2 %. The same holds true for distinct oxide particles which contain mixed copper-arsenic oxides: The few horizon 1 axes with this oxide type cluster around a trace element content of 1 % which is rather high for this group of axes. The axes of horizon 2, however, show that this oxide type occurs alongside the (Cu+Cu_2O)-eutectic down to trace element contents as low as 0.4 %. For this reason composition has an important part to play in the formation of the oxide types discussed but procedure must not be neglected either. Most likely the different frequency of both oxide types in horizons 1 and 2 is a result of the same differences in approach prior to and during casting which caused the general decline of oxides in horizon 2 axes noted above.

These findings show that it is a mistake to concentrate on the influence of composition on casting quality, in particular on a supposed de-oxidising effect of arsenic by forming insoluble oxides which are removed upon casting (Charles 1967; cf. Ottaway 1994). It is not the concentration of arsenic (i.e. the copper chosen) that reduces oxide inclusions but mainly modifications in the casting technique of horizon 2. In the same vein, attention was drawn to axes with high trace element contents showing the (Cu+Cu_2O)-eutectic oxide type and vice versa to such low in arsenic containing distinct oxide particles. There is a tendency for the (Cu+Cu_2O)-eutectic to occur in axes with low trace element contents. But here, too, aspects of procedure must not be neglected and the whole *chaîne opératoire* be taken into consideration.

This attempt at deconstructing “compositional” determinism can be taken further by reference to the Jászladány type axe-adzes from horizon 1. Despite a rather small number of samples it is quite obvious that these implements tend to contain distinctly less oxide inclusions than contemporaneous flat axes. With an average of 1.2 % they remain even below many of the younger horizon 2 flat axes (fig. 6). Horizon 1 flat axes of Szakálhát type as well as Jászladány type shaft-hole axes

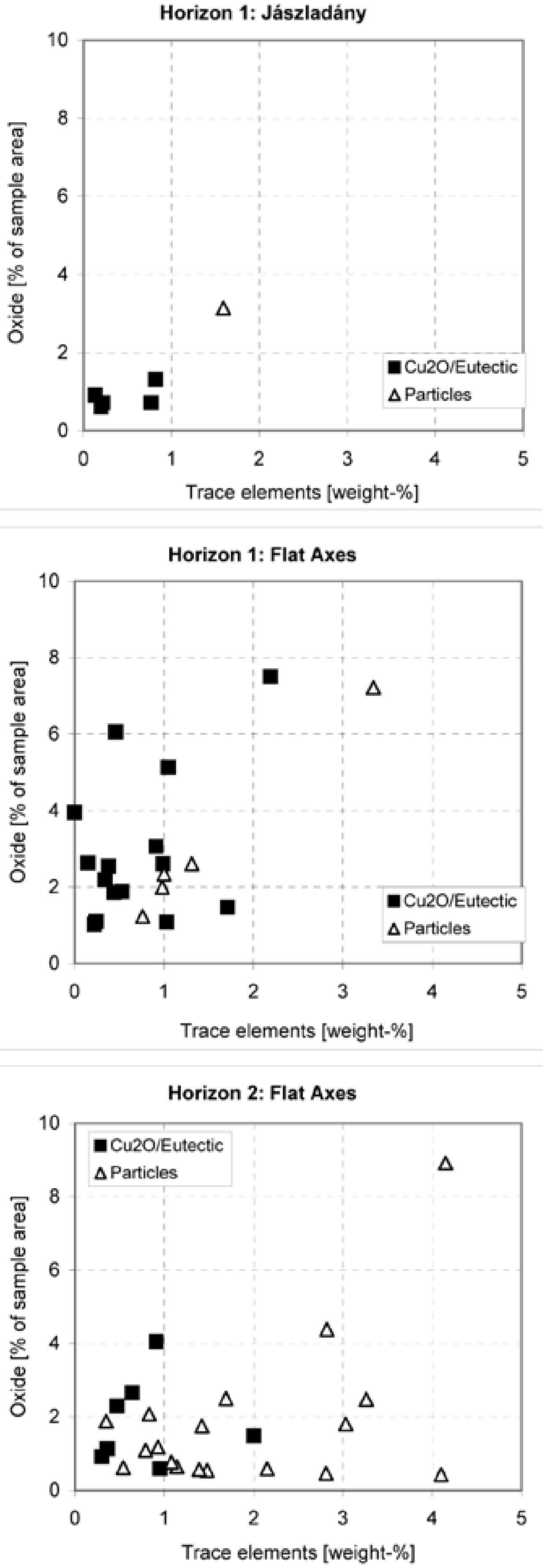


Fig. 6: Frequency (% of sample area) and type of oxide inclusions in Copper Age horizon 1 and 2 axes.

are known from graves of the Bodrogkeresztúr culture. In the hoard of Szeged-Szillér axes of both forms were found in association (Patay 1984). Hence in a Middle Copper Age context, our metallurgical horizon 1, different groups of implements occur alongside each other varying systematically in oxide content. Oxygen absorption during casting was different and since with the Jászladány axes, too, there is no correlation with trace element content handling was the decisive factor. Obviously, in casting Jászladány type axe-adzes a method was used which reduced oxygen absorption in comparison with contemporaneous flat axes. It is possible that it was deliberately attempted to control oxygen absorption and that strategies were developed to manipulate the casting atmosphere. But rather we see a cumulative effect of minor modifications to various aspects of the casting process, with attention paid to details of handling otherwise thought unimportant and greater care was taken in casting more complex forms such as Jászladány type shaft-hole tools. Both groups, however, flat axes and shaft-hole axes, contain the ($Cu+Cu_2O$)-eutectic and both types of implements benefited from the additional hardness that this oxide type provided (fig. 7)

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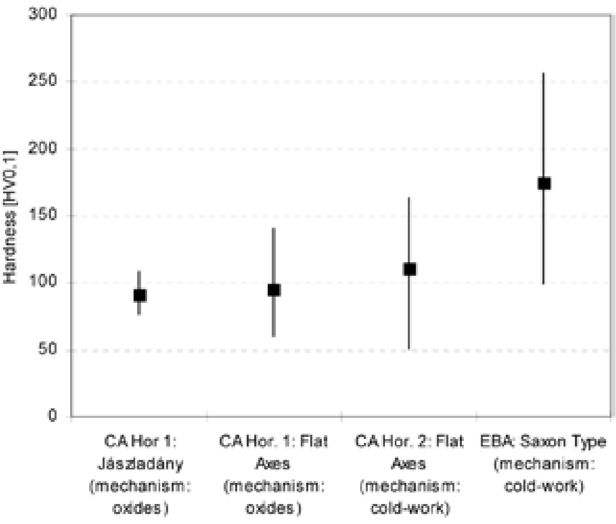
Patterns in Time: Changes in Metallurgical Practice

While the production of heavy shaft-hole implements characteristic of the Middle Copper Age declined, flat axes remained in use throughout the Late Copper Age. In our horizon 2 we see modifications of the casting technique which led to reduced oxide content. It is tempting to see this process as a move in metallurgical emphasis from the earlier shaft-hole implements of horizon 1 to what weapons or tools of copper remained – an increasing interest in and closer attention paid to the casting process of various types of flat axes in horizon 2. The development is more complex, however, as the type of oxide inclusions changed at the same time as the oxygen content declined. As a result of changes in casting technique and less so of increasing arsenic contents, the additional hardness previously provided by the ($Cu+Cu_2O$)-eutectic was lost. Instead metalworkers took to cold-working flat axes of horizon 2. This modification of the *chaîne opératoire* added complexity to the production process (cf. figs. 2 and 3) and can be taken to support the assumption that greater emphasis was placed on horizon 2 flat axes. During horizon 1 forging was intense but conceived solely as a shaping operation. Now it determined mechanical properties, perception and use of the axes (fig. 7).

Fig. 7: Comparison of the hardness values of Copper Age and Early Bronze Age axes with mechanism involved in hardening (square = mean; minimum and maximum range).



From another perspective, however, this finding may also illustrate contingency in the development of metallurgy: In working native copper by hammering and annealing there was no casting process involved which may result in oxygen absorption. Any additional hardness that may have been required had to be achieved by work-hardening, thus encouraging a final cold-work. In casting copper smelted from oxidic copper ores there was initially quite substantial oxygen pick-up and the formation of the ($Cu+Cu_2O$) eutectic increased the hardness. It is this stage of development our horizon 1 axes belong to. Their performance was improved by a "primitive" casting technique, which favoured hot-working and suspended an earlier emphasis on cold-working copper. With subsequent advances in casting technique there was a revision of this development. Axes of horizon 2 rarely show the ($Cu+Cu_2O$)-eutectic and forging again involved a cycle of cold-work, annealing and final cold-working.

Most likely this development was accompanied by changes in the perception of metallurgical practice and the objects produced. We can see the outcome of this process: a change in emphasis from the working of native copper via massive shaft-hole implements to flat axes – from cold-work and annealing via casting and forging as a shaping operation back to cold-work which also determined mechanical properties. Yet we can only speculate on some of the resulting questions: It seems that it was culture, an overriding interest in the sheer size and weight of metal objects, which prevented attempts at cold-working horizon 1 shaft-hole implements. There are traces of wear in the microstructures so they were not just intended for display. But they were certainly not up to cutting trees. In any case their hardness was felt to meet the demands in use – most likely social in the widest sense, including display and conflict. If so, how did technological change come about subsequently? Did social demands change so that massive shaft-hole implements lost their attractiveness and metallurgy followed by providing "better" flat axes instead? How then are we to conceptualize this process? Could forging just revert to traditional cold-work known since the earliest working of native copper and were parallel changes in casting technique just an epi-phenomenon? Was the move away from massive shaft-hole tools and forging primarily seen as a shaping operation just an obvious technological choice, an option consciously taken once required? Or did "traditional" practice already mean something different? Did the return to cold-work and the abandonment of shaft-hole tools require a re-negotiation of metallurgical knowledge also affecting casting technique, and in a wider sense the role of metallurgy in society?

Despite a decline in metallurgy during the Late Neolithic of Central Europe (*Spätneolithikum*; Lüning 1996) and the late Copper Age of the Carpathian basin (Strahm 1994; Kolb 1998; Taylor 1999) the approach to casting and working established in our horizon 2 was handed down to the Early Bronze Age. Only then did tin bronze emerge taking the place of pure copper and arsenical copper, and in the second half of the Early Bronze Age (A2) we witness the true transition to the "age of metal" – defined by the widespread use of metal as such for a variety of items and the general availability of tin bronze in particular. Here, too, we should be wary not to focus on composition alone, for the metallurgy of Early Bronze Age A2 is not only characterised by the adoption of tin bronze but also by a standardization of forging techniques (cf. Kienlin 2008). Only both aspects together – raw materials and metallurgical practice – account for changes in the perception of metal objects, e.g. reliable "quality" or properties of metal objects on a regular basis, and their acceptance into daily life – be on the utilitarian side of tools or on the symbolic one of markers of male and female habitus such as weapons and ornaments. For this system to come into existence new options and metallurgical knowledge had to be negotiated and their integration into traditional practice – ultimately derived from Neolithic/Copper Age horizon 2 metallurgy – be accomplished. This was not a straigthforward process and neither was the Early Bronze Age a phase of rapid and inescapable "progress". Rather there was contingency and innovations were subject to debate in a specific cultural and geographical setting. For example, the adoption of tin bronze was delayed where suitable *fahlore* copper with similar properties was available and for a transitional period in some areas metalworkers were faced with different options. The result was a temporal diversification of regional traditions: Salez type axes whose producers drew upon specific Alpine *fahlore* deposits never were alloyed with tin. Neyruz type axes consisting of copper are cold-worked rather weak while the tin-alloyed examples of this type show a tendency for more intense cold working. The opposite development is apparent for the Saxon type axes. These developments should not be judged on the basis of modern expectations as differing "optimal" implementations of technological "progress". Rather, one encounters traditions and approaches that developed in line with a regional background and should be understood in their specific cultural and historical context (cf. Roberts 2008).

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