# Emergence of Copper Pyrotechnology in Western Asia

**Thesis submitted in partial fulfillment
of the requirements for the degree of
"DOCTOR OF PHILOSOPHY"**

**by**

**Thomas Rose**

**Submitted to the Senate of Ben-Gurion University
of the Negev**

**30.09.2022**

**Beer-Sheva**

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Approved by the advisor

Approved by the Dean of the Kreitman School of Advanced Graduate Studies

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Prof. Yuval Goren
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In the Department  Bible, Archeology & Ancient Near Eastern Studies - Archeology

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# Research-Student's Affidavit when Submitting the Doctoral Thesis for Judgment

I, Thomas Rose, whose signature appears below, hereby declare that
(Please mark the appropriate statements):

X I have written this Thesis by myself, except for the help and guidance offered by my Thesis Advisors.

X The scientific materials included in this Thesis are products of my own research, culled from the period during which I was a research student.

___ This Thesis incorporates research materials produced in cooperation with others, excluding the technical help commonly received during experimental work. Therefore, I am attaching another affidavit stating the contributions made by myself and the other participants in this research, which has been approved by them and submitted with their approval.

Date: 30.09.2022 Student's name: Thomas Rose Signature: Thomas Rose

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# Chapter 1

# Abstract

The Chalcolithic Southern Levant (4500 to 3800 BCE) is especially well-known for its outstanding copper objects, such as the crowns and mace heads, found, among others, in the Nahal Mishmar Hoard as the largest and most prominent assemblage. They are made in the lost wax casting technique with polymetallic copper alloys, whose ore sources are located in the Anatolian or Southern Caucasian mountains. The combination of this metal type, exclusively used in the Chalcolithic Southern Levant, and the earliest evidence for this technologically complex casting process in West Asia attest to a unique metallurgical development in the Chalcolithic Southern Levant. Based on promising archaeological finds, Fazael was suggested as tentative production site. This metal working tradition was paralleled by an unalloyed copper metallurgy with production sites confined to the Nahal Beer Sheva, where copper ores predominantly from Faynan were smelted and the unalloyed copper was cast in open moulds to tool-shaped objects.

The major aspects of the lost wax casting process and its mould design are understood since many years from the study of mould remains attached to the metal objects and of the polymetallic copper alloys itself. However, the absence of in-situ production remains (e.g., furnaces, mould fragments) made it impossible to gather more knowledge about the operational sequence. In addition, archaeological evidence for the production and processing of the polymetallic copper alloys remains to be found; the few ore pieces with compatible chemistry in the Southeastern Anatolian sites Arslantepe and Norşuntepe were apparently not used in smelting activities. Moreover, the contrast in the preservation of production remains from the two Southern Levantine metallurgical processes seems odd, even if the lost wax casting technology is generally somewhat ephemeral.

In contrast to the lost wax casting process, the unalloyed copper process can be reconstructed in more detail. Furnace remains from Abu Matar and Shiqmim indicate the use of pit furnaces, in which the ore was smelted. In a second step, the copper prills were mechanically extracted, melted in crucibles

and then cast in open moulds. Nevertheless, important details remain unclear, such as the draught technique. Additionally, some aspects of the current process reconstructions seem very impracticable and thus questionable.

Beside these technological aspects of the Chalcolithic metallurgy in the Southern Levant, the origin and evolution of the innovation “lost wax casting” was not investigated in detail, yet. While many studies on the cultural developments and the metallurgies in the Chalcolithic Southern Levant and the other West Asian regions exist, an inter-regional perspective was rarely taken despite the clear connection between these regions by the polymetallic copper alloys and other objects. Part of the discussion about the metallurgy of the Chalcolithic Southern Levant is also the role of the metal objects in the society and their sudden disappearance at the end of the Chalcolithic. Although several studies tackled this topic already, it remains debated, not least because the general social organisation of the Chalcolithic Southern Levant remains debated.

For these reasons, this project addresses three main aims: (a) Refining the current reconstructions of the metallurgical processes in the Chalcolithic Southern Levant by combining the (re)analysis of the metallurgical assemblages from Abu Matar and Fazael with an experimental approach; (b) Tracing the evolution of the innovation “lost wax casting” in an inter-regional perspective, and (c) providing new ideas about the cultural role of the metal objects for the social system of the Chalcolithic Southern Levant. Beside the experimental and analytical work for the first part, an extensive literature review is the base for all three aims.

## 1.1 Archaeological background

The Chalcolithic Southern Levant is a continuation of the Late Neolithic and covered today’s Israel as far South as the Northern Negev, the Westbank, and the Jordan valley. It can be subdivided in two phases, termed here Early and Late Chalcolithic. The Early Chalcolithic (4500–4300 BCE) is characterised, among others, by cornets, ceramic vessel figurines, and large architectural structures (“temples”) in Gilat, En Gedi, and Teleilat Ghassul. The Late Chalcolithic (4300–3800 BCE) is characterised, among others, by the vanishing of those traits and the emergence of metallurgy. However, many aspects in the material culture remain unchanged, such as secondary burials (often ossuaries placed in caves), the lack of individually assignable burial items, stone mace heads, V-shaped bowls, and basalt bowls. Many of the metal items seem to be skeuomorphs or imitations of non-metal objects, establishing a close link between this new and the longer-used materials. Reconstructing the social organisation of the Chalcolithic Southern Levant is challenging because neither the settlements nor the burials provide clear indicators for status differences. Therefore, models of hierarchical chiefdoms exists as well as heterarchical models with heads of households. At the end, the Chalcolithic ideology and with it the entire social system seems to collapse and most of the prestige items including the lost wax cast polymetallic copper alloys disappeared with the onset of the Early Bronze Age.

The Chalcolithic in the Southern Levant is a period with many innovations. Beside horticulture and the full establishment of secondary products, the slow-turning potter's wheel and metallurgy are probably the most important ones. The innovations are paralleled by a significant increase in craft specialisation with dedicated workshops for, e.g., flint tools, basalt bowls, and metal items, as well as an increase in the standardisation of pottery, especially of V-shaped bowls. Exchange was organised in a two-tiered system. A network connecting the entire region and expressed, e.g., by a uniform *chaîne opératoire* in pottery production was overlaid by networks in the northern and southern half, characterised by perforated flint discs and unalloyed copper items plus ivories, respectively. In addition, contacts to the neighbouring cultural entities such as the Timnian in the Negev desert and to regions beyond the immediate neighbours existed. These contacts were most likely maintained by mobile parts of the population, either fully nomadic groups such as the Timnians or mobile herders from the sedentary groups. Moreover, archaeogenetic studies suggest two independent immigration waves before or during the Chalcolithic from the North.

The Southeastern Anatolian and Northern Mesopotamian region splits into several groups at the end of the Ubaid (mid-5th millennium BCE), which again can be grouped by their pottery into an Eastern and a Western group, separated by the Euphrates river. At the end of the 4th millennium BCE, the Western group splits into a northern group and a southern group, and the latter orientates itself closer to the Eastern group. A unifying element of all groups is the production of chaff-faced ware and the serial production of so-called Coba bowls. While sites in the Eastern group such as Tepe Gawra have monumental architecture, a vertically stratified society, and indicators for early urbanism, similar developments are attested in the Western group with Arlsantepe as its most important site only from the mid-4th millennium BCE on. For the time under study here, no clear evidence for a stratified society can be provided in the Western group. The vertically stratified societies in the Eastern group and later in the Western group is based on staple finance, i. e. the control over the access to and distribution of resources, most importantly food. Compared to the other regions, metal items are rare in Northern Mesopotamia and Southeastern Anatolia. From the second half of the 5th millennium BCE on, apparently only small copper tools were produced and they were probably communal items. Except for three burials with small gold and silver items, burials from the period under study do not contain metal in this region.

Cultural processes in the Southern Caucasus are still difficult to reconstruct. Most parts of the Sioni culture were assumingly mobile groups with too ephemeral remains to be readily recognisable in the archaeological record, and only the settlements of Mentesh Tepe and Ovçular Tepesi were investigated in detail, yet. In general, the Southern Caucasus appears to be strongly influenced by the regions to its South; chaff-faced ware is often found together with local pottery. Smelted copper is attested since the 6th millennium BCE but clear evidence for metallurgy dates only to the second half of the 5th millennium BCE. Some of the few excavated graves contained metal items. A reconstruction of the social organisation is not possible yet, but an organisation in large family groups was suggested. The situation changes markedly during the second quarter of the 4th millennium BCE. The Leilatepe-Berikldeebi culture features metal workshops and monumental architecture. In addition, the first kurgans are erected. They contain many metal and other prestige items, indicating a vertically stratified society at this time.

Iran is characterised by small dispersed settlements without social stratification and minor socio-economic inequality at the end of the Neolithic. Processes during the Chalcolithic are similar in all regions but happen in a different pace. Northwestern Iran is part of the Southern Caucasus-Northern Mesopotamia cultural sphere and cultural developments follow the processes there. The North Central Iranian Plateau sees a strong increase in craft specialisation, including workshop quarters with dedicated spaces for, e.g., metallurgy and pottery. Central buildings indicate some kind of coordinating entity but there seems to be no vertical stratification of the society. Examples for long-distance exchange are moulds for shaft hole axes with the corresponding axes found in the cemetery of Susa in Southwest Iran, or lapis lazuli. Metallurgy, the two-chambered pottery kiln, and textile production in Iran is first evidenced in Southeastern Iran, from where it spreads to the other regions during the second half of the 5th millennium BCE. Apart from these innovations, this region adheres to the Neolithic settlement structure and social organisation. The Zagros Mountains seem to be populated at this time by mobile groups with large central cemeteries. Some of the burials contain metal items. In all these regions, items made of metal and exotic stones seem to be used to indicate individually assigned status. A strong contrast provides Khuzestan in Southwest Iran, where monumental architecture for public and sacral purposes in Choga Mish and Susa, and elite residences in Susa indicate a development towards a vertically stratified society. The cemeteries of Susa and Chega Sofla yielded large amounts of metal items. The finds in Chega Sofla indicate a high skill of metal working unparalleled in the other Iranian regions at this time.

Southeastern Europe is included here due to the earliest evidence for copper smelting, dating to the Vinča culture (6th millennium BCE) in modern day Serbia. In the mid-5th millennium BCE this culture collapses. Settlement activities and metallurgy shifts to the Western Black Sea coast with the cemetery of Varna I being probably the most prominent site. Metallurgy in this region is characterised by a large number of heavy copper tools (more than 4300 items) and a high innovativeness with the earliest gold finds, a short episode of “natural” bronze production from stannite, evidence for the alloying of copper and gold, and lost wax casting with gold during the mid-5th millennium BCE. Similar to the Chalcolithic Southern Levant, there is no indication for social stratification in the settlements and burials, despite the large amounts of gold and copper in burials and hoards.

All of these regions were in contact with each other. Archaeological evidence for contacts between the Southern Levant and its North can be traced back as early as the Natufian (13 to 9.6 ka BCE) by Anatolian obsidian in the Southern Levant. The material remains of the Wadi Rabah culture (6th millennium BCE) have many traits that can be related to the Halaf cultural sphere in the North. Similar, Tel Tsaf (first half of the 5th millennium BCE) yielded many indicators for contacts with the Ubaid cultural sphere. During the Chalcolithic, contacts are attested by, e.g., Anatolian obsidian in Southern Levantine sites. Fan scrapers indicate a technological horizon stretching from Egypt over the Southern Levant to Northern Mesopotamia. Diversity and possibly intensity of exchange increases with the Late Chalcolithic: the polymetallic copper alloys and Canaanean Blades are clearly an import from Southeastern Anatolia/Northern Mesopotamia or the Southern Caucasus, while the slow-turning potter’s wheel is a Southern Levantine innovation that spread towards the North. Contacts with regions even further away are attested by, e.g., lapis lazuli beads in Southern Levantine cave sites. Moreover, strong similarities in the social organisation of Southeastern Europe and the Southern Levant were noted.

Nilotic shells in Southern Levantine sites evidence contacts between the Southern Levant and Egypt. In addition, the presence of a Southern Levantine population in Egypt is evidenced by vessels manufactured from local clay in the Chalcolithic Southern Levantine pottery tradition in Buto and a subterranean house in Maadi. However, extensive exchange between Egypt and the Southern Levant is best attested in Tall Hujayrat al-Ghuzlan at the Gulf of Aqaba. This site yielded evidence for extensive copper production and shipment of copper ingots to Egypt. It is culturally unrelated to the Southern Levantine Chalcolithic.

Contacts between the Southern Caucasus and the regions to its South are close since the Neolithic, as Caucasian obsidian in Anatolian sites and Halaf pottery in Caucasian sites indicate. During the period under study here, the Southern Caucasus, Northern Mesopotamia and Southeastern Anatolia are part of the chaff-faced ware technological horizon. It was suggested that differences in the material culture indicate differences between mobile highland communities with “Caucasian” material culture and lowland “Mesopotamian” settlers rather than between separate geographical regions. The emergence of the Kura-Araxes phenomenon during the first half of the 4th millennium BCE seems to be a major disruptor of the contacts between the three regions. So-called Dalma pottery attest contacts of the Southern Caucasus with Iran. In addition, shaft-hole axes were produced in both regions and their occurrence dates to roughly the same time. These axes appear already a bit earlier in Southeastern

Europe and are therefore a strong indicator for contacts with this region.

Southeastern Europe was also in close contact with Anatolia, albeit mostly with Western Anatolia. The distribution of ring-shaped idols indicate an exchange network spanning from Southeastern Europe to Northern Anatolia. However, the mountains between Eastern and Northern Anatolia seem to be a cultural border. Evidence for contacts with Southeastern Europe is missing in East Anatolia and, vice versa, there is no evidence for contacts with the Southern Caucasus in Northern Anatolia.

## 1.2 Archaeometallurgical background

The earliest known evidence for pyrometallurgy was found in Southeastern Europe, where unalloyed copper is smelted and manufactured to awls, axes, hammers and other objects since the early 5th millennium BCE. Already in the mid-5th millennium BCE, smelting activities were extensive with large amounts of heavy tools such as axes and hammers (around 4.7 t of copper in total). Compared to this huge amount of metal, the number of known smelting sites is astonishingly small. Mixtures of green and black or violet minerals were used as ore. The ores were smelted under relatively oxidising conditions in pit furnaces lined with pottery sherds, and the process yielded almost no slag. For a short period, stannite was smelted as well, resulting in tin bronze. The metal was then cast under oxidising conditions.

The earliest known smelted copper in Anatolia is the large chisels, axes and needles of Mersin-Yumuktepe (around 5000 BCE), while the earliest smelting sites date only to the first half of the 5th millennium BCE. Throughout the period under study here, there is almost no change in the smelting process. Copper ore, usually weathered sulphide ore, is smelted in crucibles, which were often placed in a pit. Subsequently, the copper prills were melted in crucibles and cast in open moulds. Beside unalloyed copper, copper with elevated levels of arsenic and sometimes nickel was produced.

In the Southern Caucasus, the earliest known metal finds are beads made of arsenic copper from the 6th millennium BCE. However, the earliest secure evidence for smelting activities dates only to the second half of the 5th millennium BCE. An ore pile found in Mentesh Tepe indicates the smelting of weathered copper sulphides from ophiolite-hosted ore deposits. Slag finds indicate relatively oxidising conditions. Tuyère remains from Ovçular Tepesi indicate the use of blowpipes. Furnaces are yet to be found while crucible fragments were uncovered, indicating that smelting and melting were carried out in crucibles. There is only minor change in the metallurgy of the Southern Caucasus during the period under study.

The earliest evidence for copper smelting in Iran dates to the first half of the 5th millennium BCE. In Tal-i Iblis, weathered polymetallic ores were smelted in crucibles. The smelting process was more reducing than in all other regions under consideration. From early on, arsenic copper is produced alongside unalloyed copper. Larger copper items are found from the 5th millennium BCE onwards, especially in the Zagros Mountains and the neighbouring Iranian regions. Advanced casting techniques are attested by the moulds for shaft-hole axes in Tepe Ghabristan, which feature movable ceramic cores for the creation of the shaft holes. As mentioned above, the largest metal assemblages were found in Susa and Chega Sofla in Khuzestan. However, smelting sites are yet to be found in Khuzestan and it seems more probable that copper was imported from the regions further North, e.g., the North Iranian Plateau.

Being one of the central topics in this study, the metallurgy of the Chalcolithic Southern Levant is extensively discussed. As already indicated, two metallurgical traditions existed: polymetallic copper alloys cast in the lost wax technique, and unalloyed copper metallurgy with open mould casting. Evidence for unalloyed copper metallurgy is confined to the Nahal Beer Sheva. The vast majority of ores was mined in Faynan and brought to the settlements for smelting. A few ore pieces were brought from Timna. Stone anvils and crushing stones with traces of copper minerals found in Abu Matar indicate the beneficiation of ores. The copper ore was directly smelted in a pit furnace of about 30 to 40 cm diameter and about 20 to 30 cm depth with a collar-shaped furnace wall of about 10 cm height. The opening in the furnace wall was about 10 cm wide. The ores were rarely fully liquefied in this furnace and the smelting products are best labelled as reacted ore rather than slag. The widespread occurrence of delafossite and cuprite indicate rather oxidising conditions, similar to the other West Asian regions except Iran. Due to the short and incomplete melting of the ore, metallic copper was present as copper prills inside the reacted ore pieces. In the next step, they were mechanically extracted, melted in crucibles and cast into objects. The crucibles are usually oval bowls with a diameter of about 10 cm and an inner depth of about 7 cm. Casting moulds are yet to be found, suggesting the use of sand moulds. Several tuyère fragments are mentioned but except one from Abu Matar no details about them are published and identification of said fragment as tyuère fragment received justified criticism.

For the lost wax casting process with polymetallic copper alloys, no archaeological finds concerning the production of this metal type exists, yet. Based on the chemistry (up to 25 % Sb and 15 % As, sometimes several per cent of Pb, Ag, or Ni) antimony-rich fahl ores were suggested as ore source. Lead isotope analyses point towards the Southern Caucasus and Southeastern Anatolia as source regions. Technological investigations especially of the metal objects in the Nahal Mishmar Hoard revealed that some were cast over cores usually made of ceramic but at least in one case also stone. Further, they revealed a very heterogeneous casting quality of these objects and the occasional repair of casting errors in the cast-on technique, probably directly after the mould was removed. Mould remains adhering to the metal objects allowed to reconstruct a multi-layered mould design with at least two layers. The inner layer is often made of a paste conssiting of clay from the Moza formation, organic temper and carbonaceous sand. The outer layer is made of either ferruginous clay or lime plaster. The outcrops of suitable raw materials for the moulds suggests a location of the lost wax casting workshop(s) somewhere in the Lower Jordan valley. During the planning stage of this project, Fazael in the Middle Jordan valley was suggested as potential production site due to the co-occurrence of crucible fragments – the first ones outside the Nahal Beer Shea sites – and a large number of fragmented lost wax cast items in its sub-site Fazael 2.

Tall Hujayrat al-Ghuzlan and Tall al-Magass at the Gulf of Aqaba revealed a proto-industrial scale of copper production with ores from Timna. These sites are not part of the Chalcolithic Southern Levant cultural sphere, as mentioned above. They differ in their copper metallurgy by the use of crucibles rather than furnaces for smelting. In addition, it seems that copper ingots were the main product at these sites while proper ingots (in contrast to metal lumps) are absent in the Chalcolithic Southern Levant.

Similar to copper metallurgy, the earliest evidence for the use of gold is found in Southeastern Europe. Although not the oldest site, the cemetery of Varna I (mid-5th millennium BCE) is the most famous one because of the large number of gold items found here. Gold was manufactured into personal ornaments, ring-shaped idols, miniature tools, and staff/sceptres. Most of the objects were cast, a few in the lost wax casting technique. As a result, this site provides also the earliest evidence for this casting technology.

In Western Asia, gold items occur slightly later as single small objects such a wires or beads, often in combination with items made of other exotic materials. Compared to the large spatial extent in the area, they are very rare. Important examples are the gold bead in a burial in Tepe Gawra and another one in a burial in Grai Resh, both dating towards the end of the 5th millennium BCE. About the same time date the few gold items found in Chega Sofla. A golden lost wax cast bead in Tepe Hissar dates to the first half of the 4th millennium BCE. The only gold items of the Chalcolithic Southern Levant are the two gold and six electrum rings from the Nahal Qanah burial cave. The earliest gold in the Southern Caucasus dates to the second quarter of the 4th millennium BCE, among them two massive lost wax cast bulls in the Maikop kurgan. With the gold mine in Sakdrisi and a crucible in the close-by settlement of Dzedzvebi (both mid-4th millennium BCE), this region yielded the earliest evidence for the mining and smelting of gold ore.

Silver objects are reported from Southeastern European sites contemporaneous with the earliest gold finds. However, their contexts are unclear and the earliest securely datable silver items in this region date to the second half of the 4th millennium BCE. They are pre-dated by finds from Southeastern Anatolia, Northern Mesopotamia, and Iran. Silver earrings found in a burial in Hacınebi date to the first half of the 4th millennium BCE, as does the first evidence for cupellation, found in Southeastern Anatolia. From the mid-4th millennium BCE on, cupellation is attested in several sites in Northern Mesopotamia and Iran. The earliest silver finds of the Southern Caucasus were found in the kurgans, among them two silver equivalents of the golden lost wax cast bulls in the Maikop kurgan. In the Southern Levant, silver is not found before the Early Bronze Age.

In addition to the archaeometallurgical background, key aspects of the smelting processes with unalloyed copper ore and fahl ores as well as the properties of polymetallic copper alloys are discussed. The draught technique, central topic in the re-assessment of the Chalcolithic unalloyed copper process in the Southern Levant, can be reconstructed from the tuyères' inner diameters. Experimental work and thermodynamic calculations showed that a diameter of 5 to 10 mm is optimal for blowpipes, while tuyères with 20 to 30 mm inner diameter are optimal for bellows.

It is highlighted that with the technology and furnaces available at this time, a reducing atmosphere and a complete melting of the ore can rarely be achieved. Instead, a solid-state reaction of the copper minerals to metallic copper happened. The use of weathered sulphide ores is beneficial for the process because the exothermic reaction of sulphur with oxygen increases the temperature and the reducing atmosphere in the furnace at least locally. Experimental studies showed that smelting of (weathered) fahl ores without prior roasting can result in the production of unalloyed copper alongside speiss of a composition similar to the polymetallic copper alloys found in the Chalcolithic Southern Levant.

Examples from other geographical areas showed that polymetallic alloys with such high levels of antimony and arsenic are exclusive to the Chalcolithic Southern Levant. An exception are ingots from the Bronze Age Eastern Alps. They have a comparable chemical composition but were alloyed with unalloyed copper and melted under oxidising conditions before casting the metal, significantly reducing the amount of arsenic and antimony in the cast items. All other finds with a comparable chemical composition have either less than 10 % Sb or very low arsenic levels.

Arsenic, and to some extent antimony, is extremely volatile under oxidising conditions. This makes the production of arsenic copper and polymetallic alloys not straightforward. Several theoretical and experimental approaches are presented but the best method with the technological knowledge of this time seems to be the production of arsenic copper through the direct smelting of heavily weathered fahl ores or the alloying of unalloyed copper with speiss.

Arsenic and antimony decrease the smelting point of copper significantly, increasing its castability. Arsenic also increases the hardness and plasticity of copper significantly, while high concentrations of antimony make copper brittle to an extent that it cannot be mechanically worked any more. Consequently, the polymetallic copper alloys used in the Chalcolithic Southern Levant could only be used for casting decorative and status-communicating items.

Depending on the different levels of the alloying elements in a metal, its colour differs. For example, depending on the levels of antimony and arsenic in the copper, the colours of polymetallic copper alloys range from copper to haematite-like, golden, and silver-like colours. The different colours of metal alloys was not only used by past metallurgists as indicator for the composition of the metals but was also deliberately exploited for aesthetic purposes, e.g., by the arrangement of differently coloured gold beads in a necklace in the Varna I cemetery. C. S. Smith concluded that aesthetic properties of new materials were always exploited before their usability for tools. Metal is not different from other materials in this regard. Consequently, the role of metal objects in past societies should be investigated as one material under many and not as superior to e.g. pottery or stone. The early metal items in Southeastern Europe are good examples for such a focus on the sensory properties of metals. They were embedded in an aesthetic concept of shininess together with graphitised pottery. It seems that the occurrence of many different metal types with different shiny colours (e.g. silver) over the 4th millennium BCE in Western Asia was motivated by the same pursuit for shiny materials. The example of the South American Muisca show that it is not necessarily the metal items that are of importance, but it can also be the production process (in this case lost wax casting) as the focal point of a ritual.

## 1.3 Lost wax casting

### 1.3.1 Visibility in the archaeological record

Despite the large number of Chalcolithic sites in the Southern Levant, all mould remains so far were found attached to metal objects in protected places such as burial caves. As a result, it remains unclear whether mould remains at the production sites are not preserved, were found but not recognised as such or are yet to be found. Although previous studies identified a multi-layered design, the use of chaff temper, and the occasional use of plaster as key characteristics of the moulds, most of these features can only be recognised with petrographical methods and not readily in the field. Therefore, an archaeological experiment was carried out based on knowledge from previous studies and complemented by ethnographical records to investigate the recognisability of lost wax casting moulds in the archaeological record. Because layers made of different clays can be easily identified in thin sections, the recognisability of layers with the same clay but with different amounts and proportions of temper was investigated.

The archaeological experiment was a multi-purpose experiment. Raw materials comparable to the materials used in the Chalcolithic were used to re-create the lost wax casting moulds. The moulds were then heated to remove the wax. At the same time, crucibles and a furnace were built according to the reconstructed furnaces of the unalloyed copper process to test their operability with bellows (see below) and to melt the copper and antimony for casting.

Four runs were carried out, in none of them was enough metal melted for a successful casting. The moulds were fragile right after casting and their fragility increased significantly in the next couple of days. Complete cross-sections of two moulds as well as partial sections of the other moulds were prepared for petrographic examination. Recorded trampling and submerging experiments with mould pieces and other metallurgical ceramics were carried out to simulate mechanical stress and their interaction with water.

Because none of the archaeological moulds showed interaction with the molten metal and the archaeological and experimental ceramic pastes are overall comparable, the experimental moulds are viable analogues of the archaeological ones. The post-experiment increase in the fragility of the moulds is best explained by the rehydration of the carbonaceous sand after heating and the associated volume increase. Crushing the moulds and sectioning them for petrography revealed that the inner and outer layer can be easily separated, masking their original multi-layered design. Petrographic analyses showed that the different layers can only be recognised by the different temper mixtures of the clay pastes. The alteration tests revealed that the mould fragments are stable when submerged for several hours but that one step is often enough to crush them into tiny crumbs, which are not recognisable in the archaeological record any more. Consequently, mould remains in archaeological sites must be expected to be rare. If preserved, they are friable and potentially rounded pieces of low-fired ceramics and, therefore, might be easily mistaken for heated soil crumbs.

An additional universally applicable characteristic of the lost wax casting moulds is suggested: the mixture of vegetal and mineral temper. The validity of this criterion is underpinned by general technological considerations. Pottery in the Late Chalcolithic Southern Levant is made exclusively with mineral temper, and metallurgical ceramics exclusively with chaff temper. In case of pottery, this temper choice maximises mechanical strength and reduces porosity of the vessels. For metallurgical ceramics, a high porosity is desirable to increase heat insulation and to prevent spreading of cracks. Lost wax casting moulds had to combine both properties: The comparably thick moulds had to be stable enough to be heated from the outside to sufficient temperatures inside. At the same time, the high porosity especially in the inner layer prevents the spreading of cracks while allowing the air in the mould to escape during casting. With this criterion at hand, mould fragments can be reliably identified regardless of their multi-layered design, as long as archaeologists are aware to collect seemingly inconspicuous pieces of heated sediment or low-fired ceramics.

### 1.3.2 The meallurgical assemblage of Fazael

Fazael is located along the riverbank of the Wadi Fazael and consists of several Chalcolithic broad room houses and other archaeological features. Excavations in the broad room house Fazael 2 yielded many fragments of lost-wax cast and unalloyed copper items together with several crucible fragments and heated sediment nodules and, thus, was suggested to having been a lost wax casting site. Metallurgical installations such as furnaces are yet to be found, though. The broad room Fazael 5 yielded a small hoard, consisting of a head-shape standard into which a chisel, an awl and a spiral-shaped object were shoved. The broad house Fazael 7 has walls preserved to a height of more than 1 m and contained many metal fragments as well as complete metal items. Fazael 2 was radiocarbon dated to 4000 to 3900 BCE, i.e. to the very end of the Southern Levantine Chalcolithic. This date is supported by an incomplete Chalcolithic material culture and the appearance of elements typical for the Early Bronze Age, such as Canaanean Blades.

Due to the already fragmented state of the many metal objects, a representative selection of them could be sectioned for metallographical investigation including SEM-EDX. In addition, several crucible fragments and heated sediment nodules were sectioned for petrography. The aim was to investigate whether the remains allow an identification of Fazael 2 as lost wax casting site and to gather new insights into the lost wax casting process.

The chemical composition of the sampled metal objects is in agreement with previous analyses from other sites, although the polymetallic copper alloys have an overall slightly depleted arsenic concentration and are slightly enriched in the other alloying elements. The items can be subdivided into three groups based on their metallographic structure: unalloyed copper objects, objects with low levels of alloying elements and objects with high levels of alloying elements. These groups correspond to the chemical composition of the objects. They confirm existing notions of the Chalcolithic metallurgy but add two important observations: the metal of some items contain large amounts of silt-sized angular quartz, and some of the polymetallic copper alloys contain inclusions of unalloyed copper and, in one case, of a multi-phase copper alloy.

The copper inclusions show that the polymetallic copper alloys were not completely melted upon casting. While a reliable estimate of the actual melting temperature is impossible due to the complex interplay of the alloying elements, all of them decrease the melting point of the alloys compared to unalloyed copper. Consequently, the metal could be liquid enough for casting well below the melting point of unalloyed copper. At the same time, the presence of unalloyed copper inclusions in the polymetallic copper alloys evidence some sort of mixing of the two metal types. In addition, the inclusions of multi-phase copper alloys in one sample indicate that such mixing must not necessarily involve only unalloyed copper. This is the first evidence for mixing of polymetallic copper alloys. The motivation for and location of the mixing action remains unknown. It could be related to, e.g., the alloying of speiss as some sort of master alloy with unalloyed copper or recycling.

The whereabouts of the quartz inclusions must remain unknown as well. In contrast to a single sample from Bir es-Safadi, they occur in the entire section and not only at the surface. This excludes their origin as contamination from, e.g., the casting mould. Options are presented but none of them could provide a convincing hypothesis why silt-sized quartz is dispersed throughout the object.

The crucible fragments can be separated into three petrographic groups. The first group does not consist of crucibles but vessel fragments made of Moza clay. The second group consists of the low-fired object F225a with a calcareous foraminifera-rich clay and carbonaceous sand. Only the third group contains actual crucibles as is indicated by the vitreous and bloated ceramic paste with vegetal matter, in good agreement with the metallurgical ceramics from the Nahal Beer Sheva sites.

The heated sediment nodules seem to be made from the same clay as the crucibles but were heated to much lower temperatures. While some of them contain no temper at all, other contain vegetal temper, carbonaceous sand, or both. One nodule features two layers of different size fractions of the same clay. F2-Y55 is distinct from all these nodules because it is entirely blackened and contains rounded inclusions of vitreous copper-free material, together with vegetal and mineral temper.

Comparison with sediments from the Wadi Fazael showed that crucibles and heated sediment nodules were made of this clay. According to the criteria established above, most of the heated sediment nodules can be reliably interpreted as remains of lost wax casting moulds. Being a single find, the function of F225a must remain unclear.

In conclusion, the study of the metallurgical assemblage of Fazael allowed identifying Fazael as production site for lost wax cast objects by the identification of in-situ lost wax casting mould fragments for the first time. In addition, it provided for the first time direct evidence for the mixing of polymetallic alloys with unalloyed copper and tentatively also with other polymetallic alloys.

## 1.4 Re-assessing the metallurgical assemblage of Abu Matar

Based on the experience from past smelting experiments, some aspects of the current reconstruction of the Chalcolithic unalloyed copper process in the Southern Levant seemed impractical, particularly the use of blowpipes through the collar opening, and covering the furnace with a large ceramic lid, as suggested by J. M. Golden. In an attempt to refine this reconstruction, the metallurgical ceramics and slag of the Abu Matar excavations in the 1990s were re-assessed and led to the identification of several important but hitherto overlooked pieces.

The probably most important ones are two pieces with a clear channel-like feature of about 2.5 to 3.0 cm diameter. While one is made of chaff-tempered ceramic and only slightly vitrified with some greenish spots, the other is completely vitrified. In addition, a large slag fragment features a similar channel with a larger diameter. Further, several ceramic objects are particularly thick, rounded on one side and have slagged sides that extent over the edge to another side. Two other ceramic rim fragments deviate visibly in their paste from the other metallurgical ceramics by the presence of carbonaceous sand and the absence of chaff temper.

The slags and some of the ceramics were sampled for microscopic and SEM-EDX analyses. For the remaining objects, the macroscopic features were of interest and sampling did not promised any additional insights.

Results of the analyses show that the sand-tempered ceramics are secondarily used fragments of a V-shaped bowl and a hole-mouth jar. While secondary use of V-shaped bowls as crucibles was already previously encountered, this is the first evidence for the secondary use of other vessel types in the metallurgical process. The slagged fracture on one side of the hole-mouth jar fragment suggest the use of hole-mouth jar sherds as furnace cover. Such a use would also allow to cover the furnace with objects that are much easier to handle than one large ceramic lid.

The completely vitrified fragment with the channel-like feature turned out to be of ceramic origin rather than slag. Together with the other ceramic fragment with a channel-like feature, they are interpreted as tuyère fragments due to the lack of other objects in the metallurgical process with such a narrow channel. Their diameters suggest the use of bellows. Operating the furnace with bellows instead of blowpipes through the collar opening appears much more sensible because it allows heating of a larger area in the furnace while operating the furnace more efficiently with less effort. In addition, the archaeological experiment showed that a bellows-operated furnace can produce sufficiently high temperatures for copper smelting.

A reconstruction for the use of the rounded ceramic fragments was not entirely possible. They do not appear to be part of the furnace wall nor do other sites report any comparable objects. It is suggested here that they may have been some kind of mobile platform for the crucibles to melt the copper prills next to the mould, and fragments of the “clay cakes” J. Perrot mentioned but described only poorly.

Based on these results and interpretations, the reconstruction of the unalloyed copper process can be refined: Smelting of copper ore in a furnace covered with hole-mouth jar fragments to keep the heat and to increase the reducing conditions. Bellows were used for draught. The furnace was operated in a rotating manner, placing fresh fuel and ore on the side opposite the tuyère and pushing it closer to the tuyère when the material there reacted. The copper prills were then mechanically extracted from the slag as previously reconstructed and then melted in crucibles. Because handling of the crucibles inside the pit furnace is difficult, they were most likely placed on small mobile platforms next to the moulds, where they were covered in small heaps of fuel. Probably, blowpipes provided draught for this step because they allow much more control over the intensity and direction of the air stream.

## 1.5 Evolution of the innovation "lost wax casting"

Based on the extensive literature review, a large West Asian interaction sphere consisting of Southeastern Anatolia, Northern Mesopotamia, the Southern Caucasus and Iran can be reconstructed. Within this interaction sphere, materials but also ideas could spread quite easily but were not necessarily adopted everywhere. Moreover, two fundamentally different status-communicating systems could be identified. The Southern Levant, parts of Iran, and Southeastern Europe communicated status through metal objects and other so-called prestige items. A characteristic of this system is the use of metal items and other exclusive goods as burial goods. In contrast, Northern Mesopotamia and other parts of Iran used monumental architecture and staple finance to communicate status. The status-communicating system of the Southern Caucasus is unclear but the absence of monumental architecture and the presence of metal items in some of the burials suggest it belongs to the former one.

On another strand, except for the Southern Levant, lost wax cast items in West Asia at this time are always made of gold and massively cast. It is therefore suggested that a technological package "lost wax casting with gold" spread from Southeastern Europe through the Caucasus into the West Asian interaction sphere, probably together with the shaft hole axes. Depending on the compatibility with the status-communicating system, this technological package was modified. While the shaft hole axes were readily adopted in the Southern Caucasus and Iran, the technological package becomes only visible in the archaeological record after some delay, seemingly unchanged but in the very different ideological setting of a vertically stratified society. In Northern Mesopotamia and Southeastern Anatolia, only the new material gold seems to be adopted. An explanation might be that the ideological aspects of the technological package – communicating status through metal objects – was incompatible with the communication of status through staple finance and monumental architecture while gold as new material was compatible to the newly discovered silver.

The Southern Levant adopted and heavily modified the technological package. Instead of gold, polymetallic copper alloys were used, the produced objects are much larger than anything else produced in this technique before, and ceramic cores were used instead of massive casts. The reasons for these modifications seem to be technological and aesthetic. Gold is not readily available in the Southern Levant and the large amounts necessary for the produced objects probably exceeded by far, what was available elsewhere – if it was available there. In addition, polymetallic copper alloys have a much lower melting point and it seems likely that it was only because of this that such large objects could be produced in the lost wax casting technique. The aesthetic component was probably equally important: Depending on the composition of the polymetallic copper alloys, not only the new materials gold and silver could be imitated but also haematite. Haematite mace heads were produced long before the advent of metallurgy in the Chalcolithic Southern Levant and vessel figurines, ossuaries and other ceramic objects often decorated with red bands. Ceramic cores were likely used to save on metal.

A key factor for this quick adoption in the Chalcolithic Southern Levant is the compatibility of the technological package with the existing social system. It is argued here that metal items in the Chalcolithic Southern Levant are representations of objects made of other materials (e.g., stone, pottery, wood). The arrival of metallurgy in general and the lost wax casting technology in particular did not only fill a need in the local population for such shiny representations. At the same time, the strong modification of the technological packages makes it likely that it was stripped from its ideological aspects except for the most basic concepts, status-communication through special items and use of shiny materials, and fully included into the local ideology.

## 1.6 Role of metal in the Chalcolithic Southern Levant

Previous research already indicated that both, the unalloyed copper objects and the lost wax cast objects were status-communicating items. Therefore, their role in the Chalcolithic Southern Levant must be discussed together. Rather than a full-fledged hypothesis, some ideas are presented.

It is suggested that all copper-based metal objects in the Chalcolithic Southern Levant are representations (skeuomorphs, imitations) of objects made of other materials. While this is rather obvious for tool-shaped objects and mace heads, other objects were likely made of perishable materials. For example, previous studies suggested that the decorated mace heads might represent seeds or bulbs and some objects in the Nahal Mishmar Hoard have similarity with reed canes.

If the ideology of the Chalcolithic Southern Levant is so heavily ritualised as suggested by some researchers, the metal objects are likely to be ritual representations of mundane objects. However, some iconic objects of the Chalcolithic Southern Levant do not have metallic representations, such as V-shaped bowls and basalt bowls. A likely explanation is that they were already ritual objects and, therefore, did not need metallic representations.

The turn of the Early to the Late Chalcolithic and the associated change from architecture to metal items for status display might indicate a shift in the ritual system of the Chalcolithic Southern Levant. It is suggested that this shift might be related to a decline of the Chalcolithic ideology due to a decreased power in explaining the changing environment. Metal objects might have been the opportunity to reinforce this power.

It is further suggested that one of the key elements to understand the role of metals in the Chalcolithic Southern Levant is their colour. We know from other cultures that gold is often associated with the sun, while silver is associated with the moon. Both were important divine entities in early farming societies. In the Chalcolithic ideology, haematite-like colours or red in general might be related to the ancestors. Thus, metallurgical practices might have been a way to connect with the divine sphere and transform objects from the mundane sphere into the ritual sphere. Smelting and melting can be easily turned into audio-visually impressive rituals, through which this communication could be performed.

Previous studies suggested that many aspects of the Chalcolithic ideology are related to a cycle of death and rebirth. Metallurgy was probably firmly embedded in it. Smelting haematite-rich copper ore to metal might symbolise the rebirth of ancestors. Transforming items symbolising them into their metallic equivalents might have been part of rituals connected to the passage of deceased into the nether world.

If they were indeed symbolic representations of the deceased, the central aspect of metallurgy might have been the ritual transformation of the mundane item into its ritualised representation. This must not necessarily be connected to metallurgical processes, i.e. their production. This could explain why metal items were part of exchange networks together with other ritual objects.

At the end of the Chalcolithic, the ideology collapses entirely and most of the prestige-items disappear. Environmental conditions probably changed to an extent that the Chalcolithic ideology could not provide suitable explanations for them anymore, leading to ritual failure. In addition, internal conflicts might have originated from the important ritual role of metal and might have contributed to the decline of the ritual framework of the Chalcolithic ideology. With the collapse of the Chalcolithic ideology, the lost wax cast items and the polymetallic alloys lose their purpose, whereas the utilitarian value of unalloyed copper was recognised, perhaps inspired from the Aqaba sites. Consequently, the lost wax casting metallurgy was abandoned while the unalloyed copper metallurgy was incorporated into the efficiency-focussed and goal-oriented mindset of the Early Bronze Age.

Keywords: Chalcolithic, Ghassulian, Southern Levant, Abu Matar, Fazael, metallurgy, copper, smelting, lost wax casting, polymetallic copper alloys, innovation

# Chapter 2

# Introduction

The Chalcolithic Southern Levant (4500 to 3800 BCE) is probably most famous for its metal artifacts. Being among the earliest ever found in this region, lost wax cast objects made of polymetallic copper alloys attest to an outstandingly high level of metalworking skills at the onset of metallurgy in this region. The most important assemblage of these items is the Nahal Mishmar Hoard (Bar-Adon, 1980). Found in the 1960s, it is still the largest assemblage of metal items from this period in the Southern Levant and with more than 400 metal objects among the largest ones in Western Asia.

Petrographic investigations of mould remains attached to the metal items revealed their manufacture as multi-layered material from Southern Levantine clay, evidencing a Southern Levantine manufacture of the objects (Goren, 2014, 2008). However, production sites remained elusive. Suitable ores for the production of the polymetallic copper alloys are absent in the Southern Levant and their lead isotope signatures point to Southeastern Anatolia and/or the Southern Caucasus as most likely ore source (Tadmor et al., 1995). Remains for the smelting of such ores could be found neither there nor in the Southern Levant. The closest finds are some ore pieces from Arslantepe and Norşuntepe in Southeastern Anatolia with a suitable chemical composition, but they seem to be unrelated to the metallurgical activities at these sites (Hauptmann et al., 2002; Zwicker, 1980). As a result, this technology remains enigmatic in most parts. Practically only the main features of the mould design can be inferred from the archaeological record. Combined with ethnographic approaches (e.g., Levy et al., 2008), they allow reconstructing the main steps of the casting process.

The technology is also singular on a wider chronological and geographical scale. Contemporary lost wax cast items are only found in the cemetery Varna I (Bulgaria) and Mehrgarh (Pakistan) where they are made of gold and unalloyed copper (later leaded copper), respectively. In difference to the Southern Levant, suitable ores can be found in reasonable distances in the two regions. While the objects from Varna predate the Southern Levantine lost wax cast items by a couple of centuries (mid-5th millennium

BCE), the objects from Mehrgarh can be only roughly dated between 4500 and 3600 BCE (Higham et al., 2018; Leusch et al., 2014; Mille, 13.06.2017). In addition, finished objects made of polymetallic copper alloys with more than 10 wt.% Sb are not reported from any other period in any other region (cf. chap. 4.3.1), emphasizing the uniqueness of the lost wax casting technology in the Chalcolithic Southern Levant.

Nevertheless, the technology did not exist in a vacuum. The polymetallic copper alloys provide unequivocal evidence for long-distance contacts. At the same time, the iconography of the lost wax cast objects indicate a deep embedding in the ideology of the Chalcolithic Southern Levant (e.g., Shalem, 2015). While the latter was investigated in several studies (e.g., Gošić and Gilead, 2015a; Levy and Shalev, 1989), a systematic approach to the inter-regional aspects of the polymetallic copper items is still missing. In a technological dimension, an unalloyed copper process complemented the metallurgy of the Chalcolithic Southern Levant. In contrast to the lost wax casting process, production sites are known and provided remains from all steps of the smelting process. They attest to the use of local ores, their processing in a two-step process, and casting of tool-shaped objects in open moulds (Golden et al., 2001; Hauptmann, 1989a; Shugar, 2000). Although the tool-shaped objects present a clear difference to the mace heads, standards, so-called crowns and many singular objects made in the lost wax casting technique, the absence of use wear on items from both metal technologies (e.g., Namdar et al., 2004) suggest that their role within the Chalcolithic ideology was similar, if not the same.

Even if the unalloyed copper process can be significantly better reconstructed than the lost wax casting process, many important aspects remain unclear, most importantly the draught technique. Moreover, some aspects of the reconstruction seem cumbersome to questionable when put into practice. Additionally, the incorporation of general metallurgical knowledge about the properties of the different metal types and the respective production processes remained a desideratum in almost all previous investigations on the metallurgy of the Chalcolithic Southern Levant. However, its incorporation might allow creating a more detailed understanding of the metallurgical processes than the scarce to absent archaeological remains alone would allow. Similarly, an inter-regional perspective on the innovation "lost wax casting" and the polymetallic copper alloys was not taken so far but promises new insights into the origin and evolution of this innovation. Combined with approaches on the perception of metals and colours (e.g., Kuijpers, 2018a; Mödlinger et al., 2018), this might even help to better understand the role of metal items in the Chalcolithic Southern Levant.

Therefore, the objective of this thesis is to include hitherto neglected approaches into the research on lost wax casting technology and polymetallic copper alloys in the Chalcolithic Southern Levant. It aims to generate new insights about the technology, its whereabouts and the use of the respective items in the Chalcolithic society. To reach this aim, the approaches mentioned above where complemented by a re-examination of the metallurgical assemblage from the 1990s excavation at Abu Matar (Gilead et al., 1991) for the unalloyed copper process, a technological study on the newly discovered metal assemblage of Fazael (Rosenberg et al., 2020) for the lost wax casting process, and an extensive literature research for the archaeological and theoretical background. Being a joint project between Ben-Gurion University of the Negev and Sapienza – Università di Roma, the site of Arslantepe in Southeastern Anatolia, excavated by Sapienza, was supposed to become the major source for the inter-regional comparison. Arslantepe is a connecting point between the Southern Caucasus, Southern Anatolia, and Northern Mesopotamia (Di Nocera, 2010) and yielded a comparatively extensive metallurgical assemblage, including the above-mentioned polymetallic ore pieces. All these factors made it the perfect reference point outside the Chalcolithic Southern Levant for this part of the project.

Research was guided by nine research questions, grouped into three topics:

1. The technology of lost wax casting in the Chalcolithic Southern Levant
    a. How were the objects cast and where did the raw materials came from (esp. the metal)?
    b. Why did the ancient metallurgists do it how they did it?
    c. How can the technology of lost wax casting be identified in the archaeological record?
2. The rise and demise of lost wax casting
    a. Why and how did lost wax casting emerge in the Southern Levant?
    b. Can lost wax casting in the Southern Levant be regarded as a "failed" innovation?
    c. What does the technology of lost wax casting tell us about the socio-technological and socio-economic aspects of the Chalcolithic Southern Levant?
3. An inter-regional perspective on the lost wax casting technology
    a. How did metallurgical knowledge from Southeast Anatolia, Transcaucasia and the Iranian Plateau contribute to the use of polymetallic copper alloys in the Southern Levant?
    b. Which role played the polymetallic copper alloys in the inter-regional relations, especially between the Southern Levant and Southeast Anatolia?
    c. Was the Chalcolithic Southern Levantine lost wax casting technology a "one off" in the overall metallurgical developments?

During the course of research, only the part of 1a concerned with the origin of the raw materials was abandoned. It was not possible to obtain new lead isotope data, precluding any advances in the reconstruction of the polymetallic copper alloys' provenance. At the same time, production remains for this metal type remained invisible, somewhat limiting the scope of the answers to many of the other research questions. As a result, the third research topic focussed on the innovation "lost wax casting" rather than the polymetallic copper alloys.

Although roughly equal amounts of time were spent on the different research questions, the outcome is not equally balanced between them concerning the depth of the discussions. The major reason is the background of the author with profound training in the technological aspects but little to no background in the archaeology of West Asia in general, and the Chalcolithic Southern Levant in particular. Additionally, the heated or baked sediment nodules found in the 2020 field season in Fazael added an unanticipated dimension to the study of lost wax casting remains. Consequently, a profound discussion of the technological aspects was possible while the necessary extensive reading for the other aspects resulted on a strong focus on metal and the metallurgical processes, while evidence from other materials could only be cursorily included in the discussion. This clearly impacts the robustness of the conclusions drawn in the respective chapters although a very cautious approach is purposefully taken when interpreting the observations made.

Therefore, the structure of the thesis does not strictly follows the research questions. Instead, it follows a more assemblage-focussed approach. Chap. 3 provides an extensive presentation of the archaeological background in the different regions under consideration in this study (Fig. 2.1, 2.2) with particular emphasis on the role of metals and the social organisation within the regions, and indicators for contacts between them. The investigated time frame roughly corresponds to the Chalcolithic Southern Levant, i.e., 4500 to 3800 BCE (Fig. 2.3), but includes older developments that resulted in to important aspects for the period under study. Later developments are briefly mentioned. They were expected to provide insights as well, but in almost all regions the second quarter of the 4th millennium BCE shows such profound changes in the social structure and/or the technological levels that they do not allow an extrapolation. Chap. 4 complements the presentation of the state of the art with a metallurgical perspective. The first part of this chapter presents the archaeometallurgical background for all regions in the period under study, focussing on the types of metals used and the metallurgical processes. The second part summarises knowledge about some general metallurgical aspects: Basics of early copper smelting processes, the production, occurrence, and properties of arsenic- and antimony-rich polymetallic copper alloys, and the importance of sensory aspects when investigating the role of metals in early metal-using cultures.

The next chapter presents and discusses the research on the technological aspects of the lost wax casting technology, i.e. the visibility of lost wax casting moulds in the archaeological record (chap. 5.1, research question 1c) and the analyses of the metallurgical assemblage of Fazael (chap. 5.2, research questions 1a and 1b for the lost wax technique). It is followed by a re-examination of the current reconstruction of the unalloyed copper process based on the metallurgical assemblage of the 1990s excavation in Abu Matar (chap. 6, research questions 1a and 1b for the unalloyed copper process). The subsequent chapter 7 discusses research questions 2a, 3a, and 3b collectively, with the mentioned modifications. Heavily drawing from the results of the literature review presented in chap. 3 and

4, it identifies a potential origin for the innovation “lost wax casting”, traces its modification in the different cultural settings and status-communicating systems prevailing in Western Asia at this time, and discusses why this innovation was incorporated into the Southern Levantine Chalcolithic. Chapter 8 provides some thoughts on the research questions 2b, 2c, and 3c, which turned out to be closely interlinked. Finally, chap. 9 summarises the results obtained in the thesis and briefly discusses the potential of the methodological approaches utilised in this thesis for future research.

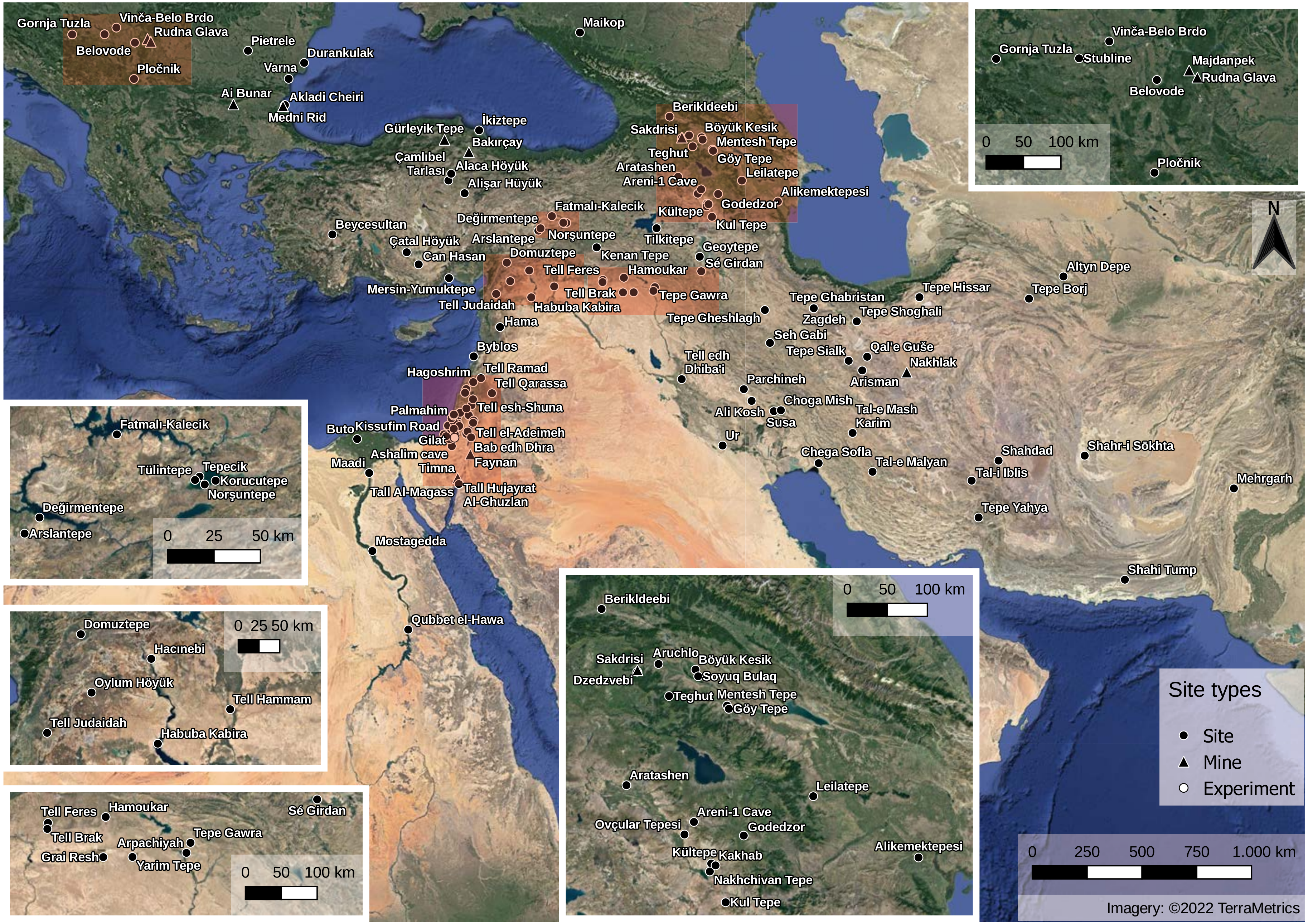


Figure 2.1: Map of West Asia and neighbouring regions with all sites mentioned in the text. Location of the insets are indicated by red rectangles. See the following page for the inset of the Southern Levant.

Imagery: ©2022 TerraMetrics

Figure 2.2: Map of the Southern Levant with all sites mentioned in the text.

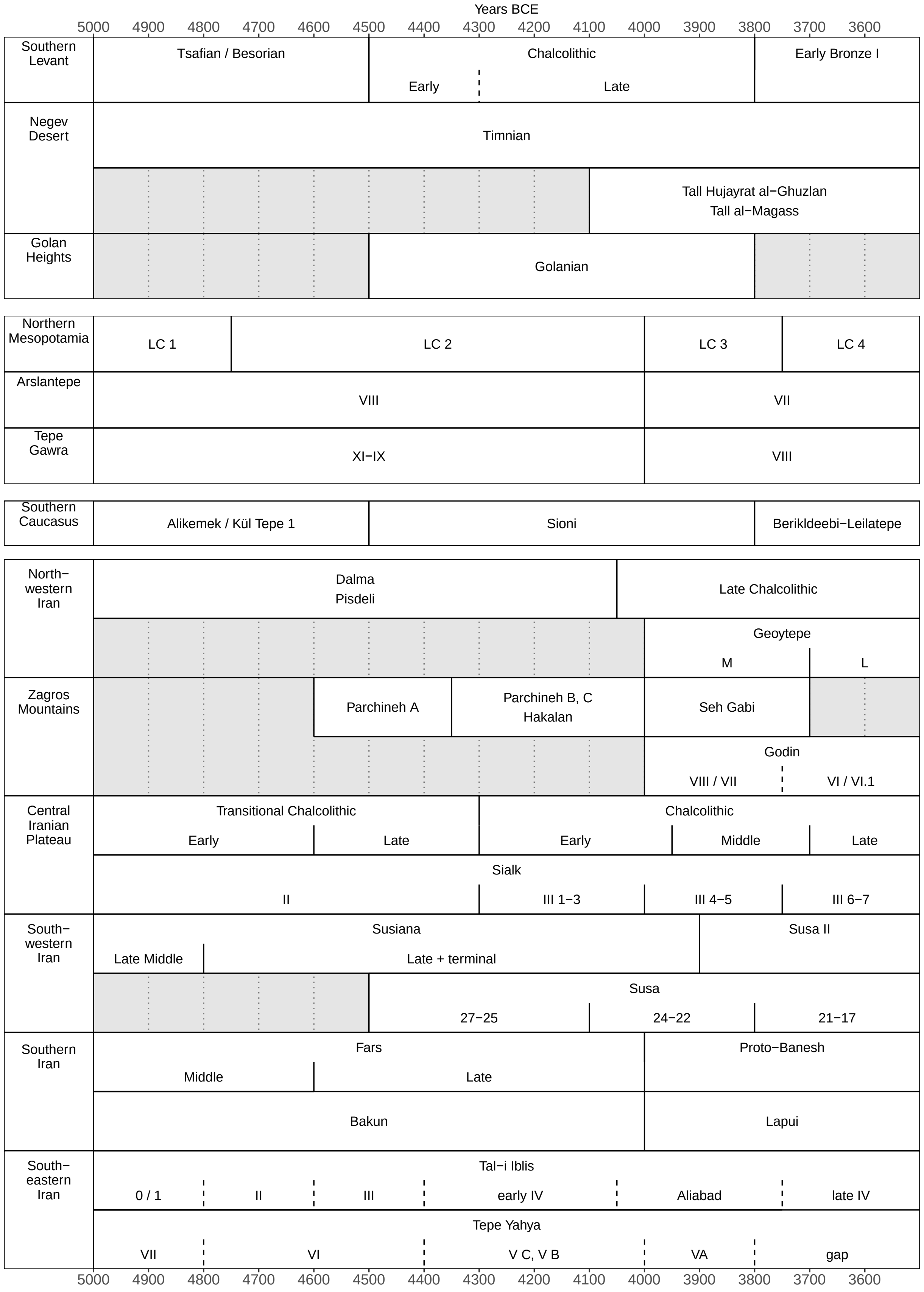


Figure 2.3: Chronological chart of the West Asian regions discussed in this study. Data compiled after: Gilead (2011) (Southern Levant), Vignola et al. (2019) and Balossi Restelli (2019) (Northern Mesopotamia, Southeastern Anatolia), Courcier (2014) (Southern Caucasus), Helwing (2013a) (Iran). Chart created with chronochrt (Rose and Girotto, 2022).

# Chapter 3

# Archaeological background

While a detailed presentation of the archaeological record in the regions under consideration is beyond the scope of this study, a good understanding of the general developments and inter-regional relations during this time is essential. This chapter aims to provide a concise overview of the respective regions focussing on the social organisation, the role of metals and the contacts between the different regions.

The focus of this project is on the Chalcolithic Southern Levant, its metallurgy, and its relations to neighbouring regions and other regions to which contacts can be traced for the reconstruction of potential technology transfer between them. Therefore, the detailedness of the accounts on the different regions vary depending on the amount of archaeological background necessary for the socio-economic context of the metallurgical developments during the period under study and their general relations to the Southern Levant. Only relations between the Chalcolithic Southern Levant and Egypt are discussed but not the cultural developments in Egypt, because Egypt did not have an own metallurgy at this time. Any necessary additional information will be provided directly in the discussions where necessary.

## 3.1 Regional developments in the mid-5th to early 4th mill. BCE

### 3.1.1 The Southern Levant

The term Southern Levant, as it is used in this study, encompasses today's Israel, the Westbank and Gaza strip, the South of Lebanon and Syria, and the western parts of Jordan. Geographically, it covers the area from the coast of the Mediterranean Sea to the Rift, from the Gulf of Aqaba to the Huleh Valley on both sides of the Jordan, the Golan Heights and the Transjordanian Plateau. A wide variety of climates prevail in this region. Deserts characterise its South (the Negev, Rift valley) and the area around the Dead Sea. The coastal plain and the northern hill countries to its West (Samaria, Galilee) have a Mediterranean subhumid climate. Steppe climates prevail in the desert transition zone to the coastal plain (Northern Negev, Judean Plateau) and the Golan Heights. Precipitation is concentrated in the rain season from November to May and might result in flash floods, especially in the deserts.

The climate during the period under study here was similar to today's climate or slightly more humid with a similarly large regional variation (e.g., Bar-Matthews et al., 1999; Frumkin et al., 1991; Schiebel and Litt, 2018). The palaeoclimate record of the Southern Levant indicates the begin of a more arid period around 4500 to 4400 BCE and a shift back to more humid conditions around 3700 BCE (Clarke et al., 2016, p. 108, with references therein). Local records can deviate. Speleothems from Soreq cave in the Judean hills west of Jerusalem, for example, indicate an overall highly variable climate during this time with a more arid episode from 3700 BCE on and very brief periods of high rainfalls around 4500 BCE, 4280 BCE, and 3800 BCE (Clarke et al., 2016, p. 108). The Northern Negev experienced increasing precipitation during the second half of the 5th millennium BCE that might have resulted in perennial river flows, before decreasing precipitations in the early 4th millennium BCE shifted the climate back to more arid conditions (Clarke et al., 2016, p. 109).

Initially defined by the material excavated in Teleilat Ghassul and hence termed "The Ghassulian Culture", the definition and labels of this cultural entity were revised several times, especially after the discovery of the Nahal Beer Sheva sites and the contemporaneous finds on the Golan (cf. Rowan and Golden, 2009, p. 11). Within this cultural entity, several regional groups can be identified. The exact number depends on the defining criteria, and at least some of them are probably the result of an adaptation to the local climatic and environmental conditions rather than cultural differences (Beck, 1989, p. 39; Levy and Shalev, 1989, p. 354; Ussishkin, 1971, p. 24). Additional to its distinct material culture, the Ghassulian is probably best characterised by an increased social stratification and the first evidence of metallurgy in the Southern Levant, making the Ghassulian a Chalcolithic *sensu strictu*. For these reasons, the period between 4500 BCE and 3800 BCE will be labelled Chalcolithic in the need of a more neutral term, following the chronological system suggested by Gilead (2007) and Gilead (2011). Other chronological systems with a broader definition of the Chalcolithic exist as well and they refer to the period under study as "Late Chalcolithic" (e.g., Garfinkel, 2009; Joffe and Dessel, 1995).

The Ghassulian did not cover the entire Southern Levant. Its southern fringe was the Northern Negev, where it was in contact with the Timnian. The Timnian is a cultural entity that encompassed the desert regions of the Sinai, the central and Southern Negev, the Rift Valley, and the southern parts of the Transjordanian Plateau. It shows a very different way of life than the Ghassulian and covers a period from the 6th millennium BCE into the 3rd millennium BCE (Gilead, 2011, p. 16; Rosen, 2013). Consequently, it will not be referred to as a Chalcolithic culture here.

To its Northeast, the Ghassulian was in contact with the Golanian, which covered the same period and encompassed the Golan heights and its western foothills. The material culture of the Golanian differs in many essential aspects from the Ghassulian, and metal seems to be unknown (Rowan and Golden, 2009, p. 21). The Golanian is therefore likely to be a separate cultural entity with close contacts to the Ghassulian (Gilead, 2011, pp. 14–16; Rowan and Golden, 2009, p. 18) and, thus, will not be referred to as Chalcolithic.

The Chalcolithic material culture was initially interpreted as the evidence for an external population that replaced the local Late Neolithic, but its local origins were soon recognised (see discussion in Gilead, 1988a, pp. 409–410). The relevant Late Neolithic cultural entities date back as far as the mid-6th millennium BCE, such as the Wadi Rabah culture and the Tsafian, and in the Northern Negev the Qatifian and Besorian (Garfinkel, 2009, p. 326, table 14.1; Gilead, 2011, pp. 16–19). A detailed discussion of the chronology and characteristics of these cultural entities is beyond the scope of this study but the elements connecting them to the Chalcolithic will be highlighted in the following paragraphs (see Rowan and Golden (2009) for a discussion of general problems and Banning (2007) for a discussion about the definition of the Wadi Rabah culture).

Notable aspects in the material culture of the Besorian are “bowls with straight wall, the precursors of the V-shaped bowls” (Gilead, 2011, p. 17), which will become one of the hallmarks of the Chalcolithic. Continuity in the flint technology during the transition to the Chalcolithic was observed as well (Gilead, 2007, p. 42).

The Wadi Rabah culture and subsequent cultural entities like the Tsafian show features that indicate in many aspects a gradual development of the Chalcolithic material culture from them (e.g., Garfinkel, 2009, p. 329). Deep V-shaped bowls and other vessel types connect Tel Tsaf and other sites from the first half the 5th millennium BCE to the lower levels of Teleilat Ghassul and the Chalcolithic pottery in general (Garfinkel, 2009, p. 328; Roux, 2019a, p. 41). It is also from this time on that basalt chalices are found in the Jordan valley (Garfinkel, 2009, p. 329). Cist burials outside of settlements like the ones from Palmahim (Gorzalczany, 2018) and infant jar burials uncovered in, e.g., Fazael 2 (Eshed and Bar, 2012) or Teleilat Ghassul (Bourke, 2013, p. 14) can be traced back to the Wadi Rabah Culture as well (Banning, 2012, pp. 409–410; Rosenberg et al., 2010, p. 283). Banning (2012, p. 409) suggested that the rectangular buildings in some Wadi Rabah sites might be the precursors of the Chalcolithic broad room architecture. Oflaz et al. (2019, pp. 144–145) showed that olives were used already in the Wadi Rabah culture but became domesticated only in the Chalcolithic. Similarly, cornets and churns, two of the hall-mark vessels of the Chalcolithic, appear first in the late Wadi Rabah sites (Golden, 2014a, p. 74; Khalaily and Goren, 2012). Flaked discs and mace-heads, two typical special items of the Chalcolithic, are also already found in Wadi Rabah sites or in the earlier Yarmoukian (Levy, 1998, pp. 239–240; Rosenberg, 2013; Rosenberg et al., 2010, p. 283).

Within the Chalcolithic, an earlier and a later phase can be distinguished. This differentiation is particularly well researched for the Northern Negev sites, which were for a long time the centre of archaeological research on the Chalcolithic beside Teleilat Ghassul. According to radiocarbon dates, the Late Chalcolithic begins about 4300 BCE (Gilead, 2007, p. 46). The most striking difference is the absence and presence of metal in the early and late phase, respectively. Golden (2014a, pp. 74, 78) therefore suggests naming the two phases “pre-metallic” and “proper” Chalcolithic, but since this is not the only distinctive feature, the more neutral terms Early and Late Chalcolithic will be used, following Gilead (2011, p. 17). They must not be confused with the Late Chalcolithic of, e.g., Garfinkel (2009), which encompasses the two periods.

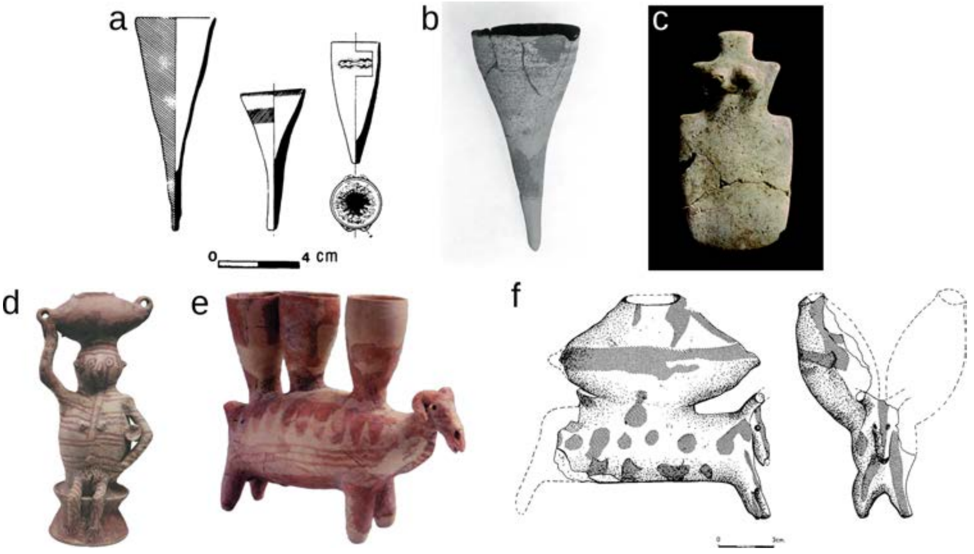


Figure 3.1: Characteristic objects of the Early Chalcolithic in the Southern Levant: Cornets from (a) Grar (Gilead, 1989) and (b) Teleilat Ghassul, height: 17.5 cm (photo: The Metropolitan Museum of Art, New York), (c) violin-shaped figurine from Peqi’in cave, height: 13.5 cm (Gal et al., 2011), vessel figurines from (d, e) Gilat, heights: 31.5 cm and 22.5 cm, respectively (The Metropolitan Museum of Art, 1986) and (f) En Gedi (Ussishkin, 1980).

A characteristic feature of the Early Chalcolithic is the vast abundance of cornets (Fig. 3.1). These cone-shaped vessels are a hallmark of the Chalcolithic but are virtually absent in the Late Chalcolithic sites with, e.g., only 0.03 % and 0.5 % of the pottery assemblage of Bir es-Safadi and Abu Matar, respectively (Gilead, 1989, pp. 390–391; Golden, 2014a, p. 78). Other distinctive features of the Early Chalcolithic pottery in the Negev are chaff temper (Golden, 2014a, p. 74) and the import of pottery (Commenge and Alon, 2002, p. 144; Goren, 2006). Both features do not occur in the Late Chalcolithic. In contrast, cream ware seems to occur exclusively in sites dating to the Late Chalcolithic (Golden, 2014a, p. 78; Rowan and Golden, 2009, p. 36), while the overall diversity in shapes and production techniques decreased (Commenge and Alon, 2002, p. 144). Further distinctive features of the Late Chalcolithic seem to be the replacement of violin-shaped figurines (Fig. 3.1) with more naturalistic ivory figurines in the Northern Negev and an increase in the pedestal height of pedestalled basalt bowls (Golden, 2014a, pp. 84–85). Gilead (1989, p. 391) suggested the presence of pig bones in the Early Chalcolithic and their absence in the Late Chalcolithic sites (Grigson, 1998; cf. Grigson, 1995) as another potential criterion but conceded that this distinction might be related to climatic conditions and not cultural aspects.

The Early Chalcolithic records the first extensive settlement activities in the North(western) Negev with its major sites Gilat and Grar thanks to the then more humid climate (Gilead, 1988a, pp. 418–419; Rowan and Golden, 2009, p. 27). The major site in the Jordan valley is Teleilat Ghassul. En Gedi is not a significant site by size but an exceptional one in its features. It was associated with the Nahal Mishmar Hoard (Ussishkin, 2014; 1980; 1971, p. 32), a cache with more than 400 unique metal objects and several ivory objects (Bar-Adon, 1980, see below), and with metallurgy in general (Goren, 2008, p. 392). However, especially the large proportion of cornets strongly suggest a date to the Early, pre-metallic Chalcolithic as defined above. Such a date might be further supported by finds of ceramic vessel figurines (Fig. 3.1). They were found in En Gedi, Gilat, Teleilat Ghassul and a couple of other sites (Alon, 1977; Epstein, 1985; Joffe et al., 2001; Seaton, 2008, frontispice; Ussishkin, 1980, fig. 11) and depict a living being that carries one or more vessels. Gilat can be convincingly dated into the Early Chalcolithic (Gilead, 2011, p. 17; 2007, p. 46; Goren, 2006, p. 381). Dating Teleilat Ghassul to the Early Chalcolithic is primarily based on radiocarbon dates because the sequence of cultural layers in Teleilat Ghassul is particularly challenging to date stratigraphically due to geologic faulting (Bourke, 1997, p. 398). The radiocarbon dates indicate a sequence from the Late Neolithic through Besorian-related material into the Early Chalcolithic (Bourke, 2007, 1997). A cluster of dates in the topmost layers at around 4400 to 4300 BCE and the lack of younger dates (Gilead, 2007, pp. 41–42) suggests an abandonment of Teleilat Ghassul at the end of the Early Chalcolithic (Gošić and Gilead, 2015a, p. 171).

The Early Chalcolithic is a continuation of the Late Neolithic not only in its material culture but also in its subsistence (Rowan and Golden, 2009, p. 23) and to some extent also in the organisation of the settlements (Banning, 2010, p. 71). Some aspects of the Late Neolithic such as mace heads (Rosenberg, 2013), silos (Garfinkel et al., 2009), and seals (Freikman et al., 2021; Freikman and Garfinkel, 2017; Gilead, 1989, p. 389) indicate a beginning social stratification of the society already at this time (Kerner, 2010, p. 191; Rowan and Golden, 2009, pp. 5–6) but without indicators for the presence of an elite, such as centralised settlement structures or prestige items (Kerner, 2010, p. 185).

The Early Chalcolithic continues this trend and reveals an increased stratification of society. Indicators for social differentiation were found in the settlement structures and notable buildings or sites are usually referred to as buildings for rituals (Banning, 2010, p. 72; Gilead, 2002; Kerner, 2010, p. 186). Originally reconstructed as the seat of religious authorities (“temples”) for the mediation of intergroup conflicts by T. E. Levy and his collaborators (Levy, 1998, pp. 235, 239; Levy and Holl, 1988, pp. 292–293; see also Milevski, 2009, p. 9) with particular focus on Gilat (Alon and Levy, 1989), the label “temple” and the general interpretation of these structures soon received criticism (Gilead, 2002; Gošić, 2013, p. 134; Guyot, 2014, p. 353) – as did his reconstruction of chiefdoms in the Chalcolithic Southern Levant in general (see below). However, the uniqueness of the sites is not debated, and although all of them are located in different settings (Teleilat Ghassul: building within a large settlement; En Gedi: isolated building at a remote location on a cliff high above the Dead Sea, Gilat: site in the centre of the Northern Negev site cluster), they show several features that set them apart from other Early Chalcolithic sites: markedly different material assemblages and unique finds (painted vessel figurines, wall paintings in Teleilat Ghassul, pits with ash and ibex/gazelle horns in Gilat and En Gedi), a similar building plan without parallels in other sites (En Gedi, Teleilat Ghassul), and a high number of primary burials (Gilat), while secondary burials outside the settlements dominate in the Southern Levantine Chalcolithic (for an extensive comparison see Gošić, 2013, pp. 131–153). A wide range of alternative interpretations was thus offered: residences of an elite (Banning, 2010, p. 81), assembly halls of the ruling families (Guyot, 2014, p. 353), Gilat as the cemetery of an upper class/elite (Ilan and Rowan, 2011, p. 102) and En Gedi as a mortuary shrine (Ilan and Rowan, 2016, p. 182), and the residences of magicians/healers (Gilead, 2002; Gošić, 2013, p. 152). Hill et al. (2016) reported evidence for feasting from Marj Rabba and suggested that a similar pit feature in Gilat might point towards Gilat as another feasting site (Hill et al., 2016, p. 136). According to its radiocarbon dates, Marj Rabbah dates to around 4300 BCE, i.e., to the very end of the Early Chalcolithic.

During the Late Chalcolithic, the settlement activities spread further into the Negev, most prominently attested by the partially subterranean dwellings in Shiqmim and the site cluster under today's Beer Sheva with Abu Matar, Bir es-Safadi/Neve Noy, and Horvat Beter. In other parts of the Southern Levant prevails the broad room architecture of the Early Chalcolithic (Rowan and Golden, 2009, pp. 27, 30). At the same time, Teleilat Ghassul might have been abandoned (see above), probably hinting to larger-scale population movements.

The stratification of the Chalcolithic population further increases, but the way this stratification is expressed changes. Special buildings or sites disappear (Banning, 2012, p. 411; Kerner, 2010, p. 186). A central building was claimed to be found in Shiqmim (Levy and Holl, 1988, p. 302), but this interpretation was challenged (see Gošić, 2013, pp. 246–248 and references therein; Gilead, 1988b, p. 148*–149*). Following Perrot (1984), T. E. Levy and his colleagues reconstructed a two tier settlement hierarchy for the Northern Negev (e.g., Levy and Holl, 1988, pp. 290–292). However, this interpretation must be questioned from a methodological perspective (Gilead, 1988b, p. 146*–147*) but also because it does not take the succession of the Early and Late Chalcolithic sites into account.

Instead of architecture, prestige items now become the preferred way of expressing status. The most spectacular among them are the metal objects (Fig. 3.2). The single find of a copper awl from the 6th millennium BCE in Tel Tsaf (Garfinkel et al., 2014) and some sparse metal objects in Teleilat Ghassul that might date to the Early Chalcolithic (Bourke, 2002, p. 156) provide evidence that simple copper objects were already available in the Southern Levant before the Late Chalcolithic. However, the absence of production remains suggests that they were imports from regions further North. Only from the Late Chalcolithic on, production remains are found, especially at Shiqmim and Abu Matar and their neighbouring sites.

Figure 3.2: Metal objects from the Chalcolithic Southern Levant: (a) The copper awl from Tel Tsaf, length: 41 mm (Garfinkel et al., 2014), (b) Various lost wax cast polymetallic copper alloy objects from the Nahal Mishmar Hoard (Sebbane, 2014), (c) the gold and electrum rings from Nahal Qanah (Klimscha, 2013a), (d) copper axe and copper chisel from Fazael (Rosenberg et al., 2020), (e) lead object on its shaft from Ashalim cave (Yahalom-Mack et al., 2015).

Metal production seems to be confined to the sites along the Nahal Beer Sheva (Golden, 2009, pp. 295–296; Levy and Shalev, 1989, p. 362). The copper ores were brought from Faynan and to a significantly lesser extent also from Timna to the settlements (Golden, 2014b, p. 113; Hauptmann, 2007, p. 269; 1989a, p. 131), probably by some expedition-like journeys (Golden, 2014b, p. 113) or by exchange with the nomads of the Timnian (Knabb et al., 2018, p. 28; Milevski, 2009, p. 4). The copper produced from these ores has only minor impurities and is thus termed “pure copper” (Hauptmann, 2007, p. 201), and more correctly from a technological perspective “unalloyed copper”. It was predominantly used to produce tool-shaped objects like axes and awls (Levy and Shalev, 1989). However, missing use wear indicates that they were rarely used as such (Golden, 2009, p. 295; Namdar et al., 2004, p. 81). Only from the Early Bronze Age on metal tools gradually replace stone tools (Manclossi, 2020; Manclossi et al., 2019; Rosen, 1984).

Besides this pure copper technology, finds from various sites indicate the presence of a copper alloy rich in arsenic, antimony, sometimes lead, and other minor impurities (Ben-Yosef et al., 2016; Golden, 2009, p. 287; Shalev and Northover, 1993; Tadmor et al., 1995). These polymetallic copper alloys were predominantly cast in the lost wax casting technique into mace-heads, standards, and other objects outstanding by shape, decoration, and complexity (Fig. 3.2). The largest assemblage of such objects was found in the Nahal Mishmar Hoard (Bar-Adon, 1980). Lead isotope studies revealed that the ore source is most likely located somewhere in the Anatolian or Caucasian mountains (Tadmor et al., 1995). Petrography of mould remains preserved on the metal objects and of the non-metallic cores they were cast over prove, however, that they were manufactured in the Southern Levant (Goren, 2014, 2008; Shalev et al., 1992). Only recently, excavations at Fazael in the Jordan valley might have revealed a production site for the lost wax cast objects with many fragments of polymetallic copper alloy objects and the only crucible fragments uncovered outside the Nahal Beer Sheva region (Rosenberg et al., 2020). Besides copper-based metals, gold and electrum rings are reported from the burial cave of Nahal Qanah (Gopher et al., 1990; Gopher and Tsuk, 1996a) and a lead mace head from Ashalim Cave in the Negev (Yahalom-Mack et al., 2015). These are single finds (Fig. 3.2) and information about their production contexts has remained elusive in the archaeological record so far.

Having such a wide variety of metals from the very start on, and being “out of the blue” one of the earliest occurrences of the lost wax casting technology in general, it is not surprising that the impact of the metal objects on the Chalcolithic society was extensively discussed (see chapter 4.1.1.5 for a discussion of the technical aspects). Not all authors follow T. E. Levy in his notion of a “metal revolution” with an impact similar to the Neolithic Revolution (Levy, 2007, chap. 2; see Milevski, 2009 for a critical review), or regard the introduction of metal as the cause for the decline of the Early Chalcolithic because they transformed the entire ritual behaviour of the Chalcolithic society (Gošić, 2013, p. 246; Gošić and Gilead, 2015a, p. 171). Nevertheless, they all agree upon a connection to and probable support for the development of some kind of elite by at least the polymetallic and lost wax cast copper objects. Whether they were burial objects of this elite (Rowan and Golden, 2009, p. 46), used to express its status (Klimscha, 2015, p. 46), whether they were items used in the burial rites (Shalem, 2015, p. 218), or their production was a public transformative and/or identity-generating act carried out by a particular group of ritual-conducting persons similar to shamans (Gošić, 2019; 2015, p. 730; Gošić and Gilead, 2015b; 2015a, p. 169), metal objects and metallurgy are always connoted with notions of limited and exclusive knowledge and/or access (e.g., Milevski, 2013, p. 201). The reason for this exclusivity is derived mainly from the general way archaeologists interpret materials that are exotic, rare, show a high level of craftsmanship, and do not seem to have been of practical use (e.g., the small diameter of the mace head shaft holes precludes their use as effective weapons). Admittedly, the dichotomy of tool-shaped objects produced from local ores in the settlements against the decorated and exotic lost wax cast polymetallic copper items without any traces of their production sites is very alluring for such an interpretation (e.g., Levy and Shalev, 1989, pp. 362, 366). The recent finds in Fazael (Rosenberg et al., 2020) from a settlement context (Bar et al., 2013) might request some adjustments to this interpretative framework. The interpretation of Gošić (2015) that all the metal objects are ritual skeuomorphs regardless of the alloy they are made of already goes in such a direction.

The metal industry is not only connected to the other parts of the material culture by the production of skeuomorphs (Gošić, 2015; Shalem, 2015, p. 224), but also by numerous parallels between the iconography of the objects found mainly in the Nahal Mishmar Hoard and, e.g., the ossuaries, pottery vessels or the wall paintings in Teleilat Ghassul (Beck, 1989; Klimscha, 2015, p. 46; Shalem, 2015). As outstanding as the metal objects may be, these connections show that it is always necessary to discuss the entire Chalcolithic material culture to understand their place in the Chalcolithic society. Consequently, metallurgy should be regarded as one of the many innovations that happened in the Southern Levant during the Chalcolithic or at least become visible in the archaeological record at this time. A similar impact from a technological perspective might be the introduction of the tournette, the slow turning potter's wheel, already in the Early Chalcolithic (Baldi and Roux, 2016, p. 236; Gabrieli, 2016, p. 165).

Another important innovation of the Early Chalcolithic is horticulture and the domestication of fruits. Remains of domesticated olives were found in Teleilat Ghassul, where they were probably cultivated for fuel and not primarily for their oil (Oflaz et al., 2019, pp. 144–145). The so-called torpedo jars, a vessel type found practically only in Gilat (Goren, 1995, p. 289) but mostly made of non-local ceramic pastes (Goren, 1995, p. 295), were interpret as containers for olive oil (Burton and Levy, 2006), and strainer vessels might be connected to its processing (van den Brink et al., 2021, p. 200). There is also some evidence for the domestication of dates and grapes but it is not as straightforward as for olives (Rowan and Golden, 2009, p. 24; Zohary and Spiegel-Roy, 1975, pp. 319–323). It was further claimed that pomegranate might have been domesticated already in the Chalcolithic (Rowan, 2014, p. 226), but the archaeological evidence points towards the Early Bronze Age (Heikkilä, 2016; Zohary and Spiegel-Roy, 1975, p. 324).

Concerning horticulture and agriculture, T. E. Levy identified dams in the Northern Negev and suggested their use for flood irrigation as another innovation of the Chalcolithic (Levy, 1998, p. 230; Levy and Holl, 1988, pp. 303–304). However, the dams cannot be reliably dated to the Chalcolithic and it seems more likely that they belong to the intensive Byzantine settlement activities in this region (Gilead, 1988a, p. 421; Winter-Livneh et al., 2010).

Secondary products were already used by the Wadi Rabah Culture (Rosenberg, 2009, p. 101) but became a firm part of the subsistence only in the Chalcolithic (Milevski, 2013, p. 198). Indicators for the use of dairy products are the increased age of butchered female ovicaprids in Bir es-Safadi, and that churns, whose reconstructed function is the production of cheese or butter (Rowan and Golden, 2009, p. 35), become a typical vessel type of the Chalcolithic (Gilead, 1988a, p. 420).

The domestication of the donkey as a beast of burden is an exception from the general use of secondary products and might indeed be an innovation of the Chalcolithic (Grigson, 1998, 1995). The faunal assemblage of Shiqmim includes 0.5 % equid bones, and this was taken as evidence for the domestication or at least regular use of equids as beasts of burden in the Chalcolithic (Levy, 1998, p. 232). This interpretation received some criticism (Milevski, 2009, p. 5). It seems more likely that domesticated donkeys become visible in the archaeological record only at the very end of the Chalcolithic and were not widely used before the Early Bronze Age (Klimscha, 2013a, p. 53; Milevski, 2013, p. 200). Of course, this does not mean that beasts of burden were utterly unknown in the Chalcolithic: the use of cattle and ovicaprids for this task is indicated by the clay figurines found in Gilat and En Gedi (Banning, 2012, p. 411; Rowan and Golden, 2009, p. 25).

Using ovicaprids and cattle as beasts of burden would fit very nicely to the overall reconstructed subsistence strategy of the Chalcolithic. In general, there seem to be no significant changes from the Late Neolithic to the Early Bronze Age (Rowan and Golden, 2009, p. 23). T. E. Levy's "specialised pastoralism" model was applied only to the Northern Negev and relies heavily on an ethnoarchaeological comparison with the traditional subsistence strategies of the local Bedouin population (e.g., Levy, 1983). Hence, it cannot be directly applied to the more humid regions of the Southern Levantine Chalcolithic. Moreover, it was challenged soon after its publication by e.g., Hanbury-Tenison (1986, pp. 53–55) and Gilead (1988a, p. 418), with the latter stating that Levy's model ignores the more humid climate in the Northern Negev during the Chalcolithic compared to today. In any case, a mixture of agriculture and pastoralism must be expected, probably with most of the population living sedentarily in the settlements and several wandering herders instead of a semi-nomadic lifestyle of the entire population (Rowan and Golden, 2009, p. 25).

Those mobile parts of the population, may they be wandering herders or nomadic groups, likely played an essential part in maintaining contacts and exchange relations with regions beyond the Chalcolithic Southern Levant and maybe also between the regions within (Anfinset, 2010, p. 170). Being constantly moving – and probably in a regular pattern –, their herds were the perfect carriers for goods (e.g., basalt objects: Kerner, 2001, pp. 155–156). Generally speaking, cooperation between nomads and settlers seems to be the preferred risk management strategy in unstable ecological environments (Vidale et al., 2018, p. 137). While little is known from the northern parts of the Southern Levant, the Northern Negev and especially the Nahal Beer Sheva was a contact zone between the sedentary settlers of the Chalcolithic and the nomadic pastoralists of the Timian in the South (Anfinset, 2010, p. 170). Especially with large parts of the Chalcolithic population being sedentary, it seems likely that the Timnians maintained contacts between Egypt and the Southern Levant (Anfinset, 2010, p. 170; Klimscha, 2011, p. 200). Likewise, the polymetallic copper alloys and obsidian might have been brought from Anatolia by nomads to the Southern Levant (Anfinset, 2010, p. 173).

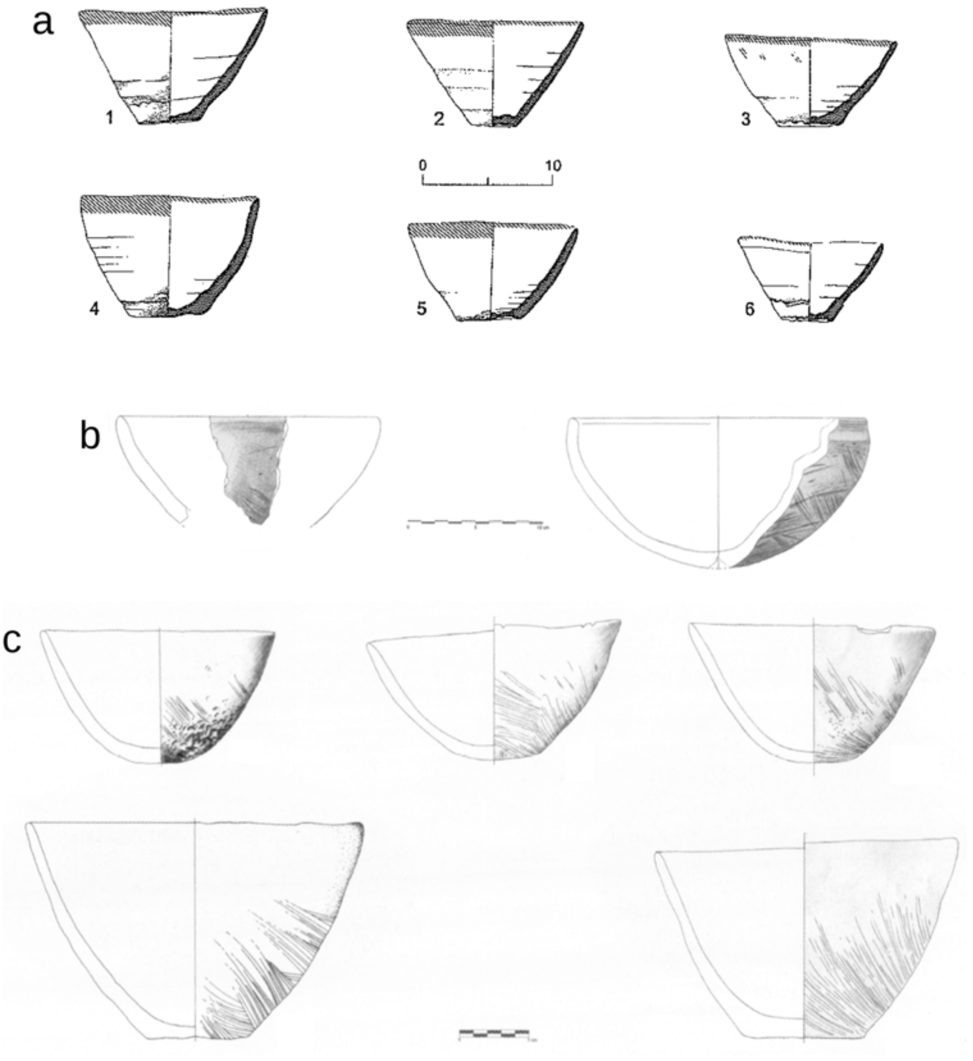


Figure 3.3: (a) Examples of V-shaped bowls found in Kissumfim Road (Goren and Fabian, 2002). Coba bowls from (b) Arslantepe VIII (Balossi, 2012) and (c) Mersin XV (Caneva et al., 2012).

The movement of people from the North into the Southern Levant during the Chalcolithic is attested by aDNA profiles of individuals buried in Peqi'in cave (Harney et al., 2018). Harney et al. (2018) showed that the genetic information of the sampled individuals could only be modelled if an Anatolian and an Iranian component were included. They further showed that the two components arrived independently in the Southern Levant and that the Anatolian component disappears with the end of the Chalcolithic. Traces of these population movements might have been preserved in the material record: The use of metals from Anatolia or Caucasia (e.g., Tadmor et al., 1995, p. 143) or the V-shaped bowls, whose shape is very close to the so-called Coba bowls (Fig. 3.3) that appear slightly earlier in Northern Mesopotamia (Baldi, 2018, p. 250; Kerner, 2001, p. 125).

The innovations went hand in hand with the emergence of specialised workshops and a markedly increased standardisation, the culmination of developments that started already in the Late Neolithic (Baldi, 2018, pp. 252–253; Kerner, 2001, pp. 126–127; Rosen, 1986, p. 30). The probably best indications for craft specialisation are the workshops of an ivory carver in Bir es-Safadi (Perrot, 1958, p. 133) and for the production of sickle blades and microliths in Horbat 'Illit B, Beit Eshel and Compound C (Milevski et al., 2013, p. 128). Fan scrapers found in Wadi Gaza Site A might indicate a specialised production of this tool type (Rosen, 1986, pp. 27–28), as does the complexity of perforated flint discs (Rosenberg et al., 2019, p. 423). At the same time, production remains of so-called *ad-hoc* flint tools are found abundantly in domestic contexts (Rosen, 1986, p. 29). This mixture of strongly standardised tool types alongside non-standardised tools was taken as evidence for the existence of part-time specialists (Banning, 2012, p. 410).

Highly standardised objects co-existed with non-standardised objects in other material categories as well. The probably most striking example is pottery. With the onset of the Chalcolithic in the mid-5th millennium BCE a unification of the *chaînes opératoires* can be observed in parallel to the first use of the potter's wheel (Baldi, 2018, p. 250). The potter's wheel was used (nearly) exclusively for the ubiquitous V-shaped bowls (Fig. 3.3), which were "mass" produced in the Northern Negev and exported to e.g., Abu Hamid (Commenge and Alon, 2002, pp. 144–145; Kerner, 2001, pp. 124–125). S. Kerner further showed that V-shaped bowls and cornets (Fig. 3.1) were produced in distinct size categories (Kerner, 2010, p. 188; 2001, p. 124), further supporting their standardised production. Another indicator for specialised pottery production is Cream ware, which appears around the same time as the potter's wheel. This ware was mainly used for specific vessel types like very large churns or miniature churns, and some of the vessels were produced with the potter's wheel as well (Kerner, 2010, p. 187; 2001, p. 124; Roux et al., 2013, p. 73). This ware might have been produced in the Northern Negev and exported into other regions, e.g., to Teleilat Ghassul (Bourke, 2013, p. 19; Kerner, 2010, p. 187). Like the flint tools, the production of all other vessel types was not specialised. Consequently, e.g., Burton and Levy (2012, p. 178) interpret the ceramic assemblage of Abu Hof as the expression of a partially specialised society.

For the metal objects, the picture is not that clear-cut. The current state of the archaeological record does not provide any production sites for the polymetallic copper alloys, yet, that would allow an interpretation of this technology's craft specialisation. Remains of pure copper metallurgy are scattered all over Shiqmim (Shalev and Northover, 1987, p. 362), while different activity areas in Abu Matar suggest a spatial separation of the different steps in the metallurgical process (Shugar, 2000, p. 250). Consequently, different models for craft specialisation in Chalcolithic metallurgy were developed. While, e.g., Levy and Holl (1988, pp. 307–308) assume that metallurgy is a specialised craft *per se*, Gošić (2013, p. 233) interprets metallurgy as a communal task. Kerner (2001, pp. 149–150) draws a more nuanced picture: The low variation of awls, chisels/axes, and mace heads indicates a low specialisation with the pure copper metallurgy being always carried out by non-specialists while specialists always handled polymetallic copper alloys. And Golden et al. (2001, p. 961) recognized a centralised workshop in Abu Matar but production on the household-level in Shiqmim. The latter two models are close to the partially specialised production models for stone tools and pottery.

Closely related to the question of whether specialised crafts existed during the Chalcolithic is the question of their context *sensu* Costin (1991), i.e., whether they were controlled by an elite ("attached") or not ("independent"). For the Southern Levantine Chalcolithic, answers to this question depends to a large extent on how the respective scholars reconstruct its social organisation. Although all scholars assume the presence of some elite (e.g., Baldi and Roux, 2016, p. 250; Dawson et al., 2003, p. 118; Klimscha, 2013b, p. 98; Milevski, 2013, p. 203), the extent of social stratification within the society and the kind of elite (e.g., chiefdom, a council of elders) differs. Additionally, most models do not consider the chronological separation into an Early and Late Chalcolithic.

The probably most famous model for the social organisation of the Chalcolithic Southern Levant is the chiefdom society, which T. E. Levy developed since the 1980s for the Northern Negev sites (e.g., Levy, 1986). According to his model, the development of specialised pastoralism, craft specialisation, metallurgy, and flood irrigation in the Chalcolithic together with elaborate and rich burials outside of settlements, a two-tier settlement hierarchy, cult places, and exotic goods indicates the existence of a social hierarchy with an elite at its top (Levy, 1983, p. 32; Levy and Alon, 1985, p. 82; 1982; Levy and Holl, 1988, pp. 290–293, 306–312). He suggested a debt-based economy as a mechanism for developing such an elite (Levy, 1998, pp. 240–241): Gifts from the economically more powerful individuals or families create a social debt of the gift-takers, resulting in a leader-followers relationship. It was shown above that Levy's interpretation of several elements in his model must be questioned, and it hence might be no surprise that his reconstruction of a chiefdom society received strong criticism (e.g., Gilead, 1988b; Gošić, 2013, pp. 246–250). Additionally, metal objects might not have been such outstanding prestige items as interpreted by T. E. Levy (cf. Rosen, 1993, pp. 49–50). Finally, T. E. Levy developed his line of evidence exclusively for the Northern Negev and not for the climatically very different regions of e.g., the Galilee or the Jordan valley. Apart from these aspects, Levy's model is too old to consider the differentiation of the Chalcolithic into an early and late phase but relies on the back then assumed contemporaneity of Gilat as cult centre with the metal objects.

Of course, this does not imply that a chiefdom society can be safely excluded for the Chalcolithic in general. A thorough update of Levy's model might provide valuable new details about the social organisation of the Chalcolithic Southern Levant. S. Kerner, for example, suggests a group-orientated chiefdom based on staple finance rather than prestige items for the Chalcolithic (Kerner, 2010, p. 192; 2001, p. 182). In addition, finds from Tel Tsaf indicate that some families might have had more control over substantial amounts of staples than others, potentially indicating the existence of an elite already in the late 6th to early 5th millennium BCE (Freikman and Garfinkel, 2017, p. 43; Garfinkel et al., 2009, pp. 321–323; Rosenberg et al., 2017b, p. 897).

Gilead (1988a, pp. 434–435) argued in favour for a more egalitarian social organisation. In contrast to T. E. Levy, he did not recognise any indicator for social stratification in the archaeological record and suggested small semi-autonomous villages with a council of elders, heads of households or other coordinating entities. Such a council would still be an elite although not that firmly set apart from the remaining population like the chiefs in T. E. Levy's model. Similarly, Gošić (2013, pp. 250–253) suggested a council of elders, maybe complemented with some specialists (craftspersons, ritual-conducting persons) as coordinating entities of an egalitarian complex village community. Different specialisations of the households guaranteed exchange relations between them and ensured that all households remained on the same level. In this model, the head of the household as a hierarchical element is assumed "in order for it to function properly" (Gošić, 2013, p. 252). Such a heterarchical organisation (*sensu* Crumley, 1995, pp. 3–4) is also suggested for the inter-community relations of the Chalcolithic (Gošić, 2013, p. 253). Support for such a social organisation comes from V. Roux, who recognised a uniform *chaîne opératoire* of the Chalcolithic pottery and concluded an egalitarian contact network between the different settlements without elites (Roux, 2020, pp. 28–29; 2019b).

Considering these models, a craft can be regarded as either attached or independent *sensu* Costin (1991). If elites are considered non-existing, craftspersons cannot be attached to it but must be independent by definition. Likewise, prestige items are always produced by attached craftspersons to maintain the elite's exclusive access to them (Costin, 1991, p. 11). For example, Baldi and Roux (2016, p. 236) concluded that the potter's wheel was used by attached specialists and all hand-made pottery either by non-specialists or independent specialists, while Kerner (2001, p. 125) concludes that pottery was generally a craft of independent specialists. And while Kerner (2001, pp. 150–151) differentiates between an attached production of the polymetallic copper alloy objects and an independent, domestic unalloyed copper metallurgy, metallurgy is always carried out by attached specialists according to Levy and Holl (1988, p. 307).

Usually, elites can be readily identified by exceptional burials. In the Southern Levant, burials with grave goods appear for the first time in the Chalcolithic (Rowan and Golden, 2009, p. 50). In contrast to the roughly contemporary sites with rich burials such as Varna (Renfrew, 1986) and Byblos (Artin, 2010), multiple burials are common and burial goods can only rarely be correlated to individuals. Hence, burials cannot be used to reconstruct the social stratification of the Chalcolithic Southern Levant (Gilead, 1988a, p. 429; Rowan and Golden, 2009, p. 50) unless the absence of exceptional burials is taken as evidence for an egalitarian society. Nonetheless, they provide a wealth of other information.

Like in Neolithic times, individuals are buried within the settlements in jars, but such burials become more rare and now contain predominantly children (e.g., Bourke, 2013, p. 14; Eshed and Bar, 2012; Perrot, 1955a, p. 173). Exceptional is Gilat with 91 primary burials in shallow pits filled with settlement debris, among them only two individuals with clearly associated burial goods (Levy et al., 2006; Smith et al., 2006).

Although primary burials occur, secondary burials outside the settlements are the characteristic burial type of the Chalcolithic Southern Levant (Rowan and Golden, 2009, p. 50). The secondary burial sites show some variety: stone cists and circular structures (e.g., Mezad Aluf near Shiqmim, Palmahim), dolmen (e.g., Tell el-Adeimeh), different types of burial caves (e.g., Peqi'in, Nahal Qanah, Horvat Qarqar, Azor, Ashalim), and subterranean chambers (Kissufim Road). An exception are burial caves in the Judean desert, which yielded only primary burials (Ilan and Rowan, 2016, p. 179).

Mezad Aluf consists of circular structures in different sizes built from different materials (Levy and Alon, 1982, p. 42). These structures contained one or multiple secondary burials (Levy and Alon, 1982, p. 46) and at least one V-shaped bowl per individual (Levy and Holl, 1988, p. 296). Based on the building material and the size of the circular structures, Levy and Alon (1982) suggested a hierarchy of the burials with four levels (contra: Gilead, 1988b, p. 148*). They further drew a parallel between the circular structures and Nawamis, circular burial structures of the Timnians in the Sinai that might have been used as family graves (Levy and Alon, 1982, p. 41). Despite the architectural similarities and the possible close contacts between the inhabitants of the Northern Negev and the Timnians, this parallel must be viewed with caution. Like in the Nawamis, one would expect primary burials (Levy and Holl, 1988, pp. 297–298), and Nawamis are equally likely to date to the Early Bronze Age as to the Chalcolithic (Rosen, 2013, p. 143). In addition to the circular structures, stone cists built into the ground were uncovered in Mezad Aluf. Because they did not contain human remains but a V-shaped bowl in each cist, Levy and Holl (1988, p. 296) suggested that they might have been used for the primary burials of the deceased.

The burial site of Palmahim North (Gorzalczany, 2018) yielded stone cists and circular burial structures as well, and again only sparse burial goods. In contrast to Mezad Aluf, some of the stone cists are arranged in chains and several circular and rectangular structures were built on top of the stone cists. The excavations of this burial site provided clear evidence that the cists and chains built into the ground were the earliest structures, followed by the rectangular structures. The circular structures were built together with the rectangular structures or shortly after. Smaller structures were built some time later, after a considerable layer of sand accumulated. Other important differences to Mezad Aluf are the regular presence of one or two ossuaries in the circular or rectangular structures and the presence of burial jars.

Dolmens occur in the northern and northeastern regions of the Chalcolithic Southern Levant. The field at Tell el-Adeimeh on the eastern side of the Jordan valley with its many stone cists and several tumuli was suggested as burial ground of Teleilat Ghassul (e.g., Bourke, 2013, p. 14). Tell el-Adeimeh probably consisted of areas for excarnation, and the tumuli were used for the secondary burials (Bourke, 2013, p. 16). Although a Chalcolithic date of at least Tell el-Adeimeh seems likely, dating of this site and dolmens in general is difficult due to the scarcity of datable materials and finds (Bourke, 2013, p.

16; Braun, 2019, p. 79; Levy and Alon, 1982, pp. 39–40).

The most common burial type in the Chalcolithic Southern Levant are burial caves with secondary burials. Natural caves were regularly used and sometimes modified with, e.g., walls and terraces (Gopher and Tsuk, 1996b, p. 130). Anthropogenic caves are also known (Rowan and Golden, 2009, p. 51). According to Nativ and Gopher (2011), the burial caves can be divided into a northern and a southern group. In the northern group, a single cave was used and the deceased persons were buried in ossuaries and stone cists while the southern group used several neighbouring caves in parallel and preferred burial jars and ossuaries (Nativ and Gopher, 2011, pp. 232–236). Several impressive caves are known from the Northern group, among them Peqi'in with 600 to 1000 buried individuals (Shalem et al., 2013) and Nahal Qanah with the only known Chalcolithic gold objects of the Southern Levant (Gopher and Tsuk, 1996c). Early Bronze Age material from the latter cave indicates that these caves were not exclusively used in the Chalcolithic. Based on anthropological studies, Nativ and Gopher (2011) suggest that only certain parts of the population, maybe members of the same lines of descent (Nativ and Gopher, 2011, p. 242), were buried in the caves of the northern group and interpret this as evidence for social differentiation (Nativ and Gopher, 2011, p. 236). Examples for the Southern group are Horbat Qarqar (Fabian et al., 2015) and Azor (Perrot, 1961). Buried individuals in this group represent the entire population according to Nativ and Gopher (2011), but the placement of burial jars and ossuaries in different caves and the absence of ossuaries in some of the burial sites (Nativ and Gopher, 2011, pp. 236–237) might indicate the separation of social groups within the burial assemblage (Nativ and Gopher, 2011, pp. 241–242). Petrographic evidence suggests that they were communal burial centres for populations from broader regions (Boness et al., 2016).

Many burial caves from both groups allow to identify two phases: an older phase with jars or stone cists and ossuaries, and a later phase where the deceased were buried either directly on the cave floor or in a perished organic receptacle. In the southern group, many individuals were also buried on top of older ossuaries (Nativ and Gopher, 2011, pp. 236, 238–239). Ossuaries from caves of the southern group further show a high degree of fragmentation which happened when the caves were still in use (Nativ and Gopher, 2011, pp. 236–237). Ossuary fragments often seem to be removed from the caves to other places – the ossuaries can only rarely be completely refitted (Nativ and Gopher, 2011, p. 239). Combining these observations, Nativ and Gopher (2011, pp. 238–239) suggest a *pars pro toto* use of the ossuary fragments in the later phase.

The last type of Chalcolithic burial ground in the Southern Levant is the underground room at Kissufim Road (Goren and Fabian, 2002). Its features resemble the rectangular subterranean rooms in, e.g., Bir es-Safadi (Perrot, 1955b), but are unparalleled in other burial sites. The room contained pits with bones, burial jars, and stone cists. Burial pits were also found outside this room. The room might have contained one primary burial.

The distribution of the different burial types – dolmens in the Galilee and Jordan valley, caves with secondary burials in the northern Coastal Plain, the centre and the Shephela, circular and rectangular burial structures in the northern Negev and the southern Coastal Plain, caves with primary burials in the Judean Desert – seem to support the differentiation of the Chalcolithic Southern Levant into regional groups (see above). However, caves with secondary burials were recently also reported from ridges a reasonable distance away from the Nahal Beer Sheva sites further into the Negev (Davidovich et al., 2018). The burials there resemble the later phase of the burial caves after Nativ and Gopher (2011), i.e., burials directly on the cave floor or in perishable materials, and include burial goods that are typical for the other burial caves such as the lead mace head in Ashalim cave (Yahalom-Mack et al., 2015). Therefore, the apparent regionalisation in the burial sites might be the result of geographical factors (e.g., availability of caves) rather than cultural ones. Alternatively, it could be the result of an incomplete archaeological record.

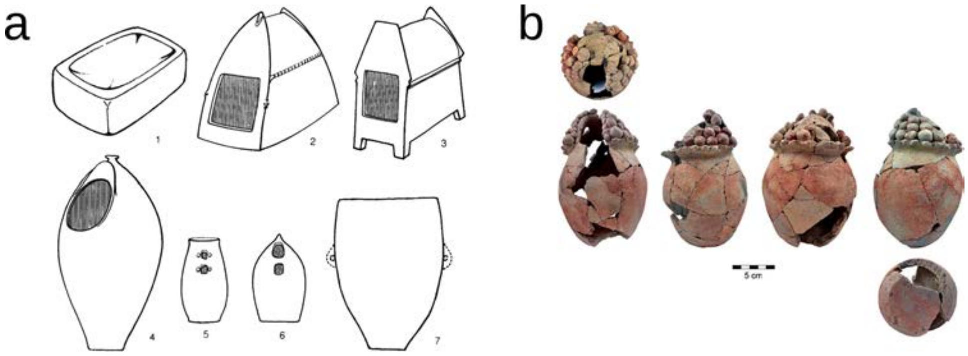


Figure 3.4: (a) The different kinds of ossuaries in the Chalcolithic Southern Levant (Ilan and Rowan (2019) based on Perrot and Ladiray (1980)); (b) The clay model of a silo found in Tel Tsaf (Rosenberg et al., 2017b).

Besides secondary burials, ossuaries as receptacles for the dead are a unifying element of the Chalcolithic Southern Levant (Fig. 3.4). While they are usually a box, the decoration (plastic and painted) of the ceramic ones is very variable, turning them into e.g., houses, humans, or animals (Ilan and Rowan, 2019). It was suggested that they might be derived from the custom of burying people under silos in the 6th millennium BCE at, e.g., Tel Tsaf (Garfinkel et al., 2009, p. 323; Rosenberg et al., 2017b, p. 896). Shalem (2015, pp. 229–230) suggested that also burial jars and the circular structures are connected to silos; the latter because silos and those structures are the only known cases of round architecture in the Chalcolithic (Fig. 3.4). Another feature are stelae or massebots that were found at Kissufim Road and in several burial caves (e.g., Givatayim), probably indicating the location of the graves (Goren and Fabian, 2002, pp. 44–48; Sussman and Ben-Arieh, 1966). The orthostats found in the burial structures in Palmahim (Gorzalczany, 2018) might be related to them, although they were not free-standing. These unifying elements of the Chalcolithic burial rites indicate that burial customs were very similar or even identical throughout the Chalcolithic Southern Levant, despite the variability in the burial sites.

Rich and diverse assemblages of grave goods were discovered primarily in the burial caves. Most of the so-called prestige items (e.g., metal, fenestrated pedestal bowls, perforated flint discs) were found here. The caves were often post-depositionally disturbed by natural processes (e.g., roof collapse, animals) or their re-use in subsequent periods (Rowan and Golden, 2009, p. 51). Consequently, the burials and also the grave goods are usually not preserved in situ, making it impossible not only to correlate them to individuals as mentioned above but also to reconstruct their specific functions within the burial rites (e.g., use of vessels as grave goods or only in the burial rites). Therefore, the so-called prestige items have not necessarily been used by an elite to display its status. Nevertheless they are unique because they are made from raw materials with geographically restricted availability (e.g., metal, basalt) or because their production requires considerably more skill than other objects made from the same materials (e.g., perforated flint discs, wheel-shaped pottery) – or a combination of both (e.g., stone mace heads, lost wax cast objects). Combining their distribution, the locations of their production sites, and the outcrops of the respective raw materials can provide insight into contact networks and exchange relations within the Chalcolithic Southern Levant.

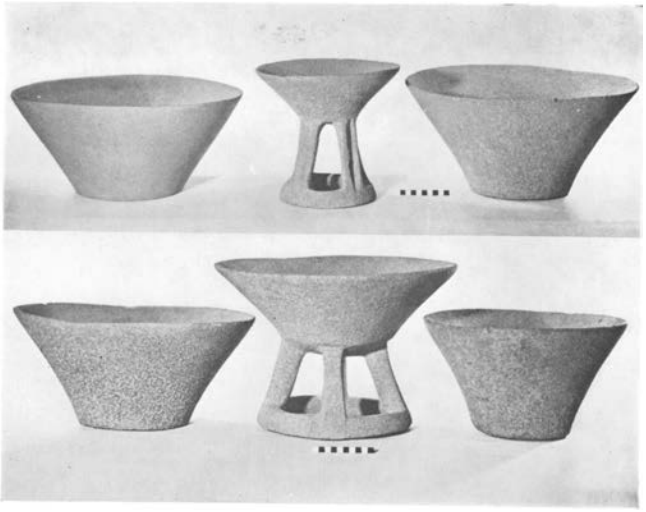


Figure 3.5: Basalt vessels from Abu Matar (Perrot, 1955c).

The origin of basalt vessels (Fig. 3.5) is usually reconstructed as being in the Golan Heights (i.e. imported from the Golanians), in the highlands east of the Jordan valley or in the Eastern Galilee with its widespread occurrences of basalt (Amiran and Porat, 1984). The phosphorite for a few vessels with identical shapes outcrops in the Transjordanian Highlands (Goren, 1991). Olives were most likely grown in this region (Rowan and Golden, 2009, p. 50) and the production of perforated flint discs and stars (Fig. 3.6) seem to be another characteristic of this area (Rosenberg et al., 2019; Rosenberg and Shimelmitz, 2017). In turn, the Northern Negev seems to have been the exclusive producer of pure copper, ivory objects (Perrot, 1958), and maybe also fan scrapers, sickle blades and microliths (see above). Production of the

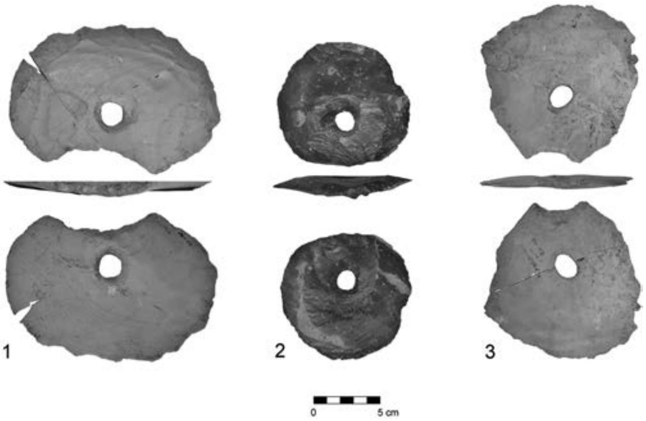


Figure 3.6: Perforated flint discs from the Golan heights (Rosenberg and Shimelmitz, 2017).

polymetallic copper objects in the Northern Negev initially seemed to be likely because all finds outside this region are from mortuary contexts (e.g., Giv'at HaOranim, Nahal Qanah, Peqi'in) or the Nahal Mishmar Hoard (see above). However, petrographic investigations of the mould remains (Goren, 2014, 2008) and recent finds from Fazael (Rosenberg et al., 2020) – and the lack of any production remains related to those alloys in the rich metallurgical assemblages of the Northern Negev sites – suggest they were produced somewhere else, maybe in the Jordan valley. Concerning the pure copper objects, ores from Faynan and Timna might indicate some exchange relations with the Timnians (Knabb et al., 2018, p. 28; Milevski, 2009, p. 4). V-shaped bowls and cream ware seem to be produced in the Northern Negev (also) for long-distance (e.g., Abu Hamid) and near-distance exchange, respectively (Commenge and Alon, 2002, pp. 144–145; Roux and Courty, 2007). Finds from Marj Rabba and Peqi'in cave indicate that also Golanian pottery was exchanged at least as far as the Galilee (Rowan and Kersel, 2014, p. 235; Shalem et al., 2013, pp. 84–85). Molluscs from the Red Sea and the Mediterranean Sea are an indicator for some kind of material flow from the coasts to the inland (Bar-Yosef Mayer, 2007).

The haematite source for the mace heads is less clear. Haematite is widely available as nodules in the Southern Negev and the Sinai (Beit Arieh, 1980, pp. 59–60; Levy and Shalev, 1989, p. 354). Bourke (2013, p. 155) suggested the Aljun mine in the Central Jordanian Plateau as a likely source for the haematite mace heads found in Teleilat Ghassul. Another source of haematite seems to be the mine Mugharet al-Wardeh, one of the region's richest and largest haematite deposits (Alamri and Hauptmann, 2008, p. 214). Chemical analyses of several mace heads from sites all over the Southern Levant match with this deposit (Alamri and Hauptmann, 2008, p. 220). Matching lead isotope signatures were interpreted as further support (Alamri and Hauptmann, 2008, pp. 220–221), although lead isotopes cannot be considered a suitable method for provenancing iron ores (Schwab et al., 2006).

It is difficult to reconstruct how this exchange was organised. Gošić (2013, p. 253) suggested to extend her heterarchical concept (see above) to the intraregional networks (Gošić, 2013, p. 253). Rosenberg and Shimelmitz (2017, pp. 296–297) identified a northern and a southern exchange network with Fazael as the contact point, characterised by perforated flint discs and stars, and copper and ivory, respectively. Because only a few objects were found in sites outside their respective network, they concluded that access to these networks was controlled and restricted (Rosenberg and Shimelmitz, 2017, p. 303). These two networks are overlaid by an extensive network that is represented by the basalt bowls, which are found in all regions of the Southern Levantine Chalcolithic (Rosenberg et al., 2017a, p. 122). The common *chaîne opératoire* of Chalcolithic pottery seems to support such an open, egalitarian contact network (Roux, 2019b). Rosenberg et al. (2017a, p. 122) suggested for the Coastal Plain fish and salt from the Mediterranean as exchange good for the basalt vessels. Commenge and Alon (2002, p. 145) suggested for the Northern Negev V-shaped bowls as exchange good, which would be in agreement with the interpretation of Roux (2019b) that ritual objects such as basalt vessels (Kerner, 2001, pp. 155–156) and V-shaped bowls (Roux et al., 2013, p. 64) were exchanged by a limited group of people within that extensive network. Occasions for exchange could have been (ritualised) social interactions like dowries (Gilead, 1988a, p. 427) or feasts (see Hill et al., 2016 for the identification of Marj Rabba as feasting site).

The value relations between these objects and of them to objects made from perishable materials such as textiles (flax/linen might have been imported from the Jordan valley to the Northern Negev: Levy, 2019, pp. 193–194) and staple goods are challenging to reconstruct. Rosen (1993, pp. 49–50) suggested that copper objects, fan scrapers and basalt vessels were equally valued. Golden (2009) took a similar but more general perspective than S. Rosen, and suggested that "The metal artifacts, in fact, both the 'pure' copper and complex metals, were but one form of valuable included as part of a burial kit that also contained ivory, basalt, textiles and fancy ceramics" (Golden, 2009, p. 294). Although many of these items were found in burials, this "kit" does not seem to be restricted to them. Polymetallic copper alloys for example were also found in settlement contexts (Baumgarten and Eldar, 1984, p. 54; Perrot, 1955c, p. 79; Rosenberg et al., 2020; Shalev and Northover, 1987, p. 358) as were basalt bowls (Bar et al., 2013, p. 178; Bourke, 2002, p. 155; Perrot, 1955c, pp. 78–79). Perforated flint discs/stars are also found outside of burial contexts (Bar et al., 2017, p. 214; Rowan and Kersel, 2014, p. 234; Vardi and Gilead, 2013, p. 112). Hence, the "kit" could also be the material expression of burial sites as gathering points of communities from all over the Southern Levant.

At the end of the Chalcolithic, the society with its exchange system and unique objects seems to collapse (Levy, 1998, p. 241; Milevski, 2009, p. 15). The production of most of the "prestige" items ceases (Genz, 2000, p. 59), and in the Early Bronze Age, neither V-shaped bowls and wheel-shaped pottery in general (Kerner, 2011, p. 160; Roux et al., 2013, pp. 74–78), nor polymetallic copper alloys or ivories are found (Milevski, 2013, p. 199). The production of stone mace heads continues, and the way they are used does not seem to change. Haematite is no longer used for them, though, and the general raw material preferences change to light-coloured stones such as limestone and alabaster (Rowan and Levy, 2011, pp. 207–208). The flint technology changes and an entirely new way of producing sickle blades comes into use (Vardi and Gilead, 2013). Additionally, burial customs change and ossuaries are no longer used (Golani, 2013, p. 104; Milevski, 2013, p. 202) and architecture shifts from broad to oval rooms (Golani, 2013, p. 101). Conversely, basalt vessels were used in the Early Bronze Age (Golani, 2013, p. 103; Hruby et al., 2021).

Together with all these changes a re-organisation of the local metallurgy is taking place. The most important aspect is a gradual but fast movement of the smelting activities from the settlements to the mines in Faynan. At the very beginning of the Early Bronze Age, smelting was seemingly carried out in the settlements (e.g., Ashqelon-Afridar, Nahal Besor site H, Abu Halif) and in Faynan, but soon after smelting remains are restricted to Faynan (Genz, 2000, p. 56; Hauptmann, 2007, p. 294; Pfeiffer, 2009, p. 314). Total copper production increases simultaneously (Klimscha, 2013b, p. 101) and copper is now brought to the settlements as ingots (Pfeiffer, 2009). It is probably this "democratisation" of copper (Klimscha, 2013b, p. 102; Levy, 1998, p. 241) that leads to the replacement of stone axes by copper axes (Klimscha, 2013b, p. 99; Manclossi, 2020; Vardi and Gilead, 2013, p. 113). Despite these profound changes in the spatial and most likely also social organisation of copper metallurgy, the technology it self does not change with the onset of the Early Bronze Age (Hauptmann, 2007, p. 262; Segal et al., 2004, pp. 314–317).

The reasons for these profound changes and the processes that led to them are still poorly understood, mostly because of a gap in the archaeological record at this transition. According to radiocarbon dates, Chalcolithic sites date until around 3800 BCE, while Early Bronze Age sites date not earlier than 3600 BCE (Braun et al., 2013). This long transition from the Chalcolithic to the Early Bronze Age might result from an actual hiatus or regional differences in the date of this transition. It presently can also not be excluded that sites or strata that cover this period exist but remain to be discovered (Braun et al., 2013, pp. 39–40).

A couple of sites could be termed "transitional" because they yielded either typical Early Bronze Age elements in Chalcolithic strata or indicate continuity in the occupation from the Chalcolithic to the Early Bronze Age. Elements typical for the Early Bronze Age are the so-called Canaanean Blades, found in Chalcolithic strata in, e.g., Ashqelon-Afridar (Golani, 2013, p. 102) and Fazael (Bar and Winter, 2010). Further, the tea pot from Fazael 2 has elements that are typical for Early Bronze Age pottery (Bar, 2019, p. 39). Unfortunately, the validity of the observations made in Ashqelon-Afridar must be strongly doubted because of an unsuitable excavation methodology (Braun, 2019, pp. 69–89) and the transition in Fazael is represented by the re-location of the settlement instead of a vertical stratigraphy. The "Deep deposits" of Modi'in-Buchman yielded a continuous stratigraphic record of Chalcolithic and Early Bronze Age strata but their radiocarbon dates do not fall within the gap (Braun et al., 2013, p. 34). Consequently, the presently available archaeological record indicates only that the changes listed above likely did not occur at the same time and that e.g., the first occurrences of Canaanean Blades slightly predate the Early Bronze Age (Bar and Winter, 2010; Vardi and Gilead, 2013, p. 117) as does the end of the V-shaped bowls in Modi'in (Roux et al., 2013, p. 78).

As cause for the end of the Chalcolithic, an external influence such as an immigration wave was suggested in the early stages of research as explanation for the perceived suddenness of the transition (e.g., Ben-Tor, 1989, p. 50; Eisenberg, 1989, pp. 38–39). Hanbury-Tenison (1986, p. 251) suggested internal processes as the cause for the transition, which later became the accepted interpretation. A potential cause for the transition could be a change in the climate. As was shown above, the Northern Negev became drier at the end of the Chalcolithic, probably leading to an abandonment of this region (Levy, 1998, p. 241). With the intense focus of past Chalcolithic research on the Northern Negev (Rowan and Golden, 2009, p. 33), this would indeed have created the impression of a collapsed Chalcolithic society. As was shown, sites outside the Northern Negev do not support such a collapse.

The disappearance of all special ("prestige") items at the end of the Chalcolithic (Genz, 2000, p. 59) indicates the end of the ideology and the social system associated with them (Joffe, 2022; Yekutieli, 2022). Roux (2010, pp. 227–228) suggested that the collapse of the Chalcolithic elite resulted in the loss of the technologies associated with the "prestige" items (V-shaped bowls, lost wax cast objects). Why the elite collapsed must remain open. A possibility might be too many failed harvests due to the changing climate, especially if this elite was based on staples as S. Kerner suggested (Kerner, 2010, p. 192; 2001, p. 182) or a failure of the entire ideology (Joffe, 2022).

During these significant changes, two sites developed at the north coast of the Gulf of Aqaba, Tall Hujayrat al-Ghuzlan and Tall al-Magass. These sites are genuinely transitional in the sense that they are spanning the Chalcolithic–Early Bronze Age transition with a continuous occupation from 4100 BCE to 3500 BCE according to radiocarbon dates (Klimscha, 2012, p. 204; 2009, p. 391). The material culture of both sites is different from the Chalcolithic and the Early Bronze Age Southern Levant (Klimscha, 2009, p. 391). The two sites revealed a large-scale copper production with cast ingots produced for export (Klimscha, 2013a, pp. 48–50; Pfeiffer, 2009) and a close relation to Egypt (Klimscha, 2011, p. 200; 2009, pp. 393–395). How these sites relate to the sites further North must remain unclear, but it was suggested that they might have been a precursor of the Southern Levantine Early Bronze Age (Kerner, 2008).

### 3.1.2 Southeastern Anatolia and Northern Mesopotamia

The East of Anatolia is geographically confined by the Pontides to the North, the tributaries of the Euphrates to the West, and the South Eastern Taurus mountain range to the South. The border to the Southern Caucasus in the East is a geographical and ecological continuum. Continental climate prevails in this region, with steppe climates at the high plains (Palumbi, 2011, p. 205). Southeastern Anatolia consists of the high plains southeast of the Central Taurus mountain range, such as the Malatya plain, and the Southeastern Taurus mountain range. Located to its South is Northern Mesopotamia and the Amuq plain (Özbal, 2011, p. 175). The tectonic setting and the river valleys dictate the main routes through Eastern Anatolia. They are often Northeast–Southwest orientated. The most important ones are the Karasu and the Murat, confluencing to the Euphrates at the modern Keban Dam. The West–East orientated Araxes and the South- and Southwest-flowing Tigris are important exceptions (Palumbi, 2011, p. 205). Settlement activities and also archaeological research concentrate on these valleys and their associated high plains (Özbal, 2011, p. 175).

The chronological units contemporary to the Chalcolithic Southern Levant are the Late Chalcolithic (LC) 1 (about 4500 to 4200 BCE), LC 2 (4200 to 3900 BCE), sometimes subsumed under the term "post-Ubaid" (Marro, 2012, p. 14; Stein, 2012, p. 129), and early LC 3 (3900 to 3400 BCE). As the name "post-Ubaid" indicates, LC 1 follows the Ubaid, an interaction sphere extending from Mesopotamia to the Mediterranean that is characterised by many similarities in its material culture, mainly its pottery (cf. Carter and Philip, 2010). In Northern Mesopotamia and Southeastern Anatolia, this coherent sphere splits around the middle of the 5th millennium BCE into five groups with differences in their material culture, which might indicate some degree of autonomy. The groups show a gradient from East to West in how strongly they deviate from the Ubaid (Frangipane, 2012, p. 42) and can be summarised into a group west and a group east of the Euphrates from LC 2 on (Frangipane, 2012, p. 47; Marro, 2012, pp. 23–26; Stein, 2012, p. 132). Although these two groups were autonomous, they were in close contact with each other (Frangipane, 2012, p. 46).

The probably most characteristic common feature of the two groups is a shared pottery technology with the use of chaff temper as earliest feature, while the morphology and decoration of the vessels is separating them (Marro, 2012, p. 26). The use of chaff resulted from the need to accelerate the production process. The most exemplary vessel type of this chaff-faced ware is the so-called Coba bowl (Fig. 3.3b), a mass- or better serially produced (Baldi, 2012, p. 404) vessel type (Marro, 2012, p. 27; 2010; Özbal, 2011, pp. 184–186; Palumbi, 2011, p. 211). The occurrence of these vessels produced in large amounts attests to a profound change in the social meaning of pottery at this time (Frangipane, 2012, p. 44) and is an answer to the changing needs of the society (Baldi, 2012). The occurrence of Canaanean Blades at the end of the 5th millennium BCE marks a change in flint technology. Their production in specialised workshops further indicates a transformation in the organisation of craft activities, moving towards the specialisation of artisans (Marro, 2012, p. 28).

Despite their similarities, the western and eastern groups differ in several aspects. Coba bowls with round bases are typical of the western group while the eastern group is characterised by flat bases (Baldi, 2012, p. 395; Balossi Restelli, 2019, p. 148). Significant differences are also observed in the role of metals and how prestige and status are communicated in general. These differences will be highlighted in the following.

The western group is probably best represented by Arslantepe in the Malatya plain. The periods relevant for this discussion are Arslantepe VIII (4700 to 3900 BCE) and the early stages of Arslantepe VII (3900 to 3400 BCE) (Vignola et al., 2019). Arslantepe VIII is currently the oldest uncovered period at the site but stray finds of Halaf pottery indicate the presence of humans from at least the 6th millennium BCE on (Frangipane, 2011, p. 971; 2000, p. 440). Arslantepe VIII comprises of 9 strata (Balossi Restelli, 2012, p. 42). Excavations so far yielded exclusively domestic contexts with kitchens, living rooms and courtyards (cf. Balossi Restelli, 2012, p. 45). Monumental architecture is absent (Balossi, 2012, pp. 237–238; Balossi Restelli, 2012, pp. 42–45). Remarkable are domed mud-brick ovens comparable with ovens from the Ubaid in Değirmentepe and the contemporary sites of Tülintepe and Tepe Gawra (Balossi, 2012, p. 239). In the earliest uncovered levels, remains of painted plaster were discovered in two of the rooms. Under the floor of another room, probably a kitchen, two urn burials of infants and a few seals were uncovered (Balossi, 2012, p. 238). The painted plaster and the burials are comparable to finds from Norşuntepe (Balossi, 2012, p. 239). Obsidian was derived exclusively from deposits in the Bingöl region east of Arslantepe at this period, maybe by a supply network established already in the Neolithic (Mouralis et al., 2018, pp. 351–352). Arslantepe VIII further yielded some small copper items like awls and sheet fragments (Fig. 3.7), but so far no indication of metallurgical activities (Di Nocera, 2013, p. 113; Heil, 2019, p. 24). There is no indication of an elite or a similar group with increased status in Arslantepe VIII.

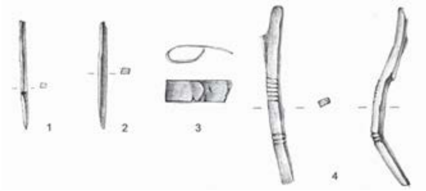


Figure 3.7: Selection of copper items from Arslantepe VIII (Di Nocera, 2013).

Another important site is Oylum Höyük in the Kilis plain. Like Arslantepe, this site yielded a typical assemblage for the post-Ubaid west of the Euphrates (Frangipane, 2011, pp. 971–972). Despite the distance of around 220 km and the Southeastern Taurus mountains between the two sites, their architecture (Özbal, 2011, p. 186) and their pottery assemblages are surprisingly similar, especially the Coba bowls (Balossi and Helwing, 2012, p. 291). Typological differences can be recognized but might be related to chronological differences because Oylum Höyük dates slightly earlier than Arslantepe VIII (Balossi and Helwing, 2012, p. 297). At the same time, pottery decoration typical for Tepe Gawra is absent. Only a few vessels specific for this region were uncovered in Arslantepe, indicating sparse contacts towards the regions of the Tigris river (Balossi, 2012, p. 246). Consequently, the reconstructed contact network of Arslantepe extended towards the Southwest with the Euphrates as a hard border to the East (Balossi, 2012, p. 246; Balossi and Helwing, 2012, p. 298) and thus defined the western group. Some decorative elements on pottery indicate that this contact network might have extended to the Northeast as far as the Southern Caucasus (Balossi and Helwing, 2012, p. 298). In general, mass-produced bowls or, more broadly, the chaff-faced ware horizon are an important indicator for contacts between the Upper Euphrates, the Tigris river valley, the Van lake region, and the Southern Caucasus in the second half of the 5th millennium BCE (Palumbi, 2011, pp. 211–212; Stein, 2012, p. 132). These connections will be discussed in chap. 3.2.3.

With the end of LC 2, the western group breaks apart. Casseroles and hammerhead bowls, typical vessels of the eastern group, are now found in Oylum Höyük and the Middle Euphrates region. This indicates a stronger orientation of this region towards the eastern group. Nevertheless, they remain absent in Arslantepe. Therefore, it was concluded that the Upper Euphrates region with Arslantepe and the Middle Euphrates region with Oylum Höyük were in close contact but developed autonomously (Balossi, 2012, p. 246; Balossi and Helwing, 2012, p. 299).

Figure 3.8: Beads made of gold, lapis lazuli, and carnelian from a child burial in Grai Resh (Kepinski et al., 2011).

Whilst data are not clear for the western group, the eastern group features a stratified society and an elite with monumental architecture and exotic burial goods (Stein, 2012, p. 135). Excavations in Tell Brak revealed monumental (public) buildings and other indicators for early urbanism, such as an extent of specialised craft activity that goes beyond production for local consumption, administration, an exceptional settlement size, and being a central site for the surrounding settlements (Oates et al., 2007, pp. 598–599). Additionally, burials with exceptional grave goods (Fig. 3.8), such as small beads made of gold, electrum, and lapis lazuli were found in the LC 2 sites of Tepe Gawra and Grai Resh (Kepinski et al., 2011, p. 33; Oates et al., 2007, p. 598). A burial in Hacınebi Phase A (4200 to 3700 BCE) contained two silver earrings (Stein et al., 1996, p. 96; Yakar, 2011, p. 67). Many of these exceptional burials belong to children and infants, which led Stein (2012, p. 135) to the conclusion that status was inheritable at this time. Stein (2012, pp. 135–138) further suggested that differences in stamp seal motifs from Hacınebi might have been another way of communicating status, but at least in LC 5 this criterion cannot be applied as studies on seals from Arslantepe showed (Frangipane, 2007).

Since LC 1 and possibly already from the end of the Ubaid on, status in Mesopotamia and Southeastern Anatolia is expressed through staple finance, i.e. the control of access to and the distribution of food. Despite the lack of data for the Western group in these aspects, centralisation and the respective stratification and complexity of the societies seems to be less developed than in the eastern group. In the eastern group, stamp seals, seal impressions and their concentration in the monumental buildings and in private dwellings with their storage rooms in e.g., Tell Brak, Hamoukar, and Hacınebi, and the use of these stamp seals for sealing storage containers for food indicates the presence of a well-developed administrative system for the storage and distribution of staples among private groups which in turn indicates the privatisation of surplus (Frangipane, 2016, pp. 473–474; Oates et al., 2007, p. 598; Reichel, 2002; Stein, 2012, p. 135). The elites seem to be established in LC 2 to the extent that they can acquire gold and exotic stones like lapis lazuli, probably in exchange for surplus goods. In the western group with Arslantepe as major site, however, elites seem absent. The only clear indication for an elite and that it is based on staple finance are the mass-produced bowls (Frangipane, 2016, p. 474). The administration is indicated by stamp seals and seal impressions, but they are found in considerably fewer numbers, and no storage rooms were found so far.

Certainly during the LC 3, i.e. around the mid-4th millennium BCE, sites in the western group reach a level of social complexity and stratification similar to what is known from the LC 2 sites in the eastern group, and the staple finance system becomes firmly established in, e.g., Arslantepe (Balossi Restelli, 2019, p. 659; Frangipane, 2010, pp. 34–35). While the older strata of Arslantepe VII are a continuation to Arslantepe VIII in their architecture (Balossi Restelli, 2019, p. 656), the use of domed mud-brick ovens, painted plaster, and urn burials (Balossi, 2012, p. 239; Frangipane, 2011, p. 972; 2007-2008, p. 174), social complexity and stratification of the society increase with time and result in the erection of a monumental temple and elite residences in the later strata of Arslantepe VII (Balossi, 2012, p. 238; Balossi Restelli, 2019, pp. 657, 659; Frangipane, 2010, pp. 34–35). The monumental building parallels comparable buildings in the eastern group (Balossi Restelli, 2019, p. 659). Changes in pottery parallel these processes (Balossi Restelli, 2019, pp. 656–657). Although the potter's wheel is introduced at the beginnings of Arslantepe VII, it is only in the later strata with the elite residences that its use is extended from the finishing of the vessel to proper wheel throwing for the manufacturing of vessels (Balossi, 2012, p. 244; Balossi Restelli, 2019, pp. 350–352). This, in turn, led to an increased standardisation of the mass-produced bowls. Moreover, the use of potter's marks indicates that at least firing of the bowls was a centralised activity in the western and eastern group (Frangipane, 2012, p. 45; 2011, p. 974; Özbal, 2011, pp. 188–189). Conversely, the burials uncovered in Arslantepe so far follow the traditions from Arslantepe VIII and contain no or only a few non-exceptional burial goods and are not found close to the monumental buildings (Frangipane, 2007-2008, p. 173).

Despite the strong contacts with Northern Mesopotamia, Arslantepe VII was not under its direct influence (Frangipane, 2010, pp. 35–36) and it seems to have extended its contacts to the Northeast. Obsidian is now imported not only from the Bingöl region but to a lesser extent also from Northeast Anatolian sources, indicating increased contacts with regions north of the Malatya plain (Mouralis et al., 2018, p. 352). The incentive for this increased orientation towards Northeastern Anatolia and the Southern Caucasus during the mid-4th millennium BCE might be the access to metal, whose increased use goes hand in hand with closer contacts to transhumant groups from these regions (Frangipane, 2017, pp. 188, 191–192).

The role of metal in all these developments remains somewhat peculiar. In contrast to contemporary regions such as Southeast Europe (see chap. 3.1.5), the Caucasus (see chap. 3.1.3), and the Southern

Levant (see chap. 3.1.1), the nearly complete absence of larger metal objects and a perceived small number of small copper objects is striking. As was shown above, only smaller objects like awls and sheet fragments were found in Arslantepe VIII (Fig. 3.7), and even from the stratified sites of the eastern group only similar small copper objects were reported. Metal is practically absent in burials – it was only found in the three burials in Tepe Gawra, Grai Resh and Hacınebi (Fig. 3.8). Arslantepe VII is not different in these regards (Di Nocera, 2013, p. 115; Heil, 2019, pp. 25–27). This situation is even more puzzling because smelting activities are attested already during the first half of the 5th millennium BCE in Mersin-Yumuktepe (Yalçın, 2000), Tülintepe (Esin, 2001a), and Değirmentepe (Yener, 2000, pp. 34–41). Norşuntepe (Yalçin et al., 1992) and Hacınebi (Özbal et al., 1999) are two major sites with evidence for copper metallurgy in the second half of the 5th millennium BCE. Therefore, the paucity of copper objects cannot be explained by the loss of metallurgical knowledge. Hansen (2013, p. 147) suggested meticulous recycling of the copper objects as a possible explanation. Stork (2015, p. 119) suggested instead that the social value of copper objects was very different compared to the other regions: they were regarded as communal objects in the LC 2 and 3 (her period under study), and their production was carried out for the benefit of the entire community instead of individuals or an elite (Stork, 2015, p. 128). Although the study is restricted to the Upper Euphrates (Stork, 2015, p. 115), this interpretation could probably be extended to the value of copper in the eastern group.

Figure 3.9: Copper axes from Mersin-Yumuktepe (Garstang, 1953).

At first sight, the large chisels from Mersin-Yumuktepe (Fig. 3.9) seem to contradict these developments. Dating to the first half of the 5th millennium BCE, they and several needles are among the earliest pieces of evidence for smelted copper in Anatolia (Yalçın, 2000, p. 110). In the second half of the 5th millennium BCE, parallel to the appearance of mass-produced bowls, large metal items become absent also in Mersin-Yumuktepe. In accordance with the overall post-Ubaid developments, the site now shows indicators for the appropriation of the staple finance system (Caneva et al., 2012, pp. 363, 370–371). The reasons for these changes are not well understood yet and likely to be more complex than a replacement of one prestige-communicating system with another one.

### 3.1.3 Southern Caucasus

The Caucasus consists of two prominent mountain ridges and the lowlands between them, which stretch from the eastern coast of the Black Sea to the western coast of the Caspian Sea. The Southern Caucasus includes the region south of the Greater Caucasus (the northern mountain range). Modern countries covering this region are the former Soviet republics Armenia, Georgia, and Azerbaijan. The Southern Caucasus seamlessly merges into East Anatolia, the Zagros Mountains, and the Alborz Mountains. Beside the highlands, it is mainly characterised by the Araxes and Kura river valleys and associated lowlands, which were the main settlement areas in this region.

Archaeological research in the Caucasus did not provide such a detailed record yet as available in Southeastern Anatolia and Northern Mesopotamia or the Southern Levant. The main reason for this situation is twofold: The Iron Curtain limited exchange and cooperation between scholars from both sides for a long time, and it is just since it fell that connections between the Southern Caucasus and Northern Mesopotamia can be studied in all their aspects. Additionally, populations during the periods under study in this project seem to have been primarily transhumant pastoralists or (semi-)nomads (e.g., Chataigner et al., 2010, p. 387; Marro et al., 2011, pp. 62–64). Consequently, remains of these peoples must be expected to be ephemeral, and most sites are single-phase settlements (Kiguradze, 2000, p. 322). Consequently, continuous stratigraphic records are widely absent, hampering a detailed understanding of the processes in this region. A comprehensive radiocarbon chronology might overcome this problem and was identified as a desideratum in the early 2000s (Di Nocera, 2000, p. 76). In the last decade, several large projects (e.g., Badalyan et al., 2014; Lyonnet et al., 2012; Marro and Stöllner, 2021) yielded a plethora of new data and started to overcome these limitations.

During the second half of the 5th millennium BCE and the earliest 4th millennium BCE, most parts of the Southern Caucasus were inhabited by the Sioni culture and the earliest phases of the subsequent Leilatepe-Berikldeebi culture. However, the major sites of the latter, Berikldeebi and Leilatepe, seem to be contemporary to the early phases of Maikop (Courcier, 2014, p. 623; 2007, p. 218). This would date them to around 3700 BCE the earliest (Ivanova, 2012, p. 10; Reinhold, 2019, p. 98), slightly later than the period under study. The Kura-Araxes phenomenon emerged around the mid-4th millennium BCE or a bit earlier (e.g., Badalyan, 2014; Kavtaradze, 2017; Manning et al., 2018), but according to C. Marro and her colleagues, pottery of the Kura-Araxes phenomenon or their precursors can be found in Ovçular Tepesi already at the end of the 5th millennium BCE (Marro et al., 2014, pp. 132–133; 2011, pp. 66–69; contra: Palumbi and Chataigner, 2015).

Two multi-phase Sioni sites have been uncovered so far: Mentesh Tepe and Ovçular Tepesi. The site of Mentesh Tepe was heavily damaged but excavations succeeded in uncovering a long occupation sequence from the Neolithic until the middle of the 3rd millennium BCE with a hiatus from the end of the 5th to the second half of the 4th millennium BCE (Lyonnet et al., 2012, p. 87). Period III dates to the second half of the 5th millennium BCE and is subdivided into three phases. The relevant phase is the middle phase, dating from 4350 to 4200 BCE and yielding extensive occupation remains, while the early and the late phase were short phases with few architectural features (Lyonnet et al., 2012, pp. 91–92). A courtyard from the middle phase yielded a small waste heap of obsidian, a small heap of crushed azurite, and several small copper items (Lyonnet et al., 2012, p. 92). Two slagged pottery fragments in other parts of the site attest to the production of copper objects in this phase (Lyonnet et al., 2012, pp. 111–113).

The Chalcolithic occupation in Ovçular Tepesi can be subdivided into an early and a late phase. The early phase revealed a settlement with houses and tents dating between 4350 and 4200 BCE (Marro et al., 2009, pp. 37–38). The later phase dates from 4200 to 4000 BCE (Marro et al., 2009, p. 38). It consists of several levels that might indicate seasonal settlement activities by semi-nomadic herders (Marro et al., 2011, pp. 62–64). The pottery is produced according to the local traditions but also consists to a significant amount of chaff-faced ware (Marro et al., 2009, p. 52). This type of pottery and architectural similarities indicate close contacts of the inhabitants with Eastern Anatolia and Northern Mesopotamia (Marro et al., 2011, pp. 64, 72–74; 2009, p. 52). The above-mentioned presence of Kura Araxes pottery in the Chalcolithic layers might indicate that also Kura-Araxes groups settled in Ovçular Tepesi. According to Marro et al. (2011, pp. 66–69), they did not use the settlement together with the Sioni people but in alternating intervals. Further, a neonate was buried with a shaft hole axe-hammer and two flat axes (Marro et al., 2011, p. 70). Two copper rings were found in another burial (Gailhard et al., 2017, p. 547).

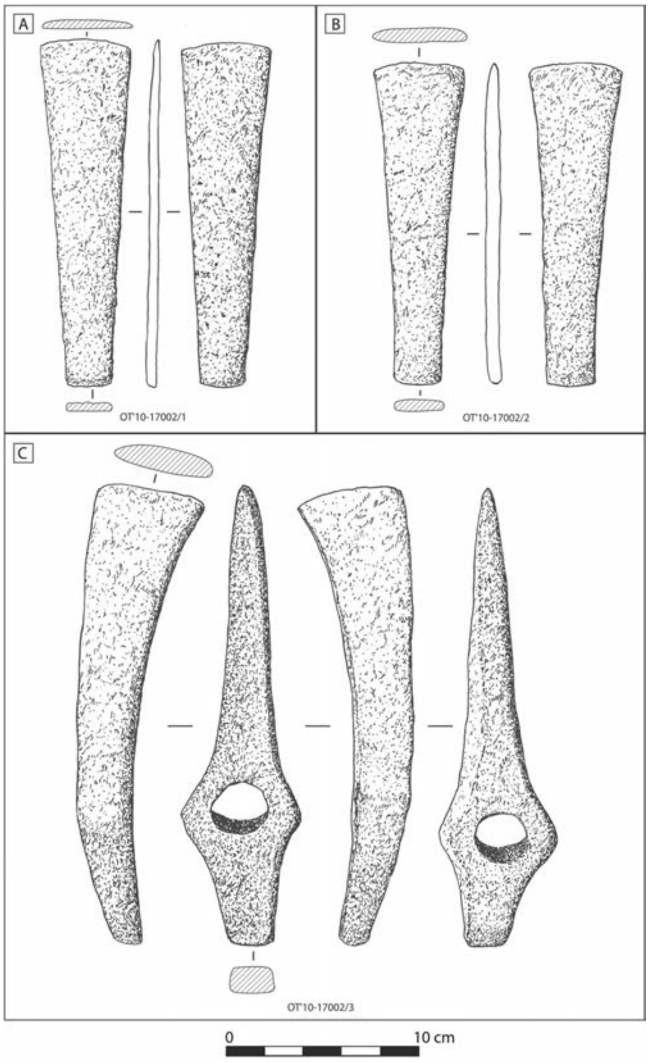


Figure 3.10: The two flat axes (A, B) and the shaft hole axe-hammer (C) from the neonate burial in Ovçular Tepesi (Gailhard et al., 2017).

The earliest currently known kurgans are located in Soyuq Bulaq. According to radiocarbon dates from two kurgans, one dates to around 3800, i.e. the very end of the period under study in this project, while the other dates to around 3700 BCE (Lyonnet et al., 2008, p. 36). In the older kurgan, the central burial contained beads made of gold, a silver alloy, and lapis lazuli (and other materials), together with a stone sceptre and a dagger (Lyonnet et al., 2008, pp. 30–31). The later kurgan yielded three silver beads (Lyonnet et al., 2008, p. 34).

It is not easy to reconstruct the social organisation of the Sioni culture from these finds. The metal grave goods from Ovçular Tepesi (Fig. 3.10) are singular (Gailhard et al., 2017, p. 547), and three other axes were found in domestic contexts at this site (Gailhard et al., 2017, p. 547). Metallurgical activities in the Sioni sites point towards a domestic mode of production and no metal workshops (Gailhard et al., 2017, p. 547), indicating that metal objects were no prestige items. Hence, their interpretation as the evidence of an elite with inheritable status (Marro et al., 2011, p. 70) should be regarded as being preliminary. Bahşaliyev (1997, p. 97) suggested that the Sioni culture was organised in large family groups. At the present stage, it cannot be excluded that some of these groups had more power because they controlled the access to important resources such as salt or copper ore (Gonon et al., 2021). Moreover, the close contacts with Northern Mesopotamia and Southeastern Anatolia (Kavtaradze, 2018) might have impacted the social organisation as well (see chap. 3.2.3). Last but not least, it must be kept in mind that the evidence presented here might over-emphasize the minor sedentary part of the population while the (semi-)nomadic majority remains poorly visible in the archaeological record.

The social organisation of the Southern Caucasus changes markedly during the first half of the 4th millennium BCE. The presence of kurgans and their burials with exotic and rare materials like gold and silver in Maikop (Reinhold, 2019), Soyuq Bulaq (Lyonnet et al., 2008), and Sé Girdan (Muscarella, 2003, 1971, 1969) indicate a significant stratification of the society with the emergence an elite in the entire Caucasian region from the second quarter of the 4th millennium BCE on. Metallurgy becomes widely spread at this time (Bobokhyan et al., 2014, p. 285), and buildings of a size without any contemporary parallels in the region were erected in Leilatepe and Berikldeebi. Their architecture might have been strongly inspired by Northern Mesopotamian architecture (Kiguradze, 2000, p. 322; Lyonnet, 2009, p. 8) and could indicate the first occurrence of monumental architecture.

### 3.1.4 Iran

Iran is probably the most complex region under consideration in this study. Extending from the Caspian Sea and the Southern Caucasus in the North to the Persian Gulf and Gulf of Oman in the South, from the western hillflanks of the Zagros Mountains in the West to the Balochistan Plateau, Sistan Plateau, and the foothills of the Hindu Kush in the East, Iran consists of several sub-regions separated by mountain ranges. Being topographically separated and often having different climatic and environmental conditions, these sub-regions remained fairly independent before the arrival of modern infrastructure such as railroads, while the high- and lowlands were closely entangled from early on (Alizadeh, 2004; Thornton, 2009a, p. 306).

Located at the periphery of the study area, a full account of the sub-region's archaeological background is beyond the scope of this study. Instead, a general outline of the cultural developments will be given. A recent extensive summary of the archaeology and the cultural developments during the 5th and 4th millennium BCE in Iran is available in Matthews and Fazeli Nashli (2022).

At the end of the Neolithic, around 5200 BCE, Iran comprised of small dispersed settlements inhabited by farming, herding, and hunting communities without social stratification and only minor socio-economic inequality (Matthews and Fazeli Nashli, 2022, p. 183). Pace and kind of the transformations during the Chalcolithic vary between sub-regions but until the second quarter of the 4th millennium BCE all regions experienced an increase in social stratification with differentiated access to and control over natural resources and human resources. Within the communities, the existence of dependencies between groups or at least of coordinating entities is indicated by the erection of large structures such as platforms, monumental ritual buildings and specialised (administrative) buildings. In addition, multi-tiered settlement hierarchies point towards dependencies not only within the communities but also between different communities. Probably not surprising, these developments went hand in hand with the rise of elaborate accounting systems (Matthews and Fazeli Nashli, 2022, pp. 183–184), including the use of tally boards, found in e.g., Tal-e Mash Karim (Niknami et al., 2018). Closely related to these socio-economic processes is the intensification and extensification of agriculture by, e.g., the use of irrigation (Vidale et al., 2018, pp. 115–116). Another characteristic of this period is an increased craft specialisation with partial standardisation of the pottery manufacturing process and the rise of new crafts by the incorporation of new materials, most prominently metals and lapis lazuli (Helwing, 2021; 2012a, p. 510), and, very recently discovered in Chega Sofla, also artificial enstatite beads (Nezafati and Moghaddam, 2021).

The cultural development of Northwestern Iran, e.g., in Tepe Gheshlagh (Sharifi and Motarjem, 2018) and Kul Tepe (Abedi et al., 2015), is closely connected to the developments in the Southern Caucasus and Eastern Anatolia (Helwing, 2013b, p. 95). Consequently, the processes outlined for these regions (Chap. 3.1.2, 3.1.3) apply also to Northwestern Iran, where they proceeded in a slow but steady pace without leaps in the social complexity of the communities (Matthews and Fazeli Nashli, 2022, p. 184).

The developmental pace in the North Central Iranian Plateau was markedly quicker. Settlements in this region concentrate around springs, and the use of irrigation was most likely one of the reasons for a population increase during the 5th millennium BCE (Helwing, 2021). A two-tiered settlement system indicates some stratification between the settlements (Helwing, 2012a, p. 509; Vidale et al., 2018, pp. 107–108). The existence of a coordinating entity or some social stratification is evidenced by specialised buildings such as the central building in Zagdeh with murals and associated burials (Fazeli, 2004, p. 194; Matthews and Fazeli, 2004, p. 63). Compared to the other Iranian regions, crafts developed particularly fast towards a more specialised organisation and a higher diversity of materials. From around 4200 BCE on, the increased political and economical differentiation of the society seems to result in a communal specialisation with Tepe Ghabristan as an example for an artisanal village specialised on copper metallurgy and pottery production (Fazeli, 2004, p. 196) and Tepe Hissar as a centre for the processing and exchange of lapis lazuli (Helwing, 2012a, p. 510). These processes were preceded by the adoption of the two-chambered pottery kiln in a local variant and copper smelting from South(east) Iran, where these innovations occur already in the 5th millennium BCE (Helwing, 2021). Contacts of the North Central Iranian Plateau region with Southwestern Iran and the Zagros mountains were already close during the 5th millennium BCE (Vidale et al., 2018, p. 108) and intensify in the 4th millennium BCE. In parallel, this contact network extends now to new regions such as Mesopotamia (Helwing, 2012a, p. 510; Vidale et al., 2018, p. 111). Copper seems to be an important good in these exchange networks. The presence of moulds for rod ingots in Seh Gabi and Tepe Ghabristan indicate that at least some of the copper was produced for exchange, most likely to Mesopotamia (Matthews and Fazeli, 2004, pp. 69–70). However, the probably best metallic indicator for long-distance exchange networks at this time are shaft hole axes. While they were produced in the North Central Plateau as indicated by, e.g., moulds in Tepe Ghabristan (Madjizadeh, 1989), a large number of these items was found in the cemetery of Susa, several hundreds of kilometres further South on the other side of the Zagros mountains (Helwing, 2021).

The Northeast of Iran provides a very limited archaeological record for this period. As a result, little can be said about the processes in this region except that there is a clear development towards an increased craft specialisation (Matthews and Fazeli Nashli, 2022, p. 184).

The archaeological record for Southeastern Iran is more complete. Massive public buildings and elaborated burial rites indicate some social stratification in this region during the 5th and early 4th millennium BCE. The Fars region in the middle South of Iran undergoes a centralisation and concentration process at the site of Tal-e Malyan, while little is changing for the village-like communities and their living mode when compared to the end of the Neolithic (Helwing, 2012a, p. 508; Matthews and Fazeli Nashli, 2022, p. 184). Several important innovations in this region date to the early 5th millennium BCE, which marks their earliest occurrence in Iran. So is the onset of textile production indicated by an increase in the amount of ovicaprids and the appearance of spindle whorls at the same time.

Two-chambered kilns and the earliest evidence of copper smelting in Iran at Tal-i Iblis provide ample evidence for the high level of pyrotechnological knowledge in this region during the 5th millennium BCE (Frame, 2012, p. 187; Helwing, 2021; 2012a, p. 508; Pigott and Lechtman, 2003, p. 296). In the early 4th millennium BCE, the settlement system collapses almost completely. Consequently, little archaeological evidence is available (Helwing, 2012a, p. 509). Nevertheless, the occurrence of bevelled rim bowls, albeit sparse, indicate contacts with the Mesopotamian Uruk culture (Helwing, 2013b, pp. 95–96).

The Zagros mountains see an intensification of the subsistence through closely connected village communities, and the performance of elaborated burial rites (Matthews and Fazeli Nashli, 2022, p. 184). Due to the absence of contemporary settlements close-by the burial grounds, e.g., in Parchineh, they were interpreted as evidence for groups with a mobile lifestyle that interacted with the local sedentary communities (Alizadeh, 2004). Metal objects can be found in some of these burials such as the mace head from Parchineh, dating to 4600 to 4200 BCE (Haerinck and Overlaet, 2002, p. 167).

The probably most pronounced changes during the 5th and early 4th millennium BCE can be observed in Southwestern Iran, today's Khuzestan. Located on the eastern flanks and piedmont of the Zagros, this region was an important contact point between groups from Mesopotamia and the highlands in the East (Helwing, 2013b, p. 96). Settlements were organised in a multi-tiered settlement hierarchy with Choga Mish as central settlement until the mid-5th millennium BCE and Susa afterwards. Elite residences as well as monumental public and cultic buildings were uncovered in Susa, providing clear evidence for a vertical social stratification of the inhabitants (Matthews and Fazeli Nashli, 2022, pp. 150, 184). In addition, recent excavations in Chega Sofla yielded another large cultic building dating to the 5th millennium BCE (Moghaddam, 2016). In Susa as well as in Chega Sofla, cemeteries with a large number of metal items were uncovered. The cemetery of Susa was excavated several decades ago but is with around 2000 burials in the layers 27 to 25 still one of the largest 5th millennium BCE burial grounds in this region (Tallon, 1987). Although low in number when compared to the number of burials, the 40 axes, 10 round discs (interpreted as mirrors), and many awls and spatulas (Tallon, 1987, p. 311) are still the major assemblage of metal burial goods from the end of the 5th millennium BCE in this region. Also the layers 24 and 23, dating to the early 4th millennium BCE, contained metal objects. Although less in number, probably because no burials of adults were uncovered (Tallon, 1987, p. 315), they are no less important. Among them are a many shaft hole axes, which allow the reconstruction of long-distance exchange networks (e.g. Rosenstock et al., 2016). The cemetery of Chega Sofla dates to a similar time frame. Although excavations started only a couple of years ago, the amount and high technological level of the metal objects already found in the graves indicates a cemetery of similar importance (Moghaddam, 2016, p. 1; Moghaddam and Miri, 2021, p. 49).

As was shown, the increased technological capabilities, craft specialisation and especially the adoption of metallurgy were key components for the developments in 5th millennium BCE Iran (Matthews and Fazeli Nashli, 2022, p. 184). Although the entire Iran is rich in (copper) ore deposits, it is probably no surprise that metal objects are most frequent during these times in the particularly ore-rich Zagros mountains and neighbouring regions (Nezafati et al., 2008a; Thornton, 2009a, p. 306). According to Helwing (2021), metal objects, exotic stones and other rare materials are status indicators during the 5th millennium BCE and embedded in a social system that emphasizes the merits individuals obtained by their actions and decisions. She also states that the settlement system was two-tiered without central places and that also within the settlements no internal differentiation existed. It was shown that this holds true for South(east) Iran but not for the North Central Plateau and Khuzestan. However, our knowledge about the social organisation in these regions is yet too limited to allow more fine-grained hypotheses about the role of metals in the social organisation of communities in the Zagros mountains and neighbouring regions to the East, with their specialised (cultic) buildings and metal burial goods, and the other regions with large specialised (mostly administrative) buildings but without metal grave goods.

As already mentioned above, metal objects and especially the shaft hole axes are one of the best indicators for long distance exchange networks. Another important tracer are bevelled rim bowls, which occur throughout Iran since the early 4th millennium BCE and are characteristic for the Uruk culture from Mesopotamia. In addition, lapis lazuli indicate exchange with regions far away in the East and practically identical shaft hole axes can be found in the Southern Caucasus and Southeastern Europe (cf. chap. 3.2.3). All these evidences indicate that Iran was an important player in the exchange networks connecting the different regions in West Asia and probably also connecting them to the regions further East (Matthews and Fazeli Nashli, 2022, p. 185).

### 3.1.5 Southeast Europe

The area of importance in this study is the region covered today by Romania, Bulgaria, the European part of Turkey, Greece, Albania, North Macedonia, Serbia, Kosovo, Montenegro, and Bosnia and Herzegovina. Although located outside Western Asia, this region is of interest because it currently holds the earliest evidence for copper smelting and the currently earliest evidence for the use of other metals and metallurgical technologies. The metallurgical developments and the role of the metal items were studied in detail in several projects. The most recent and probably the largest one is “Rise of Metallurgy in Eurasia” with its comprehensive monograph (Radivojević et al., 2021b) and a synthetical article (Radivojević and Roberts, 2021a).

The concept of and probably also the techniques for the use of copper minerals as pigments and personal adornment like beads were probably brought to Southeast Europe from South-West Asia (Radivojević and Roberts, 2021a, pp. 212–213; Rosenstock et al., 2016, p. 98), maybe as part of the Neolithic lifestyle (Pernicka, 2020, p. 38). The earliest mining activities for copper minerals were reconstructed in Rudna Glava and date to the mid-6th millennium BCE (Borič, 2009; Radivojević and Roberts, 2021a, p. 215). Around 5000 BCE, mining activities intensified. The first evidences for smelting activities can be dated to roughly the same age (Radivojević and Roberts, 2021a, p. 215). However, the lead isotope signatures from the metal objects cannot be linked to Rudna Glava, indicating that copper minerals from this mine were used for decorative objects only (Radivojević and Roberts, 2021a, p. 216).

During the first half of the 5th millennium BCE, smelting activities were limited to the Vinča culture. Remains of them are restricted to a couple of sites such as Belovode, Vinča-Belo Brdo and Pločnik (Radivojević and Roberts, 2021a, p. 218). At all sites, ores were nearly always a mixture of green and dark (blue, violet, black) minerals, while pure green copper minerals were predominantly used for decorative purposes (Radivojević et al., 2021a, p. 484; Radivojević and Rehren, 2016; Radivojević and Roberts, 2021a, pp. 218–219). Small hole-in-the-ground furnaces lined with pottery fragments were operated with blowpipes or bellows. Crucible fragments are missing so far but like casting moulds, their existence is assumed due to the contemporaneity with cast objects, among them the first shaft hole axes (Hansen, 2013, pp. 146–147; Radivojević and Roberts, 2021a, p. 219).

Parallel to the first objects made from smelted copper in the Vinča culture, most likely native copper was worked alongside malachite to beads and pendants in the Lower Danube basin and along the western coast of the Black Sea (Radivojević and Roberts, 2021a, p. 222). Metallurgical activities seem to shift towards this region with the collapse of the Vinča culture during the mid-5th millennium BCE (Radivojević and Roberts, 2021a, pp. 223–224). The earliest securely datable mining activities in Ai Bunar and Medni Rid date to this time and are accompanied by mining activities in several smaller deposits (Radivojević and Roberts, 2021a, p. 216). Among other sites, Akladi Cheiri (4450–4350 BCE) at the south-western Black Sea coast revealed well-preserved remains of a smelting furnace with close parallels to the Vinča furnaces (Krauss et al., 2020; Rehren et al., 2020, p. 142). They are accompanied by the first clear crucible fragments of Southeast Europe (Radivojević and Roberts, 2021a, p. 220). The ores used for smelting were weathered sulphide ores from which the oxidised parts were predominantly used for smelting, while the sulphides were usually discarded (Rehren et al., 2020, p. 153).

The large amounts of shaft hole axes, especially from the cemeteries of Durankulak and Varna but also from depositions outside the settlements, indicate a substantial increase in the production of copper with the first mass use of copper objects in general and of shaft hole axes in particular (Hansen, 2013, p. 149; Radivojević and Roberts, 2021a, pp. 223–224; Rosenstock et al., 2016, p. 73). It must remain open to which extent this increase in copper metal indicates a real increase in smelting activities or is the result of a bias in the archaeological record due to changed deposition practices (Radivojević and Roberts, 2021b, p. 612).

Figure 3.11: Gold objects (a) from different burials of the cemetery Varna I and close-ups of (b) objects cast in the lost wax technique and (c) a sheet-gilded copper bead (Leusch et al., 2015).

Around the mid-5th millennium BCE, new metals come into use: gold, bronze, and probably also lead. The cemetery of Varna I is unquestionably the most famous due to its large amount of gold objects: 3100 gold items with ~6.5 kg in total, together with 160 copper implements (Radivojević and Roberts, 2021a, p. 229). Nevertheless, Varna II and Durankulak date slightly earlier even though they are not as securely dated as Varna I (4550–4350 BCE, Higham et al. (2018)). Thousands of small decorative gold items were also found in other contemporaneous sites, indicating the use of gold in southeastern Romania, northeastern Bulgaria, and Northern Thessaly (Radivojević and Roberts, 2021a, p. 229). Geochemical analyses on the gold objects recovered from Varna I (Fig. 3.11) yielded four different groups, indicating that the gold was likely extracted from more than one deposit (Leusch et al., 2016; 2014, p. 179). The recent discovery of a placer gold deposit close to Varna suggests it as a potential source, but no indication about the location of the sources currently exists (Radivojević and Roberts, 2021a, pp. 230–231). Similarly, no evidence for any step of the production process other than the gold objects themselves was uncovered so far (Radivojević and Roberts, 2021a, pp. 231–232).

The gold objects are exceptional not only due to their sheer amount but also technologically. Investigations of the Varna I assemblage revealed not only the purposeful arrangement of gold objects based on their colour but also the intentional production of copper-gold alloys, indicating the importance of colour at this time (Leusch et al., 2015, p. 356; 2014, p. 175). The technology for the gold metallurgy seems to be mostly adopted from copper metallurgy (Leusch et al., 2015, p. 357; 2014, p. 176) with one crucial exception: Gold objects were also produced in the lost wax casting process (Fig. 3.11). The objects cast in this technology are a massive astragalus, a hollow bead and several rings (Leusch et al., 2015, p. 356; 2014, p. 175). While many objects appear unused and seem to be explicitly produced as burial goods, some objects have use-wear, especially the so-called ring-shaped idols (Leusch et al., 2015, pp. 364–365).

The earliest bronze finds at all date to around the same age. They were most likely produced by smelting the comparatively rare copper-tin mineral stannite ($Cu_2FeSnS_4$) with malachite, again a green-dark coloured ore (Radivojević et al., 2013). Most of the recovered objects are foils to e.g., wrap objects, similar to how several objects in the cemetery of Varna were gilded (Fig. 3.11). This and the golden colour of the bronze suggests that the bronze was produced to create a material that imitates gold by its optical appearance (Radivojević et al., 2018; Radivojević and Roberts, 2021a, pp. 225–228).

Indications for the processing of lead are scarce. A single lead slag “cake” found in Belovode dates to around 5200 BCE. Beads made of lead ore were found in several sites in contexts dating not later than the mid-5th millennium BCE (Radivojević and Roberts, 2021b, p. 606). Direct evidence for the use of metallic lead is still missing.

At the end of the 5th millennium BCE and in the early 4th millennium BCE, the centre of metal production shifts back to the West of Southeast Europe. Soon after, metallurgy spreads towards Middle Europe and the Italian Peninsula (Radivojević and Roberts, 2021a, p. 224). Similarly, the production of gold objects shifts from the Black Sea coast and Thessaly to the Carpathian Basin (Radivojević and Roberts, 2021a, p. 232). Until the first half of the 4th millennium BCE, all copper objects were made of pure copper except for the bronze foils. It is only from this time on that arsenical copper and associated production remains are found in Southeast Europe (Radivojević and Roberts, 2021a, p. 226).

Discussions about the social role of metal in Southeast Europe during the 5th millennium BCE often focussed on the cemetery of Varna I (Radivojević and Roberts, 2021b, pp. 614–615). Leusch et al. (2017, pp. 109–112) showed that if the cemetery of Varna I implies a stratification within the cemetery, the identified groups relate to different social or gender groups but not to different strata of the society. Similarly, the more wide spread shaft hole axes seem to indicate status in the burials from the second half of the 5th millennium BCE on (Rosenstock et al., 2016, p. 99). Contexts from finds in settlements and the settlement structures themselves do not indicate any hierarchical stratification at any time (Radivojević and Roberts, 2021a, pp. 229–230, 254–255). Considering that three of the eleven richest burials at Varna I are cenotaphs, it seems likely that the deposition of metal objects might be related to the definition and visibility of group identities instead of the communication of status (Radivojević and Roberts, 2021b, p. 615).

The clay figurines from Stubline (Fig. 3.12) support such an interpretation. Dating between 4650 and 4600 BCE, the assemblage consists of one bigger figurine that wears a mace head-shaped object and 42 smaller identical figurines. All figurines were arranged in front of a large domed oven. Eleven miniature models of shaft hole axes were found together with the figurines. Holes in the right shoulder of every figurine indicate that handles for such miniature tools might have been attached to all objects, and the remaining ones are not preserved. Striking is the circumstance that although the imitations of the metal items were shaped with a lot of care, rich details, and sometimes even were polished, the figurines are only roughly shaped. Radivojević and Roberts (2021a, pp. 255–256) interpret the taller figurine as a high-status person or deity while the smaller figurines are representatives of "cooperatives". They conclude that if copper objects were associated with prestige or wealth, it was equally distributed at least among these "cooperatives" – or at least it did not belong to " 'kings' or any kind of gender-exclusive community" (Radivojević and Roberts, 2021b, p. 615).

Connections between the sites further shows a well-connected region with exchange networks covering all parts of Southeast Europe. Changes in the foci of these networks correlate well with the shifting foci of cultural developments at this time (Radivojević and Grujić, 2018). These trends are visible already in the 6th millennium BCE, i.e., before the rise of metallurgy. They hence provide evidence that the networks did not emerge because of metallurgy but that it were the networks that provided an environment in which metallurgy was able to thrive (Radivojević and Roberts, 2021a, p. 256).

Figure 3.12: Selection of figurines from Stubline with their miniature tools (Radivojević and Roberts, 2021a).

## 3.2 Interregional relations in the mid-5th to early 4th mill. BCE

### 3.2.1 The Southern Levant and its North

Archaeological evidence for contacts to the North (and East) are rare except for Northern Mesopotamia and Anatolia. The reasons for this situation are twofold. First and foremost, the current political situation in the regions adjacent to the North and East of the Southern Levant prevented extensive research. Little is known yet about the archaeology of, e.g., Syria or the Jordanian desert for the period under study. Second, Anatolia and Mesopotamia are generally very well studied, and the rescue surveys and excavations flanking the Turkish dam projects boosted archaeological research in Southeastern

Anatolia, especially for the period of interest here. This situation tempts us to assume direct contact between Anatolia, Northern Mesopotamia and the Southern Levant, but we must remember that we currently lack archaeological evidence for the actual contacts between these regions at that time with some notable exceptions. This chapter also includes the scarce indicators for contacts between the Southern Levant and regions even further away (Southeast Europe, Caucasia, Iran).

Connections between the Southern Levant and Anatolia are attested since the Natufian (13 to 9.6 ka BCE) by Central Anatolian obsidian at Southern Levantine sites (Hauptmann, 2007, p. 289; Yellin et al., 1996, p. 364) and serpentinite in PPN B sites, which was probably imported from Syria or Cyprus (Rosenberg et al., 2010, p. 281). During the late Neolithic Wadi Rabah culture in the 6th millennium BCE, contacts increased and included additional materials (Garfinkel, 2009, p. 327). The raw material for chlorite vessels found in Hagoshrim in the Northern Hula valley was mined in Northern Syria, Anatolia, or maybe even Cyprus, where the closest outcrops of chlorite-hosting ophiolitic rocks are located (Rosenberg et al., 2010, pp. 285–286) and where such vessels were used since the PPN B (Rosenberg et al., 2010, p. 291). The pottery of the Wadi Rabah culture seems to be strongly inspired by the contemporaneous Northern Mesopotamian-Anatolian Halaf culture (Gabrieli, 2016, p. 165; Garfinkel, 2009, p. 327) with reported finds from e.g., Hagoshrim (Rosenberg et al., 2010, p. 281) and Qidron in the Shephela (Rosenberg et al., 2017c). Similarities between the North and the Wadi Rabah Culture were also observed in the stone tool assemblages and the styles of stamp seals and human figurines (Milevski et al., 2016, pp. 138–146; Rosenberg et al., 2010, p. 281). For these reasons, Milevski et al. (2016, pp. 146–147) suggested a common interaction sphere with a flow of impulses and material from the socio-economically more complex Halaf culture to the Southern Levant.

During the first quarter of the 5th millennium BCE, Tel Tsaf seems to be the only site with clear evidences for northwards-directed contacts. They are attested by many obsidian items and the Ubaid-related Tsaf ware (Gabrieli, 2016, pp. 172–174; Garfinkel et al., 2014, p. 1; Rosenberg et al., 2022b; Streit and Garfinkel, 2015). Moreover, the copper awl found in Tel Tsaf (Fig. 3.2) is most likely an import from Anatolia or even Armenia (Garfinkel et al., 2014, pp. 4–5). The presence of tokens and seal impressions in Tel Tsaf (Freikman et al., 2021; Freikman and Garfinkel, 2017, p. 31) and Hagoshrim (Gabrieli, 2016, p. 178) together with the silos found in Tel Tsaf (Garfinkel et al., 2009; Rosenberg et al., 2017b) and Pella (Gabrieli, 2016, p. 177) are interpreted as early evidence for a certain administrative system that seems to be absent in the remaining parts of the Southern Levant. It must remain open whether this administrative system represents a stratified society similar to the social organisation of the Northern Mesopotamian societies as suggested by Gabrieli (2016, p. 178) or if the seals and seal impressions were only used by the owner of the silos for private counting and managing as suggested by Freikman and Garfinkel (2017, p. 43). In any case, the archaeological evidence seems to support the conclusions of Gabrieli (2016, pp. 176–177) that the Northern and the Central Jordan valley was more orientated towards the northern, Ubaid-related cultural entities than it was to the Southern Levant.

During the Chalcolithic, evidence for long-distance exchange increased in the Southern Levant. Obsidian finds are reported from Gilat (Yellin et al., 1996), Teleilat Ghassul, Marj Rabba (Rowan and Kersel, 2014, p. 225), and Ashqelon-Afridar. For the latter, however, it cannot be excluded that they date to the Early Bronze Age (see discussion of the excavations in Braun, 2019). The amount of obsidian imported into the Southern Levant seem to decrease compared to earlier periods. At the same time, finds from East Anatolian obsidian indicates a diversification of source regions (Yellin et al., 1996, pp. 364–367).

Contacts with the North are also attested in the flint tools. Thuesen (1988, pl. 60) identified in Hama in the Northern Levant fan scrapers, one of the characteristic chipped stone tools of the Southern Levantine Chalcolithic (cf. Rowan and Golden, 2009, pp. 38–39). Perforated fan scrapers with removed percussion bulbs were identified as a connecting element for an extensive network that extended from the Nile to Habuba Kabira in Northern Mesopotamia (Klimscha, 2013b, p. 95) and at least towards the end of the Chalcolithic into the Eastern Jordanian Desert (Abu-Azizeh, 2013). Further, the so-called Canaanean Blades indicate close technological ties between the northern regions and the Southern Levant. Produced in specialised workshops in Northern Mesopotamia and Anatolia at the end of the 5th millennium BCE (Marro, 2012, p. 28) with potential precursors in Caucasia from the 6th millennium BCE on (Lyonnet, 2009, p. 13), their presence in Fazael and Ashqelon evidences the arrival of this technology at the end of the Chalcolithic, i.e., during the early 4th millennium BCE, before they become the characteristic blade technology of the Early Bronze Age (Bar and Winter, 2010; Golani, 2013, p. 102; Philip, 2002, p. 220; contra the dating of Canaanean Blades into the Chalcolithic: Vardi and Gilead, 2013). Perforated flint discs show that stone tools from the Southern Levant were also brought to the North. Typically found on the Golan, in the Jordan valley and in the Galilee (Rosenberg and Shimelmitz, 2017, p. 297; Rowan and Golden, 2009, pp. 16, 39; Vardi and Gilead, 2013, p. 112), some of them made it at least to Byblos (Rosenberg et al., 2019, p. 416).

Besides the perforated flint discs, direct contacts between the Southern Levant and Byblos are attested by a violin-shaped figurine, variants of V-shaped bowls, churns, and the decoration of ceramic vessels with a red band around their rim. They strongly indicates the movement of materials from the Southern Levant to Byblos during its Enéolithique récent (Klimscha, 2013b, p. 95; Philip, 2002, pp. 218–219). Although the Enéolithique récent of Byblos is contemporaneous only with the end of the Chalcolithic and mostly parallels the Early Bronze Age of the Southern Levant (Philip, 2002, p. 218), the contemporaneity of these finds with the Chalcolithic can be reliably assumed: Not only are many of these finds typical for the Chalcolithic but also do pottery from Peqi'in cave bear strong similarities with pottery in Byblos (Braun, 2015, p. 11; Gal et al., 1997, pp. 150, 154).

A genuine technology of the Chalcolithic Southern Levant that was exported to the North seems to be the potter's wheel. The earliest evidence for its use is the production of V-shaped bowls during the second half of the 5th millennium BCE (Baldi and Roux, 2016, p. 236), a defining element of the Chalcolithic Southern Levant (Fig. 3.3). Only at the beginning of the 4th millennium BCE, the potter's wheel is found outside the Southern Levant in, e.g., Tell Feres (Northern Mesopotamia) and Tell Qarassa (South Syria), where it was used in a similar cultural context (Baldi and Roux, 2016, pp. 239–243). Although Baldi and Roux (2016, p. 249) could not provide clear evidence for a spread of the potter's wheel from the Southern Levant to Northern Mesopotamia, their identified parallels between the vessel types produced with the potter's wheel in both regions and the use of clay pastes in Tell Qarassa, which could be imported from the Southern Levant, provides evidence for contacts between the Southern and Northern Levant. Their study also showed that elements of the Southern Levant pottery tradition were used alongside or mixed with elements from Byblos and Northern Mesopotamia in South Syria and today's Lebanon, respectively (Baldi and Roux, 2016, pp. 243–245). Whether the vessels were produced by local potters, imported from their typological regions of origins or if potters migrated from the Southern Levant to these sites must remain open (Baldi and Roux, 2016, p. 246). Recently, these processes were linked to groups from the northern parts of the Southern Levant migrating further North towards the end of the Southern Levantine Chalcolithic (Roux, 2022).

The ore source of the polymetallic copper alloys used in the Southern Levant was located in Caucasia from early on based on these alloys' chemical compositions. Additionally, they prove that suitable ore deposits exist neither in the Southern Levant nor in the Sinai or Cyprus (Key, 1980, p. 243; 1964, p. 1580). This reconstructed ore provenance was later confirmed by Tadmor et al. (1995), who combined lead isotopes and chemical analyses (Tadmor et al., 1995, p. 143). However, deposits in Anatolia and as far away as Iran could not be entirely excluded, and lead isotope data from Caucasia was not available for comparison at this time. A more precise reconstruction was therefore impossible. Yahalom-Mack et al. (2015, p. 5) suggested Southern Anatolia as the origin of the ore smelted for the lead of the Ashalim cave mace head (Fig. 3.13). Anatolia was also suggested by Namdar et al. (2004, pp. 77–80) as raw material provenance for the polymetallic copper objects from Giv'at HaOranim. However, they acknowledged that Caucasia could not be ruled out because no lead isotope data for this region were available for comparison. In conclusion, the ores for the polymetallic copper alloys or the alloys themselves were imported from the mountainous regions in the North and probably from more than one source region, but the available data do not allow the reconstruction of a more precise raw material provenance.

Shugar (2018, p. 288) suggested Anatolia as a source for some of the ore pieces found in Abu Matar (his group 4, see also Shugar, 2000, pp. 178–181). In contrast to the studies mentioned above, these ores are related to the pure copper metallurgy and it would be the first and so far only indication for non-local materials in this metallurgical process (Hauptmann, 2000; cf. Hauptmann, 1989a; Shalev and Northover, 1987). A closer look on their microstructure and their lead isotope composition suggests that his conclusion was based on incomplete comparative data (cf. chap. 4.1.1.5.1).

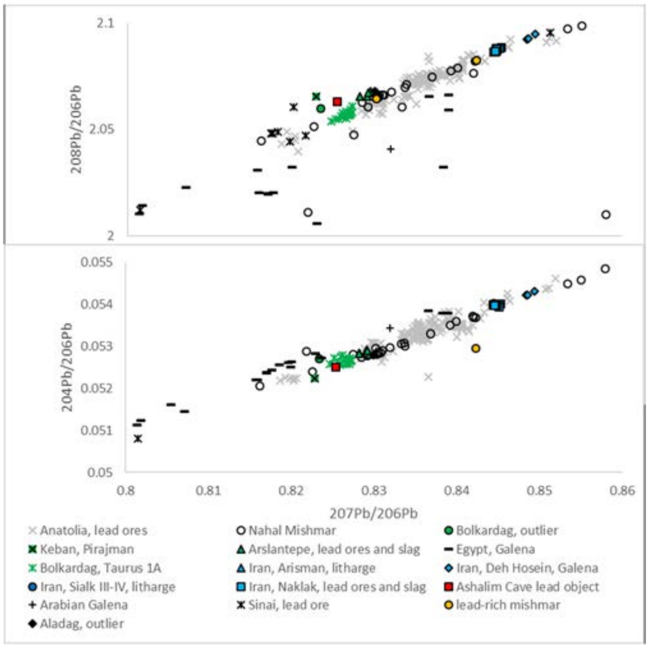


Figure 3.13: Lead isotope plots for various Anatolian and Iranian ores and finds, including the mace head from the Ashalim cave and lead-rich objects from the Nahal Mishmar Hoard (Yahalom-Mack et al., 2015).

Contacts with regions further away than Anatolia and Caucasia might be indicated in the bead production technology (Bar-Yosef Mayer et al., 2014; Bar-Yosef Mayer et al., 2004; Bar-Yosef Mayer and Porat, 2009). Bar-Yosef Mayer and Porat (2009, p. 117) concluded that the lapis lazuli for a bead in the Nahal Mishmar cave was imported from Afghanistan. Further, the manufacturing techniques of steatite beads found in Peqi'in cave and Mehrgarh (located in today's Pakistan) are comparable but deviate from the Egyptian steatite bead production. Bar-Yosef Mayer and Porat (2009, p. 117) admit that comparison with beads from Mesopotamia was impossible and that, e.g., many beads found in contemporary contexts at Tepe Gawra could be manufactured similarly. Large amounts of steatite beads were also found in the recently discovered site of Chega Sofla in Southwest Iran, dating to the mid-5th millennium BCE (Moghaddam and Miri, 2021, pp. 56–57), but their production technique is yet to be published.

The cemetery of Chega Sofla also yielded two copper objects with about 1 and 3 wt.% Sb (Nezafati, 28.01.2022). Although these concentrations are low compared to the antimony concentrations in many of the polymetallic metal objects from the Southern Levant, they presently are the closest known parallels in West Asia. More detailed information about these finds must be awaited before any conclusions can be drawn.

For regions to the West, Klimscha (2013b, pp. 97–98) noted strong parallels between the social organisation of the Levant and Southeast Europe.

All this evidence shows that the Southern Levant and the North were closely linked. Unfortunately, the type of contact often remains elusive. Many of the relevant excavations were carried out before modern documentation standards were introduced and hence do not provide well-dated stratigraphical contexts of the finds. The finds from Byblos, Peqi'in, and the results of the study by Baldi and Roux (2016), probably provide only a glimpse of how close contacts between the regions might have been. The Northern Levant, especially today's Lebanon, was most likely a contact zone between the Southern Levant and Northern Mesopotamia (Baldi and Roux, 2016, p. 246) and it is only in this region, that mutual exchange relations seem to have existed. Goods were apparently brought into the Southern Levant from regions further North, while Southern Levantine materials and influences seem to be absent there. An exception might be the potter's wheel (Baldi and Roux, 2016). One must also not forget the potential importance of goods made of perishable materials.

Archaeogenetic results suggest that contacts might have been tighter than the archaeological record suggests. Harney et al. (2018) were able to show that the gene pools of individuals buried in Peqi'in cave are a mixture of a local, an Anatolian, and an Iranian population. The Anatolian and Iranian populations arrived in the Southern Levant independently and at unknown times. While the Iranian component was still present in the Early Bronze Age, the Anatolian component disappeared. Hence, it was concluded that the Anatolian immigrants either stayed separate and did not mix with the local population or that they were driven out of the gene pool by the Iranian immigrants. If the former is the case, the seemingly one-way route from Anatolia to the Southern Levant might indicate a support route for Anatolian settlers and their descendants in the Southern Levant.

Another noteworthy aspect is the late date of many indicators for contacts to the North. The polymetallic copper alloys, Canaanean blades, the potter's wheel, and the contacts to Byblos, all date to the end of the Chalcolithic, i.e., into the very late 5th or early 4th millennium BCE. This might correlate with the beginning of the later phase of the Chalcolithic in the Southern Levant (cf. chap. 3.1.1).

Towards the end of the Chalcolithic, cultural changes in Anatolia and the Southern Caucasus might have led to an interruption of the connections or at least the supply routes from Anatolia and Caucasia to the Southern Levant. The rise of the Kura-Araxes phenomenon in Caucasia and the parallel spread of the Uruk phenomenon from Mesopotamia to the North resulted in fundamental changes in the cultural settings of Northern Mesopotamia and Southeastern Anatolia. Consequently, materials such as the polymetallic copper alloys might not have been accessible any more.

### 3.2.2 The Southern Levant and Egypt

Contacts between Egypt and the Chalcolithic Southern Levant are sparse. Egyptian material in the Southern Levant consists to a large extent of shells and mother of pearl from Nilotic molluscs. Finds were made in sites throughout the Southern Levant, such as Tel Tsaf (Garfinkel et al., 2014, p. 1), Teleilat Ghassul (Bourke, 2013, p. 19), and Nahal Mishmar (Bar-Yosef Mayer et al., 2014, p. 271) but are more abundant in the Northern Negev sites, e.g., Abu Matar, Grar, Horvat Beter, and Kissufim (Perrot, 1955c, p. 84; Rowan and Golden, 2009, p. 63). Recently found olivine beads in Tel Tsaf indicate long-distance ties to regions even further South than Egypt, probably as far as Ethiopia (Rosenberg et al., 2022a).

Ivory objects were primarily found in the southern parts of the Southern Levant with rare occurrences in rich burial assemblages further North, such as Peqi'in, Nahal Qanah, and Giv'at HaOranim. They seem absent in the Jordan valley and on the Golan (Rowan and Golden, 2009, p. 63). The few objects made from elephant ivory, and stylistic parallels between the ivory objects in the Southern Levant and Egypt (Fig. 3.14) indicate contact with Egypt (Klimscha, 2013b, p. 93; Rowan and Golden, 2009, p. 63; Scham and Garfinkel, 2000). However, ivory objects in general, and likewise ostrich eggshells, cannot be interpreted as Egyptian imports *per se*. Many ivory objects of the Chalcolithic Southern Levant are made from hippopotamus ivory and populations of both, hippopotamus and ostrich existed outside of Egypt during the Chalcolithic in, e.g., today's Jordan or the Southern Levant (Klimscha, 2011, p. 192; Knabb et al., 2018, p. 47; Rowan and Golden, 2009, p. 63).

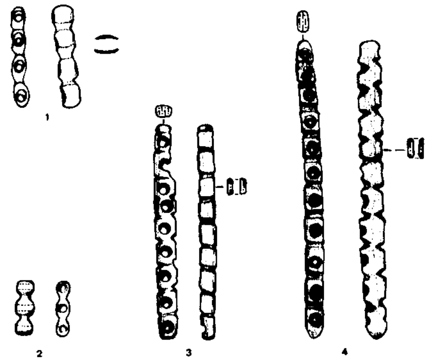


Figure 3.14: Perforated ivory rods from (1) Mostagedda, (2) Nahal Qanah, and (3, 4) Teleilat Ghassul (Scham and Garfinkel, 2000).

Egyptian pottery is only found at a few places such as Gilat and some Sinai sites, and seems to be restricted to the Early Chalcolithic (Commenge and Alon, 2002, p. 141; Rowan and Golden, 2009, p. 64). Later, the direction of the flow seems to change. Locally manufactured but typologically Southern Levantine vessels now indicate the presence of a Levantine community in Buto (Commenge and Alon, 2002, p. 145; Levy and van den Brink, 2002, p. 18). Another indicator for Levantine settlers in Egypt towards the end of the Chalcolithic is a subterranean house in Maadi that strongly resembles the subterranean dwellings in Abu Matar (Hartung, 2013, p. 184; Levy and van den Brink, 2002, p. 18).

In addition to this evidence for contact between Egypt and the Chalcolithic Southern Levant, some occasional finds are mentioned in the literature as Egyptian imports: Badarian arrow heads (Klimscha, 2013b, p. 93), some beads from Peqi'in cave (Shalem et al., 2013, p. 444), alabaster and banded calcite from En Gedi and Teleilat Ghassul (Bourke, 2002, p. 155; Ussishkin, 1980, p. 25), and maybe also some precious stones from Teleilat Ghassul (Bourke, 2002, p. 155). Additionally, the carinated and disc-shaped mace heads might be inspired by the Egyptians (Rowan et al., 2006, pp. 591–592; Rowan and Levy, 2011, p. 211), as might be the use of standards with animal motives and some elements in the iconography of the Nahal Mishmar Hoard (Gates, 1992, p. 135). In addition, the use of fan scrapers might indicate a network that extended from the Nile delta to Northern Mesopotamia (Klimscha, 2013b, p. 95).

The Sinai was always a bridge between the Southern Levant and Egypt. Hence, it is no surprise that connections between the Sinai and the Southern Levant in the Chalcolithic were suggested multiple times. Especially in the earlier days of research, its copper ore deposits were identified as possible sources for the Southern Levantine copper (Ilani and Rosenfeld, 1994), but no Chalcolithic date of mining or metallurgical activities can be provided (Pfeiffer, 2013). Based on geochemical analyses, only the pure copper objects could have been smelted from Sinai copper ore (Abdel-Motelib et al., 2012, pp. 36–41), but reports from the respective sites do not link any of the analysed ore to the Sinai (Hauptmann, 1989a; Shalev and Northover, 1987; Shugar, 2000). Another important aspect was the Nawamis, round burial buildings typical for the Sinai (Levy and Alon, 1982, p. 56; Levy and Holl, 1988, pp. 197–298). However, they are not typical for the Chalcolithic of the Southern Levant but for the Timnian (Gilead, 2011, p. 16). Although direct connections between the Southern Levant and the Sinai, and consequently also Egypt, are thus difficult to draw, the nomads of the Timnian played very likely a significant role in maintaining a contact network between the three regions. Their role as connectors and traders with a separate material culture might be underestimated so far (Anfinset, 2010, p. 170).

In sharp contrast to these scattered pieces of evidence for contacts are the finds from Tall Hujayrat al-Ghuzlan and Tall al-Magass immediately north of the Gulf of Aqaba. Settlement activities at these sites date from 4100 BCE to 3500 BCE (Klimscha, 2012, p. 204; 2009, p. 391), covering the transition from the Chalcolithic to the Early Bronze Age in the Southern Levant. The sites' material assemblage is distinct from the Chalcolithic of the Southern Levant with, e.g., the absence of stone axes and the use of copper axes instead (Kerner, 2011, p. 164; 2008, p. 164; Klimscha, 2011, pp. 195–197), despite some similarities (Kerner, 2008, p. 164; Klimscha, 2011, pp. 189, 193–194). The two sites provide numerous indicators for close contacts with Egypt, such as Nilotic mollusc shells, stone vessels, flint tools, and a ceramic figurine (Klimscha, 2011, pp. 192–197). The probably most outstanding evidence is the exchange of

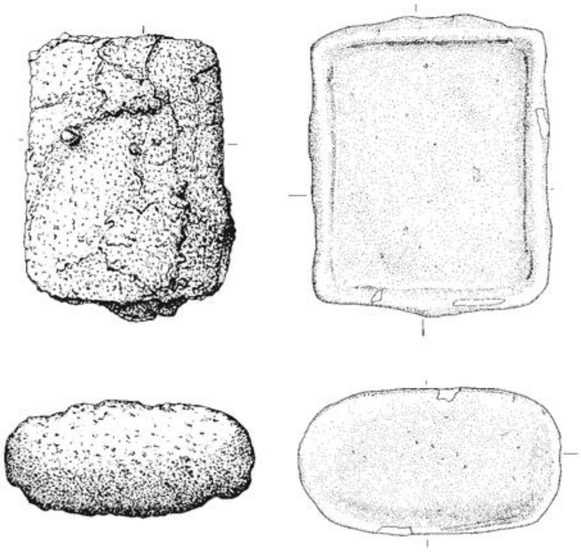


Figure 3.15: Ingots from Maadi (left) and moulds from Tall Hujayrat al-Ghuzlan (right) (Pfeiffer, 2009).

copper ingots from these sites to Egypt, especially Maadi (Fig. 3.15). Although only a few ingots were found in Maadi, their shape matches with the moulds from the Aqaba sites (Klimscha, 2011, p. 199; Pfeiffer, 2009, p. 321). Things are complicated by the circumstance that the position of the ingots in the stratigraphy of Maadi is not securely documented and that they were produced from Faynan copper according to lead isotopes (Klimscha, 2011, p. 199), while the overwhelming part of ores smelted at the Aqaba sites seems to be mined in Timna and small deposits close-by (Hauptmann et al., 2009). The amount of metallurgical debris found in Tall Hujayrat al-Ghuzlan and Tall al-Magass surpasses the evidence from the Northern Negev sites by far and indicates a full-fledged copper industry devoted to the production of copper ingots for export (Klimscha, 2011, p. 198; Pfeiffer, 2009, p. 312).

Taking all the evidence together, sparse contacts between the Chalcolithic Southern Levant and Egypt seem to dominate and almost exclusively involve sites in the Northern Negev. These contacts were most likely established by the nomadic population of the Timnian, which might explain the concentration of the material evidence on sites in the contact zone of the Timnian and the Chalcolithic. At some point, maybe at the end of the Chalcolithic, some people from the Southern Levant seem to migrate to Egypt, where they do not assimilate completely. At the end of the Chalcolithic, strong ties between Egypt and the Aqaba sites developed, probably with the rising demand for copper in Egypt as the main incentive, while contacts to the now Early Bronze Age sites in the Southern Levant seems to be absent (Kerner, 2020, pp. 419–420; 2008, pp. 158–159; Klimscha, 2009, pp. 393–395). Only with the onset of the Early Bronze Age IB contacts are re-established – but this time almost exclusively directed from Egypt towards the Southern Levant (Guyot, 2011; Hartung, 2013, p. 185; Kerner, 2008, pp. 158–159; Klimscha et al., 2014; Klimscha, 2013b, pp. 99, 101).

### 3.2.3 The Southern Caucasus and its neighbours

The population of the Southern Caucasus was closely entangled with the populations in the neighbouring regions. The archaeological and technological remains attest close contacts to Northern Mesopotamia and (South)eastern Anatolia, today’s Iran, the Northern Caucasus and the Eurasian steppe. The current limited understanding of the developments in the Southern Caucasus at this time (cf, chap. 3.1.3) impedes a complete understanding of these contacts. While it is sometimes possible to reconstruct some details of the connections between the Southern Caucasus and its neighbouring regions, it is often only possible to identify a connection without any information about e.g., its direction.

Considering the geographical and ecological continuities between the Southern Caucasus and the regions to its South, it is probably no surprise that close contacts between them have existed since the Neolithic. Archaeogenetic studies revealed that populations from Anatolia, the Caucasus, and

Northwestern Iran have been in close contact since around 6500 BCE and that these contacts might be connected to the spread of the first sedentary groups in Anatolia (Skourtanioti et al., 2020).

Firmly established contacts between Anatolia and the Southern Caucasus become visible in the archaeological record as late as during the Halaf/Late Neolithic. Caucasian obsidian was found in e.g., Domuztepe (Frahm et al., 2016). Parallels were identified in the building techniques of the Halaf and the early Shulaveri-Shomu culture at the beginning of the 6th millennium BCE (Baudouin et al., 2018). Another important line of evidence is the presence of Halaf pottery in Caucasian sites, such as Kültepe I and the lower levels of Alikemektepesi (Kavtaradze, 2018, pp. 79–80). During the subsequent Ubaid, Ubaid-related pottery from e.g., Areni-1 Cave, Alikemektepesi, Teghut, and Nerkin Godedzor attest to contacts between Northern Mesopotamia and the Southern Caucasus (Kavtaradze, 2018, p. 80).

With the end of the Ubaid in the middle of the 5th millennium BCE, the chaff-faced ware (CFW) horizon emerges with the mass-produced Coba bowls as its most characteristic vessel type (Baldi, 2012; Marro, 2010; Palumbi, 2011, p. 211). Material from several sites in the Southern Caucasus indicates almost exclusively contacts with the western regional group (cf. chap. 3.1.2). Additionally, Leilatepe and Böyük Kesik yielded material typical for the eastern group (Marro, 2010, pp. 38–40). All the sites listed by Marro (2010, pp. 39–40) indicate that these close contacts might date to the first half of the 4th millennium BCE, but finds from Ovçular Tepesi and Mentesh Tepe provide evidence for close contacts with Northern Mesopotamia already in the second half of the 5th millennium BCE (Gülçur and Marro, 2012, pp. 323–324; Lyonnet and Guliyev, 2017, p. 135; Marro et al., 2009, p. 54; Palumbi, 2011, p. 211). Pottery found in Ovçular Tepesi that is very similar to pottery in the eastern group might indicate a prevalence of contacts to Northern Mesopotamia at this site (Bakhshaliyev and Marro, 2009, p. 6; Marro et al., 2011, pp. 72–74; 2009, p. 52).

Marro (2012, p. 30) suggested that the CFW spread from the Southern Caucasus into the former Ubaid territories, maybe due to an intensified interest in exchange relations and boosted by a generally high mobility of the Caucasian population (Lyonnet, 2009, p. 11). However, CFW was found in sites of both regions from the early second half of the 5th millennium BCE on (e.g., Arslantepe VIII, cf. chap. 3.1.2). Hence, it seems that the technological features of the CFW were combined with the local typological and decorative traditions in parallel processes until a homogenised CFW horizon emerged around 4300 BCE (Marro, 2010, pp. 48–51).

Close contacts are not only attested by the pottery but also by architectural features. Excavations at Mentesh Tepe uncovered a rectangular building with a building plan that is interpreted as foreign by the excavators. They suggest that this might have been a tripartite building – a typical layout for Ubaid and post-Ubaid buildings in Northern Mesopotamia (Lyonnet and Guliyev, 2017, p. 135). For the early 4th millennium BCE, the “temple” in Berikldeebi and the “grill building” in Leilatepe are buildings, whose architecture seems to be strongly inspired by Northern Mesopotamian traditions (Kiguradze, 2000, p. 322; Lyonnet, 2009, p. 8).

Within the widely spread technological horizon of the CFW, the settlement pattern is characterised by temporary single-phase settlements in the highlands and multi-phase tell sites in the plains (Marro, 2007, p. 92). Marro (2007, p. 92) interpreted this pattern as the result of climate- and topography-related differences with Northern Mesopotamian settlers in the plains and local cultural groups in the highlands. The environmental conditions favoured a mobile nomadic-pastoralistic population with seasonal migration in the highlands and a sedentary farming population in the plains. This model is supported by the co-existence of settlements with exclusively local South Caucasian culture and settlements with Northern Mesopotamian material culture and architecture, such as Berikldeebi and Soyuk Bulaq (Lyonnet, 2009, p. 9; Lyonnet et al., 2008, p. 39; Marro, 2007, p. 90). Additionally, Lyonnet (2017, p. 193) suggested for Mentesh Tepe a co-habitation of foreign and local groups as the most likely explanation for the observations made at this site. Akhundov (2007, pp. 120–121) even suggested the incorporation of local (South Caucasian) elements into a genuinely Northern Mesopotamian material culture for the observations made at Leilatepe. The motivation for this northward movement of the Mesopotamian settlers was probably the access to raw materials like metals/ores, obsidian, and wood or exotic materials in general (Frangipane, 2017, p. 191; Lyonnet, 2009, p. 11).

During the first half of the 4th millennium BCE, the Kura-Araxes phenomenon emerged in Caucasia (Kavtaradze, 2017). At about that time, the Uruk phenomenon spreads from Southern Mesopotamia to the North and leads to the CFW horizon's decline (Marro, 2010, p. 52). The rise of the Kura-Araxes phenomenon might have disrupted the exchange relation between the Caucasus and Anatolia, restricting access to, among others, the metal or metal ores in the Caucasus. In the course of the 4th millennium BCE, the Upper Euphrates with e.g., Arslantepe VII to VI B1 maintained a close connection to the Southern Caucasus, probably to maintain access to metals and ores (Caneva et al., 1992, p. 230; Frangipane, 2017, pp. 192–193; 2007-2008, p. 181; Palmieri et al., 1999, p. 147). Northern Mesopotamia, however, established a lifestyle similar to that of Southern Mesopotamia thanks to their parallel and connected developments since the Ubaid period (cf. Özbal, 2011, pp. 189–190).

Contact with the Zagros Mountains and the Iranian plateau is attested through two aspects: shaft hole axes and Dalma pottery. The latter is typical pottery in the northern Zagros mountains during the first half of the 5th millennium BCE. It was found in, e.g., Nakhchivan Tepe and Kültepe, sometimes together with Halaf and Ubaid pottery, such as in Godedzor and Kültepe (Bakhshaliyev, 2021; Chataigner et al., 2010, p. 384). Moreover, pottery with parallels to finds from Geoytepe in West Iran is reported from Ovçular Tepesi (Marro et al., 2011, p. 75). Although Northern Mesopotamian and Iranian pottery were found together in South Caucasian sites, there is no evidence for direct contact between the two regions

(Lyonnet, 2009, p. 11) which emphasizes the importance of the Southern Caucasus for interregional contacts.

Virtually identical shaft hole axes and their moulds from the second half of the 5th millennium BCE (Fig. 3.16) in the Caucasus (e.g., Dzedzvebi: Gambashidze et al., 2016; Ovçular Tepesi: Gailhard et al., 2017) and Iran (e.g., Tepe Ghabristan: Madjizadeh, 1989) are impressive evidence for contacts between the two regions at this time (Courcier, 2007, p. 212; Gambashidze et al., 2016, pp. 114–115). However, further excavations and better-dated contexts are necessary to figure out whether the shaft hole axes spread from Iran to the Caucasus (Helwing, 2012b, p. 214) or from the Caucasus to Iran (Stöllner, 2021). Similar shaft hole axes found in Southeast Europe already at the first half of the 5th millennium BCE (Gailhard et al., 2017, p. 547; Rosenstock et al., 2016, p. 73) might support an eastward directed spread of these items (Fig. 3.16).

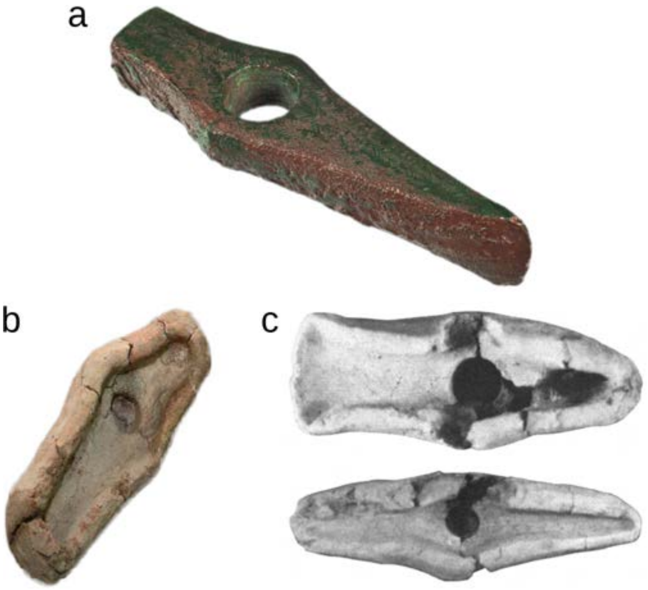


Figure 3.16: (a) Shaft hole axe from Pločnik (Radivojević et al., 2021b) and moulds for shaft hole tools from (b) Dzedzvebi (Gambashidze et al., 2016) and (c) Tepe Ghabristan (Madjizadeh, 1989).

Contacts between the Southern Caucasus and the Northern Caucasus existed without doubt but are challenging to recognise in the archaeological record. The probably clearest indicator is the strong similarities in the burial rites expressed by the first kurgans in the first half of the 4th millennium BCE that seem to cover the entire Caucasus (Lyonnet et al., 2008, p. 40). The Northern Caucasus might have played a major role in spreading metallurgy from Southeast Europe towards the South. Courcier (2007, p. 201) reports parallels between the pottery of the Svobodnoe culture in the Northern Caucasus and the pottery of the Cucuteni-Tripolye culture, which covered the Northwest of the Black Sea. He also suggests that metallurgy spread from Southeast Europe to the Caucasus, where it was adopted by a precursor of the Maikop culture (Courcier, 2014, p. 622).

### 3.2.4 Anatolia and Southeast Europe

Hansen (2007) suggested a contact network that connected Western Asia and Southeast Europe since the Neolithic and based his theory on a stylistic comparison of sculptures, especially anthropomorphic ones. Archaeogenetic investigations and pottery typology revealed that the Vinča culture in the second half of the 6th millennium BCE, the first metal-bearing culture of Southeast Europe, descends from a wave of immigrants coming from (Northwest) Anatolia after the Neolithic was introduced in Southeast Europe by an earlier wave (Hervella et al., 2015). The spread of malachite beads should be connected to this first wave because there is no chronological continuity between their appearance in the first half of the 6th millennium BCE and the earliest copper finds (Rosenstock et al., 2016, p. 98). The archaeogenetic study of Lazar et al. (2019) suggests that also the first metal objects in today's Romania were brought by Neolithic migrants of Anatolian origin. However, Mathieson et al. (2018) showed that immigration from Asia to Southeast Europe was not restricted to the Bosporus route. Based on archaeogenetic analyses, they traced a contribution from the steppe regions north of the Black Sea and from a Neolithic Caucasian group in the gene pool of, e.g., individuals buried in Varna in the mid-5th millennium BCE (Mathieson et al., 2018, pp. 200–201).

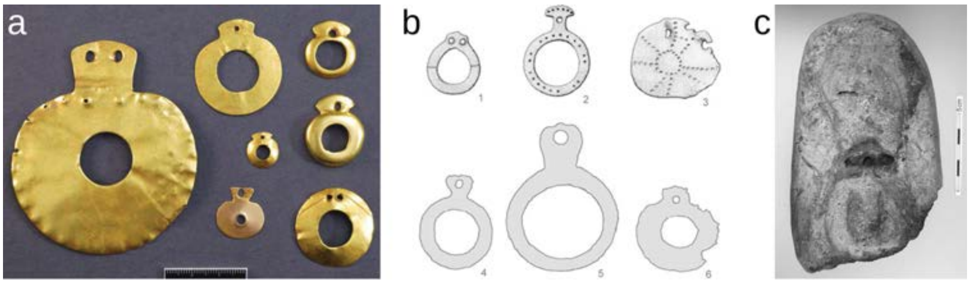


Figure 3.17: Ring-shaped idols from (a) Varna (Leusch et al., 2015), (b) İkiztepe and the region of Trabzon (Zimmermann, 2007), and (c) mould for a ring-shaped idol from Çamlıbel Tarlası (Schoop, 2011).

During the mid-5th millennium BCE, contacts between Southeast Europe and Anatolia are indicated by West Anatolian stone vessels in the cemetery of Varna (Düring, 2014, p. 15). In the other direction, from Southeast Europe to Anatolia, the so-called ring-shaped idols are probably the most impressive evidence for contacts (Lichter, 2006; Zimmermann, 2008). Often made of gold, they appear first in Southeast Europe (e.g., Varna) in the late 5th millennium BCE and are found in Anatolia in the first half of the 4th millennium BCE. Among the Anatolian finds, only the ones from İkiztepe were found in documented excavations. Unfortunately, their exact dating is debated (Özbal et al., 2008; Zimmermann, 2007, pp. 26–30). The purpose of these objects is unknown, but a mould for a ring-shaped idol in Çamlıbel Tarlası dating to the mid-4th millennium BCE (Schoop, 2011, p. 65) indicates that probably not only the objects but also the ideology of them spread from Southeast Europe to Anatolia (Fig. 3.17). Interestingly, their occurrence is restricted to Northern Anatolia. Considering the close contacts between Eastern Anatolia and the Caucasus at this time, the complete absence of Caucasian material in İkiztepe, and also the complete absence of any Southeast Europe-related material in major East Anatolian sites such as Arslantepe, might indicate two separate cultural spheres (Zimmermann, 2007, pp. 27–28).

# Chapter 4

# Archaeometallurgical background

This chapter will provide the necessary background for discussing the metallurgical processes and the spread of metal technology. The first part summarises the technological developments and characteristic features of the metallurgical techniques in the different regions, highlighting key sites and general trends. The evidence from the Chalcolithic Southern Levant will be discussed extensively to provide a foundation for the discussions in chap. 5 and 6. The second part summarises the technical and metallurgical aspects of copper smelting. It provides information about the reactions and the parameters influencing the smelting process. It also includes archaeometallurgical evidence from outside the studied regions for the smelting and use of polymetallic copper ores, including the impact of the relevant alloying elements in the Southern Levantine polymetallic copper alloys on the metal properties. In addition, examples of the importance of the metals' sensory properties for early metal-using societies are provided.

## 4.1 Metallurgical developments

### 4.1.1 Copper

Copper minerals and ores were widely used long before smelted into metallic copper. Green as colour played an important role in many early-farming societies and green stones were often used for pigments or personal adornments, such as beads or votive axes. Especially malachite was an important raw material due to its intense green colour and low hardness. The use of green stones can be traced back as far as the 11th millennium BCE in West Asia (Bar-Yosef Mayer and Porat, 2008; Hauptmann, 2007, pp. 255–261; Lehner and Yener, 2014, p. 538), from where it spread together with agriculture to Southeast Europe in the 7th millennium BCE (Borič, 2009, p. 237).

Native copper nuggets were shaped into small metal items such as rolled beads and awls by hammering and annealing since the 9th millennium BCE in West Asia (Jesus and Dardeniz, 2015, p. 232; Lehner and Yener, 2014, p. 538; Yener, 2000, pp. 18–25). The copper bead from Tell Ramad near Damascus, dating to the late 8th millennium BCE (France-Lanord and Contenson, 1973), is the only reported evidence for that phase in the Southern Levant and its neighbouring regions. The absence of native copper in this region (Hauptmann and Löffler, 2013, p. 71) suggests that the bead is likely to be imported from Anatolia (Golden, 2014b, p. 562). The earliest Iranian copper item can be dated to around the same time. Found in Ali Kosh and far away from any deposits of native copper, this bead is likely another import from Anatolia (Thornton, 2009a, p. 308).

The earliest evidence for metal pyrotechnology dates around 5000 BCE, when it appears practically at the same time in Southeast Europe, Anatolia and Iran (Pernicka, 2020, p. 41).

#### 4.1.1.1 Southeast Europe

The currently earliest evidence for copper metallurgy is reported from the Southeast European Vinča culture and date to the early 5th millennium BCE with Belovode and Pločnik as sites with well-researched metallurgical assemblages (Radivojević and Roberts, 2021a, p. 218). The onset of metallurgical activities on both sites can be dated to around 4900 BCE. They end in Belovode around 4700 BCE, while they continue in Pločnik until around 4400 BCE. Gornja Tuzla is another site that provided important information about the smelting process around 4400 BCE (Radivojević et al., 2021a, p. 487).

A characteristic of the Vinča metallurgy is the separation between manganese-rich green and dark (black) copper ores for copper smelting and green copper ores for beads (Radivojević et al., 2021a, p. 484; Radivojević and Roberts, 2021a, p. 210). Both ore types also contain some amount of primary copper sulphides such as chalcopyrite, indicating the use of weathered copper sulphide ores (Radivojević et al., 2021a, p. 484). Another characteristic of this early metallurgy is the particularly ephemeral nature of the practically slagless metallurgy (Radivojević et al., 2021a, p. 486).

Ore and malachite pieces (for beads) were found scattered over the entire excavation area in Belovode, regardless of the nature of the uncovered features. Their uniform size of 2 to 3 cm might indicate some rough beneficiation of the ore (Radivojević and Rehren, 2021a, p. 123), and the high sulphur content in two of them, radiocarbon dated to the 49th century BCE, confirm the use of weathered copper sulphide ore (Radivojević and Rehren, 2021a, p. 148). Two slagged pottery fragments were found in a pit together with fired sediments and slag (Radivojević and Rehren, 2021a, p. 123). Their fractures are covered by Mn-rich slag, suggesting their use in the metallurgical process already in a broken state. The ceramic paste consists about 50 % quartz and no organic material. Pottery sherds with similar features were found in Gornja Tuzla. They suggest the use of pit furnaces lined with pottery sherds for smelting (Radivojević et al., 2021a, p. 487; Radivojević and Rehren, 2016, p. 212). The slag pieces, often less than 1 cm in size, contain, among others, delafossite, cuprite and cuprite-saturated copper prills, indicating rather oxidising smelting conditions (Radivojević and Rehren, 2021a, p. 134). Their bulk chemistry composition is close to the pottery, suggesting they are rather melted pottery with ore remains fluxed by ash (Radivojević and Rehren, 2021a, pp. 141–142). The overall features of the slag suggest that the ore was completely melt only for a short time, resulting in a very viscous copper-rich slag (Radivojević et al., 2021a, p. 486). The shape of a copper prill in the same pit might indicate that it was spilled during casting. If so, it would indicate that multiple metallurgical steps were carried out in this feature (Radivojević and Rehren, 2021a, p. 145). While clear evidence for casting in Belovode, such as crucibles, are still to be found, metallographical analyses on some of the uncovered copper objects show that oxidising conditions prevailed during casting. Hammering and annealing, probably in multiple cycles, were used to create the final shape of the objects (Radivojević and Rehren, 2021a, p. 148). In addition to the pottery sherd-lined pit furnaces, a base of a large vessel (about 20 cm diameter) placed in the ground was suggested as potential furnace purely on the association with close-by metallurgical remains (Radivojević and Rehren, 2021a, pp. 127–128). Smelting experiments showed that metallurgical operations can be carried out in such a structure with blowpipes and would not leave any distinct traces (Radivojević and Rehren, 2021a, p. 128).

The evidence from Pločnik is in good agreement with these observations and adds two important aspects. A rectangular hearth was found with large stones on one edge, maybe the remains of a low wall. Metallurgical remains in this feature suggest that it could be related to metallurgy (Radivojević and Rehren, 2021b, p. 301). The other feature is a cylindrical pottery fragment with a reconstructed inner diameter of 2 cm, potentially from of tuyère (Fig. 4.1). According to Radivojević and Rehren (2021b, p. 305), the inner diameter is too large for a tuyère at this time. It does not bear any traces of metallurgical activities (Radivojević and Rehren, 2021b, p. 305), but this does not automatically exclude its use as tuyère (cf. Botwid and Pettersson, 2016).

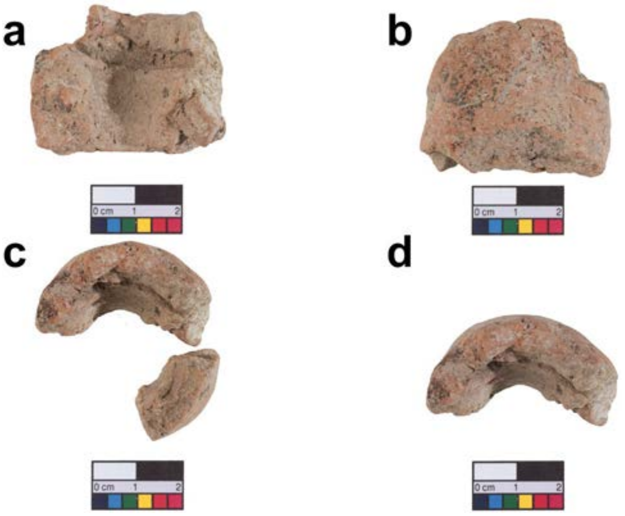


Figure 4.1: The cylindrical ceramic fragment from Pločnik (Radivojević and Rehren, 2021b).

Metallurgy spread to the Black Sea coast around the mid-4$^{th}$ millennium BCE (Radivojević et al., 2021a, pp. 487–488). The site of Akladi Cheiri (4454 BCE to 4356 cal BC) shows that the copper smelting process of the Vinča culture was adopted with only minor modifications (Krauss et al., 2020;

Radivojević et al., 2021a, p. 487; Rehren et al., 2020). Additionally, the earliest Southeast European crucible was found in Akladi Cheiri (Fig. 4.2). A thin layer of quartz was applied on the inner surface of the crucible, probably to prevent a reaction between the crucible and the melt (Rehren et al., 2020, p. 151). Moreover, investigation of the ore remains evidenced the extraction of oxide copper ores from weathered sulphide ores with the sulphides being discarded (Rehren et al., 2020, pp. 153–154).

In addition to unalloyed copper production, a short phase of bronze production is attested in Southeast Europe from the mid until the early second half of the 4th millennium BCE, basically parallel to the use of Gold (Radivojević et al., 2013; Radivojević and Roberts, 2021a, p 225–226). Radivojević and Roberts (2021a, pp. 225–226) suggested that this early bronze production was a variety of the general copper smelting process with the intentional use of stannite instead of regular copper ore to produce gold-coloured copper.

Figure 4.2: The crucible found in Akladi Cheiri. Note the bloated rim on one side (Rehren et al., 2020).

Beside small objects, such as awls and beads, larger objects like axes and chisels were produced from early on. Among them are axes and hammers with shaft holes (Fig. 3.16a), while flat axes become more common only after 4600 BCE (Rosenstock et al., 2016, p. 73). These heavy tools spread with metallurgy towards the East, leading to the emergence of regional traditions in their manufacture and style (Rosenstock et al., 2016, p. 73). They are often found in hoards and burials (Radivojević et al., 2021a, p. 486; Rosenstock et al., 2016, p. 73) and produced in large numbers with more than 4300 objects or 4.7 t of copper. This richness stands in sharp contrast to the few discovered smelting sites. As was shown above, the metallurgical process leaves only ephemeral remains and is practically slagless (less than 10 g of slag for the entire Vinča metallurgy). Therefore, smelting sites might be easily overlooked.

#### 4.1.1.2 Southeastern Anatolia

Anatolia is very rich in ore deposits. Especially its eastern part hosts several large copper ore deposits (e.g., Ergani Maden) and numerous smaller outcrops. Deposits with fahl ores, from which the polymetallic copper alloys were most likely smelted (cf. chap. 4.1.1.5.2), are available in this region as well, more precisely in the Taurides in the South and the Pontides in the North of Eastern Anatolia

(Lehner and Yener, 2014, p. 532).

'Slagged' copper-rich pieces from a feature in Çatal Höyük dated to about 6500 BCE were assumed to be the earliest evidence for deliberate copper smelting in Anatolia for some time (Neuninger et al., 1964). This interpretation has been debated ever since (cf. Radivojević et al., 2017, p. 102 and references therein) and a detailed re-examination of the material and its archaeological and technological context showed that they were most likely incidentally heated in a destructive fire of the building to temperatures sufficiently high for smelting (Radivojević et al., 2017). Similarly, the copper mace head of Can Hasan, dating to around 6000 BCE, was often assumed to be of cast copper due to its high weight (433.2 g). However, Yalçın (1998) showed that it is a large copper nugget brought into its final shape by a combination of annealing and hammering like many other contemporary copper objects.

Therefore, the earliest smelted copper items in Anatolia are the axes, chisels and needles from Mersin-Yumuktepe XVI (Fig. 3.9). Dating to around 5000 BCE, they are at the same time the oldest large metal tools found in Anatolia. Use-wear on many of them indicate that they were not produced for symbolic use only. Unfortunately, no contemporary remains of the metallurgical process like slag, furnaces or crucibles were uncovered (Lehner and Yener, 2014, p. 539; Rosenstock et al., 2016, p. 73; Yalçin, 2000; Yalçın, 2003, p. 531).

Soon after, during the first half of the 5th millennium BCE, smelting is attested in Anatolia. Although the exact date varies in the literature, the metallurgical remains and copper objects found in Değirmentepe generally date into this period (Lehner and Yener, 2014, p. 540; Rosenstock et al., 2016, p. 76; Weeks, 2012, p. 301; Yalçın, 2003, p. 531; Yener, 2000, p. 34). Metallurgical remains are spread across the entire settlement. Furnace-like installations were found between some buildings, which are interpreted as metallurgical workshops (Yener, 2000, pp. 34–36). At least one of the domed furnaces was lined with Ubaid pottery sherds (Yener, 2000, p. 36). The ovens, crucible fragments, and slag analyses suggest that smelting was carried out in crucibles (Yener, 2000, p. 39). Moreover, the nearly absent copper concentrations in several slagged accretions on crucibles indicates melting or refining of copper instead of smelting as main activity (Lehner and Yener, 2014, p. 541; Yener, 2000, p. 39). Grinding stones for ore beneficiation were found in Değirmentepe, and the association of some of them with slag might indicate that they were also used to extract the copper prills from the slag (Yener, 2000, p. 37). The ores found in Değirmentepe were oxide ores. According to their very low Fe content (< 5 %), they most likely consisted of cuprite and malachite. In addition, As-rich ores are indicated by chemical compositions of slag pieces (Yener, 2000, p. 35). Sulphur in some samples suggest that they were probably heavily weathered sulphide ores (Yener, 2000, pp. 40–41). The slag has the typical high copper content of early copper smelting slag (Hauptmann et al., 1993; Yener, 2000, p. 40). Noteworthy is a metal prill in a slag piece with 1.43 % Sb (Yener, 2000, p. 39), indicating the presence of (weathered) fahl ore in the ore charges processed at Değirmentepe.

To the Early Chalcolithic date smelting slag and crucible fragments from Tülintepe and Tepecik near Elazığ (Esin, 2001a, 2001b). The features uncovered there largely resemble the finds in Değirmentepe (Yener, 2000, p. 41). Analyses of the slag from Tülintepe indicate, like in Değirmentepe, the smelting of As-rich ores parallel to unalloyed copper ores. The low copper content in the slag proves the use of relatively unalloyed copper ores, such as malachite, and efficient extraction of the copper during smelting (Çukur and Kunç, 1989, p. 114).

The parallel use of unalloyed copper and copper with elevated levels (i.e., >1 wt.%) of arsenic and nickel continued in the second half of the 5th millennium BCE. Analyses of some of the metal objects found in Arslantepe VIII (4700 to 3900 BCE) attest to the use of at least three metal types: unalloyed copper, copper with nickel, and copper with arsenic and nickel (Di Nocera, 2013, p. 113). Only small items such as awls and sheet fragments were uncovered (Fig. 3.7). Finds related to the production of metal objects are yet to be found (Di Nocera, 2013, p. 113).

Contemporary to late Arslantepe VIII dates Norşuntepe (Yalçin et al., 1992, p. 382). It yielded ash-filled pits with close-by slag concentrations, ore pieces, and a fragment of an open mould (Pernicka et al., 2002, pp. 115–116; Schmidt, 2002, p. 40). Spoon-shaped ceramic objects found in a neighbouring room (Pernicka et al., 2002, p. 115) were interpreted as casting ladles because of the metallurgical debris close-by (Schmidt, 2002, p. 49; Yalçin et al., 1992, p. 382). Baranyi (2002, p. 144) suggests the use of bellows for smelting, probably because of three tuyère fragments found in Norşuntepe. However, they date to the Middle Bronze Age and were found in contexts unrelated to metallurgy.

Ore and slag pieces from Norşuntepe were studied in detail. They allow to identify three types of ores: a chromite-bearing ore from a sandstone-hosted deposit (Baranyi, 2002, p. 138; Zwicker, 1980, p. 13), a weathered ore with fahl ores or chalcopyrite as primary ore mineral and baryte as gangue (Baranyi, 2002, p. 142; Zwicker, 1980, p. 13), and less abundant a carbonate-hosted copper ore (Baranyi, 2002, pp. 142–143). The ores found at Norşuntepe are outstanding in their high Sb and As contents. The ore with baryte has levels of about 5 % Sb and 1.5 % As (Seeliger et al., 1985, p. 656) and Sb-rich minerals are found in all parts of the ore, including the gangue (Zwicker, 1980, p. 13). The chromite-bearing ore contains Sb as well but has low As levels and is rich in Fe (Zwicker, 1980, p. 14). The ores might have been mined from a gossan (Baranyi, 2002, p. 144). The mineralogy of the slag suggests a relatively oxidising smelting process with absent wustite, very rare fayalite, abundant magnetite and other spinel phases, and the presence of delafossite (Yalçin et al., 1992, p. 38). Analysed slag pieces can be exclusively linked to the chromite-bearing ore by their high iron content and the presence of chromites (Pernicka et al., 2002, p. 119; Zwicker, 1980, p. 17). In contrast to the other sites, only unalloyed copper items were found in Norşuntepe.

Smelting experiments by Zwicker (1980, p. 15) with the baryte-hosted ore resulted in prills with a wide variety of phases rich in Sb, As, Ni, and Pb, together with Sb- and As-free sulphide phases. Melting these prills together yielded a brittle polymetallic copper alloy rich in Sb and As, similar to the polymetallic copper alloys found in the Chalcolithic Southern Levant. The experimental smelting of the chromite-bearing ore yielded Sb-rich copper metal as well but is missing the other impurities of the Southern Levantine polymetallic copper alloys, especially the As (Zwicker, 1980, p. 15).

In Arslantepe VII (3900–3400 BCE), copper with elevated levels of As and sometimes Ni dominates (Di Nocera, 2013, p. 115; Heil, 2019, p. 102). Noteworthy are two items with elevated lead levels, one of them also with elevated sulphur levels, and another item with nearly 4 wt.% Sn (Heil, 2019, p. 102). A vessel or funnel-shaped object with an attached spout made of copper sheet indicates that the metallurgists were able to produce metal vessels and to attach metal sheets to each other (Heil, 2019, p. 25). Later strata of this period yielded ore pieces, crucible fragments, slag, and fragments of open moulds for flat axes (Di Nocera, 2013, p. 115). Copper residues in the crucibles indicate that copper was smelted in them (Di Nocera, 2013, p. 115).

Dating later than the period under study here, the metallurgical processes at Arslantepe VII will only be shortly summarised. The entire metallurgical process is attested by production debris (Di Nocera, 2013, p. 115), although furnaces remain absent. Analyses of the ore pieces found in Arslantepe VII and later periods revealed four different groups: unalloyed copper ores, lead ore, mixed ores, and copper and mixed ores from ophiolite-hosted deposits (Hauptmann et al., 2002, p. 53; Hess, 1998, pp. 55–59; Palmieri et al., 1997, p. 61; 1992, p. 393; Palmieri and Sertok, 1994, p. 122). Unalloyed copper ore is rare in Arslantepe VII (Hess, 1998, p. 63). The mixed ores contain up to 7 wt.% Sb and 8.8 wt.% As; sometimes they also have a high lead content and considerable amounts of Bi and Ag (Hess, 1998, pp. 60–62).

Hess (1998) reconstructed two different smelting processes in Arslantepe VII and VI: unalloyed copper metallurgy, and smelting of mixed ores. The unalloyed copper ores were smelted in very reducing furnace atmosphere, as the fayalite and occasional wustite in slag pieces shows. Slag adhering to the crucible has a very different composition and is interpreted as a mixture of melted copper mixed with liquefied crucible material (Heil, 2019, p. 49).

Smelting of mixed ore in Arslantepe is attested, among other finds, by a lead slag cake with Cu-As-Sb-Pb prills, some of them containing a few percent of Ni (Palmieri and Sertok, 1994, pp. 121–122). Three different crucible types can be associated to this process. Two of them are flat bowls with rounded bases and spouts that differ markedly by their size with one type (Fig. 4.3a) about double the size of the other (Hess, 1998, pp. 106–107; Palmieri and Morbidelli, 2003, p. 233). The third type has a diameter of at least 12 cm and high walls, creating a beaker-like shape with a bowl-shaped base. They have two opposing spout-shaped openings with 3 to 4 cm diameter close to their bases (Fig. 4.3b). The purpose of the openings are unclear, a use as draught inlet or as outlet of the metal melt was suggested (Heil, 2019, p. 30). While the crucibles described by Hess (1998) are in fact mass-produced bowls that were (re-)used as crucibles, the beaker-shaped crucibles are the earliest vessels in Arslantepe genuinely designed for the use as crucible (Frangipane et al., 2019, pp. 26–27).

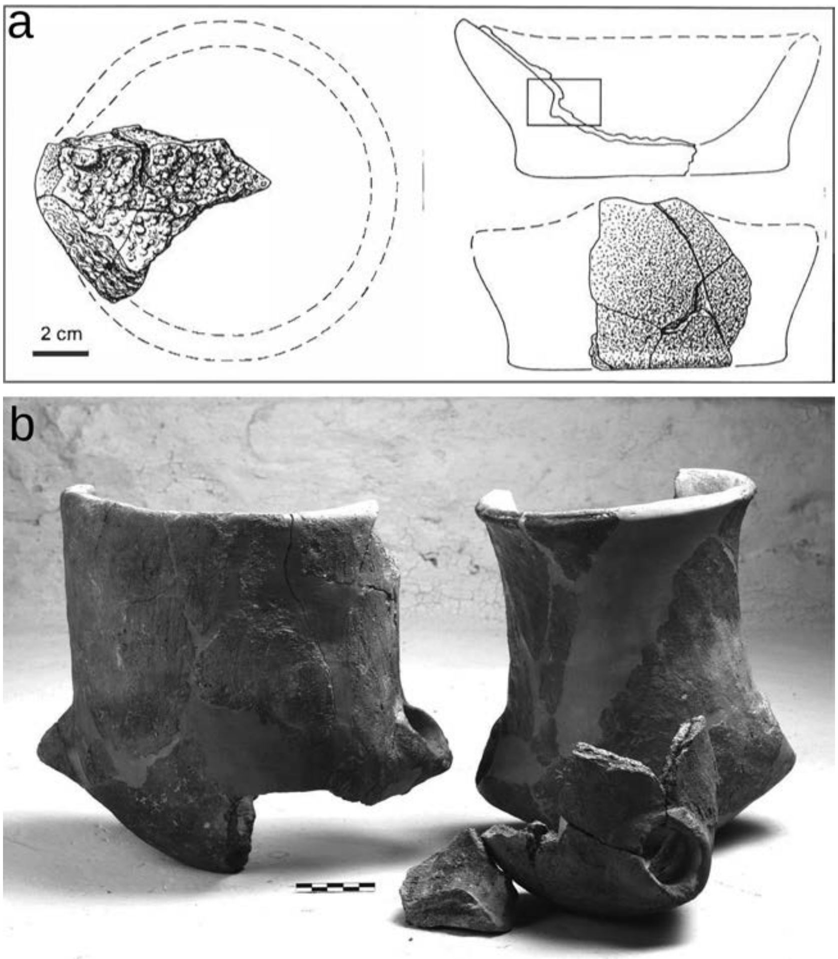


Figure 4.3: Different crucible types of Arslantepe VII: (a) flat bowl-shaped crucibles with spout on the rim (Hess, 1998), (b) beaker-shaped crucibles with spouts over the base (Frangipane et al., 2019) .

Furnace conditions for the mixed ore metallurgy were less reducing than for the unalloyed copper metallurgy. Concerning the polymetallic copper alloys of the Chalcolithic Southern Levant, speiss inclusions in the slag derived from the mixed ore process are of interest. The Ni-rich speiss has sometimes high concentrations of Pb and Sb, while the Cu-speiss does not show any elevated Pb concentrations (Hess, 1998, pp. 114–115). The lead slag of Heil (2019, p. 56) belongs to the same group. It has between 2 and 11 wt.% As, in one sample 21 wt.% Sb, and in another 10 wt.% ZnO (Heil, 2019, p. 46). This slag contains unmelted ore and furnace wall fragments, although cristobalite indicates at least partial heating beyond 1200 °C (Heil, 2019, p. 46). Speiss is subordinate in these slag pieces, while metallic inclusions are more abundant and indicate the segregation of Pb-As-Sb inclusions from As-Sb phases (Heil, 2019, p. 52). Similar to the unalloyed copper process, slag adhering to crucibles seem to be the result of the interaction between the melted metal and the crucible rather than genuine slag (Heil, 2019, p. 47; Hess, 1998, pp. 117–118). Metal objects associated to the mixed ore process are made of a two phase Cu-As-Ni metal with up to 2.17 wt.% Sb and 2.74 wt.% S (Hess, 1998, p. 116).

Moulds in Arslantepe VII are open ceramic moulds, but are considerably larger than any of the metal objects found at the site. They do not bear any traces of the casting process (Heil, 2019, p. 31).

In contrast to all other sites, the mixed ore process of Arslantepe VII connects elevated As levels with Pb-rich ores (Hess, 1998, p. 125). Nevertheless, metal items with a corresponding chemistry are yet to be found (cf. Di Nocera, 2013, p. 115; Heil, 2019, pp. 102–103). And despite the comparatively large number of ore pieces and the extensive research (Caneva et al., 1992, 1989; e.g., Caneva et al., 1988; Palmieri et al., 1992; Palmieri and Sertok, 1994), the ore deposits remain unknown (Hauptmann et al., 2002, p. 61; Heil, 2019, p. 53).

Crucible smelting is also attested in Hacınebi. Dating to the first half of the 4th millennium BCE (Stein et al., 1998, p. 145), this site yielded evidence for the use of pit furnaces in which crucibles were heated for the smelting of copper ores and/or the melting of copper for casting (Özbal et al., 1999, p. 62; Stein et al., 1998, p. 167). The size of the pits varies in publications but is rather large with a diameter of at least 45 cm (Özbal et al., 2000, p. 120; 1999, p. 62; Stein et al., 1998, p. 151). A tuyère fragment indicates the use of blowpipes (Özbal et al., 2000, p. 120; 1999, p. 62; Stein et al., 1998, p. 168). Prills in the slag revealed in a single case a Sb concentration of 2.89 % (Özbal et al., 2000, p. 122; 1999, p. 64) and consist usually of phases rich in Fe and S (Stein et al., 1998, p. 169). Similar to the other sites, they indicate the smelting of weathered sulphide ores with low Fe concentrations (Stein et al., 1998, p. 169). In addition, a single piece of a lead-copper ore was found in Hacınebi Phase A (Özbal et al., 2002, p. 433).

The presence of metal production at Hacınebi is remarkable because the nearest ore deposits are a good distance away (Yener, 2000, p. 28). The metal objects found at the site are mostly made of unalloyed copper with a few items made of copper with elevated As levels (Stein et al., 1998, p. 168) and variable Ni, Sb, and Fe concentrations. The elemental composition of the items fits well in the overall variation of Eastern and Southeastern Anatolian copper objects (Stein et al., 1998, p. 168).

The smelting site Çamlıbel Tarlası is radio-carbon dated to about 3650 to 3450 BCE (Marston et al., 2021, p. 179; Schoop, 2011, p. 65). Located in Central Anatolia, some important connections between its metallurgical process and earlier developments in the other regions must be mentioned. A detailed reconstruction of the metallurgical process is provided in Boscher (2016), and some preliminary results were published in Rehren and Radivojević (2010).

Similar to the Southeast European furnaces, the pit furnaces in the earlier levels of this site are lined with pottery sherds (Boscher, 2016, p. 133; Schoop, 2011, p. 56). Unfortunately, the literature is not clear whether a thick clay layer covered them or only a clay cap in the middle of the furnace (Boscher, 2016, p. 133; Schoop, 2011, p. 56). In addition, a ceramic mould for a ring-shaped idol (Fig. 3.17c) was found (Boscher, 2016, p. 93).

While the earlier levels suggest important influences from Southeast Europe on the metallurgical process, the later levels suggest influence from the northern Central Iranian Plateau. The resemblance between the crucibles found in Camlibel Tarlasi (Fig. 4.4) and the Iranian crucibles "type Ghabristan" Fig. 4.10) is remarkable (Boscher, 2016, p. 123; Schoop, 2011, p. 63).

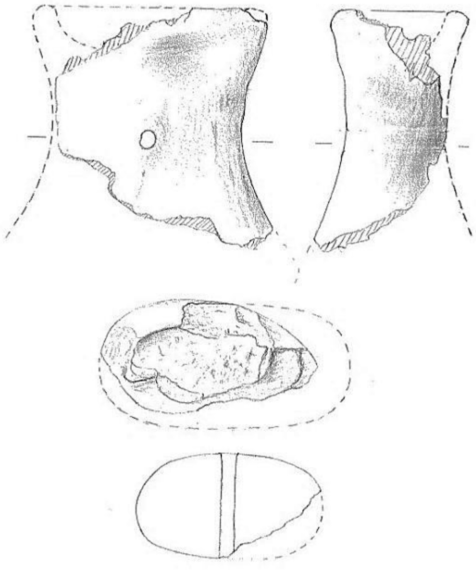


Figure 4.4: Drawing of a crucible from Çamlıbel Tarlası (Boscher, 2016).

In summary, there seems to be little development in copper metallurgy from the first half of the 5th until the mid-4th millennium BCE: copper ore was smelted in crucibles in the settlements and depending on the composition of the ore either unalloyed copper or copper with elevated levels of As and sometimes Ni was produced. The presence of Sb-rich ores in Norşuntepe, and the Pb-rich artefacts from Arslantepe VII might indicate some new developments during the period under study, probably in conjunction with the occurrence of lead and silver metallurgy at this time (cf. chap. 4.1.3). The tin-rich item from Arslantepe VII might be an imitation of the in West Asia then still rather new material gold, similar to what Radivojević et al. (2013) suggested for the early bronze items in Southeast Europe. Being single finds, their significance remains limited. With the exception of Mersin-Yumuktepe, all known copper objects are small items for personal adornments or small tools (cf. chap. 3.1.2).

#### 4.1.1.3 Southern Caucasus

In the Southern Caucasus, a prolonged phase with the use of native copper like in Anatolia seems to be absent at our stage of knowledge. Among the oldest metal items are the 57 arsenical copper beads from Aratashen which can be dated to the first half of the 6th millennium BCE (Badalyan et al., 2007, p. 52; Bobokhyan et al., 2014, pp. 285–286; Courcier, 2014, pp. 588–591; Meliksetyan et al., 2011, p. 201). Although no direct evidence for pyrometallurgy such as slag or crucible fragments was uncovered yet, the scarcity of native arsenical copper (Pigott, 2004, p. 29) might indicate that these beads were not manufactured from native copper.

Another potential evidence for smelting could be vitreous slag with copper prills from Göy Tepe which dates to the middle of the 6th millennium BCE (Courcier, 2014, p. 587). Again, other indicators (e.g., furnace remains, crucible fragments) were absent and an incidental smelting similar to the finds from Çatal Höyük cannot be entirely excluded.

Figure 4.5: Copper-rich bead from Aruchlo (Lyonnet et al., 2012).

Copper items remain rare but become more widespread in the middle Kura valley at the end of the 6th millennium BCE, towards the end of the Shulaveri-Shomu culture. Compositional analyses of some of these ornaments and small tools revealed that they are made of unalloyed copper (Courcier, 2014, pp. 587–588), probably native copper (Bobokhyan et al., 2014, p. 285). Excavations in Aruchlo (5800 to 5300 BCE) uncovered two fragments of a copper bead (Fig. 4.5) with about 6.0 wt.% Ag in one fragment, and 8.3 wt.% Sn and 3.0 wt.% As in the other (Lyonnet et al., 2012, p. 84). The significance of these fragments must be questioned because the analyses were carried out with X-ray fluorescence on the completely corroded fragments, and the original composition of the metal might be altered by the depletion and enrichment of the artefacts during corrosion, and by interaction with the soil (Radivojević and Roberts, 2021b, p. 607). Radivojević and Roberts (2021b, p. 607) even suggest that this bead could have been made of malachite and not metallic copper. In addition to the bead, three miniature vessels with copper residues were found at the site and were interpreted as potential crucibles (Lyonnet et al., 2012, p. 85). Further, several azurite pieces were found in Aruchlo (Lyonnet et al., 2012, p. 85) but as in all other sites, the presence of copper ore cannot be regarded as indicator for metallurgy because it is equally likely to have been used for, e.g., the manufacture of ornaments or as pigment.

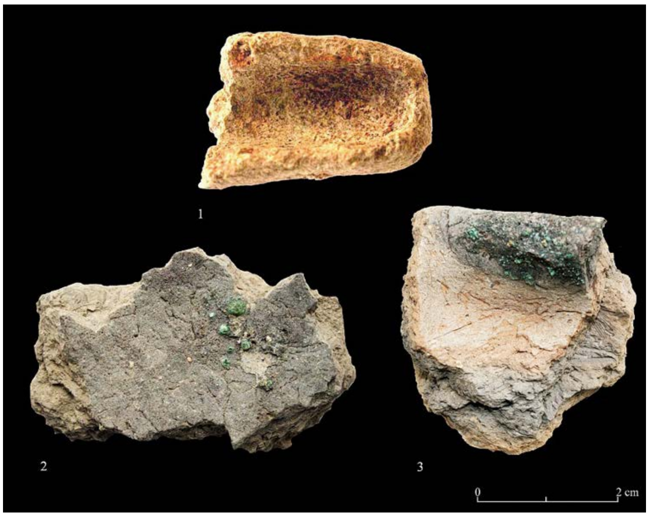


Figure 4.6: Metallurgical ceramics from Mentesh Tepe: (1, 3) mould fragments, (2) crucible sherd (Lyonnet et al., 2012).

Occupation of Kültepe might have started in the 6th millennium BCE and is likely to have lasted for a long time (Courcier, 2014, p. 592). The site yielded furnaces, a mould and several copper items, some of the latter consisting of copper with elevated levels of arsenic and nickel (Bahşaliyev, 1997, p. 96; Selimchanow, 1966, pp. 224–228). Results of the elemental analyses must be read with care because they were carried out on corrosion products and with methods that are now known to provide potentially unreliable data (Courcier, 2014, p. 594). In addition, Selimchanow (1966, p. 227) mentions that the shape of one needle suggests a date into the Bronze Age, indicating mixed archaeological contexts (Courcier, 2014, p. 592).

Consequently, the earliest unequivocal evidence for copper smelting dates to the second half of the

5th millennium BCE, the period of the Sioni culture. Especially excavations at Mentesh Tepe and Ovçular Tepesi uncovered detailed evidence for the pyrometallurgical process at this time.

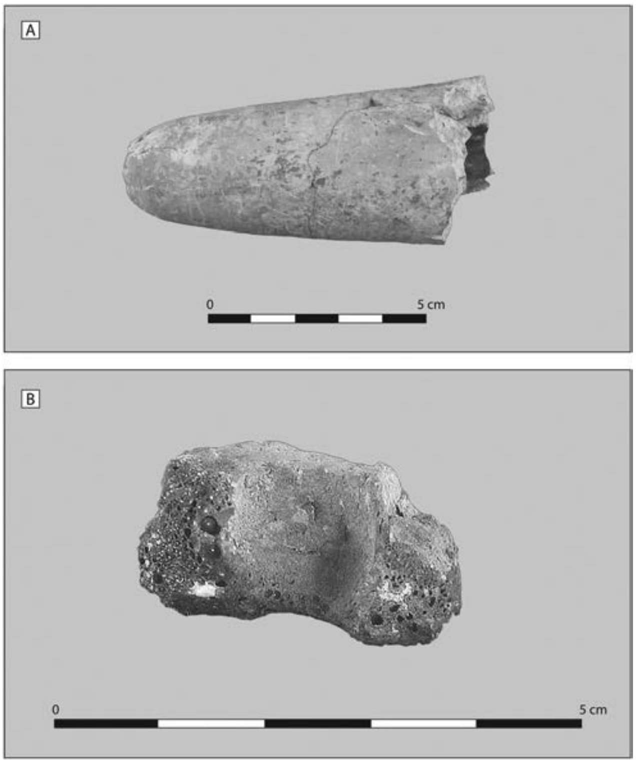


Figure 4.7: Tuyère fragments from Ovçular Tepesi (Gailhard et al., 2017).

In Mentesh Tepe, remains for the entire metallurgical process were found: copper ore, crucible fragments, a mould fragment, and copper items (Astruc et al., 2021; Courcier et al., 2017, p. 527; Courcier, 2014, pp. 595–596). Small piles of copper oxide ores (cuprite, azurite) were found together with scattered pieces of digenite ($Cu_9S_5$) and haematite (Lyonnet et al., 2012, p. 111). Their Ni concentrations indicate ophiolite-hosted ore deposits, which is confirmed by a match of the ores' lead isotope signature with such deposits near-by (Courcier et al., 2017, p. 528; Lyonnet et al., 2012, p. 118). No furnace was uncovered, but the location of the metallurgical debris close to a domestic oven suggest that it might have been used for metallurgical activities (Courcier et al., 2012, p. 210; Lyonnet et al., 2012, p. 91). Slag seems to be absent, too (Lyonnet et al., 2012, p. 111). The base of a domestic vessel made of chaff-tempered ware was secondarily used as crucible, but the slag on the sherd does not allow to differentiate between smelting or melting (Fig. 4.6). Prills in it are arsenic copper with up to 5 % As (Lyonnet et al., 2012, p. 112). Another fragment is interpreted as an unused casting mould that fell accidentally into the furnace (Lyonnet et al., 2012, pp. 112–113) or as crucible (Courcier et al., 2012, p. 213). Prills on it prove the handling of melted unalloyed copper in Mentesh Tepe. The metal objects found at the site are mostly made of unalloyed copper with a few items made of arsenic copper (Courcier et al., 2012, pp. 218–220). Analytical work on the two not entirely corroded copper objects from Mentesh Tepe indicates casting with subsequent hammering and at one of them annealing as the final step (Courcier, 2014, p. 596). Although many aspects of the metallurgical process at Mentesh Tepe remain unclear, the traces on the crucible and the mould/crucible fragment thus indicate that all the metal objects found at the site could have been produced on site.

Ovçular Tepesi yielded a similar metallurgical assemblage but adds important aspects to the metallurgical process in the second half of the 5th millennium BCE. The malachite ore and the metal objects found in Ovçular Tepesi have a unusually high molybdenum content and a very radiogenic lead isotope composition (Gailhard et al., 2017, pp. 543–544), which link them together and indicate the local production of the metal items. No furnace was found at this site. However, three pieces of slag were uncovered (Gailhard et al., 2017, p. 534) and allow the reconstruction of the smelting conditions. Originally interpret as ore, one piece consists predominantly of cuprite and delafossite, identifying it as slag or partially melted ore created under very oxidising conditions, perhaps during crucible smelting (Gailhard et al., 2017, pp. 543–544). One of the two crucible fragments was analysed. Its nearly half a centimetre thick slag layer proposes repeated use. Mullite and porcelainite at the interior of the fragment's quartz- and chaff-tempered matrix indicates heating of the crucible to very high temperatures (Gailhard et al., 2017, p. 546). Additionally, tuyère fragments are preserved in Ovçular Tepesi (Fig. 4.7). Half of the draught channel is preserved in one fragment. It is strongly vitrified, also on the cracks, and the ceramic bloated in most parts of the fragment. The other fragment is the complete tip of a conical tuyère and do not show any signs of vitrification. The inner channels of the tuyères are described as rectilinear until short before the tip, where they narrow down considerably, indicating their use as blowpipe tips (Gailhard et al., 2017, pp. 538–540). The diameter of this rectilinear section is a bit larger than 1 cm. The outlet of the tuyère has a diameter of about half the size of the rectilinear section. No mould fragments were found at the site. Among the metal objects are a few shaft hole axes and flat axes (Gailhard et al., 2017, pp. 534–536). The shaft hole axes are surprisingly similar to the shaft hole axes found in Southeast Europe and seem to be the earliest known representatives of this type in the Caucasus (Marro et al., 2011, p. 70). Two of the flat axes found in Ovçular Tepesi are made of unalloyed copper while the remaining axes, among them all shaft hole axes, are made of copper with between 1 and 2 % As (Gailhard et al., 2017, p. 542). While no archaeological evidence for or against a local production of the shaft hole axes was found Ovçular Tepesi, the slightly later mould for such an axe found at Dzedzvebi (end of the 5th to beginning of the 4th millennium BCE, Gambashidze et al., 2016), suggests a local production (Fig. 3.16b).

Similarly to Anatolia, important changes in the metal technology occur only during the second quarter of the 4th millennium BCE, i.e., after the period under study. Until this time, metallurgy seems to have consisted of smelting copper ores with or without arsenic and nickel in crucibles. Copper was cast to axes and other objects in open moulds, and the raw objects were subsequently worked into their final shape by hammering and annealing. Metallurgical practice seems to be restricted to a few sites, considerably less than one would expect from the number of copper objects found in the Southern Caucasus (Courcier, 2014, p. 643).

Metal technology changes markedly after 3800 BCE and metal production intensifies. Alongside ores and slag, a workshop with a potential furnace was discovered in Leilatepe (Courcier, 2014, p. 623). In Areni-1 cave, the workshop assemblage includes tuyères and a double-conical "ventilation pipe", grinding stones, basalt-tempered crucibles, a "pourer" (a vessel with a spout), and metal ingots (Bobokhyan et al., 2014, pp. 287–288). Excavations in the settlement of Böyük Kesik uncovered a stone mould for axes together with slag and metal objects, and another such mould is reported from Kakhab (Bakhshaliyev, 2014, p. 21; Courcier, 2014, pp. 623–625). They are more durable than ceramic moulds, adding further proof for an intensified metal production at this time.

Metal-rich burials with large amounts of copper objects, the earliest gold and silver objects in the Caucasus (see below), and other exquisite non-metal items such as lapis lazuli beads date tothe second quarter of the 4th millennium BCE as well, e.g., in Soyuq Bulaq or Maikop (Lyonnet et al., 2008; Reinhold, 2019). Beside an intensification of metal production, especially the metal items in the Maikop burial, among them copper vessels, indicate that a completely new level of metal working skills was reached (Reinhold, 2019, p. 99).

#### 4.1.1.4 Iran

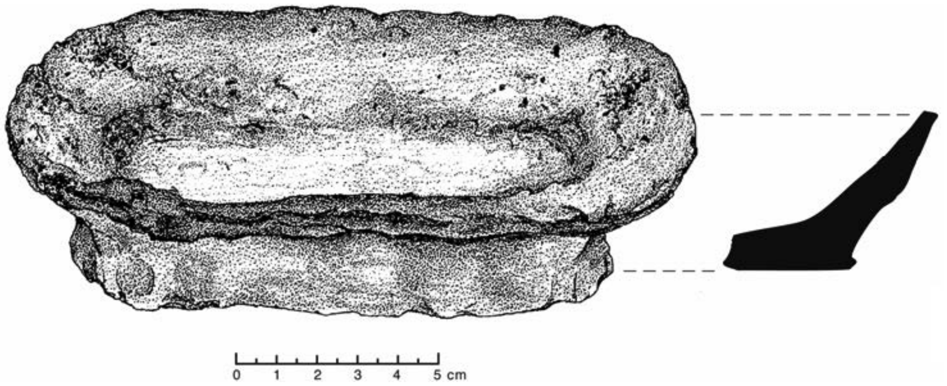


Figure 4.8: Drawing of the reconstructed crucible from Tal-i Iblis (Frame, 2009).

The earliest evidence for smelting in Iran is reported from Tal-i Iblis, where several hundreds of crucible fragments from the first half of the 5th millennium BCE (Frame, 2012, p. 187) indicate smelting of polymetallic copper ore with considerable amounts of As or Pb in a comparably large scale (Caldwell, 1966; Frame, 2012, p. 197; Pigott and Lechtman, 2003; Thornton, 2009a, p. 308; Weeks, 2012, p. 301). Thornton (2009a, p. 317) suggested the intentional use of such ores because Iran hosts a comparatively large number of deposits with unalloyed copper ores and native copper, too. However, deposits with matching polymetallic ores are outcropping in the mountain ranges immediately surrounding Tal-i Iblis and could have been mined more easily than unalloyed copper ores from deposits several hundreds of kilometres away (Frame, 2012, p. 203). The ores were smelted in bowl-shaped crucibles (Fig. 4.8). Although fragments of them are abundant, no furnaces or firing pits were found. Frame (2012, p. 193) suggests either their placement in a small pit furnace or on the ground with a support construction on the side. In any case, fuel was piled on the filled crucibles and they were then heated from above. The slag is very heterogeneous in its phase composition but the usual absence of cuprite and delafossite (Frame, 2012, p. 193) indicates more reducing furnace conditions than for the earliest smelting processes in the other regions.

While only small items seem to have been produced in Tal-i Iblis at this time (Frame, 2012, p. 184), the mace head from Parchineh in Luristan (Fig. 4.9) might indicate advanced casting knowledge already in the 5th millennium BCE (Helwing, 2013c, p. 115). According to the excavators, it is a hollow cast (Haerinck and Overlaet, 2002), but no scientific analyses are available to support this interpretation (Helwing, 2013c, p. 115). Hence, it must remain open whether the mace head was indeed cast – or hammered like the mace head from Can Hasan.

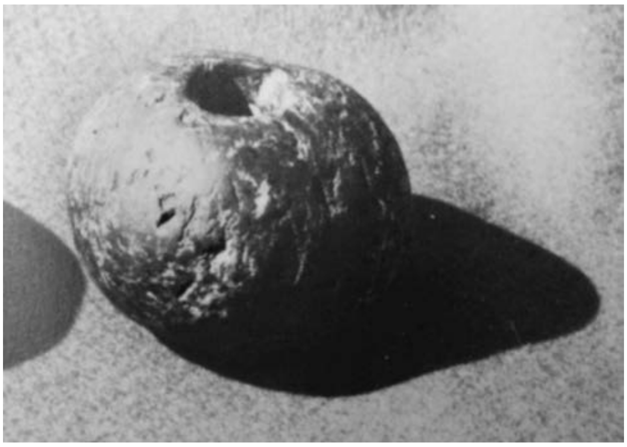


Figure 4.9: Copper mace head from Parchineh (after Haerinck and Overlaet, 1996).

From the second half of the 5th millennium BCE on, advanced casting technologies are evident from the metal workshops uncovered in Tepe Ghabristan (Madjizadeh, 1989). The two fully equipped and hastily left metal workshops with furnaces yielded used crucibles, a bowl with ore ready for smelting, and moulds for ingots and shaft hole axes (Fig. 3.16c). Together with the latter, small clay cylinders were found, which were apparently inserted into the moulds to create the shaft hole. The crucibles were used for smelting and melting operations. In addition, a clay object in the shape of flattened funnel was discovered. It is unknown whether it was another mould or a tuyère. If it was a tuyère, its diameter is a strong indication for the use of bellows (Madjizadeh, 1989, pp. 160–161, 165). The crucibles are characteristic for the northern Central Iranian Plateau at this time and labelled "type Ghabristan" (Fig. 4.10). They are round to oval bowls of about 20 cm diameter on a small pedestalled base with a horizontal perforation (Helwing, 2010, pp. 389–390; Madjizadeh, 1989, plate 28). The perforation was probably used to facilitate handling of the crucible by inserting a stick.

Figure 4.10: Crucible of type "Ghabristan" found in Tepe Ghabristan (Madjizadeh, 1989).

The existence of buildings specifically dedicated to copper metallurgy next door with pottery workshops indicate that metallurgy (and pottery) was carried out by full-time specialists in settlement areas dedicated to craft activities (Madjizadeh, 1989, p. 165; Thornton, 2009a, p. 312), which would be an exceptionally early date for this degree of craft specialisation. In contemporary Tepe Yahya the currently oldest Iranian object made of copper with elevated As levels (1.43 % As) was uncovered (Thornton et al., 2002, p. 1456). The site yielded no remains of metallurgical activities, suggesting it was an import (Thornton, 2010, p. 44).

Metal finds from the burials in Susa are the major metal assemblage from the end of the 5th millennium BCE. Strata 27 to 25 contained the earliest burials with a large number of axes, made from unalloyed copper and copper with elevated As levels (Rosenstock et al., 2016, p. 75; Tallon, 1987, pp. 311, 314). Into the same timeframe dates the cemetery of Chega Sofla (Moghaddam, 2016, p. 1; Moghaddam and Miri, 2021, p. 49), which is located in the same geographical unit. Metal objects from this site represent not only the earliest evidence for precious metal (cf. chap. 4.1.3) and artificial enstatite beads in Iran (Nezafati and Moghaddam, 2021), but fragments of copper vessels also indicate more advanced skills in copper working than previously assumed for this period (Nezafati, 28.01.2022).

The wealth of metal objects in the Susa cemetery continues into the 4th millennium BCE with picks and shaft hole axes in burials from strata 24 and 23. Some of the objects are made of copper with elevated As and Pb levels (about 1 % each), probably making them the earliest examples for the use of this metal type (Rosenstock et al., 2016, p. 75; Tallon, 1987, p. 315; Weeks, 2012, p. 311). Significant smelting activities during this time are reported from Tepe Sialk and Arisman with crucibles similar to the one in Tepe Ghabristan and a comparable smelting process (Helwing, 2011a, pp. 262–263; Thornton, 2009a, p. 313).

However, metallurgy in the Kasan region is pre-dating its later central metallurgical site Arisman. Copper ore was smelted in several small sites at the border of the desert, such as Qal’e Guše, evidenced by slag, fragments of crucibles type “Ghabristan”, and open moulds (Helwing and Chegini, 2011, p. 441; Thornton, 2009a, p. 313). Pottery found in Qal’e Guše date the site to the end of the 5th and the early 4th millennium BCE.

Activities in Arisman started in the early 4th millennium BCE with the combination of small metallurgical workshops and potteries, similar to the workshop area in Tepe Ghabristan (Thornton, 2009a, p. 313). In addition to the technological remains found in Tepe Ghabristan, the crucibles in Arisman were covered with lids (Helwing, 2011a, pp. 263–263). Like in Tepe Ghabristan, exclusively open moulds were discovered in early Arisman and the ones for shaft hole axes had a depression for clay cylinders (Helwing, 2011a, p. 266).

A full-fledged copper and lead/silver metallurgy evolved around the mid-4th millennium BCE, turning Arisman into the proto-industrial smelting site it is famous for (Helwing, 2011b, pp. 374–375; Thornton, 2009a, p. 314; Weeks, 2012, p. 282). Polymetallic ores were smelted in shaft furnaces, but the details of the metallurgical process is still under study. Based on slag finds, it was originally suggested that the arsenic copper was produced by the combination of copper and separately smelted arsenic speiss (Rehren et al., 2012). However, a recently proposed model suggests the desilvering of the ore with lead and the production of arsenic copper in a single step (Nezafati et al., 2021). A detailed account of these models is beyond the scope of the thesis, as they are several hundred years younger than the period under study and deal with a significantly enhanced technological level. Similar to the metallurgical features in Arisman are the metallurgical finds at Tepe Sialk. Although copper metallurgy was practised at this site, metallurgical activities seem to have focussed on silver production (Nezafati et al., 2008b, pp. 337–340; Thornton, 2009a, p. 314).

In addition to these sites, two finds must be highlighted. One is an awl-shaped object from Seh Gabi, dating to the earliest 4th millennium BCE. Being a typical As-Ni copper (3 % As, 1 % Ni), its many Pb-Sb-As-$Cu_2O$ inclusions are noteworthy. It was heavily worked and annealed in the last step, which made its tip too soft for being used as an awl (Frame, 2009, p. 269). The other object is a multi-layered truly refractory crucible from Tepe Yahya, dating between 3700 and 3500 BCE (Thornton and Rehren, 2009, p. 2702). In contrast to all other crucibles in all the regions under consideration, it was heated from outside rather than from above. The innermost layer of the crucible was made of crushed steatite or talc turned into a paste by mixing it with clay. Its high porosity was most likely created by the combustion of added organic matter. Under this layer was a thin layer of ochre and under it a chaff-tempered ceramic paste with a large amount of minerals such as quartz. This paste type was used for other technical ceramics and for domestic vessels in this region. The outermost layer is a white crust, which was either a mixture of the ceramic paste with furnace material and plant ash, or a slip. The outermost layers are heavily vitrified. Slag remains on and in the crucible revealed the melting of lead-rich copper, making it the only evidence for the processing of lead-rich material in this site (Thornton and Rehren, 2009).

In conclusion, the developments in Iran seem to parallel the developments in Southeastern Anatolia and the Southern Caucasus: while copper ores are smelted in crucibles throughout the 5th and early 4th millennium BCE, things change around the mid-4th millennium BCE with an intensified and diversified metallurgy on a whole new metallurgical level. Like in the Southern Caucasus with its kurgans and Southeastern Anatolia and Northern Mesopotamia with, e.g., the weapons in the palace of Arslantepe (e.g., Frangipane, 2011, p. 980), these changes happen in Iran parallel to significant social changes (Helwing, 2013c, p. 116; Weeks, 2012, p. 282). However, the vastness of the region considered today as Iran and the relative scarcity of metallurgical finds makes the summarised archaeological evidence somehow anecdotal. It might well be that future results allow to delineate independent developments in the different regions not only in the socio-economic development (chap. 3.1.4) but also in metallurgy.

#### 4.1.1.5 Southern Levant

Metallurgy in the Southern Levant appears during the second half of the 5th millennium BCE, rather late in comparison to the other regions. A possible reason might be the absence of native copper and hence of a phase of copper working without smelting (Hauptmann, 2003, p. 90; 2000, pp. 183–184). A notable exception is the copper awl from Tel Tsaf (Garfinkel et al., 2014). Dating to the first half of the 5th millennium BCE, this item (Fig. 3.2a) seems to be oldest copper object in this region after the bead from Tell Ramad, which, however, is a site north of the Southern Levant. The absence of any metallurgical production contexts led to the conclusion that it is likely to be an import. With 6 wt.% Sn and an 0.8 wt.% As (Garfinkel et al., 2014, p. 3), its composition is similar to the bead from Aruchlo (Lyonnet et al., 2012, p. 84), suggesting the Southern Caucasus as a potential region of origin (Garfinkel et al., 2014, p. 4). However, this data was obtained with portable X-ray fluorescence analysis on corrosion; neither the metal nor its microstructure is preserved (Garfinkel et al., 2014, p. 3). Thus, the significance of the high Sn content and the representativity of this data for the original metal composition is questionable (Radivojević and Roberts, 2021b, p. 607). Without any preserved microstructure, it is also questionable that the awl was cast, as is claimed by Garfinkel et al. (2014, p. 2).

Shugar (2000, p. 66) mentions several metal items and slag from Teleilat Ghassul citing Shalev (1991). Surprisingly, Shalev (1991) does not mention the axe head and the eight awls from Teleilat Ghassul reported by Shugar (2000), reducing the number of confirmed metal objects to three: two axe heads (Mallon et al., 1934) and a fish hook (see Rosenberg and Chasan, 2020, p. 230 for photo and drawing). Moreover, Shugar (2000, p. 66) mentions more than 10 g of slag at the site, citing J. M. Golden. Although copper slag from Teleilat Ghassul would be extremely important for the distinction between an early and late phase of the Southern Levantine Chalcolithic (cf. chap. 3.1.1), Golden (2009, p. 285) does not mention them in his publications and instead supports the chronological significance of metallurgy for the Southern Levantine Chalcolithic. Consequently, the nature of the slag remains obscure and their relation to metallurgy seems unlikely. The metal objects from Teleilat Ghassul are probably best explained as imports from regions north of the Southern Levant.

From around 4300 BCE on, metal items can be found especially in the burial caves and in sites between the Northern Negev and the middle Jordan valley (Golden, 2009; Rosenberg and Shimelmitz, 2017, p. 297; Shalev, 1991, p. 416). They allow a distinction between a technology that cast unalloyed copper in open moulds and a technology that cast polymetallic copper alloys rich in Sb, arsenic, nickel, and sometimes lead in the lost wax technique (Golden, 2009; Rowan and Golden, 2009, p. 41; Shalev, 1991). To the latter group belongs also a mace head made of leaded copper (Ben-Yosef et al., 2016). Production sites for the unalloyed copper metallurgy are confined to the Nahal Beer Sheva (Rowan and Golden, 2009, p. 43), while a potential production site of the polymetallic copper technology was only recently uncovered in Fazael (Rosenberg et al., 2020). Unalloyed copper was mostly cast into tool-shaped objects (e.g., axes, chisels, awls). Mace heads and other "non-utilitarian" objects such as crowns or standards were cast with the polymetallic copper alloys (Golden, 2009, p. 295; Shalev, 1991). The archaeological evidence of both metallurgical processes is discussed in detail below.

The polymetallic copper alloys disappear at the end of the Chalcolithic, while the unalloyed copper technology remains unchanged. The locations of the smelting sites, however, start to shift away from the Nahal Beer Sheva to other sites in the Northern Negev and soon after to Faynan (Golani, 2013, p. 103; Levy et al., 2002; Shalev, 1994).

Another metallurgical centre in the Southern Levant emerged around 4000 BCE at the Northern coast of the Gulf of Aqaba (cf. chap. 3.2.1). Ore from Timna and other deposits in the southern half of the Wadi Arabah was smelted to unalloyed copper in Tall Hujayrat al-Ghuzlan and Tall al-Magass (Hauptmann et al., 2009, p. 297; Ketelaer and Hauptmann, 2016, p. 180; Klimscha, 2013a, pp. 45–46). In contrast to the Nahal Beer Sheva sites, smelting was carried out in crucibles, and furnaces are yet to be found at the two sites (Klimscha, 2013a, p. 48). The amount of metallurgical debris, especially crucible fragments, indicate the production of unalloyed copper at a proto-industrial scale. That the vast majority of moulds was made for ingots adds further weight to an export-orientated focus of the smelting activities (Klimscha, 2011, p. 198; Pfeiffer, 2009, p. 312). A detailed discussion of the two sites' metallurgical assemblage is beyond the scope of this thesis. They are neither technologically nor culturally connected to the lost wax casting process in the Southern Levant, they deviate significantly in their unalloyed copper process (smelting in crucibles instead of furnaces, production of ingots for export), and are only loosely culturally connected to the regions north of the Negev (cf. chap. 3.2.2).

Compared to the other West Asian metallurgical traditions, the Chalcolithic Southern Levant is standing out by several features. Its unalloyed copper technology is set apart by the comparably early use of furnaces instead of crucibles for smelting. The abundance of large items such as axes or chisels is another important difference to the Anatolian metallurgy at this time. Further, the Chalcolithic Southern Levant yielded by far the largest assemblage of lost wax cast objects, in numbers and in object size. The use of the polymetallic copper alloys is even more startling because it is the only type of metal in West Asia and Southeast Europe that was melted locally but must have been imported; with the closest deposits around 1000 km farther North. As will be shown below, the first appearance of gold, lead, and silver in the Southern Levant is roughly contemporary to the other West Asian regions but what makes them special in the Southern Levant is again that suitable ores are not available here. Consequently, every metal other than unalloyed copper was clearly imported, even if it was locally processed.

**4.1.1.5.1 Unalloyed copper** In contrast to the other regions under consideration here, copper ore deposits are not that abundant in the Southern Levant. Timna and Faynan are major deposits of relatively unalloyed copper oxide ores that were exploited and surveyed throughout the ages (e.g., Hauptmann and Weisgerber, 1992) with Faynan being threatened only recently from a revival of mining activities (ICOMOS-Jordan, 2021). The earliest mining activities of the two deposits date to the Chalcolithic (Hauptmann, 2007, pp. 112–149; Hauptmann and Löffler, 2013, pp. 71–72; Shaw and Drenka, 2018). Minor outcrops of copper ores are located south of Faynan and Timna and are metallogenetically closely linked to them (e.g., Ketelaer and Hauptmann, 2016).

Copper deposits are also outcropping in the Sinai. They were suggested as potential sources for the Chalcolithic copper in the Southern Levant, including the As-rich objects (Ilani and Rosenfeld, 1994). It currently cannot be excluded that they were already mined at this time. However, smelting remains date only to the mid-4th millennium BCE and later, i.e., after the end of the Chalcolithic in the Southern Levant (Pfeiffer, 2013, p. 95). Moreover, the chemical composition of the Sinai ores is not compatible with the copper objects of the Chalcolithic Southern Levant (Abdel-Motelib et al., 2012, p. 36; Hauptmann et al., 1999, p. 10).

Consequently, the ore for the unalloyed copper technology in the Northern Negev sites was mined either in Faynan, Timna, or in both deposits. Ores from Faynan and Timna widely overlap chemically and isotopically because they were once a large deposits that was subsequently split by the Dead Sea Transform (cf. chap. 4.3 of Hauptmann (2007) for the geological history of the deposits). Nevertheless, some formations in the two deposits can be distinguished by their lead isotope signature and chemical composition if the corresponding formation of the other deposit was not exploited or not accessible at the same time. An example is the copper-rich Dolomite-Limestone-Shale unit in Faynan, which was actively but not exclusively exploited during the Chalcolithic while the corresponding formation in Timna was not accessible (Hauptmann, 2007, p. 66). Petrographic features can differentiate between the two deposits more reliably. Plant fossils with chalcocite are typical for Timna ore (Hauptmann, 2007, p. 72; Lupu and Rothenberg, 1970, p. 93), and the so-called tile ore is characteristic for the sandstone-hosted copper ore in Faynan (Hauptmann, 2007, p. 71; Hauptmann et al., 1992). The tile ore consists of cuprite with iron (hydr)oxides, relictic chalcocite, and quartz. It is sometimes brecciated with malachite as cement (Hauptmann, 2007, p. 71).

Analyses of ores from several Northern Negev sites revealed that nearly all of them were mined in Faynan and only a minority in Timna (Hauptmann, 2000, p. 171; 1989a, pp. 121–123; Segal et al., 2015; Shugar, 2018, p. 288). The structure of the ore pieces rich in chalcocite from the 1955 excavation of Abu Matar is typical for Faynan ore (Hauptmann, 1989a, p. 126). All analysed ores found in Shiqmim are from Faynan (Golden et al., 2001, p. 953; Shalev and Northover, 1987, p. 362); most of them tile ores (Golden et al., 2001, p. 953). It seems that the Chalcolithic miners and metallurgists targeted tile ore as the best-suited ore for their smelting process (Golden, 2014a, p. 113). The probably most detailed study of ores used in the Chalcolithic metallurgy of the Southern Levant was conducted by A. Shugar as part of his PhD thesis on the metallurgical assemblage of Abu Matar (Shugar, 2018, pp. 279–283; 2000, pp. 158–181). He identified five ore types by petrography: sandstone ore with secondary copper oxides (e.g., malachite, atacamite) and small cuprite and haematite inclusions, tile ore, weathered secondary copper sulphides (e.g., chalcocite, covellite) with iron (hydr)oxides, nodular and banded secondary copper sulphides with iron oxides and silicates, and iron ores (haematite, iron rich dolomite). Lead isotope analyses confirmed the petrographical interpretation of the first three ore types as being mined in Faynan (Shugar, 2018, p. 288). The iron ores are typical for the Negev and the dolomites might be brought from Faynan. Shugar (2018, p. 283) interprets them as fluxing material. The fourth group, the nodular and banded secondary copper sulphides, have similarities with the second and third ore type but its structure is unknown in Faynan (Shugar, 2000, p. 164). Shugar (2018, p. 288) suggests Anatolia as their most likely source region because neither Faynan nor Timna fit in their lead isotope signatures and Anatolian ores are the closest fit. However, this conclusion seems to have been drawn from an insufficient reference database for the two deposits because lead isotope data of this ore type are in fact compatible with Faynan and Timna ores (Fig. 4.11). Even more important, sulphide nodules with iron oxides and quartz are a characteristic feature of Timna ore (cf. Hauptmann, 2007, p. 72). Unfortunately A. Shugar does not discuss other potential sources such as Timna for this ore type, although it is is the largest ore group in his sample set, would be the only imported ore type connected to the unalloyed copper process, and apparently went unnoticed in earlier studies (Hauptmann, 2000; cf. Hauptmann, 1989a; Shalev and Northover, 1987).

The site F2 in Timna was claimed for some time as evidence for mining activities already in the Neolithic or Chalcolithic (Merkel and Rothenberg, 1999; Rothenberg and Merkel, 1995; Segal et al., 1998) but was proven to be of a younger date (Ben-Yosef et al., 2010). Further, site 39 in Timna was interpreted as a Chalcolithic smelting site that provided evidence for fluxing, i.e., the intentional addition of material to lower the melting point of the furnace charge (Merkel and Rothenberg, 1999; Rothenberg, 1978). The site was later absolutely dated into the second half of the 4th millennium BCE (Rothenberg, 1985).

The earliest accepted evidence for ore processing and metallurgy in the Southern Levant are several sites along the Nahal Beer Sheva with the largest metallurgical assemblages found in Abu Matar, Neve Noy, Horvat Beter, and Shiqmim. Despite more recent discoveries (e.g., Ackerfeld et al., 2020; Rosenberg et al., 2020), the notion that unalloyed copper metallurgy is confined to this region (e.g., Golden et al., 2001, p. 960) still stands. The site of Abu Matar was excavated by J. Perrot in the 1950s (Perrot, 1955b, 1955a, 1955c, 1955d) and I. Gilead, S. Rosen, and P. Fabian in the 1990s (Gilead et al., 1991). Rich metallurgical assemblages were uncovered in both excavations and analysed by Golden (2014a) and Shugar (2000), respectively. Metallurgical debris in Shiqmim was found in many places but seem to concentrate on room 1 in area A. This room contained the only furnace found in Shiqmim, slag, and a copper standard, while domestic items were absent (Levy and Alon, 1985, p. 77). Archaeometallurgical investigations focused on the material from this room (Golden et al., 2001; Shalev and Northover, 1987). Like Abu Matar, Horvat Beter was subject to several excavation campaigns due to building activities. They yielded a large amount of archaeometallurgical debris, mostly slag and crucible fragments, but no furnace was encountered on the excavated plots (Ackerfeld et al., 2020). In Neve Noy, a workshop was uncovered. It contained metallurgical debris, a vessel interpreted as pit furnace next to an oven with a crescent-shaped construction on top, and faïence beads (Baumgarten and Eldar, 1984; Eldar and Baumgarten, 1985, pp. 137–138). Unfortunately, this assemblage does not seem to have been further analysed.

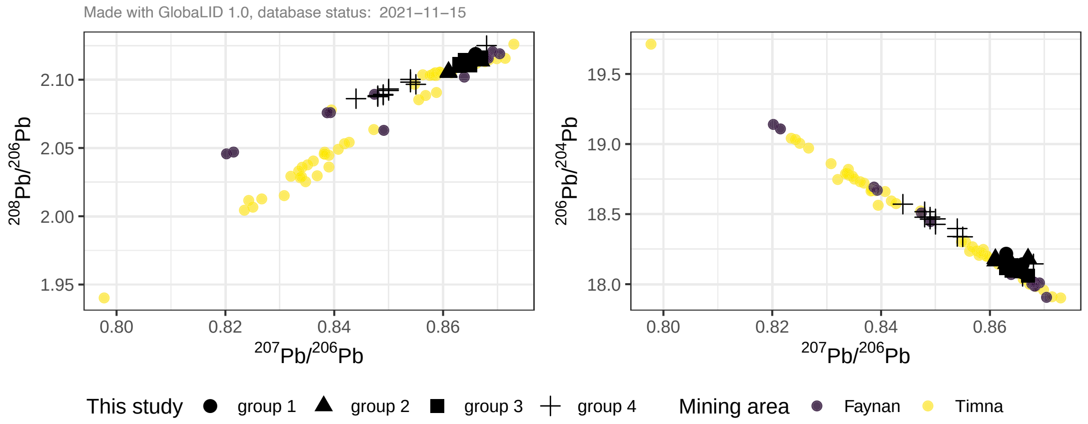


Figure 4.11: Comparison of the lead isotope data from ore pieces found at Abu Matar (Shugar, 2018, 2000) with lead isotope data from Faynan (Hauptmann et al., 1992) and Timna (Asael et al., 2012; Harlavan et al., 2017). Figure created with GlobaLID (GlobaLID Core Team, 2021; Klein et al., 2022; Westner et al., 2021).

Evidence for the beneficiation of the ores were observed in Abu Matar and Neve Noy. J. Perrot found in at least two rooms of the subterranean dwellings in Abu Matar several flint anvils with use traces from crushing, and sometimes ore pieces close-by (Perrot, 1955c, p. 79). Additionally, Gilead et al. (1991, p. 176) found in Abu Matar a pit with numerous pebbles. Based on their use traces, they were used to crush ore. In Neve Noy, several large stone slabs with nearby pieces of copper ore are interpreted as grinding stones for copper ore (Eldar and Baumgarten, 1985, pp. 136–137).

Furnaces were found in Abu Matar and Shiqmim. J. Perrot excavated the first furnaces in Abu Matar.

He describes feature 244 as an oval depression of 8 m length and 6 m width with an about 1 m thick layer of ash and sand, in which many furnace wall and crucible fragments were found. Feature 244 contained numerous furnaces of 40 to 50 cm diameter. The furnaces have an inner diameter of 30 to 40 cm and were 12 to 15 cm high, with thick vertical walls made of chaff-tempered clay. The furnace walls were vitrified or even melted on the inside but (nearly) unfired on the outside (Perrot, 1955c, p. 79). He further describes the base of the furnaces as a probably movable "flat cake of earth" with a depression in its centre (Perrot, 1955c, p. 80). Other remains suggest that the furnaces could have been made from "juxtaposed flat bricks" (Perrot, 1955c, p. 80). Unfortunately, no drawings of the furnaces nor of feature 244 are provided. He further reports malachite powder on burnt sediment around hearths in the subterranean houses 134 and 202 and interpret this as evidence for a roasting step prior to smelting (Perrot, 1955c, p. 79). Based on these observations and inspection of the remains on site, Tylecote et al. (1974, p. 34) suggested a shaft furnace in which a crucible was placed in a charcoal bed on a perforated floor, with the draught coming from below.

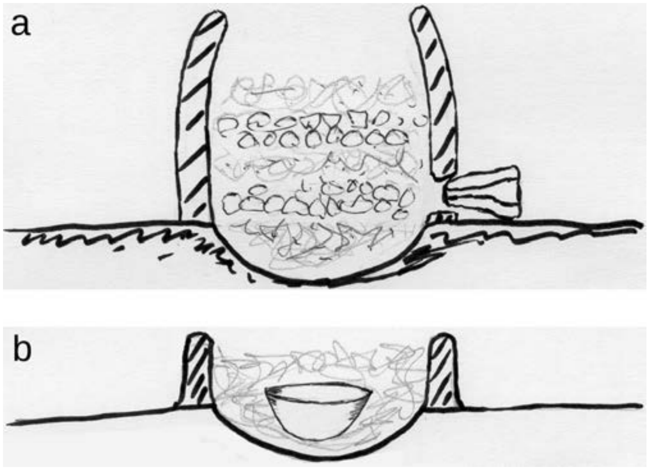


Figure 4.12: A. Shugar's reconstruction of the furnaces used in Abu Matar for (a) smelting the ore, and (b) melting the copper (Shugar, 2000).

The excavations in the 1990s at Abu Matar yielded further furnace remains. The probably best preserved was a pit of about 50 cm diameter with hard fired walls in area A, close to the excavation area of J. Perrot. Many crucible fragments were found inside and outside the pit (Gilead et al., 1992, pp. 12–13; 1991, p. 175). Based on this feature, the excavators suggested that the ore was smelted in crucibles (Gilead et al., 1992, pp. 12–13; 1991, p. 175). A. Shugar interpret it as a metallurgical workshop (Shugar, 2000, pp. 44–45). In Area M, about 100 m SW of area A, a furnace wall fragment with a reconstructed diameter of about 35 cm was found. Mostly houses were uncovered in area M, together with a lot of metallurgical debris, usually slag, and, compared to area A, only few crucible fragments. While Gilead et al. (1991, pp. 176–177) did not reconstruct this area explicitly as smelting area, Gilead et al. (1992, p. 13) did. Because of the large amount of (crushed) slag, Shugar (2000, p. 250) interpret the area as beneficiation area, where the copper prills were mechanically extracted from the slag and sometimes technical ceramics. A few pieces of metallurgical debris were also found in area B, north of area A, but they do not seem to be related to any specific installation or occupation area (Gilead et al., 1991, p. 177). Based on the materials from this excavation, A. Shugar reconstructed two kinds of furnaces (Fig. 4.12). A shaft furnace for the smelting step with a diameter of 22 to 30 cm. The slightly inward curved furnace walls were between 15 and 30 cm high, about 3 cm thick and very porous. Draught was inserted into the furnace by either blowpipes or bellows through a tuyère at the furnace's bottom (Shugar, 2000, p. 245). The second furnace type is a pit furnace of 20 to 30 cm diameter with 5 to 8 cm high furnace walls, used to melt the extracted prills and for casting (Shugar, 2000, p. 248). The design for the melting furnace is taken from J. M. Golden's reconstruction based on the material of J. Perrot's excavation, and A. Shugar links it to hearths in the subterranean dwellings (Shugar, 2000, p. 248). However, J. Perrot does not mention in his excavation report that feature 244 – the only feature he provides details of the furnace dimensions for – is underground. On the contrary, his site plan suggests that it is one of the few surface features (Perrot, 1955d, fig. 3), which is sensible with regards to the oxygen supply for the fuel and more importantly the persons operating it. A paste of local loess tempered with chaff was used for all technical ceramics in Abu Matar (Shugar, 2000, p. 97).

The furnace uncovered in Shiqmim is reconstructed by Golden et al. (2001, pp. 956–957) as a pit of 30 to 40 cm diameter that is 20 to 30 cm deep. The pit was surrounded by about 10 cm high, slightly inwards inclined furnace walls with an opening of about 20 % or even more, leading to a collar-shaped furnace wall (Fig. 4.13). The furnace walls are slagged on one side and the slag has partially flown down the furnace wall into the pit, indicating a directed and steady stream of air. The collar was set on the unprepared ground. The pit surface was unlined and heavily slagged in some areas, similar to the furnace walls. The reconstructed mode of operation is smelting directly in the furnace with the draught coming from blowpipes positioned in the collar opening. Large disc-shaped ceramic fragments about the diameter of the furnace and slagged on their flat side could have been used as lid to enhance the reducing conditions in the furnace (Golden et al., 2001, pp. 956–957).

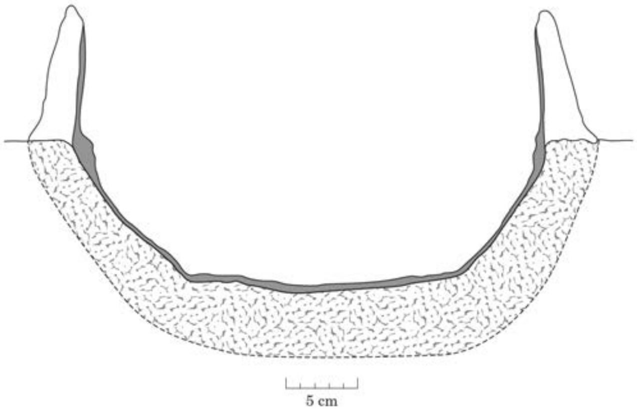


Figure 4.13: Reconstruction of the furnace in Shiqmim (Golden et al., 2001).

Based on the excavation results from Shiqmim and from J. Perrot's excavations at Abu Matar, Golden (2014a, pp. 120–122) suggests to reconstruct the Chalcolithic furnaces as pits of 30 to 40 cm diameter and with a depth of 20 to 30 cm. The furnace walls are collar-shaped with a slight inward inclination and a height of about 10 cm. The collar opening is about 10 cm wide. According to Golden (2014a, p. 120), the furnace remains indicate the covering of the pit with a reed mat before it was lined with clay (Golden, 2014a, p. 120).

The last furnace type mentioned in the literature is the vessel used as furnace in Neve Noy (Eldar and Baumgarten, 1985, p. 137). The vessel was buried in the ground with its rim slightly sticking out of the surface. The rim diameter of the vessel is 16 cm, rather small compared to the other furnaces. The vessel was strongly heated and a tuyère fragment was found close-by. These observations were sufficient evidence for Eldar and Baumgarten (1985, p. 137) to suggest its use as a furnace/crucible for copper smelting, although they report neither slag nor slagging or at least vitrification of the vessel's surface.

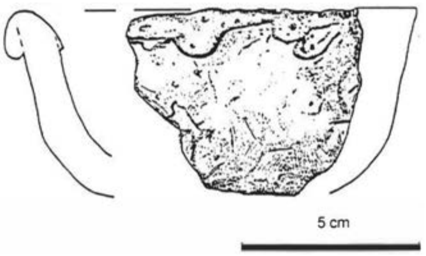


Figure 4.14: Drawing of a crucible from Abu Matar found in J. Perrot's excavations (Hauptmann et al., 1993).

Similar to the furnaces at the different sites, the crucibles follow the same general design but vary in the details. The crucible fragments found in Abu Matar by J. Perrot, among them nearly complete crucibles, are small oval bowls of 11 cm x 8 cm size and are about 7 cm deep (Fig. 4.14). They are made of carefully purified clay mixed with finely chopped chaff (Perrot, 1955c, p. 80). Golden (2014a, p. 115) confirmed the dimensions of the crucible (oval with about 10 cm diameter) and reports that they have a spout. Unfortunately, he provides neither photographs nor drawings of the spouted crucible parts. He further reports the re-use of V-shaped bowls as crucibles (Golden, 2014a, p. 118).

The crucibles found in the later excavations were about the same size. Gilead et al. (1991, p. 175) and Gilead et al. (1992, pp. 12–13) report their dimension as 6 to 8 cm in diameter and depth and do not mention spouts. Shugar (2000, p. 97) reconstructs the same material to spouted crucibles with an oval shape of 12 cm in diameter, narrowing down to 5 cm diameter at the spout. Their inner depth is about 7 cm. The crucible rims are slightly pinched. The walls are in average 0.92 cm and rarely more than 1.2 cm thick (Shugar, 2000, p. 97). Unfortunately, also A. Shugar does not provide any photographs or drawings of the spouted parts. The ceramic paste was prepared from local loess and finely chopped grass (Gilead et al., 1992, pp. 12–13; Shugar, 2000, p. 99). The rims of the crucible fragments are completely vitrified on their interior side and sometimes on their outside (Gilead et al., 1992, pp. 12–13). No details about the crucible fragments excavated in Shiqmim are provided; it is only mentioned that they are rare in comparison to Abu Matar (Golden et al., 2001, p. 956).

The crucibles from Horvat Beter (Fig. 4.15) are large flat bowls with a depth of about 7 cm and a diameter of about 20 cm that vary in their size to some extent (Ackerfeld et al., 2020, pp. 4, 12). Concerning their use traces, such as vitrification, they are comparable with the finds from Abu Matar. Ackerfeld et al. (2020, p. 12) interpret the high copper concentrations at the rims as evidence that the lower parts of the crucibles were carefully scrapped to extract also small prills. However, it seems they did not take into account that when heated from above – indicated by vitrification restricted to the rims – the copper oxidises in this area, while the absence of oxygen prevents slagging in the lower part. At the same time, the difference in surface density between metal melt and ceramic body increases with increasing temperatures and prevents any interaction between the two materials (Sak et al., 2017). As a result, the crucible part covered by metal melt remains unaffected by it.

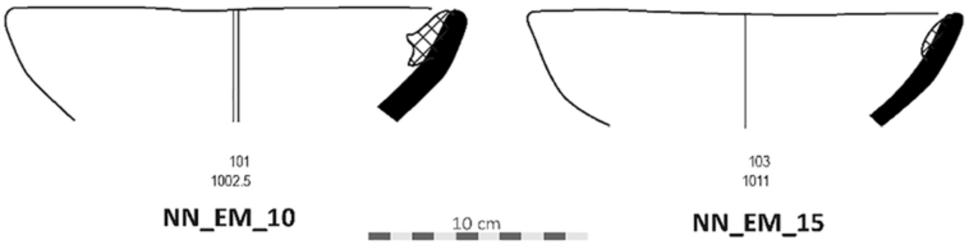


Figure 4.15: Drawing of crucible sherds from Horvat Beter (Ackerfeld et al., 2020).

The slag in Abu Matar was subdivided into 5 morphological types by Shugar (2000, pp. 105–110): irregularly shaped pieces, vitrification/slag on ceramic surfaces, irregularly shaped slag aggregates on ceramic surfaces, thick and often porous slag layers on ceramic surfaces, and pouring extensions (slag that flowed out or was pushed to the outer site of the rim during pouring). The thick and often porous slag layers are exclusively found on furnace wall fragments. A thin red layer on their surface indicate that the slag came in contact with air while the furnace was still hot, e.g., because the content of the furnace was removed right after the smelt was finished (Shugar, 2000, p. 109).

Petrographic analyses of the first slag type revealed that the smelting process often contain partially reacted ore (Shugar, 2003, p. 454), i.e., the ore was not fully liquefied. The regular presence of delafossite, cuprite, and magnetite indicates rather oxidising conditions (Hauptmann, 1989a, pp. 123–126; Shugar, 2003, p. 453). Magnetite is the main phase in these slag samples (Shugar, 2003, p. 453). Shugar (2003, p. 452) further reports fayalite in the smelting slag found in the 1990s excavation, while Hauptmann (1989a, pp. 124–126) states that the furnace conditions were just reducing enough for magnetite and only in rare cases suitable for the formation of fayalite or pyroxene. Instead of fayalite, he identifies laihunite, a phase with fayalite structure but a significant amount of three valent iron, i.e., “oxidised fayalite” (Hauptmann, 2000, pp. 114–115). This difference in the oxidation state leads to a nominal iron content of about 49.5 wt.% compared to about 55 wt.% Fe in fayalite. A. Shugar provides in his thesis compositional data only for the fayalite in sample M-F-05 as “typical” example for fayalite in Abu Matar slag (Shugar, 2000, p. 187). The electron microprobe analysis of this fayalite is closer to the nominal composition of laihunite than fayalite and thus seems to support the interpretation of A. Hauptmann. While quartz is common in smelting slag and most likely is an unmelt component of, e.g., the sandstone ore, it is rarely found in slag attached to crucibles and if so, only as small rounded grains (Shugar, 2003, p. 454). The slag has generally high Ca concentrations, with a significantly higher content in the crucible slag compared to furnace slag. The opposite is true for the slag's Fe content (Shugar, 2003, p. 456).

The type of fuel used for metallurgical activities in the Chalcolithic Northern Negev is unknown due to a lack of research on this topic. The closest related studies were carried out in Faynan, but their earliest material date to the Early Bronze Age. At this time, trees, mostly juniper, were preferentially used as fuel (Baierle et al., 1989, p. 218; Engel and Frey, 1996, p. 32). Research in Timna provide data as early as the Iron Age and indicates the preferential use of acacia wood in this period (Lupu and Rothenberg, 1970, p. 95). The remains of the olives from oil production provide a high-quality fuel and could have been used as well (Oflaz et al., 2019, p. 133). There is currently no evidence for the use of dung as fuel in the Chalcolithic. Nevertheless, as the most readily available fuel in a semi-arid environment, its use should not be readily excluded – it was recently shown for copper smelting in pharaonic Egypt that it was regularly added to save on wood (Verly et al., 2021).

Evidence for the draught technique are tuyères as the usually inorganic compounds of blowpipes and bellows. For the Chalcolithic Southern Levant, tuyère finds are reported from Abu Matar and Neve Noy by Gilead et al. (1991, p. 175) and Eldar and Baumgarten (1985, p. 137), respectively. Unfortunately, they do not provide any details about them. Shugar (2000, p. 98) identified a tuyère fragment in Abu Matar (Fig. 4.16). His interpretation was doubted (e.g., Bourgarit, 2007) and it was recently shown that the features of this fragment are identical with furnace wall fragments (Rose et al., 2021a). Rose et al. (2021a) identified in their preliminary report two other fragments as potential tuyère fragments. They will be discussed in more detail in chap. 6. As it is common for Chalcolithic smelting (cf. Bourgarit, 2007, p. 7), the absence of tuyères lead to the assumption that blowpipes were used (Golden et al., 2001, p. 951; Hauptmann and Weisgerber, 1996, p. 99), although there is currently no archaeological evidence for or against blowpipes or bellows.

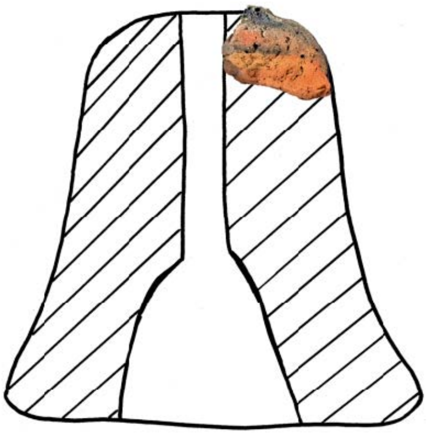


Figure 4.16: The fragment from Abu Matar identified by A. Shugar as tuyère fragment and his reconstruction of the tuyère (Shugar, 2000).

The metallurgical remains of the Northern Negev allow reconstructing a uniform two-step process for the unalloyed copper technology of the Chalcolithic Southern Levant: Smelting beneficiated ore, preferentially tile ore from Faynan, in the pit furnace, and the melting and casting of the copper (Golden, 2014a, p. 122; Golden et al., 2001, p. 960). The partially reacted ore pieces show that the ore was not heated long and/or strong enough to melt completely. They further indicate very heterogeneous and unstable furnace conditions with unsteady temperatures between 800 and 1200 °C (Hauptmann and Weisgerber, 1996). The relatively oxidising furnace atmosphere indicates that there was only a small heap of fuel on top of the furnace charge.

The result of the smelting process is a mixture of slag pieces with copper prills, partially melted ore, and unmelt ore (Golden, 2014a, p. 122). The process was technically a solid-state reaction, which reduced the copper minerals in their place, and not smelting in the sense that copper was separated from the slag by density segregation (Hauptmann, 1989a, pp. 123–125). The relatively oxidising conditions argue against the use of a shaft furnace as suggested by A. Shugar (e.g., Shugar, 2003, p. 457). The partially vitrified furnace in Shiqmim provides an explanation for the unvitrified furnace wall fragments in Abu Matar, hence they are not necessarily an argument for a shaft furnace. The regular presence of sulphides in the ore might have helped to keep the furnace atmosphere reducing, but with the highly variable furnace conditions and the ore rarely melted, this effect was assumedly very localised.

The copper prills were mechanically extracted from the slag and subsequently melted in crucibles into a larger amount of copper. At the same time, any slag on the copper was removed in this step (Golden, 2014a, p. 122). As it is typical for crucible melting, this process was oxidising, probably to oxidise and slag any remaining iron and other impurities in the metal. Vitrification restricted to the rim of the crucibles indicates that the surface of the crucible charge was sufficiently protective to maintain a reducing atmosphere underneath. A slag piece from Shiqmim invokes the impression that it was just poured onto the soil (Shalev and Northover, 1987, p. 363). Unfortunately, no information about its phase composition is provided. It seems probable that it is slag that was skimmed from the surface of the metal melt before casting, or slag poured out of the crucible after casting – slag can be easily held back with a stick during casting and would act as a protective layer against oxidation of the metal melt.

The objects were then cast, likely directly after melting the prills. The shape of the unalloyed copper items (mostly axes, chisels, awls) show casting in open moulds. Casting moulds are yet to be found (Ackerfeld et al., 2020, p. 3; Hauptmann, 2000, pp. 166–167). Therefore, the use of sand moulds seems likely (Ottaway and Seibel, 1998, p. 60), i.e., casting directly into the ground. The Negev loess was used for furnace walls and crucibles alike and could have been used for casting as well. Sand moulds are easily prepared but do not leave any traces in the archaeological record (Ottaway, 2003, p. 345). The exception to the rule is the discoid mace head found in the Cave of the Sandal, which is made of unalloyed copper but cast in a bivalve mould (Segal and Kamenski, 2002, pp. 159, 161). After casting, the items were sometimes reworked with the last step being annealing or hardening (Namdar et al., 2004, p. 81; Segal and Goren, 2013, pp. 382–383).

It seems that ingots become only widespread in the Early Bronze Age (cf. Pfeiffer, 2009). However, a few copper lumps found in Chalcolithic sites could have been used as ingots. The probably best known example made of unalloyed copper was discovered in Shiqmim (Golden, 2014a, p. 146; Golden et al., 2001, p. 960), and two more potential unalloyed copper ingots are reported from Abu Matar (Golden, 2009, p. 288).

**4.1.1.5.2 Polymetallic copper alloys** Initially, prestige items seemed to be made exclusively from polymetallic copper alloys cast in the lost wax casting technique, and "utilitarian" (i.e., tool-shaped) objects are made of unalloyed copper metal cast in open moulds (e.g., Shalev, 1991). Later research showed that the two technologies are not entirely isolated. For example, a few mace heads in the Nahal Mishmar Hoard were lost wax cast with unalloyed copper (Tadmor et al., 1995, p. 132), and so were a mace head and a crown fragment found in Giv'at HaOranim (Namdar et al., 2004, pp. 77–80). Moreover, the functional distinction between lost wax cast prestige items and utilitarian unalloyed copper items must be questioned for archaeological reasons (cf. Golden, 2009, p. 295). It hence seems more appropriate to make the distinction based on technological criteria: polymetallic copper is very well suited for lost wax casting due to is significantly lower melting point compared with unalloyed copper (cf. chap 4.3).

Several researchers suggested the sites of the Nahal Beer Sheva as production sites for the lost wax casting process. Abu Matar was interpret as a production site for arsenic copper (Shugar, 2000, p. 252) based on comparatively high arsenic levels of up to 6.72 % in some (corroded) copper prills (Shugar, 2000, pp. 204–205). Unfortunately, A. Shugar does not provide any specific data about the number of As-containing metal prills but only minima, maxima and averages (Shugar, 2000, pp. 204–205). Arsenic becomes enriched during melting at the interface of ceramic and metal melt and in the ceramic body. Additionally, corrosion preferentially removes the copper, leading to an enrichment of arsenic relative to the original metal composition. Therefore, prills from furnace and crucible walls as well as corroded prills cannot be assumed to be representative for the (s)melted metal (Craddock, 1995, p. 286). The data provided in Shugar (2000, pp. 204–205) are in accordance with this behaviour. Consequently, it must remain open how they really relate to the overall composition of the copper produced in Abu Matar.

Based on the concentration of arsenic in human bones from Shiqmim, this site was identified as a potential site for the processing of arsenic copper, too (Oakberg et al., 2000). This interpretation of the arsenic concentration in the human bones was soon criticised by Pike and Richards (2002). They showed that the arsenic concentrations are not a marker of metallurgical activities but the result of diagenetic processes.

Recently, Fazael was suggested as site for the pyrometallurgical processing of polymetallic copper alloys and lost wax casting because of the co-occurrence of large numbers of metal items and crucible fragments (Rosenberg et al., 2020). The site yielded the largest number of metal objects ever found in the Chalcolithic Southern Levant after the Nahal Mishmar Hoard. It is presented in more detail in chap. 5.2.1 as part of the technological analysis of this assemblage.

The most important source to reconstruct the production of the polymetallic copper alloys is still the Nahal Mishmar Hoard (Fig. 3.2b). Wrapped in a reed mat and hidden in a niche of a cave in a cliff high above the Nahal Mishmar (Bar-Adon, 1962, p. 218), it consists of 429 objects. Among them are six made of ivory, another six made of haematite, and one from another type of stone. All remaining 422 objects are made of metal, among them 240 mace heads and only a couple of unalloyed copper objects, such as axes and chisels (Bar-Adon, 1980; Sebbane, 2014). Radiocarbon dates of the reed mat scatter too widely across the late 5^th and first half of the 4th millennium BCE to date the hoard precisely into the Chalcolithic (Aardsma, 2001), leading some researchers to date it into the Early Bronze Age (e.g., Klimscha, 2009, p. 383). However, the iconography and typology of the objects date the hoard firmly into the Late Chalcolithic (Bar-Adon, 1962, p. 218; Beck, 1989; Gilead and Gošić, 2014, pp. 232–233; Tadmor et al., 1995, p. 136).

Already the very first analyses showed that the copper is rich in other elements, especially arsenic (Key, 1980). Regrettably, the used instrumentation strongly underestimated the Sb content of the polymetallic copper alloys (Shalev and Northover, 1993, p. 42). New elemental analyses by Shalev and Northover (1993, p. 42) showed that the metals in the Nahal Mishmar Hoard are in fact comparable to other metal objects of this period, in which the high Sb content was recognised in the meanwhile. The most extensive analytical investigation on the Nahal Mishmar Hoard was carried out by Tadmor et al. (1995) with the aim to provide in-depth knowledge of the production technology through radiography and optical examination, and to reconstruct the ore provenance with lead isotope analyses and chemical analyses. The latter showed a wide range of the alloying elements' concentrations: 1 to 25 % Sb, 0.4 to 15 % As, several objects with several per cent of Ni, Pb, Ag, and two objects with about 1 % Bi (Tadmor et al., 1995, p. 134). Together with sulphide inclusions, this elemental composition points towards the use of fahl ores as raw material for the polymetallic copper alloys (Tadmor et al., 1995, p. 131). Even the unalloyed copper some of the mace heads and standards are made of was significantly enriched in these elements compared to the unalloyed copper used for the tool-shaped objects cast in open moulds (Tadmor et al., 1995, pp. 132–133). Based on this observation, Tadmor et al. (1995, p. 137) suggested that a particularly "unpure" copper mace head with an inferior casting quality was the attempt to create a cheap copy of a mace head with contaminated unalloyed copper.

The overall large variation in the chemical composition of the polymetallic copper alloys resembles the natural variation of these elements in ore deposits rather than intentional mixing to create alloys with a defined composition (Tadmor et al., 1995, pp. 132–139). It must remain open whether several deposits with a similar mineralogy or one very heterogeneous deposit was exploited (Tadmor et al., 1995, p. 139). Ore pieces with a suitable chemistry were found in Norşuntepe and Arslantepe (Tadmor et al., 1995, p. 141). The lead isotope signatures of the objects support a link to Anatolia or Caucasia. It was not possible to identify the specific ore deposit(s) of the ore pieces found in these sites or of the polymetallic copper alloys in the Nahal Mishmar Hoard (Tadmor et al., 1995, p. 139) and this did not change since.

With no archaeological traces for the smelting of ores to polymetallic copper alloys, the location of this operation must remain open. From an economical perspective, it seems to be more sensible to produce the alloys near the ore deposits and bring them to the Southern Levant instead of importing ore and smelt it in the Southern Levant. The high arsenic and Sb contents of the polymetallic copper alloys are not far from the composition of speiss, a usually unwanted side product of smelting As- and Sb-rich copper ores. Thus, the production of speiss as mother alloy cannot be ruled out (Hauptmann, 2020, p. 283; Zwicker, 1980, p. 15).

If the polymetallic copper alloys were brought to the Southern Levant as metal and not as ore, they were brought as some kind of ingot by definition. Lumps of polymetallic copper alloys were found in Nahal Qanah cave (Gopher and Tsuk, 1996b, p. 114) and Bir es-Safadi (Golden, 2014a, p. 143) and could be such ingots. Additionally, a metal lump with a plano-convex shape similar to the unalloyed copper “ingot” found in Shiqmim was recently found in Ashqelon-Agamim and is made of arsenic copper (pers. comm. Y. Goren, 2021).

The objects’ shapes indicate their casting in the lost wax technique (Potaszkin and Bar-Avi, 1980, p. 235). The iconography and typology of the objects made of polymetallic copper alloys clearly indicates that the lost wax casting was carried out in the Chalcolithic Southern Levant (Beck, 1989; Tadmor et al., 1995, p. 136). The only material evidence for the casting beside the metal objects are mould remains preserved on the metal objects, and the cores over which some of the objects were cast. They confirm a Southern Levantine production of the metal items (Goren, 2014, 2008, 1995).

The wax for the model was most likely based on beeswax. Ethnographical records suggest it might have been mixed with tree resin to make it more resistant against deformation in the high environmental (summer) temperatures of the Southern Levant (Anfinset, 2011, p. 72; Levy et al., 2008, pp. 54–57). Cornets were suggested as containers for the beeswax used in the lost wax casting process (Namdar et al., 2009, p. 653) but it was recently shown that the used methodology is insufficient to securely identify beeswax (Chasan et al., 2021, pp. 3–4). Chasan et al. (2021) showed that beeswax remains are very rarely preserved in the Southern Levant and it was more likely used as sealing of the vessel’s surface. Hence, the material used to create the model must currently remain unknown.

Investigations on a crosscut mace head revealed that it was cast around a ceramic core (Potaszkin and Bar-Avi, 1980, p. 235). The metal layer between shaft hole and ceramic core had some holes, most likely negatives of the twigs or bones, which connected the core to the mould (Potaszkin and Bar-Avi, 1980, p. 235). X-ray analyses of about 200 objects of the Nahal Mishmar Hoard confirmed this practice but further revealed that some objects are massively cast while others are just a shell with or without core (Tadmor et al., 1995, p. 101). At least for a mace head found in Shiqmim, glauconitic chalk was used as core material instead of ceramics (Shalev et al., 1992, p. 68). Glauconitic chalk crops out in the Western Negev and the central Arabah valley (Goren, 1995, p. 303; Shalev et al., 1992, p. 68).

The mould remains preserved on the metal objects allow reconstructing a multi-layered mould design (Goren, 2014, 2008). Most of the sampled 75 objects had mould remains made of a ceramic paste prepared from clay and marl of the Moza formation with a high proportion of organic temper (chopped grass or straw), sand-sized carbonate grains (limestone, dolomite, chalk) and sometimes also chert. Where a second layer was preserved, it is either a ferruginous clay with well-rounded and well-sorted sand-sized quartz, compatible with weathered Lower Cretaceous Sandstones, and a variable amount of charred plant material. Or, more rarer, the second layer is a plaster-like paste. This paste is lime plaster or Moza clay, both with a high proportion of crushed basalt and plant material, or it is lime plaster with quartzite sand. Coprolites could indicate the presence of dung as additional component in the plaster or the addition of the plant material using herbivore dung (Goren, 2008, pp. 380–386).

Goren (1989) suggested several workshops for the production of these moulds, but he later suggested a single workshop because of their homogeneous design (Goren, 2008, p. 390). The raw materials for the pastes were specifically selected for their refractory properties; hence, they do not necessarily need to represent the geologic situation in the immediate surrounding of the workshop (Goren, 2008, p. 390). Nevertheless, “the best possible location for all these materials should be looked for in the lower Jordan Valley or the Dead Sea basin, where [the raw materials] coexist in close proximity.” (Goren, 2008, p. 391), probably in En Gedi (Goren, 2014, pp. 263–265; 2008, p. 392).

Archaeological remains for melting the wax and casting the object are yet to be found. The wooden pieces found in some items of the Nahal Mishmar hoard, especially a wooden awl-shaped object in one of the standards (Bar-Adon, 1980, p. 40), could be related to the removal of the mould from the object.

In most cases, the casts were not flawless. In general, the casting quality varies considerably and all objects have some porosity (Tadmor et al., 1995, p. 127). Holes, resulting from large casting errors especially in the crowns, were sometimes repaired by a cast-on technique. It is not clear why some items were repaired and others were not (Tadmor et al., 1995, p. 127). Initially, lead was identified as the metal used for those repairs (Key, 1964, p. 1579), but analyses with more advanced methods revealed that metal with a composition similar to the initial cast was used, maybe even the same metal batch (Tadmor et al., 1995, p. 133). The Nahal Mishmar Hoard also contained a standard whose lower end is completely missing due to a failed cast; probably it is cast in unalloyed copper (Key, 1964, p. 1579).

The last step was the treatment of the surface by hammering and polishing. This did not only create a shiny surface but was also a good way to even out and mask casting errors and porosity – hammering was predominantly applied to objects with a high porosity and pores on or under the surface (Tadmor et al., 1995, p. 127). According to Key (1964, p. 1579) unalloyed copper objects in the Nahal Mishmar hoard were never polished while all objects made of polymetallic copper alloys were. However, this differentiation should be taken with caution and Tadmor et al. (1995, p. 128) showed that the situation is much more complex with only the outside of e.g., crowns being polished.

### 4.1.2 Gold

The oldest evidence for the use of gold is currently reported from Southeast Europe (Pernicka, 2020, p. 43). The cemetery of Varna I (4550 to 4350 BCE) is the most prominent example (Higham et al., 2018; Leusch et al., 2015, p. 353) but date slightly later than the gold-containing burials at Varna II and Durankulak, and it is paralleled by several other sites (Radivojević and Roberts, 2021a, p. 229). While the other sites yielded usually small gold items such as beads, the items of Varna I show a variety of objects (Fig. 3.11) with ring-shaped idols, gilded staffs/sceptres, miniature tools, and the infamous "penis sheath" of burial 43 (cf. Leusch et al., 2014). Additionally, Varna I is outstanding by the high level of metalworking attested in these objects and indicators for an early serial production of gold beads (Leusch et al., 2014, p. 173).

Figure 4.17: Beads of different colours from the Varna I cemetery (Leusch et al., 2015).

Many of the beads were cast instead of cold-formed (Leusch et al., 2015, p. 356) but some beads neither were cast nor hammered gold items but sheet-gilded copper beads (Leusch et al., 2015, p. 359). Gold sheet was also used to "repair" a spondylus bracelet by covering the damaged parts with it, and for the decoration of hammer axes, bows and apparently textiles and clay heads (Leusch et al., 2015, p. 359). Most importantly, a few objects were made in the lost wax casting technique. They are either thin-walled hollow objects (e.g., bracelets) or massive casts with complex shapes such as the golden astragalus from burial 36 (Leusch et al., 2015, pp. 356–357). While the outer surface of the lost wax cast objects is well overworked and polished, the inner surface was generally left in an as-cast state

(Fig. 3.11b). In addition, the high Cu content in some items exceeds the range of copper concentrations in natural gold, indicating alloying (Leusch et al., 2015, p. 356; 2014, p. 175), while the Ag-rich gold could be natural (Leusch et al., 2015, p. 359; 2014, pp. 176–177). In any case, beads with different colours and, therefore, metal compositions were seemingly purposefully arranged in necklaces or bracelets (Fig. 4.17) to enhance the visual effects of the metal objects (Leusch et al., 2015, p. 357).

Chemical analyses on the artefacts yielded several compositional groups that correlate with typological groups and are probably representing different gold deposits. If so, the correlation might indicate a limited variety of products manufactured in the respective regions (Leusch et al., 2014, p. 179). Matching deposits are yet to be found. A recently discovered gold placer deposit close to Varna might have been a source for the Varna gold, but archaeological evidence is pending (Radivojević and Roberts, 2021a, pp. 230–231).

Figure 4.18: The gold wire from Ubaid Ur (Jansen and Benati, 2020).

In West Asia, the earliest gold finds date parallel or slightly later than Varna I and are mostly single finds of small objects. Therefore, they will be presented in chronological order.

The probably oldest find is a small piece of gold wire found in the Ubaid layers of Ur in Southern Mesopotamia (Fig. 4.18), dated by associated pottery between 4800 and 4300 BCE (Jansen and Benati, 2020, pp. 319–320). Gold beads in Tepe Gawra date to the second half of the 5th millennium BCE (Jansen and Benati, 2020, p. 319; Moorey, 1994, p. 221), and a gold bead in a burial of Grai Resh, layer IV (Fig. 3.8) can be dated to 4250 to 4150 BCE (Jansen and Benati, 2020, p. 319; Kepinski et al., 2011, pp. 30, 33).

Figure 4.19: Metal objects from the cemetery of Chega Sofla: (1–3) copper weaving hook and knives, (4) copper axe, (5) copper discs, (6) silver bracelet, (7) gold ring, (8) small gold plates, (9) gold bead (Moghaddam and Miri, 2021).

To the late 5th and early 4th millennium BCE date the two gold and six electrum rings from Nahal Qanah cave in the Southern Levant (Gopher et al., 1990; Gopher and Tsuk, 1996c) – which look like large versions of some of the Varna beads (Fig. 3.2c, Fig. 4.17) – and small items found in the cemetery of Chega Sofla (Fig. 4.19) in Iran (Moghaddam, 2016, p. 4; Moghaddam and Miri, 2021, pp. 46, 56–57). Traces of gold on a copper vessel from Chega Sofla might also indicate the gilding of larger copper items (Nezafati, 28.01.2022). Thornton (2009b, p. 49) further reports a gold artefact from Tepe

Borj near Nishapur in Northeast Iran without any details about the object.

A lost wax cast bead from Tepe Hissar in North Iran dates to the first half of the 4th millennium BCE (Jansen and Benati, 2020, p. 319), as does a decorative gold sheet with silver rivets from Tell Brak in Northern Mesopotamia (Hansen and Helwing, 2016, p. 44). The earliest known gold finds in the Southern Caucasus are beads in the Soyuq Bulaq kurgans (Fig. 4.20), dating to around 3800 BCE (Courcier et al., 2008, pp. 21–22; Lyonnet et al., 2008, p. 31). The gold objects in the Maikop kurgan in the Northern Caucasus, among them two bull figures made in the lost wax casting technique, are slightly younger (Reinhold, 2019, p. 99). The kurgans of Sé Girdan also yielded several hundreds of gold beads (Muscarella, 1971, pp. 11, 18; 1969, p. 20) and although they are difficult to date, numerous parallels suggest a close connection to the early Caucasian kurgans (Lyonnet et al., 2008, p. 40).

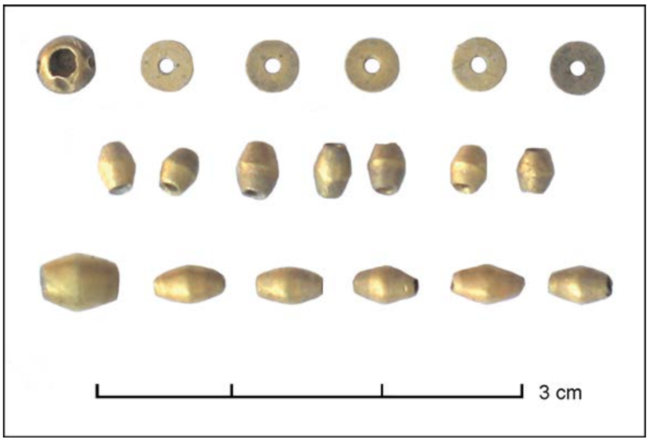


Figure 4.20: Metal beads from kurgan 1 in Soyuq Bulaq (Lyonnet et al., 2008).

Two small gold objects from Arisman B date to the middle of the 4th millennium BCE but not later than the 34th century BCE (Helwing, 2011b; 2011a, p. 272). To around the same time or maybe a bit earlier date the "very rare" gold items from the burials in Byblos (Artin, 2010, p. 82). A solid gold knob-headed "rivet" was found in uncertain contexts at Tell Zidaya and is likely to date into the 4th millennium BCE (Moorey, 1994, p. 221). Examples for later gold finds in Anatolia are the three beads and a spiral found in the "royal" tomb at Arslantepe VI B1 (3200 to 3000 BCE) and the two golden mace heads from Alaca Höyük from the 3rd millennium BCE (Palmieri and Di Nocera, 1999, p. 180; Primas, 1988, p. 169)

Like in Southeast Europe, production contexts related to gold metalworking are yet to be found. A notable exception are the neighbouring sites Dzedzvebi and Sakdrisi in the Southern Caucasus. Research in Sakdrisi provided evidence for gold mining during the mid and second half of the 4th millennium BCE, making this site the oldest known gold mine (Stöllner, 2011; Stöllner and Gambashidze, 2014). In Dzedzvebi, a crucible was found in contexts from the first half of the 4th millennium BCE. Its interior surface is enriched in silver, indicating the (s)melting of noble metals (Stöllner, 2016, p. 218; Stöllner and Gambashidze, 2014, p. 107). Because there are no silver mines in the region and the site did not yield any indication for cupellation, this crucible was most likely used to (s)melt gold (Stöllner, 2016, p. 218). Additionally, houses with large rooms were identified as workshops for gold ore from the mine (Stöllner and Gambashidze, 2014, p. 107). Dzedzvebi dates to the later first half of the 4th millennium BCE (Stöllner, 2016, p. 218) and is thus contemporary with the earliest gold items in the

Southern Caucasus.

### 4.1.3 Lead and silver

Native silver is usually found as thin wires with dull surfaces, making it difficult to recognise it and to extract it from its host rock. The only way to metallurgically produce silver in prehistory was by cupellation, i.e., smelting silver-rich lead ores, usually galena (lead sulphide) or cerussite (lead carbonate), and subsequently oxidise the metallic lead to separate it from the un-oxidised silver (Pernicka, 2020, p. 42). Therefore, large amounts of lead were an integral part of silver pyrometallurgy and the presence of litharge (lead oxide absorbed in crucibles) is often indicating silver metallurgy. Based on the metallurgical assemblage from Arisman, it was recently suggested that silver-rich polymetallic copper ores might have been used as silver source already in the mid-4th millennium BCE (Nezafati et al., 2021), a later widely used technique (Agricola et al., 1950, bk. XI). It must not be forgotten that lead was also used as metal on its own and was in some areas an important alloying agent for copper.

#### 4.1.3.1 Southeast Europe

The earliest evidence for the pyrometallurgical handling of lead could be the lead slag "cake" from Belovode (around 5200 BCE) in Southeast Europe (Radivojević and Roberts, 2021a, p. 233). However, neither the site nor other contemporaneous sites yielded indicators for the processing or use of lead, and it must remain unclear why and in which context it was produced. Similarly, the biconical and partially slagged vessels with litharge found in Pietrele (4400 to 4300 BCE) are not associated with other remains of lead smelting. Based on their shape, the production of litharge from lead ore is more likely than the production of lead or their use in a cupellation process (Hansen et al., 2019).

Silver objects are reported from sites in the Carpathian Mountains as being contemporaneous to the earliest gold items (late first half of the 5th millennium BCE). Unfortunately, all of them are found in uncertain contexts (Radivojević and Roberts, 2021a, p. 232). The earliest reliably datable silver objects in Southeast Europe were found in modern Greece and on several Aegean Islands. Dated between the mid-5th and early 4th millennium BCE, they seem to predate the earliest litharge from this region, which dates to the early 4th millennium BCE (Radivojević and Roberts, 2021a, pp. 232–233).

#### 4.1.3.2 Anatolia and Northern Mesopotamia

The earliest lead and silver objects found in Anatolia and Northern Mesopotamia date to the 6th millennium BCE and are a lead bracelet found in Yarim Tepe, a conical lead piece from Halaf Arpachiyah (Kohlmeyer, 1994, p. 41; Moorey, 1994, p. 294), and two beads made of native silver from Domuztepe

(Lehner and Yener, 2014, p. 538). During the 4th millennium BCE, lead and silver become more widely available. Two silver earrings from Hacınebi Phase A date between 4200 and 3700 BCE (Özbal et al., 2000, p. 122; Stein et al., 1996, p. 96). Dated to the first half of the 4th millennium BCE are, e.g., a bent lead pin in Tell Judaidah (Kohlmeyer, 1994, p. 41), a lead ball and a lead spectacle pendant from Norşuntepe (Schmidt, 2002, Pl. 57, 86), a silver wire in Hamoukar (Hansen and Helwing, 2016, p. 44), and the silver rivets of the decorative gold sheet in Tell Brak (Hansen and Helwing, 2016, p. 44). Towards the mid-4th millennium BCE date a lead wire fragment from Çamlıbel Tarlası (Schoop, 2011, p. 62), and two silver beads and a silver sheet of Arslantepe VII (Balossi Restelli, 2019, p. 558). In addition, Arslantepe VII yielded lead rich slag. However, without any production contexts, it cannot be differentiated if they are related to lead metallurgy or the processing of lead-rich copper ores (Heil, 2019, p. 57; Hess, 1998, p. 112). In the subsequent phase Arslantepe VI A1, some swords found in the palace were decorated with silver inlays (Frangipane, 2011, p. 980), a technique so far unattested elsewhere in Anatolia and Northern Mesopotamia.

Other finds can only be broadly dated into the 4th millennium BCE. Among them is the silver ring from Beycesultan. While excavators dated it to the second half of the 5th millennium BCE (Lloyd et al., 1959, pp. 47–48), making it the earliest known Anatolian silver object, other researchers dated it to the first half of the 4th millennium BCE (Kohlmeyer, 1994, p. 41) or generally into the 4th millennium BCE (Hansen and Helwing, 2016, p. 44). The silver rings from Alişar Hüyük also date to the first half of the 4th millennium BCE according to Hansen and Helwing (2016, p. 44). Likewise, the silver objects in two graves of Korucutepe were dated to the second half of the 4th millennium BCE by the excavator (van Loon, 1973, pp. 358–359), while Hansen and Helwing (2016, p. 44) date them to the first half of the 4th millennium BCE. The burial in layer 37 contained, among other finds such as an iron ore mace head and a copper dagger, a band with spiralled ends and a stamp seal, both made of silver (van Loon, 1973, p. 359). In addition, a burial in the stratigraphically younger layer 34 contained a crescent-shaped sheet and two hair rings made of silver, as well as a silver headband with red and white beads (van Loon, 1973, pp. 360–361). If they indeed date to the first half of the 4th millennium BCE as suggested by Hansen and Helwing (2016), these objects are the largest known assemblage of silver objects from this time.

Production sites in Anatolia and Northern Mesopotamia are reported from Fatmalı Kalecik and Habuba Kabira. Fatmalı Kalecik yielded silver-rich lead slag and litharge but no cupels or furnaces. The site dates to the end of the 5th and the early 4th millennium BCE. A date in the 4th millennium BCE is more likely due to contemporary pottery with Korucutepe (Hess et al., 1998, pp. 58–59). Habuba Kabira dates to around 3300 BCE and revealed lead objects and litharge pieces. The litharge pieces are interpret as either furnace wall fragments or cupels inserted into the furnaces (Pernicka et al., 1998, pp.

124–125). One litharge piece has about 5 % Sb and about 5 % As, perhaps pointing to the processing of silver-rich fahl ores (Pernicka et al., 1998, pp. 127–128).

#### 4.1.3.3 Caucasus

Evidence for lead and silver in the period under study is very limited in the Caucasus. Courcier (2014, p. 601) mentions some analyses that indicate the existence of lead ingots and other lead objects in the Darkveti Culture at the western half of the Greater Caucasus' south flanks but is sceptical about their reliability due to the early date of the analyses.

The incipient use of silver seems to be closely linked to the appearance of kurgans. All pre-Kura Araxes silver objects are burial goods in kurgans dating to the second quarter of the 4th millennium BCE. Soyuq Bulaq yielded beads made of silver and silver alloys with copper and sometimes also gold (Courcier et al., 2008, pp. 21–22; Lyonnet et al., 2008, pp. 31, 34, 38). The alloys could be natural (Lyonnet et al., 2008, p. 38). The silver objects in the Maikop kurgan are the largest amount of silver in the first half of the 4th millennium BCE. They consist of beads, two lost wax cast bull figurines, and several silver vessels, some with detailed embossed figural decoration (Reinhold, 2019, p. 99). Two silver vessels and a silver wire were found in kurgan III of Sé Girdan (Muscarella, 1969, p. 20), a kurgan field in Northwest Iran with close connections to the earliest Caucasian kurgans (Lyonnet et al., 2008, p. 40).

#### 4.1.3.4 Iran

Silver in Iran appears in the early 4th millennium BCE and its production is well attested by litharge and cupellation workshops at several sites. The currently oldest silver object is a bracelet found in the cemetery of Chega Sofla (Fig. 4.19), dating to the end of the 5th and early 4th millennium BCE (Moghaddam and Miri, 2021, p. 55). Slightly later, to the first half of the 4th millennium BCE, date two small silver caps from Tepe Sialk III.5 (Ghirshman, 1939; Helwing, 2013c, p. 120; Kohlmeyer, 1994, p. 42).

Excavations of Tepe Sialk and Arisman yielded several hundreds of kilograms of metallurgical debris, among them litharge. The finds allow the reconstruction of the entire metallurgical process in the phases Sialk III and IV (Nezafati et al., 2008b, pp. 337–338), i.e., from the mid-4th millennium BCE onwards (Nezafati and Pernicka, 2012, p. 39). The two sites implemented the same process with the same materials and ores. Evidence from both sites show that cupellation was a well-established and extensively practised craft (Nezafati et al., 2008b, p. 337; Pernicka, 2004, p. 237). Moreover, lead ingots found in Arisman (Helwing, 2011a, p. 265) attest to a production for export.

Finds of furnace batteries in Tepe Shoghali show that cupellation reached a proto-industrial scale in the second half of the 4th to the early 3rd millennium BCE (Nezafati and Hessari, 2017, pp. 67, 70). In contrast to Arisman and Tepe Sialk, there are no copper smelting activities (Nezafati and Hessari, 2017, p. 70). The chemical composition of the lead objects from Tepe Shoghali suggest the use of polymetallic copper ores, such as fahl ores, as raw material (Nezafati and Hessari, 2017, p. 72).

#### 4.1.3.5 Southern Levant

Only two Chalcolithic sites in the Southern Levant yielded evidence for the use of lead: Ashalim Cave with a pure lead mace head (Fig. 3.2e) and Bet Shemesh with a leaded copper mace head (Ben-Yosef et al., 2016; Yahalom-Mack et al., 2015). The metal for them was most likely imported from the North (Yahalom-Mack et al., 2015), analogous to the polymetallic copper alloys. Two other objects made of leaded copper were found in Ashqelon-Afridar but date to the Early Bronze Age (Segal et al., 2002).

Silver finds date not before the Early Bronze Age and were found, among others, at Tell esh-Shuna (Philip and Rehren, 1996, pp. 129–131), Bab edh-Dra', Azor, and Tel el-Far'ah North (Philip and Rehren, 1996, p. 137). Silver is with 230 items the most abundant jewellery material in the Byblos cemetery. The burials likely date to the mid-4th millennium BCE or slightly younger (Artin, 2010, p. 82). With regards to the close ties between Egypt and the Southern Levant from the Early Bronze Age on (Hartung, 2013, p. 185), the small objects made of silver and silver-gold alloys found in Egyptian tombs from the 4th millennium BCE (Hansen and Helwing, 2016, p. 43; Philip and Rehren, 1996, p. 137) must also be mentioned.

### 4.1.4 Lost wax casting

Lost wax or investment casting allows to cast objects with a complex three-dimensional shape. The general process of this casting technique comprises of five steps, preceded by the optional preparation of a core made of, e.g., ceramic, to provide more stability for the model and/or save on metal: (1) modelling the shape of the object in wax or a wax-like material (2) covering the model in heat-resistant material to create a mould, (3) heating the object to remove the wax, (4) the actual casting of the object, and (5) removing the mould to retrieve the cast object. Compared to other casting techniques such as open mould casting, the necessary effort for an object is substantial. Additionally, the wax model and the mould cannot be reused after, making every object cast in this technique a single item (Davey, 2009).

Lost wax casting becomes archaeologically visible around the mid-5th millennium BCE in the cemetery of Varna I and in Mehrgarh (modern-day Pakistan). The respective layer in Mehrgarh can only be dated imprecisely to 4500 to 3600 BCE (Mille, 13.06.2017, p. 42), making these objects potentially contemporary also with the lost wax cast objects of the Late Chalcolithic Southern Levant and maybe even of the Maikop kurgan (3800 BCE or later).

The lost wax casting technique is connected to a specific metal in every region: in Varna I all objects were made of gold (Leusch et al., 2015, p. 356), in Mehrgarh unalloyed copper was predominantly used and later also leaded copper (Mille, 13.06.2017, pp. 111, 153), and polymetallic copper alloys were the metal of choice in the Southern Levant (Shalev, 1991; Tadmor et al., 1995, pp. 129–133). While suitable ore deposits for the gold in Varna and leaded copper in Mehrgarh can be found within a reasonable distance from the site (Mille, 13.06.2017, p. 186, p. 188; Radivojević and Roberts, 2021a, pp. 230–231), the polymetallic copper alloys for the Southern Levant are imports from deposits at least about 1000 kilometres away (e.g., Tadmor et al., 1995).

Lost wax cast objects in the cemetery of Varna I are bracelets, beads and an astragalus (Leusch et al., 2015, p. 356), all of them comparatively small (Fig. 3.11). The objects found in Mehrgarh are small as well but in contrast to Varna all of them are spoked wheel-shaped "amulets" (Fig. 4.21) except for one stamp seal (Mille, 13.06.2017, pp. 62–63, 150–154). The features of these round "amulets" clearly indicate the production of the wax model from wax threads (Mille, 13.06.2017, p. 107). This technique provides a direct link to several ceramic objects, which were also created in the thread technique (Mille, 13.06.2017, pp. 141–143). Unfortunately, no production debris or any kind of production site for the lost wax cast objects was found (Mille, 13.06.2017, p. 110). Tomographic analyses of one "amulet" revealed a high amount of cuprite in the cast metal, indicating very oxidising casting conditions (Thoury et al., 2016).

Figure 4.21: Lost wax cast spoked wheel-shaped objects from Mehrgarh; diameter: 20 mm (Thoury et al., 2016).

The lost wax cast objects of the Chalcolithic Southern Levant (Fig. 3.2b) stand in sharp contrast to these finds. As already discussed above (cf. chap. 4.1.1.5.2) they show a wide variety in their shape and are sometimes richly decorated (cf. Bar-Adon, 1980; Namdar et al., 2004). Additionally, they are much larger by dimension and weight than the objects in the other two regions and some of them are cast over ceramic or stone cores (Potaszkin and Bar-Avi, 1980, p. 235; Shalev et al., 1992, p. 68; Tadmor et al., 1995, p. 101). Petrographic analyses of mould fragments left on the objects and samples from these cores evidence their local production (Goren, 2014, 2008; Shalev et al., 1992, p. 68). Recently, Fazael was suggested as potential production site of these objects (cf. chap. 4.1.1.5.2).

Outside these three "hot spots" of early lost wax casting, this technology is attested in Caucasia in the second quarter of the 4th millennium BCE by the four bull figurines from the Maikop kurgan (Reinhold, 2019, p. 99). Surprisingly, lost wax cast objects are not reported from Anatolia, Mesopotamia and

Iran with the exception of a golden lost wax cast bead in Tepe Hissar in Northern Iran, dating to the first half of the 4th millennium BCE (Jansen and Benati, 2020, p. 319). Other lost wax cast items in Southwestern Iran or Mesopotamia date at the end of the 4th millennium BCE or younger (Moorey, 1994; Tallon, 1987).

## 4.2 Smelting processes and influencing parameters

Chemically, copper smelting is the reduction of copper into its elemental (metallic) state by stripping it of oxygen and sulphur, and separating it from other compounds in the ore. The following paragraphs introduce briefly the general chemical reactions relevant for early smelting processes and their main parameters. An in-depth summary of the smelting reactions was recently given for example in chap. 6.2.3 of Hauptmann (2020).

A reducing agent is required to remove oxygen from copper. One of the most efficient reducing agents is carbon monoxide (CO). CO can be produced by the oxidation of carbon, e.g., by burning fuel such as wood or charcoal, in an atmosphere with reduced oxygen availability. In prehistoric times, this was the only possibility to create a sufficiently reducing atmosphere for smelting. CO will react with the oxygen in the ore to carbon dioxide ($CO_2$) at sufficiently high temperatures, reducing the metal in the ore to its elemental state. Consequently, oxide ores such as malachite or azurite can be easily reduced to metallic copper by heating them under a cover of charcoal. They will react at around 250 °C to copper oxide, and at around 800 to 900 °C CO reacts with copper oxide to metallic copper and $CO_2$. The exact temperature depends on the specific furnace conditions and chemical composition of the ore charge. Pollard et al. (1991a, p. 133) for example managed to reduce secondary copper minerals to metallic copper in laboratory smelting experiments already at 700 °C. In any case, this reaction happens well below 1085 °C (Lorenzen, 1966, p. 16), the melting point of copper.

Smelting a mixture of oxide and sulphide ores, such as weathered copper sulphides, is called co-smelting. Co-smelting reactions of copper-rich ores were investigated in detail by Rostoker et al. (1989) and Rostoker and Dvorak (1991). For the ore deposits of the regions under study here, relictic sulphides in the oxide ores must be expected. The intentionality of co-smelting, e.g., collection of suitable ores or intentional mixing of oxide and sulphide ores into a suitable ore charge, must remain unclear; likewise, whether the effect of the sulphur content on the smelting process was noticed. In general, co-smelting has several advantages compared to the smelting of pure oxide ores. Sulphur acts similar to CO in that it reacts with the oxygen from the ore charge or in the furnace atmosphere to gaseous $SO_2$ and hence helps to create and maintain a reducing furnace atmosphere (Bourgarit, 2007, pp. 9–10; Roberts et al., 2009, p. 1017). Additionally, the oxidation of sulphur to $SO_2$ is exothermic and thus helps to heat the furnace. A too high sulphur content in the ore charge or a too reducing furnace atmosphere would result in the production of matte, a mixture of different Cu-(Fe-)S phases, instead of copper because not enough sulphur is oxidatively removed from the ore charge. The matte can be further processed by roasting it, i.e., oxidatively removing the sulphur in a separate step and subsequent conversion of the roasted matte to copper and slag by smelting in a reducing atmosphere. However, this process does not seem to have been performed in the period under study. On the contrary, the discarded primary copper sulphides found in Akladi Cheiri (Rehren et al., 2020, p. 153) and the abundant but discarded matte in the slag from Çamlıbel Tarlası (Boscher, 2016, p. 162) nearly 2000 years later seem to indicate that iron-rich copper sulphides were not deemed suitable materials for copper metallurgy during this period.

Slag is the most important material for the reconstruction of metallurgical processes and their details, such as the maximum temperature reached and the furnace atmosphere. Smelting slag is a waste product, ideally consisting of everything from the ore except the target metal (and volatile elements), melted furnace wall (if any), and ash. The phase composition and structure of the slag is the result of a complex interplay, mainly of the ore charge, the furnace temperature, and the furnace atmosphere. Therefore, it provides valuable insight into how reducing the furnace atmosphere was, the maximum temperature of the furnace, how quickly the slag cooled down, and which ore was used (Bachmann, 1982; Hauptmann, 2020, chap. 5). The ideal copper smelting process would result in a slag that consists mostly of fayalite, an iron silicate with a comparatively low melting temperature that forms at reducing conditions, and was long enough fully liquefied to let the denser copper segregate at the bottom of the furnace. However, slag from early metallurgical operations show that it was impossible to achieve a slag even close to this ideal slag. The ore was not fully liquefied or only for too short a time to let the copper segregate from the slag. Consequently, the copper prills remained in the slag and needed to be extracted mechanically (Bourgarit, 2007, p. 5). The furnace conditions were also too oxidising to produce fayalite, except for some rare instances (Hauptmann et al., 1993). Early copper smelting slag can generally be divided into two types by their phase composition: A type with common delafossite and cuprite, pointing to a rather oxidising furnace atmosphere; and a type with magnetite as major phase, which indicates a more reducing furnace atmosphere than the first type but still a too oxidising one for the formation of fayalite (Bourgarit, 2007, p. 8). The ores chosen by early metallurgists were often self-fluxing, i.e., their silica and iron content was by nature close to the ideal composition for copper smelting (Hauptmann, 2020, p. 248). Intentional fluxing, i.e., the optimisation of the furnace charge by adding materials that lowers the melting point of the ore charge and/or shifts it towards a fayalitic composition, seems to be unknown to early metallurgists (Bourgarit, 2007, pp. 6–7; Hauptmann, 2020, p. 245). The impact of unintentional fluxing by fuel ash must not be forgotten.

It would have reduced the viscosity of the slag and can be traced by increased Na and K contents in the slag (Rostoker and Dvorak, 1991, p. 11).

Crushing the slag to extract the copper prills inevitably resulted in the fragmentation of the often already small slag pieces. Ethnographical observations indicate that the slag might have been even ground to retrieve the smallest copper prills. Therefore, the "slagless smelting" initially suggested for early metallurgy due to the perceived widespread absence of slag in the archaeological record (e.g., Tylecote, 1992, p. 9) seems to be more likely the result of the post-smelting treatment of slag, and that slag was not recognised as such during excavation (Bourgarit, 2007, p. 5). This does not mean that slagless copper metallurgy is impossible or did not exist. In general the purer the copper ores in the furnace charge are, the less slag will be produced. However, the very pure ores necessary for a slagless metallurgy, especially in sufficient amounts for regular smelting operations, were most likely the absolute exception in the regions under study here as indicated by the slag finds in many sites. The metallurgical tradition closest to a slagless metallurgy could be the Vinča metallurgy, which can be considered as being almost slagless because of the extremely small amount of slag found in the smelting sites compared to the amount of copper metal known from this period (Radivojević et al., 2021a, p. 486).

As already shown, the furnace atmosphere is a crucial parameter for a successful smelt. Some kind of draught is necessary to increase the temperature high enough to smelt ore and to supply oxygen that can react to CO. However, a too strong draught will counteract a reducing atmosphere because the oxygen from the air blown into the fire does not have enough time to react with the fuel to CO and $CO_2$ before reaching the ore. Additionally, a strong air stream could chill the furnace – the air is too fast to heat up before reaching the ore. To reliably maintain a reducing atmosphere, the ore charge must also be covered with sufficient burning or at least glowing fuel to react with any oxygen from the ambient air. Draught was created in the early metallurgical processes by either blowpipes or bellows. Usually, the use of blowpipes is assumed, but indicators for the draught technique, such as blowpipe heads or tuyères made of ceramics, are scarce (Bourgarit, 2007, p. 7). They are not only necessary to protect the organic material of which the blowpipes and bellows were made (e.g., reed, leather), but also to focus the air stream (Roden, 1988, p. 68). Experiments showed that they are not likely to be preserved in the archaeological record because they will neither get slagged nor fired to high temperatures when used correctly and thus will degrade over time (Botwid and Pettersson, 2016, pp. 26–27; Bourgarit, 2007, p. 7; Lorscheider et al., 2003, p. 304).

Important parameters for the use of blowpipes and bellows were reconstructed by thermodynamic calculations and experiments. If operated by humans, the maximum penetration depth of the air stream into the furnace with both techniques is about 40 cm. This is most likely the reason why furnaces with an inner diameter larger than 40 cm are rarely found at early metallurgical sites (Craddock, 1995, p. 171). To reach a high penetration depth, an initial downwards inclination of the air stream of about 15° is optimal (Rehder, 2000, p. 67). Bellows are in general advantageous over blowpipes because they are much easier to operate continuously, require a lower level in training, and reduce the number of people per furnace volume because of the significantly larger air flux into the furnace (Rehder, 2000, p. 76; 1994, pp. 347–349). However, blowpipes allow better modulating and focusing of the air stream. Calculations by Rehder (1994, p. 349) showed that blowpipes are best operated with an outlet diameter of 5 to 10 mm while the tuyère openings of bellows should have a diameter between 20 and 30 mm. Therefore, the inner diameter of tuyère fragments could help to reconstruct the draught technique, if the measurement is taken close to the opening.

The maximum temperature reached during smelting can be reconstructed from the phase composition and morphology of the slag and the crucible and furnace walls. Usually local clays were used for early metallurgical ceramics, often optimised by the addition of vegetal material to create porosity. They cannot be considered as refractory and would readily melt above 1000 °C (Freestone, 1989, p. 156; Martinón-Torres and Rehren, 2014, p. 108). Obviously, they were sufficient for the smelting and melting operations, either because the temperatures achieved during smelting were not that high for a prolonged time or because the heat was very well directed on the charge and did not affect much of the furnace or crucible.

As was shown in previous chapters, only crucibles and pit furnaces were used as smelting installations in the period under study. With exception of the crucible from Tepe Hissar (Thornton and Rehren, 2009), all crucibles indicate heating from the top with draught pressed through the fuel cover into the ore (or metal) charge. This way, the heat was not only directly applied to the crucible content, but the crucible walls also served as isolators to keep the heat inside the crucible. In addition, a much smaller amount of fuel is necessary because only the top of the crucible must be covered. In principle, pit furnaces could be operated like larger crucibles, but this would not result in any advantages. Especially when bellows were used, the draught came most likely from the side and not from the top. Pit furnaces reached in experiments temperatures up to 1500 °C and regularly more than 1200 °C, which would be more than sufficient for a liquid slag (Rehder, 2000, pp. 85–86). The amount of oxygen from the draught, which can react to CO before it reaches the top of the fuel cover and escapes to the atmosphere instead of reacting with the ore, is limited because the draught enters close to the surface. This circumstance also limits how reducing the respective furnace atmosphere can be (cf. Rehder, 2000, p. 85). According to Rehder (2000, p. 85), pit furnaces were most likely operated in a rotary principle with preheating the fuel and ore on the side opposite of the tuyère and then pushing the material closer to the tuyère into the most reducing area of the furnace. There, the ore reacts to copper and slag before it sinks down into the deeper parts of the furnace. Important parameters for the operation of pit furnaces are the size of the fuel and ore pieces, and the velocity of the draught. Both control, among others, how deep the draught can penetrate into the pit and thus how large the reaction zone for the ore will be (Rehder, 2000, pp. 86–87).

Another important aspect for early smelting is the type of fuel. Charcoal is commonly assumed, probably because it was the preferred fuel in later times, although production sites for charcoal are yet to be found. Moreover, charcoal as heat source is inferior to wood (Rehder, 2000, p. 60) because the reaction heat from the volatile wood compounds is lost during coal making. Additionally, wood would turn to charcoal during smelting anyway if the fuel pile is high enough to prevent significant inflow of oxygen from the ambient atmosphere. Verly et al. (2021) showed for later periods that dung was mixed to the wood-based fuel. Adding dung has the advantageous effects of slowing down the combustion process and blocking the air stream in the shaft furnace. Therefore, the use of dung in early metallurgy could be an additional option, especially in areas where wood supply was limited.

Fuel supply and consequently wood management are crucial but often neglected parameters for an understanding of the scale and the impact metallurgical operations had on the landscape. Goldstein and Shimada (2013) showed for their study region that dead wood and comparatively young branches were used, leaving the trees intact and ensuring a sufficient long-term supply. For the periods and regions under study here, wood management seems to have been only studied for Çamlıbel Tarlası. Charcoal at this site attests to the preferential use of thick branches over entire trees from layer 3 on, probably indicating a change in wood management towards a more sustainable wood supply at this time (Marston et al., 2021).

## 4.3 Polymetallic copper

Fahl ores and their weathering products were the only quantitatively important ore type for Sb-rich polymetallic copper alloys in early smelting processes. They were the raw material for the Chalcolithic Southern Levantine polymetallic copper alloys (Tadmor et al., 1995, p. 140) and, therefore, will be discussed in more detail. The term “polymetallic copper alloys” also comprises compositions without Sb, most prominently As-(nickel-)rich copper. Such metals were found in the Chalcolithic Southern Levant as well, but in contrast to the Sb-rich copper, arsenic copper was the dominant copper type in Western Asia before the advent of tin bronze (cf. Weeks, 2012, p. 307) and is not exclusive to the Southern Levant during the Chalcolithic. Consequently, the ores for and the occurrence of arsenic copper objects are not discussed here. Nevertheless, its production will be included in the discussion because As and Sb behave similarly in many aspects. While many studies were carried out for As, none focused on Sb in that much detail, yet.

Fahl ores are a complex solid solution of copper sulphosalts with the most important end members being tennantite ($Cu_{10}(Fe,Zn)_2As_4S_{13}$) and tetrahedrite ($Cu_{10}(Fe,Zn)_2Sb_4S_{13}$). Due to the complexity of the fahl ore group, varieties rich in other elements such as Hg or Bi exist as well. Especially Sb-rich fahl ores can also contain considerable amounts of Ag and were used as silver ores (cf. Bachmann and Stöllner, 2003). Fahl ores have a characteristic grey-metallic colour (Charles, 1967, p. 25), and weather into a wide range of green or grey secondary minerals rich in As and Sb (Ixer and Pattrick, 2003).

Some ore pieces with a suitable chemistry for the Chalcolithic Southern Levantine polymetallic copper alloys were found in Arslantepe and Norşuntepe (Hauptmann et al., 2002, p. 53; Zwicker, 1980, pp. 14–15). However, compatible slag was not found (Hauptmann et al., 2002, p. 57; Zwicker, 1980, p. 17). Consequently, information about the smelting of fahl ores must be gathered from other regions and experimental studies to get a better grasp of the general concepts of the West Asian fahl ore metallurgy during the 5th to early 4th millennium BCE. Another important aspect for an understanding of why and how the polymetallic copper alloys were handled is the impact of As, Sb, and other elements on the mechanical and casting behaviour of the alloys.

### 4.3.1 Occurrence of Sb-rich fahl ore copper outside Chalcolithic West Asia

The use of polymetallic copper alloys in the Chalcolithic Southern Levant might be exceptional due to its distance from the ore sources and it is certainly outstanding by the generally high Sb content of the metal. It also is currently the earliest evidence for the use of fahl ore copper in Western Asia. The Sb and Pb-rich polymetallic copper ore piece from Catal Höyük dating to around 6500 BCE, once interpreted as the earliest evidence for smelting (Neuninger et al., 1964), turned out to be the result of an accidental smelt of pigment or ornament in a destructive fire (Radivojević et al., 2017). Nevertheless, the polymetallic copper alloys in the Chalcolithic Southern Levant are not unique in their chemical composition when other regions and periods are taken into account. Evidence from there might provide valuable indicators to the features of the respective ore deposits and to how potential remains of the metallurgical process producing the polymetallic copper alloys of the Chalcolithic Southern Levant might look like.

A list of Anatolian and Caucasian finds made of Sb-bearing alloys was recently compiled by Dardeniz (2020). It shows that these alloys only come into use in Anatolia in the late 4th millennium BCE. The Sb concentrations of objects compiled by Dardeniz (2020) do not exceed 3 %, much lower than the levels of many polymetallic copper objects in the Chalcolithic Southern Levant. Surveys in Northern

Turkey identified the deposits of Bakırçay and Gürleyik Tepe in the Merzifon region as suitable ore sources for such a metal. Slag at Bakırçay indicate metallurgical activity in the region, probably dating to Ottoman times. Evidence for Chalcolithic mining or smelting activities remained absent (Özbal et al., 2002, pp. 433–434).

In Iran, Sb-rich polymetallic copper alloys are rare but not absent. A "dirty lump" of copper with 28.2 wt.% Sb, 2.8 wt.% Ag, and 1.5 wt.% As from Tal-e Malyan in Western Iran dates to the second half of the 4th millennium BCE. An amorphous prill from the same layer contains only 1 wt.% Sb but similar levels of Ag (2.4 wt.%) and a much higher As content of 7.15 wt.% (Pigott et al., 2003, pp. 98, 154). It must remain open whether the lump was ready for use, discarded, or represents unrefined metal. Another example for the use of fahl ore copper in Iran is the mace head from Shahdad (2600 to 2400 BCE) with 4.14 % Sb and 4.66 % As (Vatandoust, 1999, p. 134). According to Vatandoust (1999, p. 134), the metal composition was intentionally produced to create a silvery colour.

In the Caucasus, Sb-rich copper alloys were used from the 3rd millennium BCE on to imitate silver (Badalyan et al., 2014, pp. 203–209; Stöllner, 2016, p. 214). They are widely spread since the Middle Bronze Age alongside many other copper alloys types, but remain sparse in total number when compared with other contemporary alloy types, such as tin bronze (Hauptmann and Gambaschidze, 2001; Meliksetyan et al., 2011).

A centre of fahl ore smelting outside Western Asia are the Eastern Alps and their neighbouring areas. In the Inn valley (Austria), fahl ore smelting started around 4300 to 4200 BCE, contemporary with the developments in Western Asia. To this period date a cast "cake" with 10.2 % Sb and 6.7 % As, and slag pieces with up to 4 % Sb, all from Mariahilfbergl. Antimony-rich fahl ores are the main ore of vein deposits in the Inn valley. Fractures in the vein deposits created a mixture of weathered and unweathered ore instead of the usual spatial separation of an oxidation (alteration) zone at the surface and a deeper unaltered zone with primary ores (Martinek and Sydow, 2004, p. 202). The result is comparatively large amounts of fahl ores suitable for early smelting processes. Ores from these deposits were still smelted in the early 2nd millennium BCE, as is indicated by speiss with more than 70 % Sb and raw metal with 4 to 10 % Sb from Buchberg (Martinek and Sydow, 2004, p. 209). To the Late Bronze Age (roughly 1st millennium BCE) date several ingots from Velem-Szentvid (alternative writing: Velem St. Vid, today in Eastern Hungary) with Sb and As levels similar to the metal finds from Buchberg, and elevated Ag levels of about 1 % (Haubner et al., 2020; Otto and Witter, 1952, p. 204; Tarbay et al., 2021). Silver-rich ingots from the 1st millennium BCE were also found in Rannersdorf near Vienna (Reiter and Linke, 2016), and a comparable chemistry (up to 11.7 % Sb, 9.36 As, usually > 1 % Ag) was also found in plano-convex ingots from Arbedo in the Trentino (Northover, 1998a). The two ingots from Guzów/Guschau in Western Poland with around 16.5 % As, 13 % Sb, and 16 to 19 %

Ni (Otto and Witter, 1952, p. 44) are singular in their region but could be imports from the Eastern Alps. In all these sites, metal objects with a similar chemistry are rare to absent.

### 4.3.2 Smelting of polymetallic ores and processing of polymetallic copper alloys

Smelting (weathered) fahl ores is in principle no difference from smelting copper sulphides or co-smelting. In comparison to other primary copper ores, fahl ores are low in iron, resulting in much less matte and slag. Smelting fahl ores was probably similarly challenging as the smelting of oxide ores because the large amount of sulphur in fahl ores will create a reducing atmosphere even if the general conditions of the furnace were quite oxidising – which was the case for early smelting installations. Moreover, fahl ore smelting is rather different because Sb and As are available in significant concentrations and can create speiss, an intermetallic compound of arsenides and antimonites. Speiss will capture a lot of Cu during smelting and is too brittle for mechanical deformation. Consequently, speiss is usually an unwanted phase and indicator for a suboptimal or even failed smelt (Hauptmann et al., 2003, p. 201; Merkel and Shimada, 1988, p. 6; Müller et al., 2004, pp. 45, 50). However, this notion does not hold true for fahl ore copper because otherwise e.g., speiss or speiss-like ingots would not have been produced and used (see above). Smelting weathered fahl ores allows using the miscibility gap in the Cu–S–As+Sb system to produce polymetallic copper alloy and matte. To hit the miscibility gap, the fahl ore must be sufficiently weathered, i.e., copper must be enriched relative to the other elements, so that the oxides shift the ore's reaction path into the miscibility gap. Otherwise, the reaction path will not cross the miscibility gap and speiss will be produced (Moesta, 2004, pp. 270–271; 1998, pp. 199–200).

Thus, it is probably not surprising that an ethnographer observed the smelting of fahl ore in a pit without any fluxes and forced draught in 1833 on Luzon (Philippines) (Bachmann and Stöllner, 2003, p. 29), and also that fahl ore was smelted from the local beginnings of metallurgy on in the Inn valley (see above). Pollard et al. (1991b) showed in experiments with synthetic and natural As and Sb-rich ores, that both elements become enriched in the metal. They further showed for As that it is readily included in the metal if the metal is melted, while only a minor part of the As in the ore diffuses into the solid metal. Lorscheider et al. (2003, p. 303) managed in an experiment to directly smelt fahl ore with 6 wt.% As and 1.6 wt.% Sb to copper with 1 wt.% Sb and matte. The As in the metal was below the detection limit. Özbal et al. (2002) experimentally smelted fahl ore from Bakırçay into copper and refined it. Similar to the observations of Lorscheider et al. (2003), the majority of As was lost after refinement. The refined metal still contained 7.71 % As, 7.88 % Sb, and 13.1 % Pb (Özbal et al., 2002, p. 434). They concluded that a refinement step is always necessary, regardless of adding speiss as As source to the raw metal. During refinement As, Fe, and Zn become strongly depleted in the metal, while nearly no Sb and only little Pb is lost (Özbal et al., 2002, pp. 436–437). They further concluded that either Pb-free copper ore was used to produce arsenic copper, or the refined copper was alloyed with As (see below for the impact of Pb on As during smelting). The strong loss of As was also observed by Neuninger et al. (1970). Their experiments were designed according to the process on Luzon, and As was nearly completely gone after the matte was roasted twice.

The observed loss of As (and Zn) can be readily explained by their volatility in oxidising conditions (e.g., McKerrell and Tylecote, 1972, p. 211). Arsenic is only volatile if free oxygen is available (Sabatini, 2015, p. 2989), i.e., when it is present as As oxide. As soon as the oxygen is missing, i.e., as soon as even weakly reducing conditions are reached, As volatility decreases rapidly (McKerrell and Tylecote, 1972, pp. 201–211; Rostoker and Dvorak, 1991, pp. 12–13). This is in perfect agreement with the observations of Tylecote et al. (1977, pp. 329–330) that As and Sb are enriched in the metal when smelting oxide copper ores, but lost due to roasting (i.e., oxidation) when sulphide copper ore is used. The same is true for Pb, although the effect is less pronounced. The loss of volatile elements by roasting might also explain why R. F. Tylecote and his colleagues observed the loss of As, Sb, Pb, Bi, and Zn in the matte smelting step, while all of them are not enriched in the slag during smelting (Tylecote et al., 1977, p. 330). In contrast to this behaviour, non-volatile Ni and Ag behave like Cu, resulting in little change of the Cu/Ni and Cu/Ag ratios between ore and metal. Nickel and silver become even enriched in the metal relative to the ore (Tylecote et al., 1977, p. 329). Moreover, these reactions are temperature dependent. While As, Sb and Ag partition into the copper between 600 and 900 °C, Ni becomes enriched in the metallic phase only at temperature beyond 900 °C (Pollard et al., 1991a, p. 133).

Investigations on the behaviour of As in melted copper revealed that it behaves like an over-saturated solution: the hotter the melt, the higher the volatility (Sabatini, 2015, p. 2989) and if As can be completely dissolved in copper, i.e., when a homogeneous single phase melt exists, As loss is considerably lower than in a multi-phase melt (Mödlinger et al., 2019, p. 139). In general, it seems that As loss occurs especially if the metal is kept in a melted state over a prolonged time (Boscher, 2016, p. 47; Mödlinger et al., 2019, p. 139). The oxidation of As results in As compounds with a strongly decreased vapour pressure and is thus the main source for As loss (Sabatini, 2015, pp. 2989–2990). This happens especially during refinement and casting, and when a melt is cooling down (Mödlinger et al., 2019, p. 139). Nickel stabilises As in copper melt (Sabatini, 2015, pp. 2987–2988; Tylecote, 1992, p. 11), while Pb supports its removal (Earl and Adriaens, 2000, p. 14).

The effect of As on the copper metal is also significant during the casting step and in post-casting treatment. Due to the large difference in the melting temperatures of Cu and As (see below), the As-rich phases will solidify at much lower temperatures than the Cu-rich phases. In combination with an overall volume decrease during solidification, this can lead to a squeeze-out effect of the remaining As-rich melt, resulting in the enrichment of As-rich phases on the surface of the object. This process is called "inverse segregation" in the archaeometallurgical literature (Mödlinger et al., 2018, p. 2506) and becomes more pronounced the higher the cooling rate was (Budd and Ottaway, 1991, p. 138; Charles, 1973). Corrosion can lead to an enrichment of As on the surface as well and might result in a taphonomical plating of the object (Craddock, 1995, p. 286; Mödlinger et al., 2018, p. 2506). In contrast, annealing of the object will result in the loss of any As enrichment due to its oxidation (McKerrell and Tylecote, 1972, p. 213; Mödlinger and Sabatini, 2016, p. 67). For these reasons, Mödlinger and Sabatini (2016, pp. 67–73) suggested that the silvery surfaces of arsenic copper objects were artificially created by selective oxidation of copper or cementation of the object with As after the object was given its final shape. They further suggest that this technique was specifically used for prestige items. Experiments have shown that such a plating effect can be comparatively easily achieved by burying the object for some time in wet salt-rich soil (Ryndina, 2009, pp. 9–10). Because of all these processes, the original As content of the metal objects cannot be reconstructed due to the unknown As loss after casting (McKerrell and Tylecote, 1972, p. 216).

Because As is readily oxidised and removed from the metal melt as soon as it gets in contact with oxygen, the production of arsenic copper is not straightforward. Özbal et al. (2002, p. 437) reported that their experiment with arsenopyrite as alloying agent was not as successful as was expected. Their observation might be closely related to the main challenge in the production of arsenic copper: How to keep As in the copper while removing the sulphur? Arsenic is usually bound in sulphide ores (e.g., realgar, fahl ores, arsenopyrite), and it oxidises more easily than sulphur. Consequently, roasting of the ores inevitably result in the loss of most As before the sulphur is removed. Adding such material directly to the melted copper only shifts the problem further down in the process. The easiest approach would probably be to alloy copper with As, but As in its native state is extremely rare and there is no evidence for the production of As in prehistory (Mödlinger et al., 2018, p. 2506). As a result, five models for the production of arsenic copper were developed based on experiments and archaeological observations (cf. Mödlinger et al., 2018, p. 2506): Melting of native copper with Cu-As minerals, melting of As-rich copper minerals such as fahl ores or cementation as the equivalent solid-state reaction (e.g., Dardeniz, 2020, pp. 19–20; Lechtman and Klein, 1999; Pollard et al., 1991b, p. 170; 1990), reductive smelting of roasted As-rich sulphide ores (e.g., Keesmann and Moreno Onorato, 1999), co-smelting of copper ore and As-rich ores (e.g., Doonan et al., 2007, pp. 111–113; Lechtman and Klein, 1999, p. 522; Rostoker and Dvorak, 1991, pp. 6–7), and alloying of copper with speiss. The alloying of copper with ingots of arsenic copper was also suggested (Eaton and McKerrell, 1976, p. 178; Zwicker, 1980, p. 15) and could be subsumed under alloying of copper with speiss. There is currently no archaeological evidence for the cementation of copper with As (Mödlinger et al., 2018, p. 2506).

It was shown above that the smelting of fahl ore could produce polymetallic copper or even speiss, i.e., a material so rich in As (and Sb) that it could have been easily used as alloying agent. Roasting As-rich sulphides requires minerals similarly rich in As as fahl ores because not enough As would have been left afterwards. The use of weathering products of such ores would be equivalent with the suggested co-smelting. The deliberate production of speiss from e.g., arsenopyrite can be an alternative if no fahl ores or other copper-As ores are available. Speiss is usually interpreted as discarded material, as is the case for speiss prills in Almizaraque (Spain), and Batán Grande (Peru), or even as evidence for a failed smelt, e.g., in Shahr-i Sōkhta (Hauptmann et al., 2003, p. 201; Merkel and Shimada, 1988, p. 6; Müller et al., 2004, pp. 45, 50). The deliberate production and usage of speiss was already suggested by Tylecote (1992, p. 11) and Zwicker (1991) based on, e.g., the ingots found in Guschau (see above). Late Bronze Age speiss ingots from Southeast Europe (Paulin et al., 2000) and the production of speiss from ores low in copper at the Roman site of Mon Faulat in France (Marechal, 1985, pp. 31–32) were taken as additional evidence for an intentional production of speiss.

The probably best evidence for the deliberate production of speiss was found in Arisman. From the second half of the 4th millennium BCE on, two different types of slag can be found at the site: copper slag and iron-speiss slag. Based on analyses of these slags, Rehren et al. (2012) suggested the smelting of arsenopyrite to speiss as a way to create an As-rich but S-free material. Because it is Cu to which S is so strongly bound that it oxidises after As, smelting of As-rich but Cu-free ores to iron speiss would effectively remove S without losing most As. Subsequently, the speiss was added to the copper, which was smelted at the site, and the iron from the speiss slagged. This model was recently contested by Nezafati et al. (2021), who showed that the two slag types were produced in the same process instead of separate operations. They concluded that only one smelting operation was carried out to create Ag-rich lead and arsenic copper, with speiss being a waste product of this process.

The alloying with speiss was also suggested for Arslantepe. A crucible and slag pieces with speiss-prills were found in Arslantepe VII (Hess, 1998, p. 130). However, no further evidence supports the production of arsenic copper by using speiss, and the observed materials could be the result of a deliberate use of Pb arsenates to create a slag with a low melting temperature (Hess, 1998, p. 133).

### 4.3.3 Influence of alloying elements on the metals' properties

All elements altering the properties of a metal in a perceptible way are considered alloying elements in this thesis. Therefore the term "alloy" does not necessarily describe an intentionally mixed metal, such as tin bronze or leaded copper, but also includes natural alloys, such as fahl ore copper or arsenic copper. The concentration with which an element has a perceptible influence on the properties of a metal depends on the property. For example 1 % of As improves the castability of copper, but only from 2 % As onwards the mechanical properties are noticeably different (Frame, 2009, p. 183). For these reasons, fixed concentration thresholds cannot be applied.

How the different elements influence the properties of the metal is the result of a complex interplay of the involved elements, their concentrations, and their solubility, as well as the pressure (for volatile elements), cooling rate, and homogeneity under which the melt solidified. All these parameters control which phases will form during solidification but cannot be reconstructed from the archaeological material (Mödlinger et al., 2018, p. 2506). Phase diagrams are helpful indicators to infer which phases can be expected at e.g., a given composition and temperature. However, they are based on equilibrium conditions such as a perfectly homogeneous melt and (very) slow cooling rates, conditions that are unobtainable in (early) metallurgical processes with, e.g., high cooling rates after casting. Mödlinger et al. (2018), for example, confirmed in their experiments previous observations for the Cu–As system that the $\gamma$-phase already forms in metals with less than 1 % As, several per cent lower than at equilibrium conditions (Boscher, 2016, p. 40; Northover, 1989, p. 111). They further showed that the higher the cooling rate of the melt, the lower will be the As concentration necessary for the formation of the $\gamma$-phase (Mödlinger et al., 2018, pp. 2507–2508). Consequently, phase diagrams must be used with caution (Mödlinger et al., 2018, p. 2509). They also pointed out that already a few percent of another element can alter the phase composition of the metal, even if this content is usually regarded as negligible (Mödlinger et al., 2018, p. 2509).

For As and Sb-rich metals, this last point is important to keep in mind because Co and Ni have a higher affinity to them than Cu, Fe and Pb (Tafel, 1951; cited in Hess, 1998). Consequently, the presence of Ni (and/or Co) in the ore charge enriches these elements most likely in the speiss phases, resulting in a copper not only rich in Sb and/or As but also in Ni and Co. As was mentioned above, Ni helps to keep As in the copper and thus alters the phase composition of the alloy.

The influence of As on the properties of copper is much better investigated than the impact of Sb. It was claimed for a long time that As acts as a desoxidant and removes the oxygen from the melt by degassing as As oxide (e.g., Charles, 1967, p. 21). However, this is not the case (Budd and Ottaway, 1991, p. 135). It is true that As readily reacts with oxygen in the melt and is thus an effective protection against the formation of CuO, but it will remain in the melt and forms a Cu–$As_2O_5$ mix (Charles, 1967, p. 21; Junk, 2003, pp. 32–33). The As oxide could make up most of the As contained in the copper. Because it is not part of the metallic phase, it would not alter the mechanical properties of the metal (Northover, 1989, p. 111). It was further assumed that As effectively reduces the porosity in the metal because it binds the oxygen in it. For concentrations up to 1 % As this is indeed the case, but higher As concentrations have the opposite effect and significantly increase porosity (Dies, 1967, p. 665; Junk, 2003, p. 21). At the same time, As generally increases porosity from hydrogen (released from, e.g., water in the mould), but without any significant effect on the metal (Charles, 1967, p. 21).

Arsenic considerably improves the mechanical properties of copper. It massively increases the plasticity, allowing hammering arsenic copper without cracking to a much higher extent than unalloyed copper (Boscher, 2016, p. 43; Charles, 1967, p. 24; Dies, 1967, p. 667). Similarly, As increases the hardness of the copper significantly; arsenic copper can be cold-worked to a higher hardness than tin bronze. However, this only holds true as long As is completely dissolved in the copper, i.e., it is a single-phase alloy. Otherwise, it becomes too brittle for cold-working (Boscher, 2016, pp. 42–43). Arsenic further increases the recrystallization temperature to 600 to 650 °C (Boscher, 2016, p. 45; Charles, 1967, p. 23) and improves resistance against corrosion (Charles, 1967, p. 24; Dies, 1967, p. 699).

Besides the increased hardness, As significantly increases the castability of the object by a long interval between the initial and the complete solidification of the metal, i.e., the liquidus and the solidus (Junk, 2003, p. 21). The melting temperature of the Cu-As eutectic is at 685 °C (Fig. 4.22), several hundred degrees Celsius below the melting point of unalloyed copper. This helps to keep the metal liquid because the already crystallised phases can swim in the remaining melt. The downside is a heterogeneous As distribution in the metal. During solidification, the remaining melt becomes increasingly enriched in As, often resulting in coring (Junk, 2003, p. 21) and a multi-phase composition, which again can have a negative effect on the mechanical properties of the metal (see above).

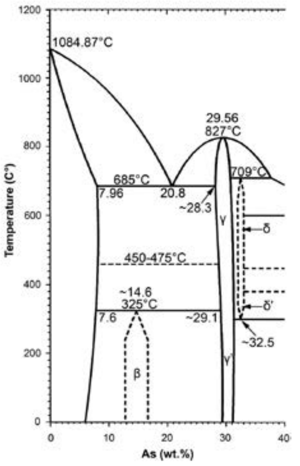


Figure 4.22: Cu–As phase diagram (Mödlinger et al., 2018).

Similar to As, Sb is not volatile under reducing conditions but very volatile under oxidising ones, although less than As (Junk, 2003, p. 26; McKerrell and Tylecote, 1972, p. 211), and it is not a desoxidiser (Junk, 2003, p. 33). Most of the Sb will react with oxygen in the melt to antimonates (Junk, 2003, p. 27). The mechanical properties are similar to arsenic copper as well (Junk, 2003, p. 28): 3 to 7 % Sb increase the hardness of the alloy, but concentrations beyond 7 % Sb make the metal brittle up to the point that it cannot be cold-worked any more (Dies, 1967, p. 676; Charles, 1980 cited in Hauptmann, 2020, p. 394). This corresponds with a good cold-workability and the possibility of hot-shortening only at low Sb concentrations (Junk, 2003, pp. 28–29; Kuijpers, 2018b, p. 109). All in all, the mechanical properties of Sb copper were evaluated as that bad by Hauptmann (2020, p. 394), that it cannot be used except for decorative objects because any mechanical stress applied to the object will be problematic due to its high brittleness – a sharp contrast to the effect of As. In contrast to As, Sb also does not improve the corrosion resistance of the metal (Dies, 1967, p. 676).

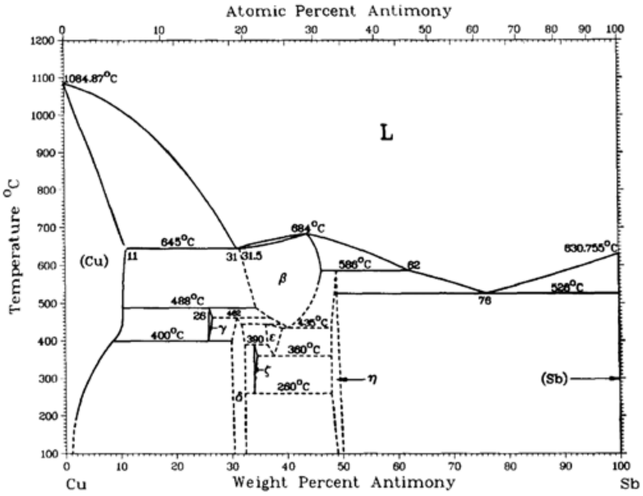


Figure 4.23: Cu–Sb phase diagram (Massalski, 1986).

With a solidus temperature of 645 °C (Fig. 4.23), the solidification interval of antimony copper is even larger than for arsenic copper. Phase transformations during cooling are more complex than for As and segregation was observed at temperatures down to 300 °C (Dies, 1967, p. 673). Antimony significantly increases the occurrence of shrink holes during cooling, in addition to coring (Dies, 1967, p. 672). Therefore, it could be regarded as an porosity-increasing element.

The colour of antimony copper changes markedly with the Sb content. While it has in general a violet colour, about 6 % Sb create a bluish colour, and about 7 % Sb give a whitish copper. At about 10 % Sb, the metal is golden, and at about 20 % Sb silvery (Kuijpers, 2018b, pp. 100, 106; Pike et al., 1996, p. 11). This provides a very good optical indicator for the brittleness of the alloy (Kuijpers, 2018b, p. 111) – everything whitish and beyond should not be cold-worked any more.

The combination of Sb and As in a polymetallic copper alloy will result in the exclusive presence of ternary phases but does not significantly change the alloy's microstructure, at least up to 0.5 % Sb and 0.53 % As (Junk, 2003, p. 31). Antimony will increase the tensile strength of arsenic copper, especially if the object was annealed (Junk, 2003, p. 31). The mechanical properties of cast As-Sb copper seems to be predominantly governed by grain size, which in turn is directly correlated to the cooling speed and the mould material, and only secondarily controlled by the alloy's chemical composition (Boscher, 2016, p. 40; Junk, 2003, p. 167).

Unfortunately, no phase diagram is available for the ternary system Cu–As–Sb, making it difficult to assess the combined effects of As and Sb on the phase composition. Northover (1998a, p. 306) estimates a liquidus temperature as low as 600 °C for plano-convex ingots from Late Bronze Age Arbedo (Trentino, Italy) with up to 11.7 % Sb, usually between 2 and 9.36 % As, and more than 1 % Ag. This would indicate, that the eutectic in the Cu–As–Sb system could be shifted to lower temperatures compared to the Cu–Sb and Cu–As systems. Support for this estimate is supported by the eutectic's temperature in the Sb–As system at 612 °C (Massalski, 1986, p. 222). Such low liquidus temperatures make Sb-As alloys particularly well suited for complex casting techniques, such as the lost wax casting of detailed objects (Thornton et al., 2009, p. 309). Nevertheless, also in the ternary alloy Cu–As–Sb, a good amount or even the majority of As and Sb can be present as oxides and will neither influence the mechanical properties of the alloy nor its phase composition. Therefore, the bulk composition of the alloy would thus not accurately represent the chemical composition relevant for the information displayed in phase diagrams (Junk, 2003, p. 33).

The addition of Pb can significantly decrease the melting temperature of Cu-Sb-As alloys (Thornton et al., 2009, p. 309). While the effect on unalloyed copper is not that pronounced with a eutectic temperature at 955 °C (Massalski, 1986, p. 946), the liquidus temperatures of the As–Pb and Sb–Pb eutectics are as low as 288 °C and 252.2 °C, respectively (Massalski, 1986, p. 217; Okamoto, 2011, p. 567). An appropriate amount of Pb could, therefore, lower the melting point of Cu-Sb-As alloys even below 600 °C. Lead is not soluble in Cu, As, and Sb (Massalski, 1986, pp. 217, 946; Okamoto, 2011, p. 567), and would exist in the solidified metal as a separate phase or in a eutectic intergrowth with Sb or As.

In addition to these elements, elevated concentrations of Bi were measured in many Chalcolithic Southern Levantine polymetallic copper alloys (Ben-Yosef et al., 2016, supplementary data; Rosenberg et al., 2020, p. 144). Bi has detrimental properties in copper alloys. It is insoluble in Cu and because of its extremely low melting point (eutectic in the Cu–Bi system at 99.5 wt.% Bi with 270.6 °C) it will always be the last phase to solidify (Massalski, 1986, p. 498). Compared to Cu, Bi is very soft. Additionally, it solidifies along the grain boundaries and already low concentrations will significantly increase the brittleness of the alloy (Dies, 1967, p. 677). Even more detrimental is the "anomalous" behaviour of Bi, i.e., an increase in volume during cooling. As a result, Bi will disrupt the grains in the metal matrix, making the alloy unworkable and prone to fracturing even at low levels of mechanical stress (Junk, 2003, p. 29). Arsenic and Sb can neutralise Bi concentrations of up to 0.2 % in the alloy by binding on it and preventing the solidification of Bi along the grain boundaries (Junk, 2003, p. 34).

Nickel is also present in some of the Chalcolithic Southern Levantine polymetallic copper alloys. Nickel and copper are perfectly miscible up to 30 wt.% Ni and the melting temperature of Ni is higher than that of copper (Massalski, 1986, p. 942). Consequently, Ni will slightly counteract the effects of As and Sb on the melting temperature. Nickel oxidises only under strongly oxidising conditions and is more likely to be removed from the melt as dross than by oxidation and evaporation (Sabatini, 2015, p. 2990).

## 4.4 Examples for the importance of the sensory properties of metals

In a recent review, Radivojević and Roberts (2021c, p. 36) identified five interpretative narratives, in which the first metal-using societies, the early metallurgists, and metallurgy itself is traditionally embedded. All of them are deeply rooted in notions of the 19th century which equate metallurgy and other pyrotechnological abilities of a society with higher stages in an evolutionary scheme of societal development:

- The necessary knowledge for metallurgical operation represents a technological revolution.
- The first metal objects had a huge impact on the political, ideological and social aspects of the respective societies.
- Metallurgy can only be carried out by specialists, and early metallurgists held a special status in a society due to their exclusive metallurgical knowledge.
- Metals are intrinsically attractive for societies not used to them due to their properties (colour, lustre, mechanical properties, castability).
- Metals were an integral part for the development of stratified societies and the elevated status of an elite.

Although Radivojević and Roberts (2021c, p. 36) focus on Southeast Europe, their observations can also be considered valid for early metal-using societies in other regions. With respect to Western Asia these notions are for instance apparent in the definition of Levy's chiefdoms in the Chalcolithic Southern Levant and the general notion of metal objects as prestige items (cf. chap. 3.1.1). There is without doubt a strong connection between the use of metals and early elites. However, for the regions under study here it was shown that metal objects, also the ones usually interpreted as "prestige" or status items, either precede a clearly set-apart elite in the archaeological record (e.g., Southern Levant, Southeast Europe) or that elites developed without relying on metal objects for the display of their status (Southeastern Anatolia, Northern Mesopotamia). Only from the second quarter of the 4th millennium BCE on, metals become closely linked to elites as a way to display their status (e.g., palace hoard in Arslantepe, kurgan burials in the Southern Caucasus). Furthermore, it often seems to be ignored or overlooked that other crafts show a similarly high degree of specialisation at this time (e.g., certain flint tools in the Chalcolithic Southern Levant, serially produced bowls in Southeastern Anatolia, Northern Mesopotamia, and the Southern Caucasus). Likewise, other materials were traded over long distances long before the appearance of metals (e.g., obsidian and chlorite from Anatolia to the Southern Levant).

Despite these notions still being strong in scholarship, alternative approaches to an understanding for the appropriation and/or integration of metal objects in a society were developed more than half a century ago. C. S. Smith developed the hypothesis that the initial use of metals is the result of aesthetic and socio-cultural factors. According to him, new techniques and innovations are always observed in aesthetic objects first and new (artificial) materials (not only metal but also e.g., plants and pottery) were used for ornaments and symbolic objects before they were used for utilitarian tasks (Smith, 1975, p. 606; 1970, pp. 498–499).

Indeed, the aesthetic properties of metals seem to have been more important than their mechanical properties in several early metal-using societies. A very good example are the West Mexican cultures before the Spanish invasion, where the archaeological evidence can be compared to written accounts on the symbolism of metal in the indigenous societies. Hosler (1995, pp. 102–103) was able to show that arsenic copper and tin bronze were deliberately used to obtain certain colours. Further, the contents of the alloying elements were higher than it would have been necessary for the beneficial mechanical properties in status items only, most likely because the higher concentrations of the alloying elements influenced the alloys' colours. D. Hosler further showed that the golden tin bronze and the silvery arsenic copper were used for objects connected to the sun and moon, respectively (Hosler, 1995, p. 105), and that the sound of the alloys was mythically closely interlinked with their colour (Hosler, 1995, p. 113). At least the deliberate use of arsenic copper for silvery objects and of tin bronze for golden objects was not restricted to Western Mexico but can be found all over Mesoamerica (Jones, 2004, p. 332).

Colour and brilliance were also postulated as aesthetic concept for the use of early metals in Southeast Europe (Chapman, 2007; Radivojević et al., 2018). Metals do not seem to play an outstanding role during this time and similar developments towards more "shiny" and colourful materials can be observed in other materials too, such as the graphitisation of pottery or the production and arrangement of beads (Amicone et al., 2020; Chapman, 2007; Leusch et al., 2015, p. 357). According to Sherratt (2019, p. 98), the 5th and early 4th millennium BCE was a phase of experiments, in which ancient metallurgists were constantly looking for new colours. S. Sherratt focusses on the spread of silver, whose discovery she interprets as a successful result of this search (Sherratt, 2019, p. 98). The use of silver became widely spread during the mid-4th millennium BCE (Sherratt, 2019, p. 102), parallel to the first occurrence of large scale cupellation activities (see chap. 4.1.3), and probably in combination with wine (Sherratt, 2019, p. 102). Originally used only for small personal ornaments, it became quickly fashionable because of its new colour, while copper was already available for a long time and not considered special any more (Sherratt, 2019, p. 102).

It was already indicated with the graphitised Vinča ceramic that the aim for "shiny" objects was not necessarily restricted to metal objects. Another example for lustre as important aesthetic property of materials could be the grey-metallic ware from the Early Bronze Age Southern Levant (Philip and Rehren, 1996, pp. 144–145). Vessels of this ware are typologically connected to tableware or representative vessels and are predominantly found in burials. Their colour resembles tarnished silver. For these reasons Philip and Rehren (1996, pp. 144–145) suggested that this ware type could imitate silver vessels, whose earliest occurrence in the Southern Levant dates to this period.

Besides the aesthetic dimension of colour, sound, and lustre, it must not be forgotten that especially colour and sound provide important sensory information about, e.g., an alloy's composition and its degree of cold working (Mödlinger et al., 2017). Therefore, they did not only provide crucial information for early metallurgists but could have also been used as quality indicator in exchange relations. The linkage between colour and mechanical properties of different copper alloys were extensively investigated by M. H. G. Kuijpers (e.g., Kuijpers, 2018b) but won't be discussed in more detail here, because they are not related to the choice for certain alloys or metals by their aesthetic properties.

Not directly related to the aesthetic properties of the alloys, but an important aspect for the motivation to include metal objects into a social system, is the performative act of smelting and casting (Molloy and Mödlinger, 2020, p. 207). Ethnographic studies of traditional iron smelting in Africa and other regions revealed a very complex systems of beliefs, rituals, and taboos connected to smelting (Gošić and Gilead, 2015b and examples therein). Based on these observations, Gošić and Gilead (2015a, pp. 169–171) suggested for the Chalcolithic Southern Levant, that metallurgy as such was embedded in a performative public ritual to strengthen the group identity.

Admittedly, the ritual aspects of early metallurgy can almost never be reconstructed. A rare exception is gold casting in the Muisca culture (Eastern Highlands of Colombia). This culture cast gold in the lost wax casting technique to produce votive figurines. Lost wax casting was adopted as innovation, although the offerings were never displayed and many of the items could have been produced in a less demanding casting technique. Although the Muisca used several different metals, gold was exclusively used in this context. Moreover, the quality of the cast and the final product did not seem to be of interest for the Muisca – casting seams were not removed and casting errors were ignored even if half of the figurine was missing (Martinón-Torres and Uribe-Villegas, 2015, p. 378). In addition, it was important to cast every object in a single event even if it would have been easier to cast different parts and assemble them afterwards (e.g., free-moving earrings, separate figurines in a group). The wax models were very detailed, sometimes wax strings with less than 1 mm diameter were used. The result is a sharp contrast between the care and effort in the preparation of the wax models and moulds, and the actual cast (Martinón-Torres and Uribe-Villegas, 2015, p. 382). For these reasons, Martinón-Torres and

Uribe-Villegas (2015, p. 383) came to the conclusion that not the objects but the creation of the wax model and the lost wax casting as transformative act was the central element of this ritual, expressing the strong connection of gold and wax in the Muisca mythology (Martinón-Torres and Uribe-Villegas, 2015, pp. 384–385).

Admittedly, these examples from the other side of the globe might seem random. They were presented to highlight that in addition to the current narratives about the use of metals in the Chalcolithic Southern Levant, which exclusively focus on metal items as such and the novelty of the material metal, alternatives approaches exist to reconstruct which meaning metal items and metallurgical practices might have had within a society. Besides a focus on the sensory properties as the most important property of metal items by some societies, the last example is particularly important as it shows that metal and metal items are not necessarily the focal point of metallurgical practices. Including such approaches into the discussion about the role of metal in the Chalcolithic Southern Levant opens up new lines of thought, especially if the Chalcolithic Southern Levant was indeed that heavily ritualised as suggested by some researchers (e.g., Ilan and Rowan, 2011; Joffe, 2022).

# Chapter 5

# Lost wax casting technology

## 5.1 Visibility of moulds in the archaeological record

### 5.1.1 Introduction

The emergence of lost wax casting technology, also called investment casting, is probably one of the most enigmatic phenomena in the development of early metallurgy. This complex technology, which requires mastering the high-temperature behaviour of different materials, accompanied the earliest use of metal alloys and copper smelting in some regions.

The earliest known lost wax cast objects, dating to the mid-5th millennium BCE, were made of gold and found in the cemetery at Varna, Bulgaria (Higham et al., 2018; Leusch et al., 2015). Probably contemporaneously (4500 to 3600 BCE) unalloyed copper was exclusively used for lost wax casting in the region of Baluchistan. Small amulets and seals cast in this technique were recovered at Mehrgarh (Mille, 13.06.2017; Thoury et al., 2016) as well as the famous „leopards weight“ from Shahi Tump (Mille et al., 2004). Similarly, at the end of the 5th and into the early 4th millennium BCE, polymetallic alloys rich in arsenic and antimony were nearly exclusively used for lost wax casting in the Chalcolithic Southern Levant (Golden, 2014b; Shalev et al., 1992; Shalev and Northover, 1993). Compared to the objects from other regions and besides the „leopards weight“, the so-called crowns and standards found, e.g., in the Nahal Mishmar Hoard (Bar-Adon, 1980), were by far the most elaborate objects cast by this technology at this time.

To date no early production sites are known thus leaving the origins and development of this innovation and its technical details practically unknown. A potential first evidence for for such sites in the Southern Levant was recently discovered at Fazael in the Jordan valley. Part of the metallurgical assemblage included fragments of lost wax cast objects and crucible fragments in close spatial proximity (Rosenberg et al., 2020). Apart from these finds, the earliest secure production remains of lost wax casting date to the end of the 3rd millennium BCE. At Altyn Depe (Turkmenistan), sprues (inlet channels) were found in an area with abundant metallurgical debris (Salvatori et al., 2002). An unused mould was recovered in a metal workshop in Tell edh Dhiba'i (Southern Mesopotamia), dating to the first quarter of the 2nd millennium BCE. The best-preserved remnants of a lost wax casting workshop were found in a tomb in Qubbet el-Hawa (Egypt), dating to the late 6th and early 5th century BCE. It featured an assemblage of moulds ready for de-waxing and casting, together with moulds with failed casts (Auenmüller et al., 2019). The latter two sites date much later than the Chalcolithic Southern Levant. However, they seem to be the only other sites in the wider region with clear evidence for layered lost wax casting moulds – indicating how elusive production remains of this technology seem to be in general. Moreover, the thorough analytical and experimental work on the moulds and the technological reasoning behind their design by Auenmüller et al. (2019) makes their study an important reference point for this study.

The absence of production sites using investment casting during the Chalcolithic period might not be surprising given the general scarcity of such production sites throughout time and the small number of uncovered objects from the early metal cultures manufactured in the lost wax technique. However, in the Chalcolithic Southern Levant hundreds of objects made in this technique were recovered from the Nahal Mishmar Hoard alone (Bar-Adon, 1980), indicating an intensity in production comparable to the pure copper technique, for which productions sites are known (Golden, 2014a; Golden et al., 2001; Shugar, 2000). In addition, mould remains can be found directly preserved on the metal objects (Goren, 2014, 2008, 1995). Therefore, other factors than the general scarcity of such remains in the archaeological record might be the reason for the invisibility of the production sites.

### 5.1.2 Recognisability of early lost wax casting moulds

The lost wax casting technology has been the subject of several ethnographic studies (e.g. Anfinset, 2011; Levy et al., 2008; Smith and Kochhar, 2003), which allow, in conjunction with the mould remains from the Chalcolithic Southern Levant, the experimental reconstruction of the production process (Goren, 2014; Shalev, 1999).

In brief, lost wax casting consists of seven different steps: (1) making a ceramic core to create a base; (2) coating it with wax, a wax-resin mixture, or any other material with a low melting point that can be hand-shaped but is stable at ambient temperatures; (3) shaping the wax coat to the shape of the desired object, often adding „gates“ to improve the metal flow and sprues; (4) applying fine, then coarse layers of refractory materials (in prehistoric times usually clays with different mixtures of temper) on the wax model to create a mould and let it dry; (5) removing the wax by melting and pouring, or burning, thereby baking or firing the mould; (6) casting the metal into the so-produced cavity, and (7) breaking the mould to retrieve the cast object (Fig. 5.1). Because every object is a copy of the wax model and the mould is crushed, each of them becomes an individually produced, unique creation.

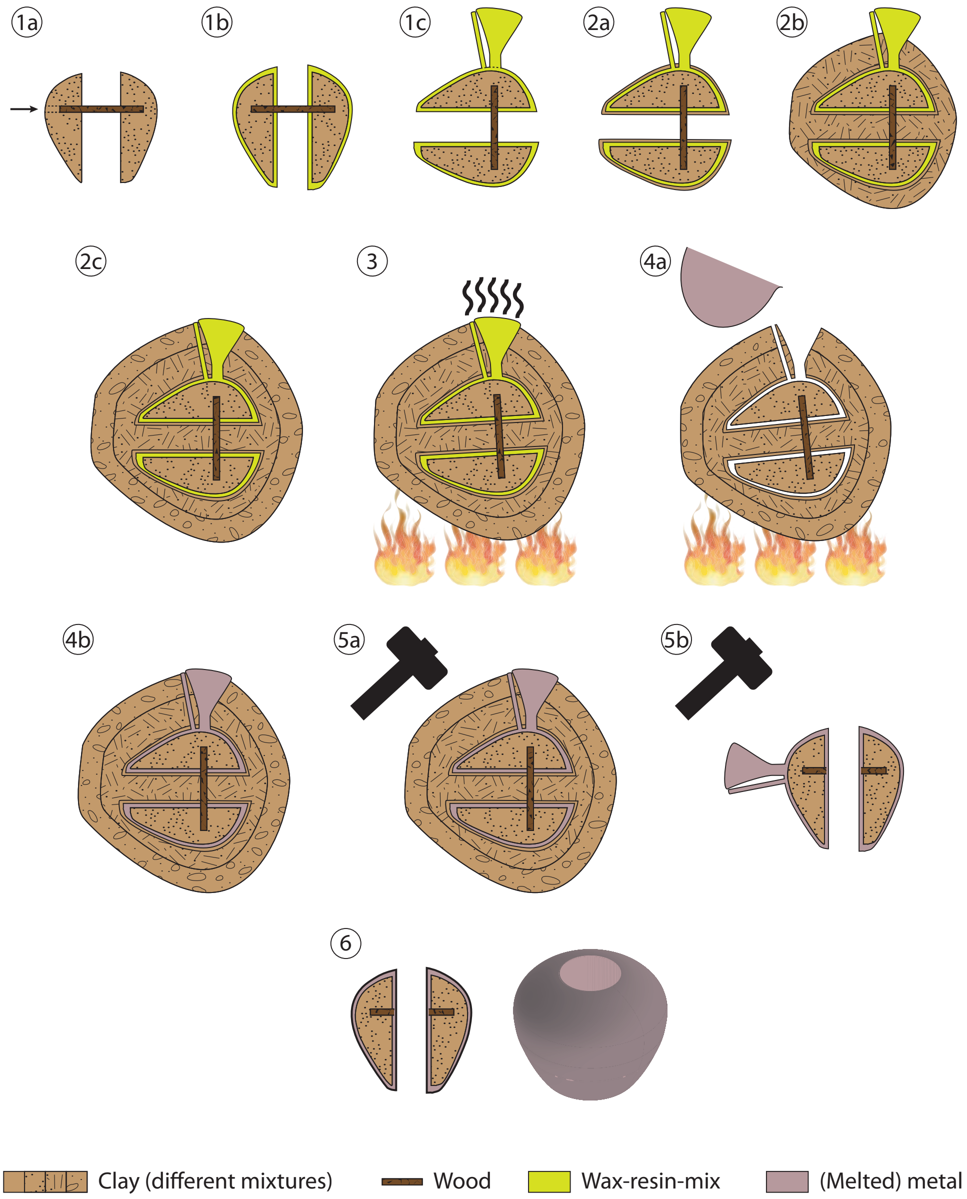


Figure 5.1: The reconstructed lost wax casting process of a Southern Levantine Chalcolithic mace head as implemented in the archaeological experiment. (1) Making the wax model: (a) shaping the ceramic core; (b) application of the wax-resin-mix and beeswax; (c) attachment of a casting sprue and air outlet; (2) Construction of the mould: applying (a) the defining layer; (b) the second layer with calcareous sand; (c) the third layer with quartz sand; (3) De-waxing; (4) Casting the object: (a) casting, (b) cooling of the mould; (5) Removing the mould: (a) crushing the mould, (b) removal of the casting sprue and reworking of surface (e.g., polishing); (6) Finished object.

In contrast to casting in, e.g., sand moulds, which would not leave any trace in the archaeological record (Ottaway, 2003), lost wax casting moulds were made with a ceramic paste and at least baked, sometimes even fired. While it might be sufficient to heat the moulds to remove the wax, the interior parts inevitably are fired to some extent by the cast metal melt. Consequently, remains should survive in the archaeological record. Nevertheless, lost wax casting and especially the mould fragments might not be very indicative. Metallurgical remains from these times are rare in general. Additionally, similar moulds, crucibles, and furnaces might be employed for open casting and the lost wax casting technique. However, the (almost) exclusive use of a specific alloy for lost wax casting (Mille, 13.06.2017; Shalev and Northover, 1993), at least for the Chalcolithic Southern Levant and Baluchistan, should be in principle traceable by chemical analyses of the metal and slag remains on the crucible. Another explanation for the near absence of lost wax casting workshops in the archaeological record may be that they existed away from settlements to keep the technology secretive and exclusive, as Goren (2008) and Gošić and Gilead (2015a) suggested for the Chalcolithic Southern Levant. Further, additional preservation bias is introduced as the workshops most likely consist only of a few highly fired pits, especially if metal debris was collected for recycling, or the place was cleaned to disguise the secret of this technology. Under such circumstances, the production sites may be invisible, remote from habitation sites, devoid of production refuse, or any combination of them. Hence, they are potentially overlooked by archaeological surveys.

Archaeological data are inherently incomplete and often replete with a myriad of unknowns. Scientific research is further complicated by the excavation, recording, and post-excavation treatment of the archaeological materials. Depending on the region of origin, they might have been excavated by field archaeologists or untrained workers, who are neither fully aware of the full range of scientific methods nor specified research questions concerning the materials, processes, and expected leftovers of past technologies. In our region of interest, soil that was exposed to elevated temperatures is often overlooked, ash and other sediments from the depositional immediate surroundings of the objects are dumped, and fine, contextual details are not recorded. Further, relevant materials, such as ore and slag are not always recognized and incorrectly attributed to other categories.

As a result, technological finds brought to the laboratory for analysis might be wrapped in unsuitable materials, „cleaned“ for documentation, and coated in protective materials as a conservation measure prior to analysis. For example, mould pieces stuck to the metal were either removed in antiquity or even „cleaned“ in modern times by conservators, as in the case of some Chalcolithic objects from Israel (Goren, 2008). Only in a minority of cases do field archaeologists focus specifically on the history of technology and direct their excavations with this goal in mind. This leads to a permanent loss of critical micro-archaeological records that are expected to accompany pyrotechnology, such as micro-artifacts and technological by-products. If recognised, they are predominantly studied as part of post-excavation activity. This further emphasizes the preservation and excavation bias, as research is led by the incidentality of discovery.

Because the mould must be carefully crumbled to expose the metal object without damaging it (Auenmüller et al., 2019), lost wax casting moulds end up as small crumbs, and thus are not easily recognizable in the archaeological record. Moreover, due to post-depositional processes, larger mould fragments may further lose their shape and indicative features that can be identified by the naked eye. In such cases, micro-archaeological techniques are required. Among them, petrography is a cost-efficient and quick method to gain information about the fabric, structure, estimated heating temperature, and mineralogical composition of the mould remains. In a number of studies from the

Chalcolithic Southern Levant, remnants of moulds preserved on lost wax cast items dating to the earliest phase of this technology were identified by petrographic analyses (Goren, 2014, 2008, 1995). The same clays were used for moulds and pottery (Goren, 2008, 1995), strongly limiting methods for a chemical distinction of the two. Generally, moulds were multi-layered with an inner layer made of calcareous clay with calcareous sand and a high amount of fine vegetal temper. If the outer layer was preserved, it was made either from ferruginous clay with quartz sand and vegetal temper or plaster. The use of dung in the plaster is indicated by abundant spherulites (Goren, 2008). The results allow the deduction of three characteristic features of lost wax casting moulds: multi-layered design, high content of vegetal matter, and the use of plaster as outer layer.

In the Chalcolithic Southern Levant, the use of plaster was very limited and seems to be restricted to mural paintings from Teleilat Ghassul, with additional small fragments from Abu Hamid (Ilan and Rowan, 2011) and the Chalcolithic shrine at Ein Gedi (Ussishkin, 1980). Hence, even a small fragment of plaster, and especially if it is far away from buildings, can be regarded as a strong indicator for a lost wax casting mould. The use of vegetal matter in turn is not indicative of lost wax casting moulds but of metallurgical ceramics in general. It is absent in pottery of the Late chalcolithic southern Levant which preferred wadi sand as temper material (Burton et al., 2019; Gilead and Goren, 1989; Goren, 2006, 1995; Shugar, 2000). Multi-layered ceramics again can be regarded as being indicative for lost wax casting moulds in the Chalcolithic Southern Levant because no other appearances of such a designed ceramic are known. As a result, fragments of lost wax casting moulds in the Chalcolithic Southern Levant, if preserved, can be positively identified as such by a combination of at least two of these features.

### 5.1.3 Aim of the study

The experiment aimed to test how recognisable mould fragments are if they are not attached to a metal object. Lost wax cast objects in the Chalcolithic Southern Levant were often found in protected places like caves (e.g., Bar-Adon, 1980; Gopher and Tsuk, 1996b; Namdar et al., 2004; Shalem et al., 2013; Yahalom-Mack et al., 2015), in pits as caches, or in subterranean rooms (Eldar and Baumgarten, 1985; Perrot, 1955c). Since no other region with early lost wax casting (i.e. Southeastern Europe/Varna and Baluchistan) has reported remnants except for the finished objects, the Southern Levant will be used as a reference region.

An archaeological experiment was conducted to create comparable moulds and to use them for the casting of polymetallic alloys. The archaeological material offers little knowledge about the different steps involved in the creation of the mould (Goren, 2014, 2008; Tadmor et al., 1995). Therefore, observations from previous experiments tackling this technology (Goren, 2014; Shalev, 1999), from other finds and experiments (Auenmüller et al., 2019; Davey, 1983; Martinón-Torres and Uribe-Villegas, 2015), and ethnographical studies (Anfinset, 2011; Levy et al., 2008; Smith and Kochhar, 2003) were combined to reconstruct the process as close to what is known from archaeological remains as possible. All steps in the experiment were guided by the principle of simplicity as defined by Auenmüller et al. (2019, p. 153): "This principle of reproduction serves to create a model-artefact from a process comprised of steps as simple and as efficient as possible using only tools attested in archaeological contexts."

Some aspects purposely deviate from the archaeological record to enhance the information gained from the experiment and they will be discussed in the respective parts of the experimental set-up. Most importantly, the same clay was used for all layers. Telling apart different ceramic pastes or even a ceramic paste from plaster is comparatively easy and therefore the experiments were taken as an opportunity to investigate how well different ceramic pastes made from the same clay can be distinguished.

After the archaeological experiment was conducted, the moulds were cut and sampled for petrography to gain information about their structure and alterations. For comparison, the unfired raw materials were examined too. Additionally, a selection of raw materials, mould fragments, and other fired ceramics (e.g., furnace walls, tuyères) were subjected to simple alteration experiments to analyse their mechanical and water resistivity (cf. Orfanou et al., 2022 for a similar approach).

## 5.1.4 Experiment

### 5.1.4.1 Materials

The most abundant core/mould material found on lost wax cast objects from the Chalcolithic Southern Levant is a ceramic paste made of Moza clay mixed with a high proportion of chopped grass and sand-sized rounded grains, mainly limestone and quartz (Material A1 in Goren, 2008). Hence, this mixture was chosen as a standard for the ceramic pastes used in the experiment.

The Moza clay was collected from the type locality of the Moza Formation (Taitel-Goldman et al., 1995). Vegetal matter was removed by hand before the clay was crushed to a grain size of $< 5$ mm. Depending on the layer of the mould, fractions with smaller grain size were produced by further crushing and sifting. Small animal bedding was used to prepare the vegetal temper by sorting out straw and stalks before chopping it. Sediment from Wadi Fazael (Lower Jordan valley) was used to extract the calcareous sand by elutriation. Sifting of the obtained fraction indicated an almost perfect separation of the sand fraction (grain size $> 62$ µm) from silt and clay (grain size $< 62$ µm).

Dung temper was purposefully not used in the ceramic pastes although it is regularly reported in ethnographical studies (Anfinset, 2011; Levy et al., 2008). It had been used in previous experiments (Goren, 2014; Shalev, 1999) but Goren (2008) reports spherulites only for the lime plaster and no other indicators for the use of dung temper in the mould materials. Admittedly, due to the high temperature environment, easily reaching temperatures above 800 °C near the melted metal, dung temper might be invisible in ceramic pastes (Amicone et al., 2021). However, the reconstructed function of dung temper in lost wax casting moulds (cf. Auenmüller et al., 2019) was achieved differently (see below).

For the wax model, a mixture of equal quantities of tree resin and wax was prepared. The use of such a mixture is attested from finds in similar climatic conditions (Auenmüller et al., 2019) as well as ethnographical studies (Anfinset, 2011; Levy et al., 2008). Its use is necessary because the high ambient temperatures of tropical and subtropical climates can easily soften thicker layers of pure beeswax to an extent that the wax model loses its shape before the mould is made (Anfinset, 2011; Levy et al., 2008). The details of the wax model were made with pure beeswax.

#### 5.1.4.2 Preparing the mould

In total, six moulds were prepared. The template object was a mace head with a ceramic core. It is the most abundant object type made by lost wax casting in the Chalcolithic Southern Levant (cf. Bar-Adon, 1980). Further, the simple shape and comparatively small size allow us to gain practical knowledge of the process with limited expenditure on the materials.

To model the ceramic cores, 60 vol.% Moza clay and 40 vol.% calcareous sand were mixed and water was added until the paste was not sticking to the fingers any more. All subsequent ceramic pastes were prepared in a similar fashion. Vegetal matter was not incorporated into the experimental cores to eliminate the risk of fracturing or even explosion of the core due to the release of water and carbon dioxide when unburned vegetal matter is charred during casting. The diameter of the dry cores ranged from 46.7 to 48.5 mm, their height from 38.7 to 42.6 mm. The diameter of their shaft hole ranged from 17.6 to 18.7 mm. Taking into account the metal shell enclosing the ceramic cores after casting, the mace heads would be a bit larger than the average size but well within the dimensions of the mace heads found in the Nahal Mishmar Hoard (Bar-Adon, 1980).

The ceramic paste was shaped around a stick with smooth surface and suitable diameter for the shaft hole. The stick was removed after shaping the core around it. In the still wet paste, two small wooden sticks were inserted into the shaft hole to connect the core with the mould later. The cores were dried for several weeks (Fig. 5.2a).

The dry cores were repeatedly dipped in the liquid wax-resin mixture (heated to 80 to 85 °C) until a

3 to 5 mm thick layer had accumulated around the core. To shape the contours of the top and bottom, they were partially dipped in beeswax. Subsequently, the cores were submerged to coat them with a thin continuous wax layer, and the core's number was applied onto it with a string of wax. Last, the wax was removed from the wooden sticks with a thin spatula, and the separately modelled sprues (diameters between 13 and 21 mm) and negatives for the air outlets were applied (Fig. 5.2b). Tadmor et al. (1995) report that the sprues were located at the base of the objects, while Shalev (1999) reconstructed the location of the sprue on the side. In our experiments, we followed the reconstruction by Shalev (1999) because the sprue position does not seem to have a significant influence on the mould material and it seems easier to remove it from a flatter area. However, this was only possible because we applied a separate outlet for the air. Well-trained founders do not necessarily need an air outlet (cf. Auenmüller et al., 2019) but then, the position of the sprue on the base (or top) of the core is required to achieve a high-quality cast (Garbacz-Klempka et al., 2017).

Afterwards, the „defining layer" (sample Raw-M0, Tab. 5.1) was applied. It defines the shape of the cast object and must perfectly cover the details of the wax model. Remaining air bubbles will result in casting errors, as they will be filled with melted metal. To create a suitably fine paste, a portion of Moza clay with a grain size of < 62 µm was prepared and mixed with water to slurry. As was shown above, a good separation at 62 µm can be achieved without sieves by elutriation. As reported by Auenmüller et al. (2019) it indeed attached poorly to the wax. However, the slurry bonded perfectly on areas with remains of dry fine clay. Hence, instead of degreasing the wax as suggested by Auenmüller et al. (2019), a very thin layer of dry fine clay was applied to the wax models and any non-attaching material was blown away. After this preparation, the slurry was applied without any problem. The dry layer was about 0.2 mm thick. Drying cracks only developed in areas with considerable increased layer thickness (especially around the numbers, Fig. 5.2c). This may be mitigated in future experiments by drying the slurry after each dip or increasing its fluidity. As a result, the use of dung temper at least for this clay type is dispensable to achieve sufficient plasticity and cohesion of the clay (cf. Auenmüller et al., 2019).

For the second layer, ceramic pastes were made from Moza clay crumbs of < 1 mm grain size, grass chopped to < 2 cm (mainly < 1 cm), and calcareous sand. Ceramic pastes with different quantities of each were mixed with water to form a non-sticking paste and applied on the wax models (samples Raw-M1 and Raw-M2, Tab. 5.1). Care was taken to closely cover the inner layer and the paste was thoroughly squeezed into the shaft hole to prevent the inclusion of air bubbles as the thermal expansion of air trapped in them might break the moulds during heating. The moulds were dried for several days, the last day under direct sun (Fig. 5.2d). The minimal thickness of the dried second layer varied from 5.3 to 8.6 mm, depending on the mould.

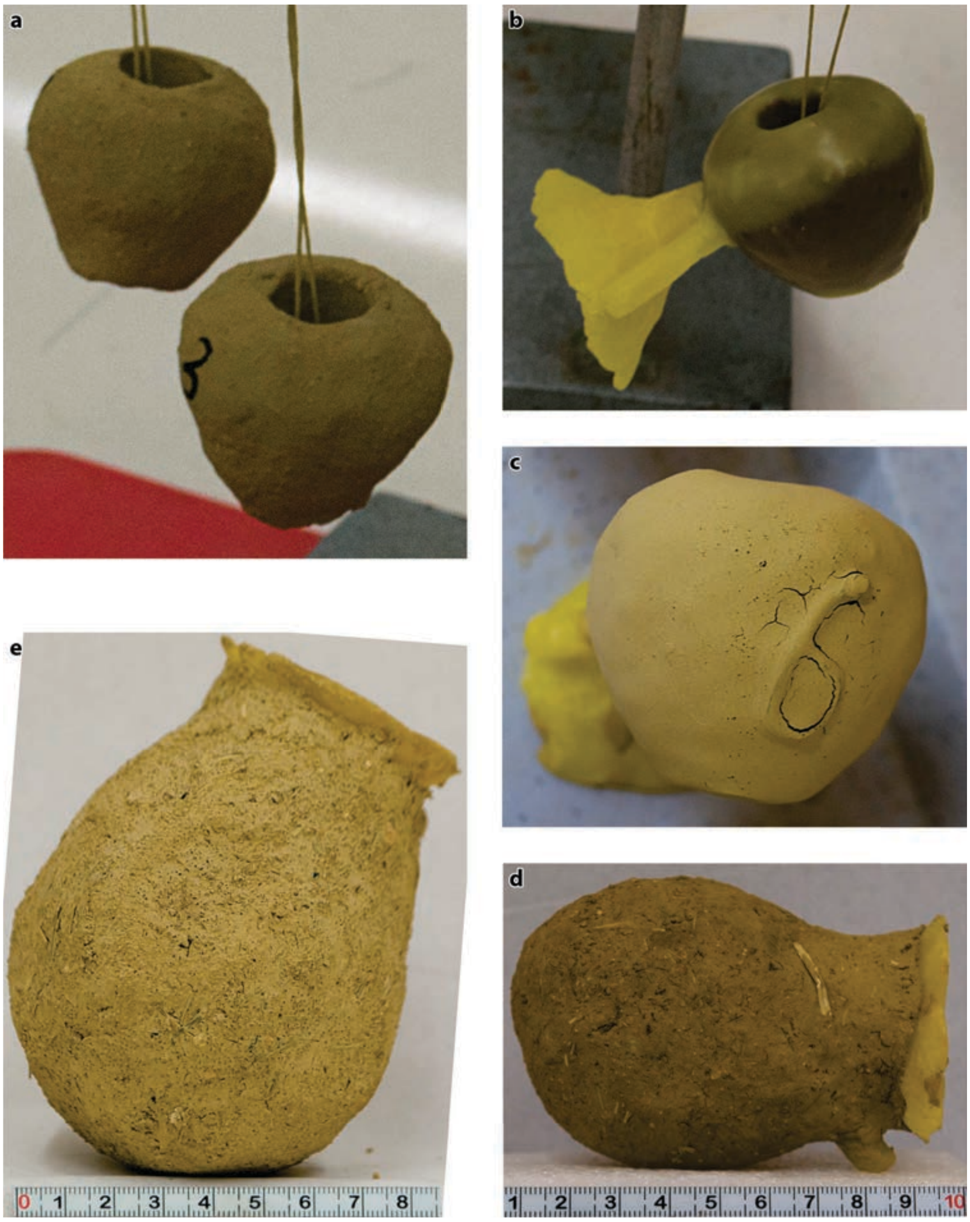


Figure 5.2: Production of the mould: (a) the ceramic core; (b) the finished wax model with sprue; (c) the dried defining layer; (d) the applied second layer (with calcareous sand), (e) the applied third layer (with quartz sand).

The outermost layer (Raw-M5, Tab. 5.1) was applied to ensure that the mould is thick enough to withstand the heat and pressure of the melted metal. According to Goren (2008), this layer is always made from another material. As highlighted previously, multi-layered ceramics can serve as clear indicator for mould remains of the lost wax casting technology. In order to test how easily layers of the same material could be distinguished, Moza clay was used again. To provide sufficient stability to the mould, the Moza clay was tempered with large amounts of quartz sand (comparable to the mineral temper of material B in Goren (2008) but with overall larger grain size: 0.5 to 1 mm) and coarser chopped grass (up to 5 cm length, Tab. 5.1). The composition further emphasizes the difference of this layer from the second one. The moulds were dried for over a week, first inside the laboratory for some days, later in an open shaded area, before exposing them for several days to the bare sun (Fig. 5.2e). The minimal thickness of the finished moulds varied between 9.7 and 18.9 mm.

Table 5.1: The composition of the ceramic pastes used in the experiment.

| Label | Layer | Material | vol.% | Fraction |
|---|---|---|---|---|
| Raw-M0 | ”defining layer” | Moza clay | 100.0 | < 62 µm |
| Raw-M1 | second layer, Exp. 1, 3, 4 | Moza clay | 50.0 | < 1 mm |
| | | Calcareous sand | 20.0 | 62 µm – 1 mm |
| | | Vegetal matter | 30.0 | < 2 cm |
| Raw-M2 | second layer, Exp. 2 | Moza clay | 40.0 | < 1 mm |
| | | Calcareous sand | 10.0 | 62 µm – 1 mm |
| | | Vegetal matter | 50.0 | < 2 cm |
| Raw-M5 | third layer | Moza clay | 32.5 | < 5 mm |
| | | Quartz sand | 50.0 | 0.5 – 1 mm |
| | | Vegetal matter | 12.5 | 2 – 5 cm |

#### 5.1.4.3 Firing and casting

The casting experiments were carried-out in late August 2020 on the banks of Nahal Beer Sheva, several kilometres east of Beer Sheva. Two furnaces were constructed (Fig. 5.3). To melt the metal in a crucible, a furnace was made according to the reconstructions of contemporaneous furnaces found in Abu Matar and Shiqmim on the riverbanks of the Nahal Beer Sheva (Golden, 2014a; Golden et al., 2001; Shugar, 2000). As no information is available about how the moulds were de-waxed, a small separate furnace was prepared for de-waxing and firing the mould. Each furnace was heated with a bag bellow made of cow leather. Citrus charcoal was used as fuel. Different mixtures of copper filings, antimony shot, and lead granulate were used to simulate the polymetallic alloys used for lost wax casting in the Chalcolithic Southern Levant (arsenic was omitted for health reasons). The temperatures were recorded with an infrared pyrometer.

Initially, it was intended to pour the liquid wax from the mould and then fire it at high temperatures. However, when starting the experiments, it seemed more appropriate to let the wax burn off. Due to the unanticipated general high temperature of the glowing charcoal even without bellowing, it could not be excluded that the wax flowing out of the mould would uncontrollably catch fire when the mould is placed with the pouring cup on the side/bottom. Hence, the moulds were placed with the pouring cups upwards and the wax was burned off under controlled conditions. Although removing the wax by pouring is more widespread, burning it off is known from ethnographical studies (Capers, 1989; Smith and Kochhar, 2003).

Figure 5.3: The furnaces used in the experiment to fire the moulds: (a) The furnace to melt the metal in a crucible before kindling the fire; the later position of bellow 2 is indicated. (b) The furnace for de-waxing; (c) The location of the moulds from experiment 1 to 3 in the furnace for wax removal; (d) The crucible furnace with the mould from experiment 4 placed between the tuyères. The tuyères are located under the cobble stones.

In three of the four experiments (Tab. 5.2), the mould was placed in the de-waxing furnace (Fig. 5.3c). The arrangement in the crucible furnace was changed for the last experiment and the mould placed between the two bellows (Fig. 5.3d). In the third experiment, the mould was extensively heated to test the behaviour of the ceramic paste at high temperatures while in the fourth experiment, heating was comparatively gentle (Tab. 5.2).

The experimental part concerned with the heating and melting of the metal is described in detail by Rose et al. (2021b). It is not related to the fate of the moulds and it might suffice here to say that due to several circumstances we did not succeed in melting large amounts of copper. Consequently, no proper casting could be done. Only during the third experiment a small amount of copper (based on its colour) was melted. However, the casting process was impeded by small pieces of charcoal falling off the crucible and blocking the pouring cup before the melt reached the mould (Fig. 5.4a). In the fourth experiment, metal mixed with a high proportion of antimony was used and it was possible to cast the melted antimony (Fig. 5.4b). Judging by the whitish colour of the cast metal and the remaining crucible batch, the copper remained almost unmelted.

Table 5.2: Summary of the experiments and the mould characteristics after the experiment.

| Experiment | $T_{max}$ [°C] | Duration [min] | General state | Paste colour | Inner surface | Vitrification |
|---|---|---|---|---|---|---|
| Exp. 1 | 800 | 76 | very crumbly, second and third layer easily detachable | beige to grey | beige to grey; many little cracks | yes, close to tuyère |
| Exp. 2 | 927 | 65 | very crumbly, second and third layer easily detachable in smaller fragments | beige (third layer), grey to black (second layer) | grey; little cracks | yes, close to tuyère |
| Exp. 3 | 1038 | 81 | friable but not crumbly | half beige, half grey to black (with second layer black and third layer grey) | half beige with pronounced cracks; half grey with no visible cracks | yes, close to tuyère |
| Exp. 4 | 312 | 81 | stable, second and third layer not detachable | black to grey, one small area on the outside orange, another one beige | black to grey, beige close to the pouring cup, few cracks | no |

### 5.1.5 Post-experiment examination

#### 5.1.5.1 Petrography

Selected cores and mould fragments were sampled for microscopical analysis. All samples were embedded in epoxy resin under vacuum conditions to allow proper penetration of the resin into the voids. Petrographic thin sections were prepared according to standard procedures and analysed under a petrographic microscope with plane (PPL) and cross-polarised light (XPL).

#### 5.1.5.2 Alteration experiments

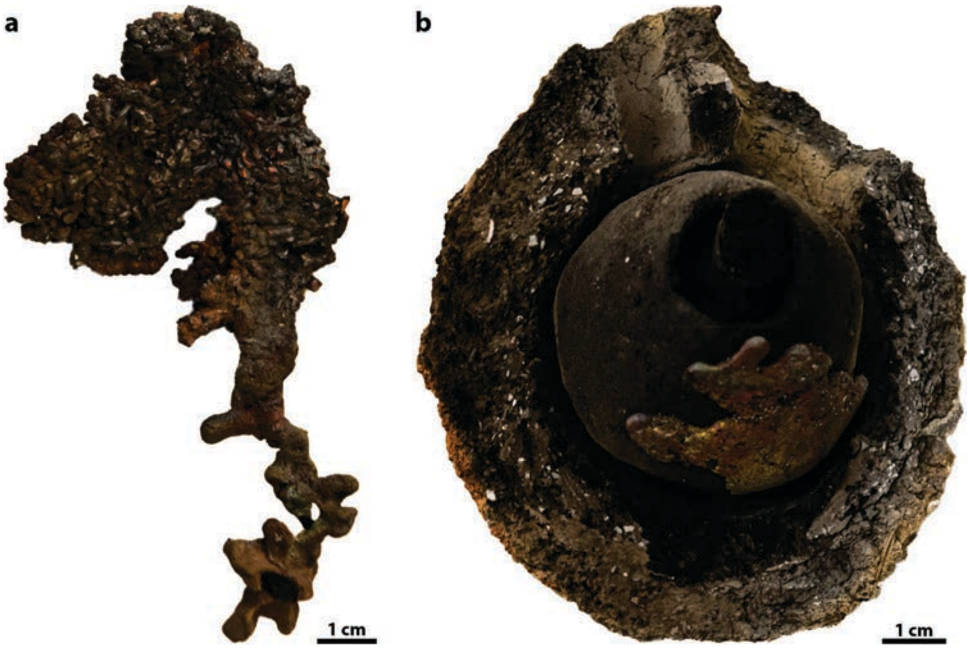


Figure 5.4: The melted metal from (a) experiment 3 and (b) experiment 4. In experiment 3, the metal ran down outside of the mould.

To analyse the durability of the mould remains and other metallurgical materials (tuyères, furnace wall), selected samples underwent simple alteration experiments. The aim of the experiment was to acquire a (rough) qualitative estimate on how easily the materials could be turned into a state that makes them invisible in the archaeological record (cf. Orfanou et al., 2022 for a similar approach). It focussed on accidental events, because intentional destruction would have resulted in sufficient efforts to achieve this goal. To a check for mechanical resistance, a person with ~ 80 kg body weight and sneakers stepped on the materials with a defined number of steps to simulate accidental trampling. Resistivity against water was tested by submerging the samples in water and stirring after defined times. Admittedly, this cannot properly simulate e.g. the impact of flash floods but provides an estimate on whether the materials can dissolve in rain like unfired clay. The degradation of the samples was recorded after each interval (Tab. 5.3, 5.4). Although this contribution is focusing on the moulds, the other materials are included for comparison.

Table 5.3: Results of the trampling experiments.

| Sample | Material | after 1 step | after 5 steps | after 10 steps | after 20 steps |
|---|---|---|---|---|---|
| Planum0-Rest-1 | Furnace wall | very fragmented | powdery | | |
| Planum0-Rest-2 | Furnace wall | very fragmented | powdery | | |
| Planum0-Rest-3 | Furnace wall | very fragmented | powdery | | |
| T2-setup | Furnace wall | fragmented | powdery | | |
| Exp4-C1 | Ceramic core | broken in half | broken in larger pieces | larger pieces crumbled a bit | pieces □1 cm |
| Raw-Cr-F | Unfired raw material for crucibles (1:1 mix Wadi Fazael clay and chaff) | fragmented | powdery | | |
| Raw-Cr-N | Unfired raw material for crucibles (1:1 mix Negev loess and chaff) | fragmented | powdery | | |
| Exp2-C1 | Ceramic core | no changes | broken in half | broken in large pieces | rounded edges |
| Exp2-M1 | Mould fragment | Experiment not carried out, already crumbling under a bit harder grip with hands | | | |
| T1-1 | Tuyère, tip | fragmented | powdery | | |
| T1-2 | Tuyère, bellow end | unchanged | widely cracked | mostly powder | |
| T1-S | Support for tuyère | very fragmented | powdery | | |
| T2-S | Support for tuyère | fragmented | powdery | | |

Table 5.4: Results of the submersion experiments. No changes were observed after 75 min.

| Sample | Material | after 5 min | after 15 min | after 25 min | after 35 min | after 45 min | after 75 min |
|---|---|---|---|---|---|---|---|
| Planum0-Rest-1 | Furnace wall | unchanged | unchanged | unchanged | unchanged | unchanged | unchanged |
| Planum0-Rest-2 | Furnace wall | integrity partially lost | integrity lost | | | | |
| Planum0-Rest-3 | Furnace wall | unchanged | unchanged | unchanged | unchanged | unchanged | unchanged |
| T2-setup | Furnace wall | unchanged | unchanged | unchanged | unchanged | unchanged | unchanged |
| Exp4-C1 | Ceramic core | unchanged | unchanged | unchanged | unchanged | unchanged | unchanged |
| Raw-Cr-F | Unfired raw material for crucibles (1:1 mix Wadi Fazael clay and chaff) | integrity lost | | | | | |
| Raw-Cr-N | Unfired raw material for crucibles (1:1 mix Negev loess and chaff) | integrity lost | | | | | |
| Exp2-C1 | Ceramic core | unchanged | unchanged | unchanged | unchanged | unchanged | unchanged |
| Exp2-M1 | Mould fragment | unchanged | a bit crumbled away | unchanged | unchanged | small part crumbled | broken in several larger pieces |
| T1-1 | Tuyère, tip | unchanged | unchanged | integrity lost | | | |
| T1-2 | Tuyère, bellow end | very soft | integrity lost | | | | |
| T1-S | Support for tuyère | integrity lost | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| T2-S | Support for tuyère | unchanged | few material crumbled away | unchanged | unchanged | unchanged | unchanged |

## 5.1.6 Results

### 5.1.6.1 Macroscopic examination

Figure 5.5: The mould of experiment 1 after it was accidentally broken in the field. The separation of layers 2 and 3 is especially clear at the larger fragments.

Different aspects of the moulds fragments' appearance after the experiments are summarised in tab. 5.2. In the first three experiments, the moulds became very friable and could be easily crumbled between fingers. The calcareous sand grains were powdery. The mould of experiment 1 accidentally broke in the field (Fig. 5.5). At this point, the core did not show any fractures and the second and third mould layers had partly separated. At the end of the day, the ceramic core was fractured without any additional mechanical influence and large parts of the mould crumbled away during the transport to the laboratory. Likewise, the moulds of experiments 2 and 3 became significantly more friable after the end of the experiments. New cracks and propagation of existing ones were observed after they arrived in the lab, even though they were carefully packed for transport (Fig. 5.6). Moreover, the friability seemingly increased during storage in closed zip-lock bags during the 10 days that followed the experiments, while no condensed water was observed in the bags.

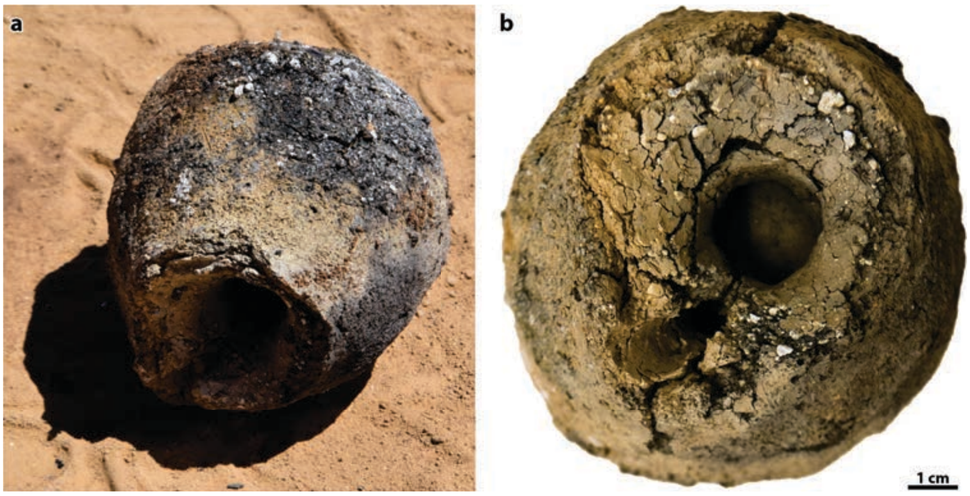


Figure 5.6: The mould of experiment 2 (a) immediately after the experiments and (b) ten days later in the laboratory with new or considerably enlarged cracks.

Some moulds revealed abundant thin cracks on the inside. However, it is unclear whether they arose from impact or firing. The surface and ceramic body of the mould as well as the surface of the ceramic core exhibited different shades of grey (Fig. 5.7). After experiment 1, the ceramic paste was beige, like the unfired clay, or pale grey. The grey colour of some areas in the other two experiments indicates that the carbon from the vegetal matter was not fully combusted. This stands in line with previous experiments (London, 1981), indicating the resistivity of grassy material within fired clay to relatively high temperatures. Additionally, all moulds were superficially vitrified closest to the tuyère albeit to different extents.

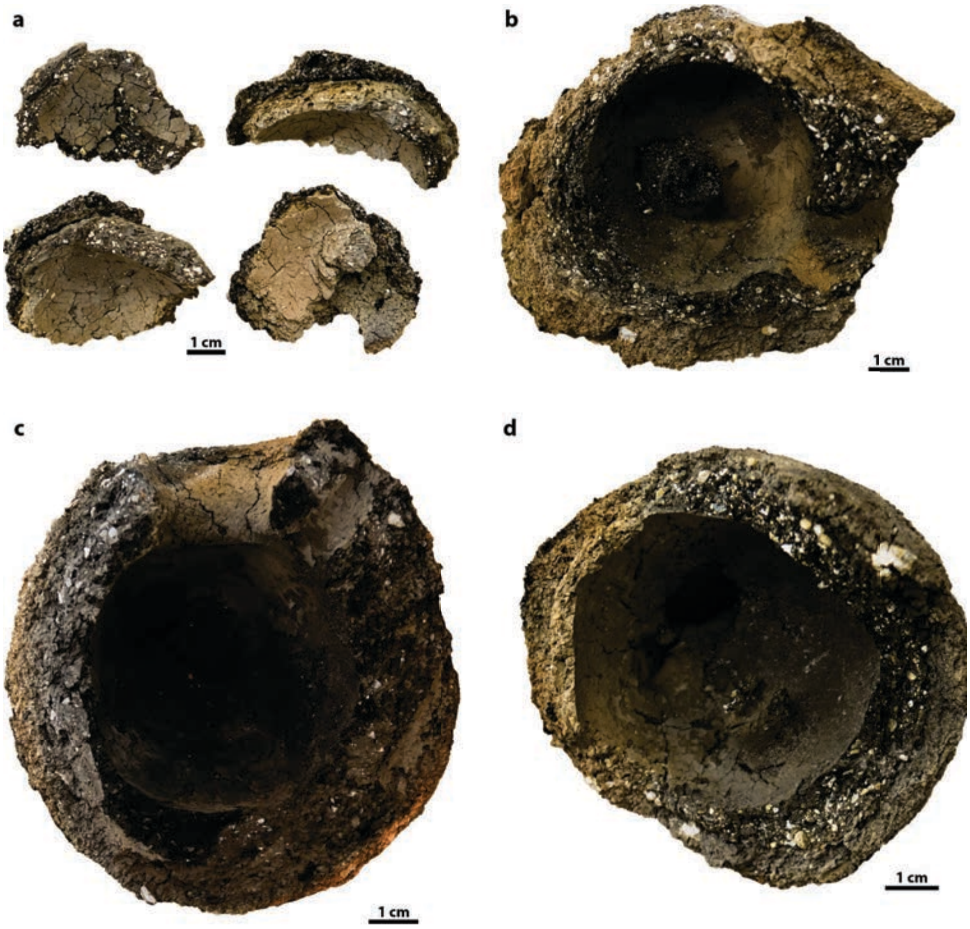


Figure 5.7: Mould fragments from (a) experiment 1, (b) experiment 2, (c) experiment 4, and (d) experiment 3.

The two outer mould layers of experiment 1 to 3 cracked and separated at the pouring cup. The two layers of the previously broken mould of experiment 1 easily separated in some areas. The ceramic pastes of the moulds obtained in experiments 2 and 3 behaved similarly when the moulds were cut. Separation of the layers occurred especially during the extraction of samples for petrography, although this was not the case for large fragments. In all three experiments, the layers could be partially distinguished by their different colours (Fig. 5.7).

The mould of experiment 4 behaved differently. It neither crumbled nor did it reveal major cracks. Nonetheless, it became brittle and required care during jigsaw cutting in order to prevent breakage instead of cutting. The colour of the ceramic paste is mostly black to grey, except for two small opposing patches on the outside, which are orange and beige (Fig. 5.7). Only the inner surface of the mould close to the pouring spout is beige, while the other parts of the mould and the ceramic core are grey to black, sometimes covered with a thin layer of soot. The small amount of melted metal sank down to the bottom of the mould and was easily detached from the mould and the ceramic core.

In all the experiments, the shaft hole paste filling exhibited the darkest shade. The wooden sticks to keep the ceramic core in place were burnt, but charred remains were observed in the ceramic cores of experiments 2 and 4.

### 5.1.6.2 Petrography

Photomicrographs of all the ceramic pastes used in the study are provided in fig. 5.8. The clay is identical to Material A described by Goren (2008). The calcareous sand fits the description provided there, although it includes a larger amount of coarse sand than the archaeological mould material.

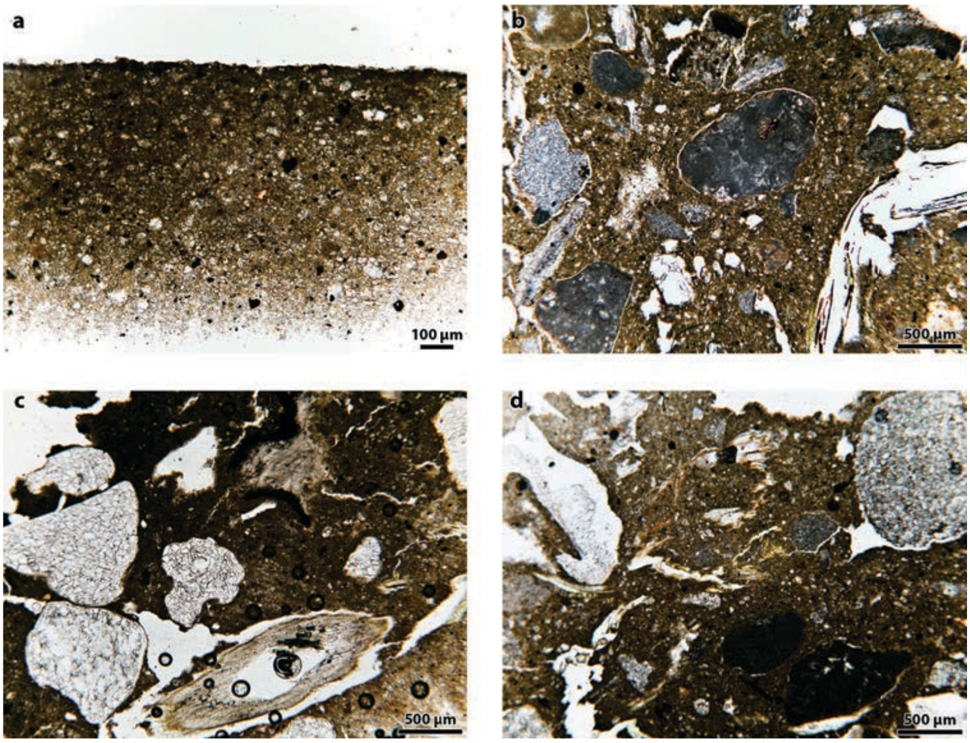


Figure 5.8: Photomicrographs of the unfired ceramic pastes in plane-polarised light, (a) Raw-M0; (b) Raw-M1; (c) Raw-M5; (d) Raw-M2. Please note the different scale in (a).

Thin-sections of the fired moulds were prepared, predominantly of the moulds from experiments 3 and 4. Only they allowed the extraction of cross-sections through the entire mould without significant crumbling (Fig. 5.9). Additionally, the ceramic cores of experiments 2 and 4 were sampled. The colour of the matrix corresponds to the macroscopic observations: sections from grey and black coloured areas show matrices in the same range of colours under PPL, often masking the petrographic properties of the matrix in XPL. Where it could be observed, the clay exhibited some optical activity except for the very outside of the mould in section Exp3-M1. The heat affected all the carbonate grains, with less impact on the calcareous sand in the ceramic cores and even less in the shaft hole filling. The vegetal matter was burnt in all sections but charred remains were always present.

In all thin-sections, the different layers of the mould could not be readily distinguished by their matrix or structural features therein. Their most obvious difference is their different tempers (no temper, calcareous sand, quartz sand). Occasionally, fractures align with the interface of two layers (Fig. 5.9) but more often they are slightly shifted into the interface derived from the temper. The „defining“ layer can be recognized as a band of temper-less paste, sometimes with aligned temper and pores on top of it (Fig. 5.9).

#### 5.1.6.3 Alteration tests

The mechanical resistivity tests revealed that all sampled materials except for the ceramic cores (Exp2-C1 and Exp4-C1), and a tuyère (T1-2) became powdery after a maximum of 5 steps (Tab. 5.3). The mould sample from experiment 2 (Exp2-M1) was excluded from this test because it was already crumbling when touched. The same result was achieved for T1-2 after 15 steps. After 10 steps, Exp2-C1 was crushed to pieces sizing ~ 20 mm and the edges showed significant rounding (Fig. 5.10a). For Exp4-C1, 20 steps were necessary to achieve the same result (Fig. 5.10b).

Submersion tests were carried-out on parts of the same samples. As expected, the unfired and very low-fired ceramics (Planum0-Rest-2, Raw-Cr-F, Raw-Cr-N, T1-1, T1-2, T2-S) fully disintegrated after 5 to 25 min (Tab. 5.4). The furnace wall samples and T1-S were not or only slightly affected by the water. Ceramic cores Exp2-C1 and Exp4-C1 were not visibly affected by the water at all, while Exp2-M1 started to crumble before it broke into several pieces after 75 min. The samples were submerged in water for a total of 405 min but no changes were observed after 75 min.

### 5.1.7 Discussion

#### 5.1.7.1 Suitability of the experimental moulds

Because no sufficient amount of metal melt for casting was produced, the comparability of the experimental moulds with archaeological casting remains requires further discussion. Although the crucibles became hot enough to melt copper, the melted crucible walls indicate that the hottest zone was not suitably placed to efficiently heat the copper to the melting point. In experiment 3, a small volume of copper was melted but the voids between the copper filings may have created an internal layer of air, which isolated most of the charge from the heat (Heeb, 2009).

Copper alloys rich in arsenic and antimony can be fully melted at temperatures as low as 600 °C (cf. chap. 4.3.3). In previous experiments, Cu-As-Sb alloys were cast at 800 to 900 °C and the moulds fired at 600 to 700 °C (Shalev, 1999). This is comparable to the firing temperatures of the moulds in experiments 1 to 3. For simple undecorated objects such as mace heads, moulds can be heated to significantly lower temperatures while still achieving a high casting quality. In this case, the temperature difference between the liquidus of the melt and the mould is large enough, allowing the melt to fill the entire cavity before it solidifies. This was observed in experiment 4, where the melt, despite being too cold to melt copper, reached the bottom of the mould (Fig. 5.4b).

Figure 5.9: Cross sections through (a) the complete mould of experiment 3 (Exp3-M3); (b) the mould of experiment 4 with layer 3 detached during sampling and the outer part of layer 3 missing (Exp4-M3). The approximate locations of the interfaces between the layers are indicated. Composite images.

Another aspect is the missing interaction between the mould and the melted metal, and the resulting absence of strongly reducing conditions at the metal–mould interface. The significance of such an interaction must be questioned for the Chalcolithic Southern Levant, because Goren (2008) does not report any traces of a high-temperature impact. On the contrary, the clay matrices of his samples exhibited birefringence, indicating that the calcareous clay did not reach high enough temperatures for a sufficient length of time to completely decalcinate and to sinter. In addition, plant material was not combusted but charred. This suggests rapid cooling due to the slim thickness of the moulds on these parts (especially within the shafts of the objects, from where most of these samples were taken). It certainly does not exclude the existence of such areas. Even if they occurred and stuck to the metal object, it seems most likely that they were removed by grinding in order to protect the surface of the cast. These small crumbs (Goren, 2008) are barely recognizable in the archaeological record.

The ceramic pastes are sufficiently comparable with Chalcolithic materials. In general, it is virtually unachievable to perfectly reconstruct a paste recipe based on petrography or analytical data alone.

Solely, relative amounts of the different components can be estimated as a percentage of area or volume. A direct application to the raw materials is impossible as factors such as the volume of pore space of unconsolidated materials cannot be reconstructed with the employed methods. To reduce the risk of drying cracks, estimates for the temper (sands and chopped grass) leaned towards higher quantities, resulting in higher proportions than observed in the archaeological pastes. Generally, the raw materials are comparable and all steps of the experiment could be performed in the Chalcolithic. From the observations discussed below, it can be inferred that a higher proportion of calcareous sand will increase the friability of the mould at sufficiently high temperatures, whereas a higher proportion of vegetal matter will increase its pore volume and hence its brittleness.

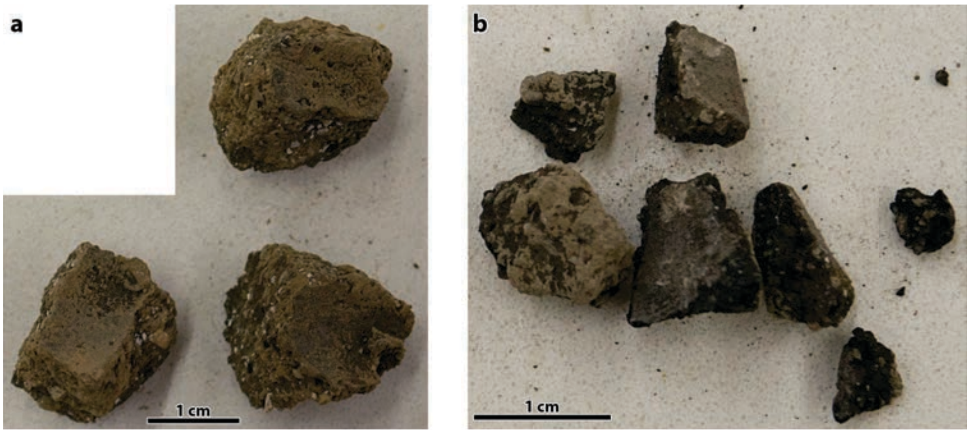


Figure 5.10: The fragments of the ceramic cores of (a) experiment 2 and (b) experiment 4, after 20 steps.

In combination, all three aspects confirm that the fired moulds are sufficiently comparable to the archaeological ones. General trends inferred from the experiment will help to identify the preservation potential of mould remains in the archaeological record, their probable appearance when not protected by their metal objects, and from taphonomic depositional changes occurring for nearly six millennia on archaeological sites.

#### 5.1.7.2 Identification of mould remains

Three features are characteristic for mould remains in the Chalcolithic Southern Levant: layers of different materials, among them plaster, and the use of vegetal matter as temper. Studies of vast numbers of Ghassulian Chalcolithic vessels from most of the important sites of the Southern Levant (e.g. Boness et al., 2016, with references therein) have clearly evidenced that this culture prefers sand temper for pottery production. Hence, it may be categorically deducted that vegetal temper was solely restricted to metallurgical ceramics for technical reasons and, therefore, is a reliable indicator for metallurgical ceramics (Goren, 1995; Perrot, 1955c; Shugar, 2000). The same holds true for plaster fragments, which are a very strong indicator for a mould (see above). However, not all observed mould remains had a layer of plaster (Goren, 2008). This might be related to sampling, as the mould fragments surviving on metal objects only represented the inner parts of moulds. Both features can be easily identified in thin section and sometimes even with the naked eye; hence, they do not require a detailed discussion. The identification of layers of different (ceramic) pastes within one fragment is more complex because they easily separate after firing. This aspect as well as some more general ones necessitate a detailed discussion on the stability of mould remains.

Identifying a mould fragment during excavation can be difficult. It must be large enough to be recognized as an artifact and can very easily remain unnoticed by an untrained eye. Preservation of multi-layered structures requires even larger fragments depending on the occurring breakage during the removal from the cast, none withstanding the effects of post-depositional processes. Furthermore, the different layers may not be distinguishable on the surface any more but only in a fresh cross-section or petrographic thin section. Consequently, the layering may not be recognized if the mould fragment was broken parallel to the orientation of the layers rather than across them.

Besides these considerations, how may a mould fragment have looked like after the mould was broken? A mould material that easily crumbles away from the cast, or at least is very fragile after cooling, is highly desirable. It allows minimising the force necessary for removal of the mould from the metal, hence minimising the risk of damage to the final product (Auenmüller et al., 2019). Such crumbly material will most likely be badly preserved by design. Experiments 1 to 3 attained such highly friable material, most likely due to the calcareous sand. Micritic limestone, like chalk, is the main constituent of the used sand. It starts decalcinating above 600 °C. The same process occurs to sparitic (coarsely crystalline) limestone heated to 650 °C and above. With pure calcite, the process begins at somewhat higher temperature (Shoval et al., 1993). Therefore, it is not surprising that in the experiments most of the calcium carbonates in the mould (and partially also in the core) reacted to calcium oxide. Calcium oxide is very reactive, and it often reacts with the clay body surrounding it when it is found as inclusions in pottery. As soon as cooling starts, calcium oxide will react with water and water vapour in the air to calcium hydroxide, gaining a much larger volume (Shoval et al., 1993). This in turn will result in fractures around the former calcite grains. The reaction and its temporal extent due to the restricted access to water, would also explain the increase of the mould's friability over time. Due to the comparatively low firing temperatures of the mould in experiment 4, this reaction did not occur and the mould remained more stable.

Another parameter that influences the stability of the mould material is the materials' breakability. This parameter was studied using experiment 4 as well as other low-fired materials (furnace walls, tuyères, and their supports). The correlation between the volume of vegetal temper in a clay body and its breakability after firing is obvious: burnt disintegrated organic matter creates pores, resulting in a reduced resistance against impact but an increased stability to thermal shock (Bronitsky and Hamer, 1986). This was observed during the trampling experiments (Tab. 5.3). Only materials with a low proportion of vegetal matter were resistant to breakage after trampling. Increased porosity of the mould material is beneficial for the lost wax casting process because the pores prevent the propagation of cracks during heating. Further, they allow gases to escape even if the mould does not have a designated air outlet (cf. Auenmüller et al., 2019). The porous and brittle material can easily be reduced to crumbs by limited mechanical forces. Therefore, ancient casters desiring to keep their technology secret could have easily trampled or crushed the moulds and ceramic by-products. If the destruction was unintentionally, e.g., caused by simply leaving the material on site and walking over it or by post-depositional processes, it is highly likely that fragments can be recovered from the archaeological record.

The final investigated characteristic was the visibility of the different layers. Our experiments indicate that different layers, even of the same clay type, can easily separate after cooling. The detached surfaces were sufficiently clean with no implication of any former additional layers. Similar features can be seen on the (unused) lost wax casting mould from Tell edh Dhiba'i (Davey, 1983, Plate II). It may be that small pores were entrapped along the interface (Fig. 5.9, inner layer), or that the temper was aligned in a preferred orientation parallel to the surface whilst it was smoothed to minimise the risk of entrapping air in larger pores before applying the next layer (Fig. 5.9a, second layer). This enriches the contact between different materials on the interface. Additionally, the underlying layer must be dried completely before applying the next one. Otherwise, the remaining moisture may crack the mould during firing (Anfinset, 2011; Levy et al., 2008). In the experiment, wet ceramic pastes could seldom stick to a previous dried layer, even if they were of the same clay type. This was overcome by applying a sufficiently large lump of clay to enclose the previous layer. Another option was to slightly moisten the dry surface. If done carefully, the water evaporated completely when the new layer dried.

However, the experiments highlighted that this procedure did not guarantee strong cohesion of the layers during firing and cooling. The layer interfaces become structurally weak regions in the mould. During heating, the differences in the physical properties of the layers such as their thermal expansion, may result in different behaviours. This induces mechanical stress on the layers' interface (e.g., the inner layer pressing against the outer one due to a higher thermal expansion). Likewise, gases in a porous inner layer could generate pressure on a less porous outer layer. In any case, cracks will evolve at the interface to release mechanical stress. Continuous increase in stress, e.g., due to further heating, will most likely propagate these cracks. Crack propagation always follows the weakest structural points in a material, in this case the interface of the layers with its enrichment in pores and temper. This process continues even after the mould is discarded (e.g., the moulds from experiment 2 and 3) as daily changes in ambient temperature or differences in humidity can accumulate stress in the material over time, and consequently create or propagate fractures.

Goren (2008) and Goren (2014) outlined that larger mould fragments generally consisted of two different materials. However, it remains unknown how many production sites and mould manufacturing techniques existed. Therefore, this mould design might not be a general trait and mould types with layers made from the same clay may exist as production debris in other archaeological sites. The experiments indicated that such mould material would be very difficult to identify. In our experiment, identification was possible due to prior knowledge of the distinctive features of the experimental moulds and later based on structural features such as the alignment of pores and temper. Especially without a sufficiently large fragment or a section through the interface of both layers, it seems more likely that such differences might be assigned to a heterogeneous paste instead of two different pastes based on the same clay. This problem might be even more pronounced when less well-separated clays are used and non-plastic inclusions in the paste came directly with the clay instead of being deliberately added as temper.

In conclusion, it seems that a good portion of luck is necessary to find and identify a mould fragment during an archaeological excavation, especially because the perfect mould material would be one that crumbles away after the cast metal solidified. Moreover, due to the low melting point of the polymetallic copper alloys used in the Chalcolithic Southern Levant, baking of the mould rather than firing could have been sufficient and such material often deteriorates easily back into clay afterwards. Nevertheless, it is not impossible in well-preserved archaeological contexts in arid environments with a low impact of post-depositional movement/mechanical stress.

The recognition of relevant fragments is much more problematic. Except for plaster, no typical feature of mould materials is likely to be preserved on the macro-scale to a degree that will be easily visible to the untrained naked eye. However, it might be possible to identify mould remains made of ceramic pastes based on features not hitherto discussed in the literature. Regarding the Chalcolithic of the Southern Levant, this is especially the combination of vegetal and non-vegetal temper. In contrast to mould remains, metallurgical ceramics, i.e., crucibles and furnace walls, were exclusively fashioned with vegetal matter as temper (Shugar, 2000), while only non-vegetal temper was found in pottery (Boness et al., 2016; Burton et al., 2019, and references therein). This criterion is easily recognisable and independent of any other aspect discussed above.

From a technological perspective, the differentiation is straightforward. Crucibles are heated from the top/inside, therefore being exposed to much lower temperatures on the outside. Crucible walls are often considerably thinner (usually < 1.2 cm, Shugar, 2000) than lost wax casting moulds, which may have been dug into the ground for heat insulation and stability between the heating and the casting steps. The thin crucible wall efficiently cools the ceramic paste and contains most of the heat within the crucible filling. A high proportion of vegetal temper, resulting in high porosity, increases the insulating properties while reducing the propagation of heat cracks. At the same time, the crucible must withstand rapid temperature changes (e.g., when taken from the furnace to cast the melted metal). Consequently, the absence of non-vegetal inclusions or a paste entirely made from clay and vegetal matter would be ideal for this task.

In contrast, moulds for lost wax casting are comparatively thick and must be heated from the outside. Therefore, the use of vegetal temper is similarly necessary and additionally facilitates air evacuation during casting (cf. Auenmüller et al., 2019). The comparatively thick walls and outside heating requires the inclusion of non-vegetal temper. It provides the necessary stability of the clay paste when modelled, and reduces the risk of drying fractures. During heating, it acts as a scaffold and keeps the shape of the mould when the clay minerals become soft.

In pottery production, the use of vegetal matter is not necessary and was not practised in the Late Chalcolithic. Firing conditions are more or less homogeneous and the non-vegetal matter provides the necessary stability of the shape during firing. Additionally, a low porosity enhances the mechanical resistance of the vessel.

The use of clays with large amounts of (natural) non-plastic inclusions might obscure the differences between clay and deliberately added non-vegetal temper. Therefore, the applicability of the suggested criterion might be not easily transferable to archaeological remains. Petrographic analyses of crucibles indicate that non-vegetal inclusions are not common (Shugar, 2000). However, all these objects were made from Negev loess and our own petrographic analyses on e.g., the tuyères indicate that this sediment contains by nature only a very small amount of larger non-plastic inclusions. This implies that no removal of larger non-plastic inclusions was involved in the preparation of the clay. Since metallurgical remains are currently confined to the Nahal Beer Sheva (Golden, 2014b) but the mould remains indicate a production site at En Gedi or in the Jordan valley (Goren, 2008), the investigations cannot be regarded as representative for the entire metallurgy of the Chalcolithic Southern Levant. Further studies are necessary and the recently reported crucible fragments from Fazael in the Jordan Valley (Rosenberg et al., 2020) might pose such an opportunity (chap. 5.2).

### 5.1.8 Conclusions

In the Chalcolithic Southern Levant metal objects and mould remains adhering to them are the only surviving remnants of early lost wax casting technology. Consequently, production sites are unknown. Because, e.g., crucibles can also be used for other casting techniques, mould remains might be the only clear evidence for lost wax casting at a site. To investigate how they could be identified in the archaeological record, an archaeological experiment was conducted based on the reconstruction of the lost wax process in the region. The obtained mould materials were petrographically examined and underwent simple alteration tests. The results were combined with general technological considerations.

The alteration experiment indicated that the preservation of mould fragments might only be possible in sites with a very low impact of depositional and post-depositional processes and if the moulds were not only baked but fired. Even then were the mould fragments so brittle or friable, that they effortlessly turned into crumbs under little mechanical stress. This is particularly relevant for multi-layered materials because they are the most striking characteristic of lost wax casting moulds in the Chalcolithic Southern Levant. Different physical properties of the layers' pastes seem to favour their separation and detachment, either during cooling, crushing of the mould, or in post-depositional processes, therefore reducing the recognisability of this feature in the archaeological record.

Widely unnoticed in previous studies, the combination of vegetal- and non-vegetal matter seems to be a specific and characteristic feature of the lost wax casting moulds of the Chalcolithic Southern Levant. General technological considerations highlight the excellent suitability of the mixture for this specific purpose. However, general validity of this feature must be examined in further studies. Currently, comparative material, e.g., of other metallurgical ceramics like crucibles is only available from the Nahal Beer Sheva valley. Since only very pure loess was used at these sites, no inferences about clays naturally rich in non-vegetal inclusions can be drawn.

The findings in this study should only be considered indicative for the Chalcolithic Southern Levant as no production remnants are known from other regions with early lost wax cast items. In general, it seems likely that only a combination of intricate fieldwork and scientific methods will allow the identification of mould remains for what they are.

## 5.2 The Fazael metallurgical assemblage

Being the first Chalcolithic metallurgical objects of the Southern Levant beyond the confines of the Nahal Beer Sheva, the assemblage from Fazael bears a high potential for new insights into the metallurgical practices of the Chalcolithic Southern Levant. The occurrence of polymetallic copper alloys and crucible fragments at the same site might even suggest that Fazael is one of the long-searched production sites of these polymetallic copper alloy objects. Therefore, the aim of the technological investigation was twofold: gain new insights into the metallurgical practices of the Chalcolithic Southern Levant, and investigate whether the Fazael assemblage provides direct evidence for the presence of lost wax casting activities at the site.

### 5.2.1 The site

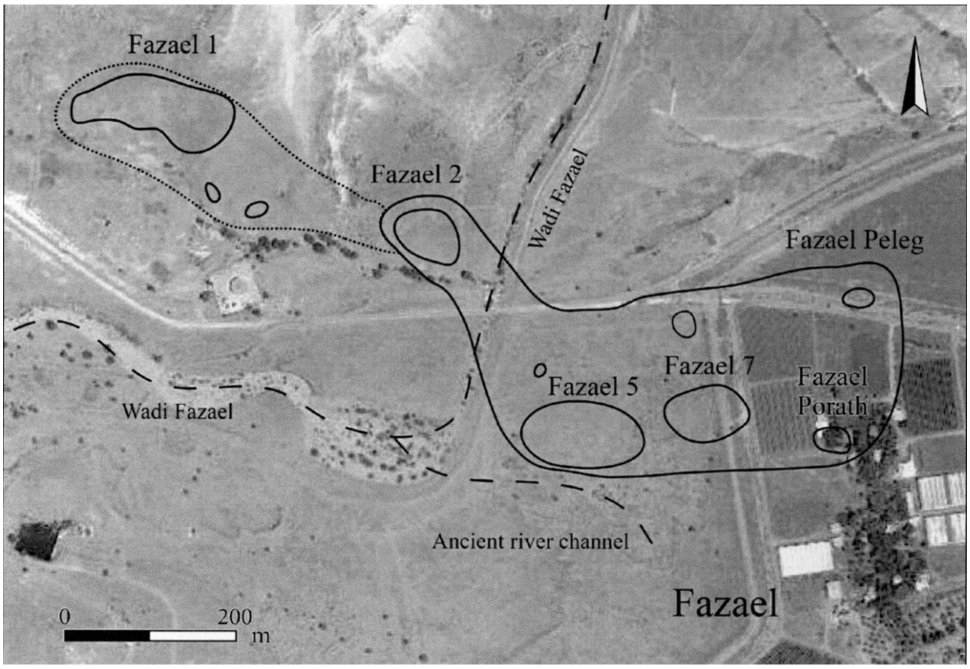


Figure 5.11: Satellite image of the Fazael site cluster with the different sites and the ancient and present course of Wadi Fazael (Bar et al., 2014).

Fazael is a multi-site cluster along the northern riverbank of the Wadi Fazael in the Lower Jordan valley (Fig. 5.11. The oldest site and the site furthest West is Fazael 1, a multi-strata settlement site with material culture typical for the Chalcolithic Southern Levant. Settlement activities shift east towards the end of the Chalcolithic, where the areas Fazael 2 (Bar et al., 2013), 5 (Bar et al., 2015), 7 (Bar et al., 2017), and Porath 1985 excavation (Porath, 1985) were excavated. All of them are broad room houses, some connected to courtyards, and share the same general stratigraphy of three strata and the material culture. Therefore, it is assumed that all of them were part of one large settlement.

The lowermost stratum 3 contains a few pits with typical Chalcolithic material and no architectural remains. It attests to some activity prior to the erection of the buildings in stratum 2 at all sites (Bar et al., 2015, 2013). Stratum 2 is the main settlement phase. In Fazael 2, several rooms around a large courtyard were build (Bar et al., 2013). In Fazael 5, only one broad room was excavated yet and does not seem to be connected to a courtyard (Bar et al., 2015). Fazael 7 features two adjacent courtyards, one with a four-roomed building, whose walls are preserved to more than 1 m height, and one with a broad room. Based on wall-relationships of the four-roomed building, the respective courtyard was built first, followed by two rooms and a subsequent extension with the other two rooms. While all of the Fazael buildings are larger than usual Chalcolithic houses, the four-roomed building with its courtyard is currently the largest known Chalcolithic building in this region with an area of 120 $m^2$ (Bar et al., 2017). At all sites, the outer walls and courtyard walls are made with two rows of large stones (up to 1 m size) and an infilling with gravel and earth. Remains of clay bricks were found on top of them in Fazael 2 (Bar et al., 2013). Walls of smaller stones divide most of the rooms into smaller rooms.

Within these rooms, one phase with careful maintenance of the building was identified in Fazael 7 (Bar et al., 2017). Only one floor per room was observed in Fazael 5, too (Bar et al., 2015), while Fazael 2 yielded several floors per room (Bar et al., 2013). One of the rooms at Fazael 2 contained two infant burials (Eshed and Bar, 2012).

Stratum 1 in Fazael 5 yielded pits with Chalcolithic pottery that cut through the eastern wall of the broad room (Bar et al., 2015). In Fazael 2, two installations and some walls can be assigned to this stratum. The stratum does not contain datable material but the absence of finds post-dating the Chalcolithic suggest a Chalcolithic date of this stratum (Bar et al., 2013).

The ceramic assemblage of Fazael is in many traits compatible with the Chalcolithic pottery assemblages in other sites but is atypical in several others. For examples, S-shaped bowls were found in strata 2 and 3. These bowls are attested from other Late Chalcolithic sites but become wide-spread only in the Early Bronze Age. Their proportion increases from the third to the second stratum. Large jars, cups and hemispherical bowls found in these strata are also known from other Chalcolithic sites in the Jordan valley, but Fazael deviates markedly from them in the amount of hemispherical bowls and the small proportion of undecorated vessels. Moreover, the complete absence of churns and fenestrated bowls, typical representatives of the Southern Levantine Chalcolithic, is striking. If these differences indicate

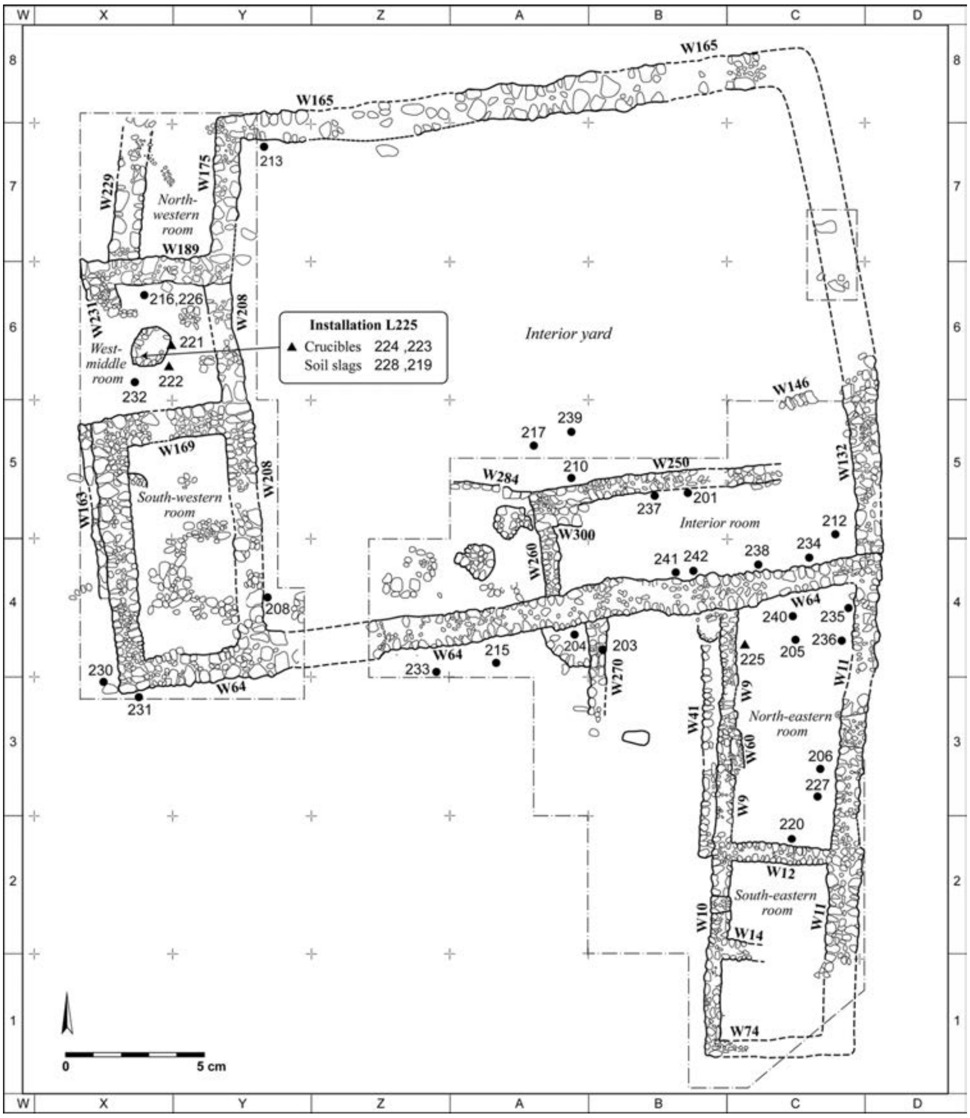


Figure 5.12: Plan of Fazael 2 with the location of metal items (dots) and crucible fragments (triangles) (Rosenberg et al., 2020).

chronological differences, they would date Fazael to the very end of the Chalcolithic (Bar et al., 2017, 2015, 2013). The single file of a cornet tip in Fazael 2 (Bar et al., 2013) supports a Late Chalcolithic date of the site.

The chipped stone tool industry is in many aspects typical for the Chalcolithic, such as the predominance of flaked tools. However, while Chalcolithic sickle blades were produced in Fazael 2, the characteristic bi-facial tools are almost absent in all sites (Bar et al., 2017, 2015, 2013). Moreover, Canaanean Blades were found at all sites. Similar to the S-shaped bowls they are found already in sites dating to the very end of the Chalcolithic but become wide spread in the Southern Levant only during the Early Bronze Age (Bar and Winter, 2010).

The grinding stones invoke the same impression of an incomplete Chalcolithic material culture with Early Bronze Age elements. The raw materials for a majority of them was collected within 10 km distance from the site, in agreement with other Chalcolithic sites. However, mortars are more abundant than grinding stones, a sharp contrast not only to other Chalcolithic sites but also to Fazael 1 (Cohen-Klonymus and Bar, 2016). In contrast to Fazael 5 and 7, a particularly large number of basalt bowl fragments was found in Fazael 2 (Bar et al., 2017). Additionally, Fazael 2 yielded two mace head fragments, one made of haematite, the other of basalt, and a haematite pendant (Bar et al., 2013).

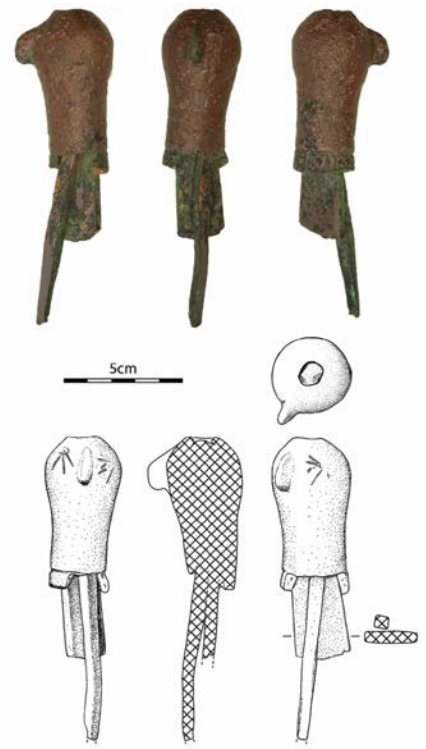


Figure 5.13: Head-shaped standard from Fazael 5 with an awl and a chisel pushed into its shaft hole. X-raying revealed the presence of a now inaccessible spiral-shaped object on the top end of the shaft hole (Rosenberg et al., 2020).

The faunal remains consist predominantly of sheep and goat, followed by cattle and local wild fauna. Cattle is more abundant than wild fauna in Fazael 2, while the opposite is true for Fazael 5 and 7, indicating hunting as an additional food source. Butchery marks or other signs of consumption are rare and found only in Fazael 7, where many bones are entirely burnt, especially the ones found around the two hearths (Bar et al., 2017). Both types of modification are entirely missing in Fazael 2 (Bar et al., 2013). Based on the age of the animals and the unbiased distribution of skeletal parts in the faunal remains, it is concluded that livestock was predominantly raised and exploited for meat and that all parts of the animals were consumed (Bar et al., 2017, 2013).

Taken all these aspects together, the incomplete Chalcolithic material culture in combination with several items and elements typical for the Early Bronze Age in all aspects of the material culture indicate that the Eastern Fazael sites date to the very Late Chalcolithic or into a transitional period between the Late Chalcolithic and the Early Bronze Age (cf. also Braun, 2022). This date is supported by radiocarbon dates of charcoal from stratum 2 of Fazael 2. They yielded a date between 4000 and 3900 BCE but could not be corrected for the old wood effects and, therefore, might even be a bit younger. Consequently, they confirm the very late date of the site (Bar et al., 2013).

Besides its chronological position, Fazael is particularly interesting because of the many metal objects found here. The Fazael metal assemblage is by number the largest one of the Chalcolithic Southern Levant after the Nahal Mishmar Hoard (Rosenberg et al., 2020). They are most abundant in Fazael 2 (34 items), followed by Fazael 7 (14 items) and Fazael 5 (4 items). Most of them are fragments of standards, crowns, mace heads, and chisels, but excavations also uncovered complete chisels, a mace head placed in a wall at Fazael 7, and, probably most outstanding, a head-shaped standard at Fazael 5 (Fig. 5.13), into which's shaft hole an awl, a chisel, and a third object were shoved (Bar et al., 2017, 2015; Rosenberg et al., 2020). The metal items in Fazael 2 and Fazael 7 are scattered over the entire site without any apparent pattern (Fig. 5.12). In addition, to the characteristic polymetallic copper with high sb and As levels, pXRF analyses of many objects identified an unusually high Pb content of > 0.5 wt% and one object seems to be made of a copper enriched in Pb and Bi. As generally the case with pXRF data, caution is necessary and the analyses are clearly intended as being preliminary (Rosenberg et al., 2020).

Beside to the metal objects, Fazael 2 yielded several crucible fragments (Fig. 5.12), as indicated by the corroded metal prills attached to some of them and the bloated rims. Their co-occurrence with the many metal fragments lead Rosenberg et al. (2020) to suggest pyrometallurgical processing of polymetallic copper alloys in Fazael 2, probably for the recycling of outdated or broken cultic metal objects. A furnace and slag are yet to be found (Rosenberg et al., 2020).

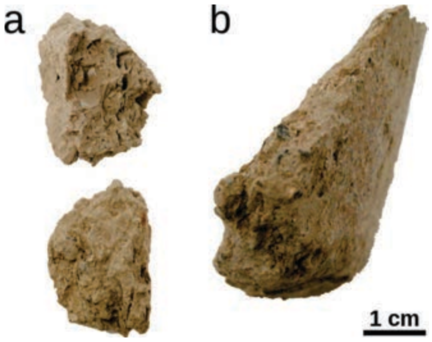


Figure 5.14: Selected samples from Fazael: (a) Sample F225a, the potentially smoothed site is on the left of the upper photo, (b) profile of F225, highlighting it is a base fragment of a bowl shaped vessel. See fig. 12.5 in Rosenberg et al. (2020) for additional photos of F225, and Fig. 12 and 13 for photos of the other crucible fragments.

Excavations in Fazael 2 are still ongoing and yielded several new metal items. Due to time constraints it was not possible to include them into the present study but finds of what might be casting gates (channels that facilitate the distribution of the metal in the mould) re-inforce the interpretation of this site as workshop for the processing of polymetallic copper alloys and lost wax casting (pers. comm. Y. Goren, 2022). In addition, nodules of what appears to be baked or heated sediment were uncovered and collected for further investigation (see below).

### 5.2.2 Material

15 metal objects and six ceramic fragments of the assemblage presented in Rosenberg et al. (2020) were sampled for metallography and petrography, respectively. The metal samples represent the full range of the reconstructed object types (e.g., crown, axe, potential production remains), alloy types as identified by pXRF analyses on the (partially) corroded surfaces, and sub-sites of Fazael (Tab. 5.5). Of particular interest is F236. By its shape, it is very likely a casting prill. In addition to the Chalcolithic finds, an axe from the Early Bronze Age site Fazael 4 was sampled (F4-107, Fig. 5.16), resulting in a total of 16 sampled items for metallography. Six fragments of crucibles and burnt glazed sediments, exclusively found in Fazael 2, were sampled for petrography. Five of them were previously reported by Rosenberg et al. (2020). F225a is newly reported here. It is a piece of hardened sediment with an irregular shape and one potentially smoothed side (Fig. 5.14a), and has the same find tag as F225.

Pieces of what appears to be baked or heated sediment nodules were excavated in 2020 in the eastern rooms of the broad house at Fazael 2. They are up to 4 cm in size, rounded, and brittle. Some of them broke in the field and exposed a reddish or black ceramic-like material of varying colour (Fig. 5.15). They were taken from the excavation directly to the lab without any further treatment. Nine of them were sampled for petrography. Among them, F2-Y39, F2-Y42, F2-Y50, F2-Y52, and F2-Y55 were found in the same spot, making it likely they belong to the same deposition event.

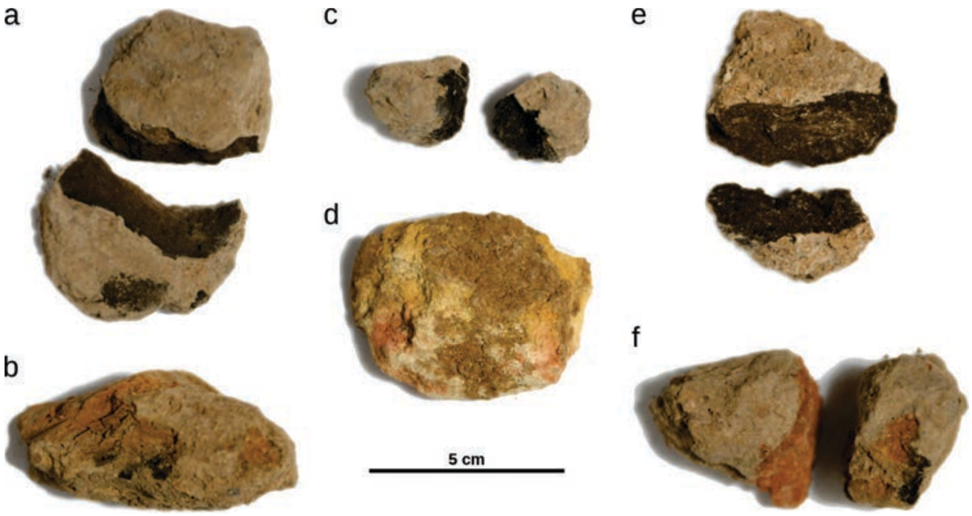


Figure 5.15: Selection of sediment nodules from Fazael: (a) F2-Y42, (b) F2-Y50, (c) F2-Y55, (d) F2-Y57, (e) F2-YA3, (f) F2-Y64 (Photos: Yuval Goren).

Table 5.5: Key characteristics of the sampled metal items. ”polymet. low” and ”polymet. high” denote polymetallic copper alloys with low and high levels of alloying elements, respectively.

| | | | | | Inclusions | | |
|---|---|---|---|---|---|---|---|
| Sample | Type | Metallographic group | Corrosion | Porosity | pure Cu | Quartz | Sulphides |
| F203 | standard (fragment) | high polymet. | yes | yes | no | yes | no |
| F204 | mace head (fragment) | low polymet. | yes | yes | Metal + corrosion | no | yes |
| F205 | crown (fragment) | low polymet. | yes | yes | Corrosion | no | no |
| F206 | axe (fragment) | low polymet. | yes | yes | Corrosion | no | yes |
| F208 | mace head (fragment) | low polymet. | yes | yes | Corrosion | no | yes |
| F217 | standard (fragment) | pure copper | yes | yes | Corrosion | yes, in some areas | no |
| F220 | mace head (fragment) | low polymet. | yes | yes | no | yes | yes |
| F231 | crown (fragment) | F231 | yes | yes | Metal + corrosion | no | no |
| F234 | axe (fragment) | pure copper | yes | no | no | no | no |
| F236 | metal chunk | high polymet. | yes | yes | Metal | no | yes |
| F238 | crown (fragment) | high polymet. | yes | yes | no | no | yes |
| F241 | mace head (fragment) | low polymet. | yes | yes | no | no | no |
| F4-107 | axe | pure copper | yes | no | no | yes | no |
| F502 | axe (fragment) | F502 | no | no | no | yes | no |
| F703 | fragment | pure copper | yes | no | no | yes | no |
| F709 | metal chunk | pure copper | yes | yes | no | no | no |

### 5.2.3 Methods

#### 5.2.3.1 Metallography

Metal objects were cut at the indicated positions (Fig. 5.16, chap. 5.2.7). The standard fragment F203 was sampled in a section perpendicular (F203-m1) and a section parallel (F203-m2) to the shaft hole. Crown fragment F238 was sampled on the rim (F238-m1) and the opposite corner of the fragment (F238-m2). The mace head fragment F220 was sampled in different depths because the corrosion layer was so deep that the first section (F220-c) contained almost no metal and, therefore, will not be included in this study.

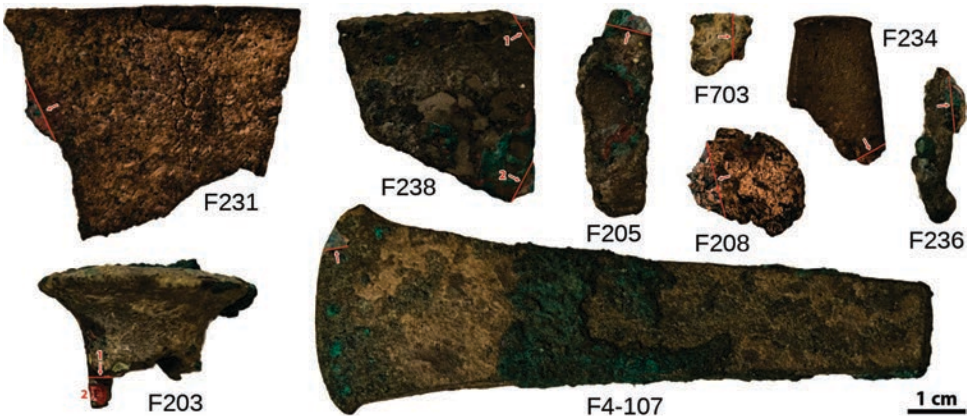


Figure 5.16: Selection of sampled metal items with the locations of the sections. The arrow indicates the direction of view of the slides.

All sections were embedded in epoxy resin, ground with silica carbide powder and polished with alumina powder down to 0.3 µm grain size. The polished samples were examined with the metallographic microscope Leica DMI 500 M, equipped with a Leica MC170HD digital camera. Sections were etched with FeCl$_3$-HCl solution in ethanol for 20 s if mechanical deformation was indicated by deformed pores, preferential orientation of inclusions, and deformed or fractured inclusions. The sections were subsequently coated with carbon and analysed with the SEM Hitachi S-2500 at the Metallography Laboratory of the Dipartimento Ingegneria Chimica Materiali Ambiente, Sapienza – Universitá di Roma, equipped with a ThermoFischer EDS system to analyse the chemical composition of the different phases. The SEM was operated with an acceleration voltage of 25 kV and a working distance of 35 mm in high vacuum mode. Life time per EDS analysis was at least 10 s. Pseudo-bulk compositions were determined by EDS analysis of representative areas on the sections at low magnifications. The presence of elements in the spectra was manually determined by the presence/absence of their peaks. Spectra were quantified with the Thermo Electron® NORAN System SIX 1.8 software using the ZAF method. Because the overlap of the Pb L$\alpha$ and the As K$\alpha$ lines impedes a reliable quantification of Pb and As by their main peaks, the Pb M$\alpha$ and As L$\alpha$ lines were checked to determine whether only one or both elements are present. If peaks could be observed at both lines, they were chosen for quantification. If they indicated the presence of only one element, the Pb L$\alpha$ or As K$\alpha$ line was chosen for quantification because of their better peak-to-background ratios. In none of the analyses, As, Pb, and S were present simultaneously, thus the overlap of the Pb L$\alpha$ and S K$\alpha$ lines was unproblematic.

#### 5.2.3.2 Petrography

The crucible fragments and the burnt glazed sediments were carefully inspected with a stereomicroscope to identify any adhering slag remains or copper prills. They were subsequently sectioned and the sections embedded in epoxy resin under vacuum. The baked sediment nodules were partially immersed in epoxy resin under vacuum before cutting to increase their mechanical stability. Petrographic thin sections were prepared from all samples according to standard procedures and analysed with a petrographic microscope. The chemical composition of isotropic amorphous inclusions in F2-Y55 was determined with the SEM-EDX FEI Quanta 200 of the Ilse-Katz-Institute for Nanoscale Science & Technology, Ben-Gurion University of the Negev, Beer Sheva (Israel). It was operated at 25 kV acceleration voltage in high vacuum mode on uncoated sections.

### 5.2.4 Results

#### 5.2.4.1 Metal items

The key characteristics of each section are summarised in tab. 5.5 and described in detail in the catalogue (Chap. 5.2.7). The microstructure of the sections can be subdivided into three groups: unalloyed copper, polymetallic copper alloys with low levels of alloying elements, and polymetallic copper alloys with high levels of alloying elements. Polymetallic copper alloys with low levels of alloying elements differ from unalloyed copper by being a multi-phase metal and/or showing a heterogeneous copper matrix. Sections were classified as polymetallic copper alloys with high levels of alloying elements when the copper matrix coexists with a network of other phases (Fig. 5.17a-c). Two sections revealed singular microstructures. F231-m is a polymetallic copper alloy with low levels of alloying elements but clearly differs by the morphology of its phases (Fig. 5.17d) and thus was not assigned to this group. F502-m has a homogeneous multi-phase microstructure unique among the sections (Fig. 5.17f). Except for F4-107-m, all sections are affected by corrosion to varying degrees. Cuprite inclusions are abundant in some samples of the unalloyed copper group (Fig. 5.17f), and five samples (three unalloyed copper, two polymetallic copper alloys, Tab. 5.5) contain abundant angular inclusions of pure silica, most likely silt-sized quartz (Fig. 5.17e). Sulphide inclusions were observed in the sections of seven samples, all belonging to the polymetallic copper alloy groups. Moreover, sections of seven samples contain distinctive orange-reddish phases, usually with a rougher texture than the surrounding phases. Some are embedded in the copper matrix, some are in contact with the other metal phases. In several sections, they are also in contact with corrosion phases, with some of them having a partly hexagonal shape. In section F236-m, some of them consist of at least two phases (Fig. 5.18). Most of the sections in the polymetallic copper alloy groups show considerable porosity, mostly from the casting process (Tab. 5.5).

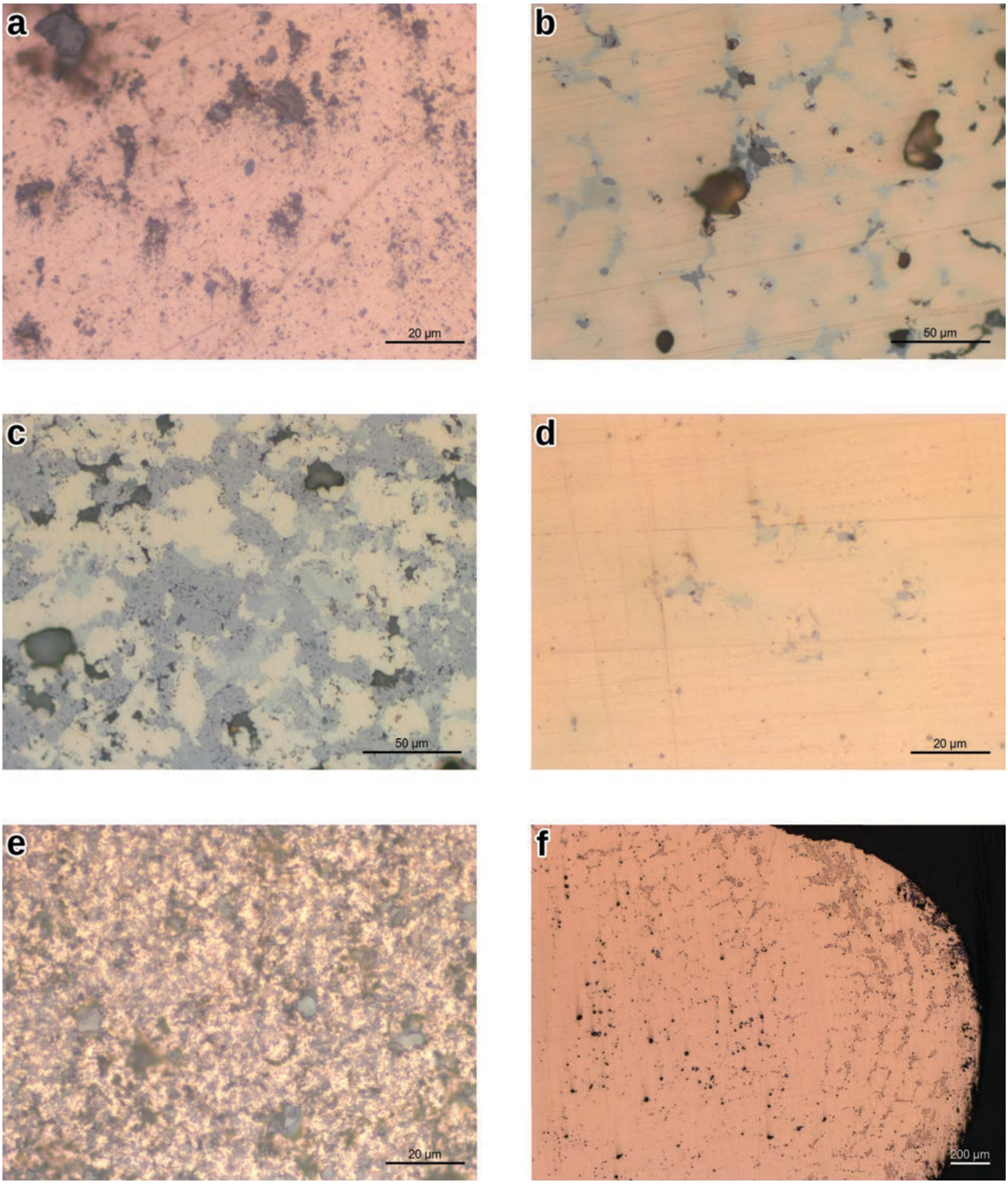


Figure 5.17: Typical examples for (a) the unalloyed copper group, section F4-107-m, with quartz inclusions, (b) polymetallic copper alloys with low levels of the alloying elements, F206-m, (c) polymetallic copper alloys with high levels of alloying elements, F238-m1, (d) F231-m, (e) F502-m, and (f) cuprite inclusions, F234-m.

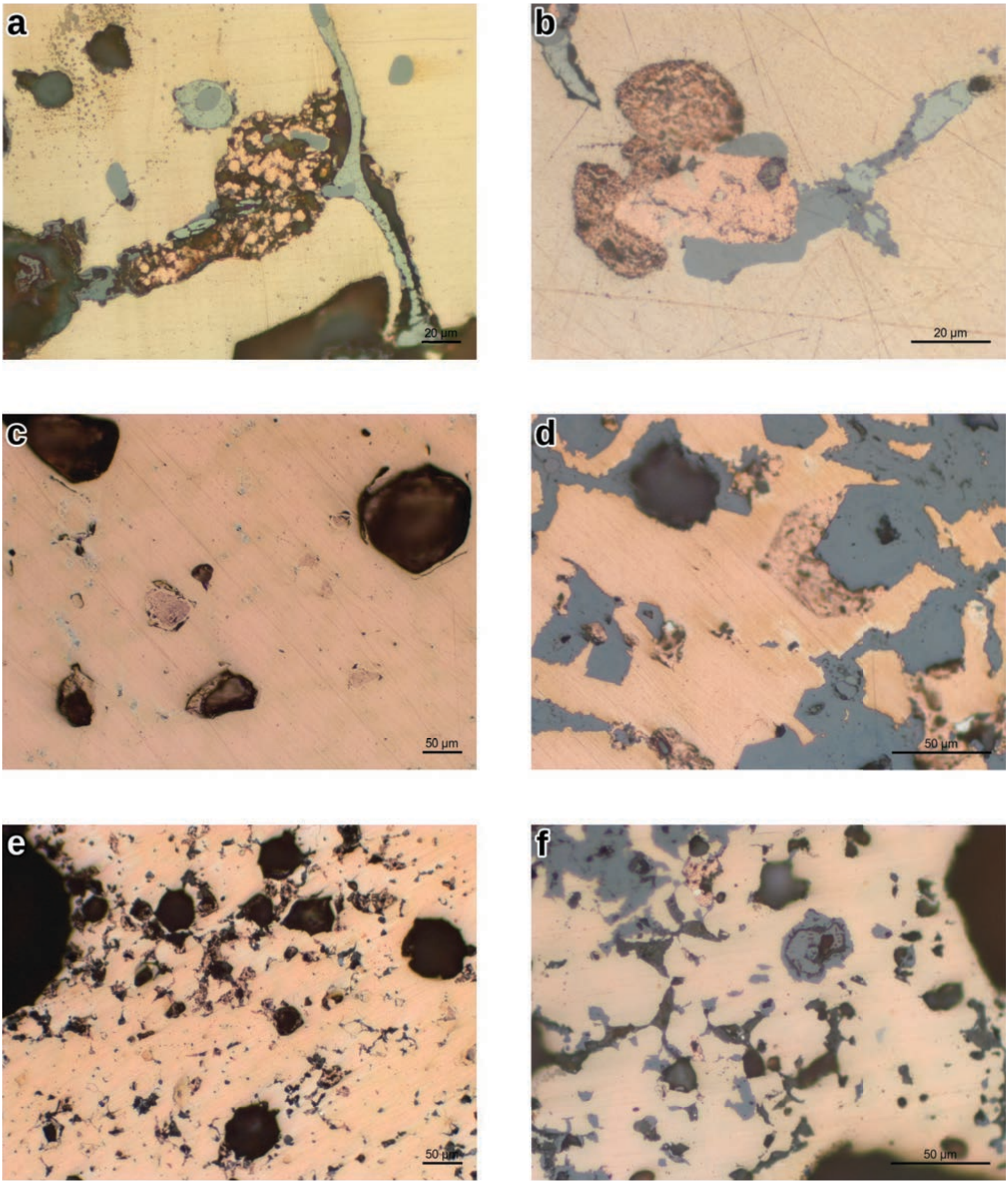


Figure 5.18: Examples for copper inclusions: (a) F236-m, with a dendritic microstructure, (b) F236-m, inclusion with copper and another, whitish phase, (c, d) F231-m, (e) F205-m, (f) F204-m.

Only the section of F234, from the rear part of an axe, was etched because a wave-like orientation of its cuprite inclusions indicates potential post-casting treatment. Etching revealed a gradient from up to 800 µm large grains and a granular microstructure in the centre of the section to about 10 µm large grains and a dendritic microstructure close to the surface (Fig. 5.19). The section taken from the blade of F4-107 does not show any traces of deformation or fracture of the abundant quartz inclusions (Fig. 5.17a).

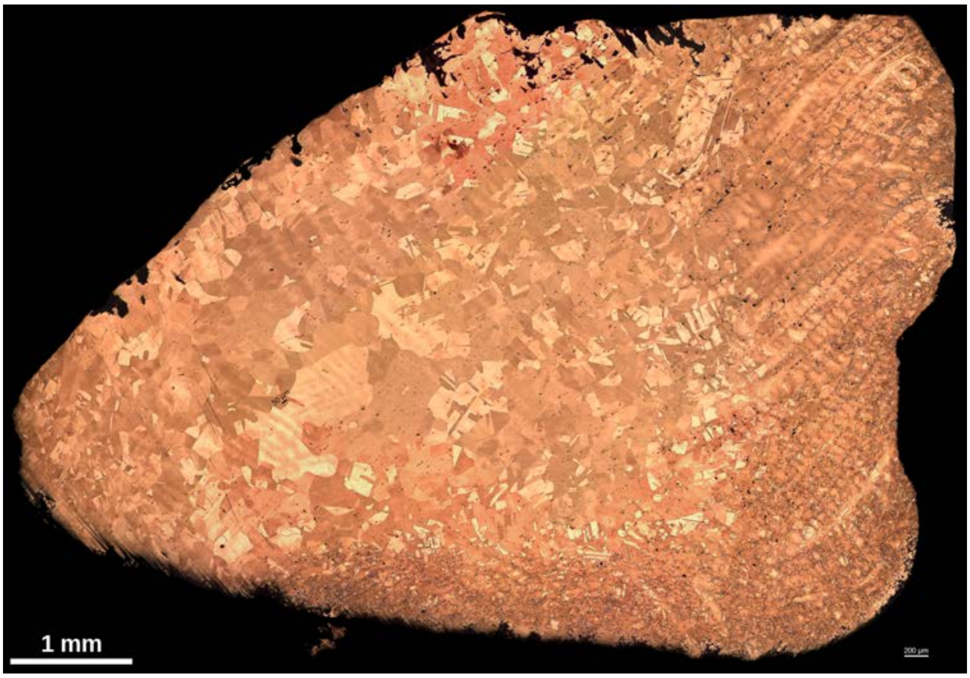


Figure 5.19: F234-m, etched with ferrichloride in ethanol for 20 s, composite image.

SEM analyses largely confirm the observations made with the optical microscope. Chlorine concentrations indicate the presence of corrosion phases in several analyses. Unfortunately it was not possible to differentiate and, therefore, analyse all phases identified with optical microscopy in the polymetallic copper alloys with high levels of alloying elements in the SEM. Alloying elements are Sb (present in ten samples), Pb (10), As (9), Ni (2), Bi (6), and Ag (4). Ni occurs only in combination with Cu and As and never with Sb, Pb, Bi, and Ag. Pseudo-bulk compositions are provided in Tab. 5.6 and single phase compositions in the catalogue (Chap. 5.2.7). Where measured, multiple pseudo-bulk compositions from the same sections gave identical compositions within analytical uncertainties (Tab. 5.6). The metallographic groups are consistent with the bulk chemistry of the sections: > 30 wt.% of alloying elements in the polymetallic alloys with high content of alloying elements, between 9 and 4 wt.% of alloying elements in the polymetallic alloys with low content of alloying elements, and < 2 wt.% of alloying elements in the unalloyed copper group. Exceptions are F208 and F220. Although pseudo-bulk analyses of these samples indicate the absence of alloying elements, polymetallic phases were observed with the optical microscope and with the SEM. Their low abundance makes it likely that the overall amount of these phases is too low for a detectable contribution to their pseudo-bulk composition. In contrast to all other samples, F231 is dominated by Bi as alloying element, supporting its classification as not belonging to any of the metallographic groups. F502 is an As-Ni copper with > 1 wt.% Ni and about 1 wt.% As. Although no pseudo-bulk analysis could be obtained from F236 due to its extensive porosity, the chemical composition of its phases (chap. 5.2.7) identify it as one of the two As-Ni coppers among the sampled metal items and confirms its metallographic classification as polymetallic copper alloy with high levels of alloying elements.

The two sections of F203 and F238, respectively, did not show any difference in their microstructure. Nevertheless, the pseudo-bulk composition of F238-m2 has significantly higher concentrations of the alloying elements compared to F238-m1. At the same time the 3.95 wt.% Cl indicate a significant impact of corrosion in section F238-m2, which might have resulted in the depletion of copper relative to the alloying elements, as was shown for As by Craddock (1995, p. 286). In addition, some heterogeneity in the chemistry must be expected due to the complex interplay of the alloy's constituents, likely to result in local differences in the phase evolution during cooling.

Comparing the metallographic groups with the object types confirms the well-known general separation between tool-shaped unalloyed (pure) copper objects and so-called prestige items made of polymetallic copper alloys (e. g. Shalev, 1991; Tadmor et al., 1995). Three exceptions from this pattern can be identified: The axe fragment F206 and the axe F502, which are polymetallic copper alloys, and the standard fragment F217, which was classified as unalloyed copper. All other items in the unalloyed copper group are tool-shaped or their original shape cannot be reconstructed (F703-m). Similarly, except F217 all fragments that can be reconstructed as parts of mace heads, standards, or crowns are polymetallic copper alloys. It must remain open whether mace heads fall exclusively in the category of polymetallic copper alloys with low levels of alloying elements or if this is an effect of the small number of investigated items in the other polymetallic copper alloy group (n = 3). In addition, SEM analysis of the axe fragment F234-m revealed a couple of polymetallic inclusions. However, it was kept in the metallographic group "unalloyed copper" because the overall appearance of the metal is typical for unalloyed copper.

Table 5.6: SEM-EDX pseudo-bulk analyses in wt.% for the metal sections. ”polymet. low” and ”polymet. high” denote polymetallic copper alloys with low and high levels of alloying elements, respectively. Due to the high porosity of section F204-m, alumina polishing powder could not be completely removed, resulting in the $Al_2O_3$ signal of this sample. No pseudo-bulk analysis could be obtained for sample F236 because of high porosity.

| Section | Object | Metallographic group | Cu | Sb | Pb | Bi | As | Ni | Ag | $SiO_2$ | Cl | $Al_2O_3$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| F203-m1 | Standard (fragment) | high polymet. | 65.68 | 17.74 | 3.49 |  | 7.74 |  | 1.19 | 4.15 |  |  |
| F204-m | Mace head (fragment) | low polymet. | 90.54 | 5.63 | 0.11 |  |  |  |  | 0.25 |  | 3.47 |
| F205-m | Crown (fragment) | low polymet. | 95.41 | 1.69 | 1.56 |  | 1.34 |  |  |  |  |  |
| F206-m | Axe (fragment) | low polymet. | 90.98 | 6.44 | 0.62 |  | 1.58 |  |  |  | 0.38 |  |
| F208-m | Mace head (fragment) | low polymet. | 100.00 |  |  |  |  |  |  |  |  |  |
| F217-m | Standard (fragment) | pure copper | 98.58 |  |  |  |  |  |  | 1.42 |  |  |
| F220-c | Mace head (fragment) | low polymet. | 97.32 | 1.27 | 1.20 |  |  |  |  |  | 0.22 |  |
| F220-m | Mace head (fragment) | low polymet. | 92.51 |  |  |  |  |  |  | 7.49 |  |  |
| F220-m | Mace head (fragment) | low polymet. | 93.20 |  |  |  |  |  |  | 6.80 |  |  |
| F231-m | Crown (fragment) | F231 | 98.62 | 1.38 |  |  |  |  |  |  |  |  |
| F234-m | Axe (fragment) | pure copper | 99.35 | 0.65 |  |  |  |  |  |  |  |  |
| F238-m1 | Crown (fragment) | high polymet. | 65.11 | 19.83 | 10.65 | 0.17 | 4.25 |  |  |  |  |  |
| F238-m2 | Crown (fragment) | high polymet. | 45.50 | 18.74 | 24.70 |  | 5.54 |  |  | 1.56 | 3.95 |  |
| F4-107-m | Axe | pure copper | 75.58 |  |  |  |  |  |  | 24.42 |  |  |
| F4-107-m | Axe | pure copper | 76.28 |  |  |  |  |  |  | 23.72 |  |  |
| F502-m | Axe (fragment) | F502 | 69.94 |  |  |  | 0.96 | 1.68 |  | 27.42 |  |  |
| F502-m | Axe (fragment) | F502 | 69.21 |  |  |  | 1.04 | 1.36 |  | 28.39 |  |  |
| F703-m | Fragment | pure copper | 86.98 |  |  |  |  |  |  | 13.02 |  |  |

### 5.2.4.2 Crucibles and burnt glazed sediments

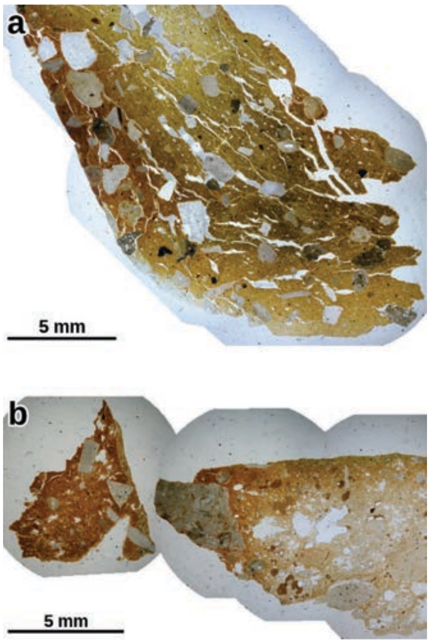


Figure 5.20: Photomicrographs of thin sections (a) F225-cr, and (b) F229-cr.

Crucibles and burnt glazed sediments can be separated into three petrographic groups. The first group comprises of F225 and F229 (Fig. 5.20). No indication for extensive heating such as vitrification or slagging was observed. Reddish soft material on the concave side of both sherds could indicate localised strong heating. The cross section of F225 suggests that it is a base fragment of a bowl-shaped vessel with a flat base (Fig. 5.14b) and the subparallel cracks in the section align with its inner surface (Fig. 5.20a). The clay in the sections of both items is orange-brown, calcareous, has abundant rhomboidal carbonate crystals, and, less abundant, iron oxide aggregates. It is optically active with domains subparallel to the convex surface in F225-cr. Also in F225-cr, a few foraminifera were observed in the clay matrix. The sand-sized non-plastic inclusions are predominantly subangular carbonate grains and in decreasing abundance chert, larger iron oxide aggregates, and molluscs. Vegetal matter is absent except for a single grass leave in F229-cr. This paste corresponds very well with clay derived from the Moza formation (Goren, 2008, 2006, 1995).

F225a is the only member of the second group. Similar to the first group it is made from an orange to brown calcareous clay with iron oxide aggregates. However, rhomboidal carbonate crystals are absent and foraminifera considerably more abundant than in the former group (Fig. 5.21a). It is weakly optically active with some randomly orientated domains. The most abundant non-plastic inclusion is grass, followed by sand-sized carbonates and rare molluscs, chert, and quartz grains. The greyish or darker colour of some areas in F225a-cr could be an indicator for heating (Fig. 5.21b) but based on its overall appearance only to relatively low temperatures.

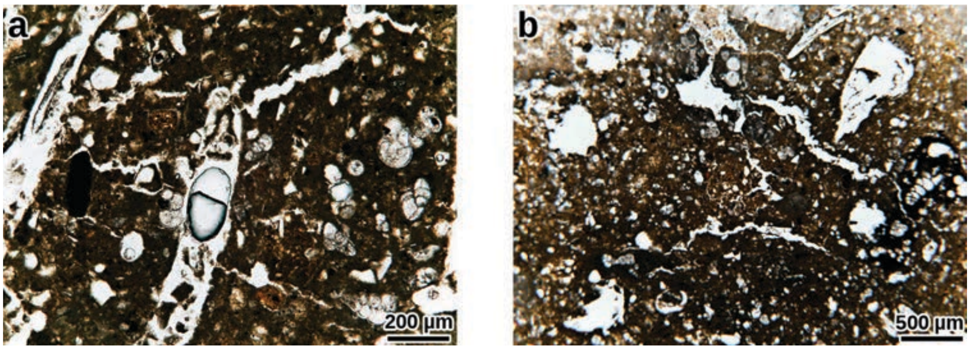


Figure 5.21: Photomicrographs of F225a, plane-polarised light.

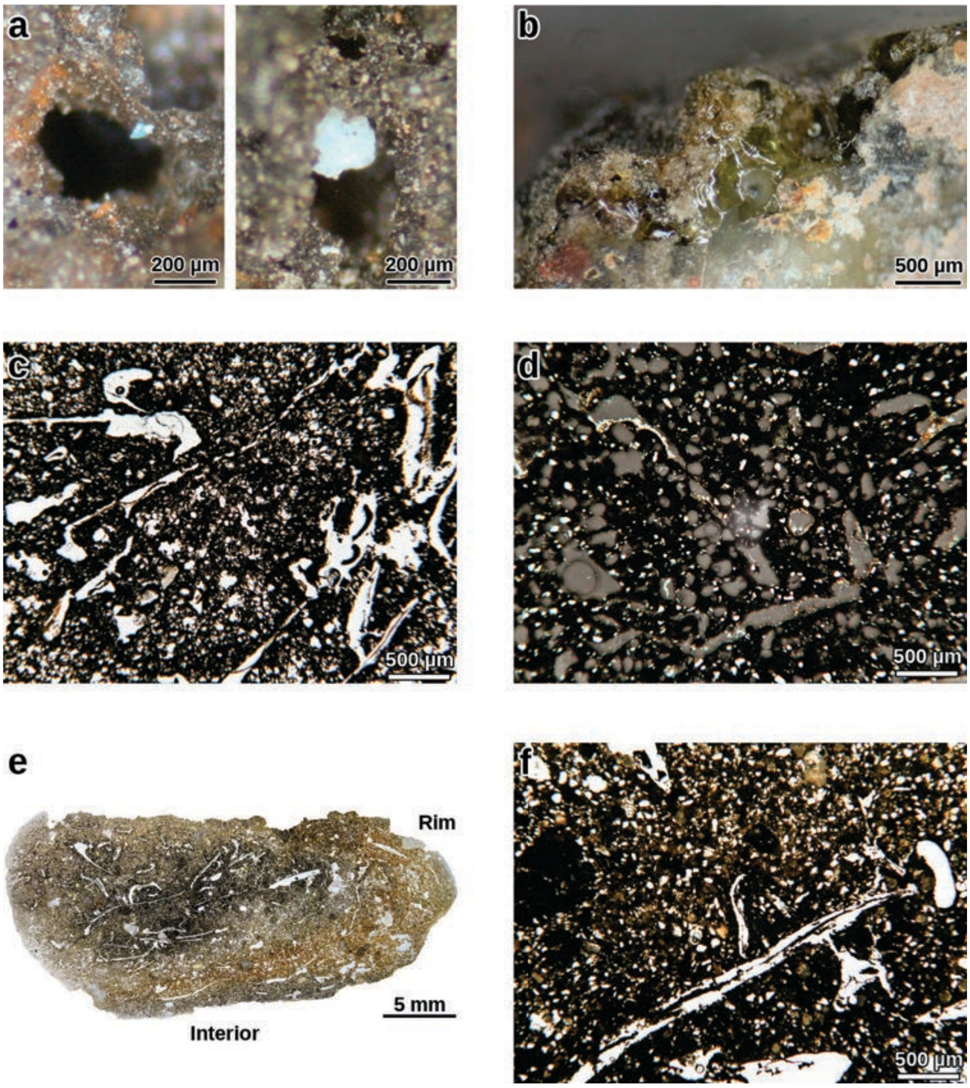


Figure 5.22: Photomicrographs of (a) secondary blueish minerals and (b) slag on the rim of F219. Photomicrographs of (c) F219-cr in plane-polarised light and (d) F228-cr in crossed-polarised light. (e) Composite image of the thin section F222-cr showing the differently coloured areas in the section. (f) Photomicrograph of the same section in plane-polarised light.

The last group comprises of F219, F222, and F228. This group is clearly different from the other two groups by the black colour of the sherds. F219 and F228 show extensive bloating due to excessive heating. Under the stereomicroscope, small blue minerals and small vitrified patches were found on F219 (Fig. 5.22a,b). Unfortunately, the vitrified patches could not be analysed because they are on the top of the rim and the fragment is too large to fit in an upright position into the sample chambers of the available SEMs. The intense green and red colour of the slag as well as the blue colour of the crystals might indicate elevated levels of copper and divalent iron, respectively. In contrast to the information provided by Rosenberg et al. (2020, Tab. 4), no slag could be observed on F222.

The clay is very rich (about 50 area%) in silt-sized angular quartz. Iron oxide aggregates and subrounded carbonates are common. The clay itself was completely opaque black for F219-cr and F228-cr (Fig. 5.22c,d). Unblackened patches in F222-cr indicate a yellowish/orange to brown colour. Additionally, the cross-section of F222-cr reveals a succession of black and red areas (Fig. 5.22e). Bloating in F219-cr intensifies towards the rim. A similar gradient of bloating can be observed in F228 as well but the orientation of this fragment cannot be reconstructed. The paste contains a large proportion of grass, indicated by the shape of the negatives and the regular presence of charred remains in them. The alignment of the plant material in F222-cr indicates a preferred orientation subparallel to the surface of F222. Although not as clear as in F222-cr, the same can be observed for F228-cr. Rare sand-sized carbonate grains were observed in all sections. Additionally, F222 contains distinctive rounded aggregates of up to 1 mm size that can be easily distinguished from the clay matrix by the rare occurrence of angular quartz in them and their consistent black colour, even if the clay matrix around them is not blackened (Fig. 5.22f).

#### 5.2.4.3 Baked/heated sediment nodules

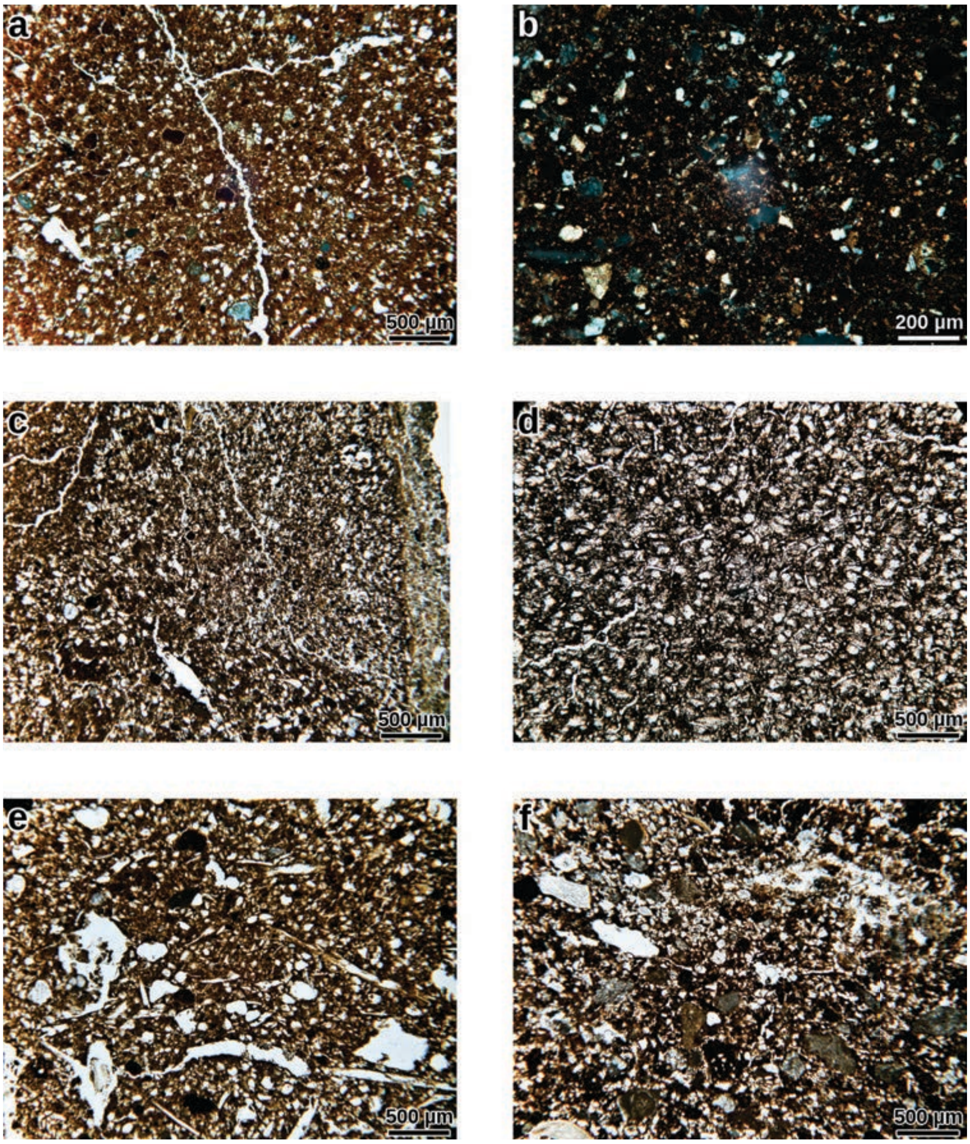


Figure 5.23: Photomicrographs of (a) F2-Y52, (b) F2-Y42, (c) F2-Y39, (d) F2-Y57 (Photo: Yuval Goren), (e) F2-Y64, (f) F2-YA3; (a,c–f) in plane-polarised light, (b) in crossed-polarised light.

All sampled sediment nodules are made of the same clay. It is red to dark brown with a large proportion of iron oxides. Between 30 and 50 area% are silt-sized angular minerals, predominantly quartz but also chert, feldspar and heavy minerals such as amphibole and tourmaline. Carbonates in the size of fine sand occur but are much less abundant. Molluscs can rarely be found. F2-Y42 and F2-Y52 consist exclusively of this clay; neither mineral nor vegetal non-plastic inclusions were observed (Fig. 5.23a,b). In section F2-Y39 a layer made of another paste was observed (Fig. 5.23c). This paste seems to be a finer fraction of the described clay with less iron oxide aggregates and a smaller average grain size. F2-Y50 features in some areas a high proportion of roughly chopped vegetal matter in a subparallel orientation to each other (Fig. 5.24), while in other areas sand-sized carbonates are abundant. The vegetal matter appears in two "layers" with inclusion-free clay in between. In contrast to this heterogeneous distribution of non-plastic inclusions, the clay itself is homogeneous and no material contrast is observed. The clay is partially blackened around the vegetal material and has areas where the silt-sized fraction is less abundant or even nearly absent. F2-Y57 is an example with a particularly high proportion of the silt-sized fraction (Fig. 5.23d) and like F2-Y42 and F2-Y52 does not contain any non-plastic inclusions. The clay has a dark brown to black colour in this specimen. F2-Y64 features a high proportion of vegetal matter but in contrast to F2-Y50 more finely chopped and randomly orientated (Fig. 5.23e). F2-YA3 features a high proportion of the silt-sized fraction in the matrix together with about equal proportions of vegetal matter and a sand-sized mixture of mainly carbonates with chert and shell fragments. Compared to the other sections, it is the most rich in non-plastic inclusions (Fig. 5.23f).

F2-Y55 is distinct from these nodules. It is entirely black to the naked eye. The section shows a black opaque matrix with a less abundant silt-sized fraction than in the other nodules. Similar to F222-cr, rounded areas with less or very little of the silt-sized fraction are present. Non-plastic inclusions are in about equal proportions vegetal matter, carbonates, cherts and shells (Fig. 5.25a). Additionally, several inclusion of up to 0.3 mm size are unique to this section. They are orange-brown in plane-polarised light and translucent at crossed polarisers (Fig. 5.25b), indicating a glassy material. SEM analyses of three such inclusions revealed a silicate phase with variable concentrations of K, Mg, Ca, Al, and Fe (Tab. 5.7). Two analyses are similar in their chemical composition while the third is very rich in Ca and contains significantly less K, Al, Si, and Fe. All of them contain a considerable amount of carbon, suggesting that the dark opacified areas in the glass could be carbon (Fig. 5.25b).

Table 5.7: SEM-EDX analyses in wt.% for three vitreous inclusions in section F2-Y55.

| Point | K | Fe | Mg | Ca | Si | Al | O | C |
|---|---|---|---|---|---|---|---|---|
| 6_02glass | 3.98 | 14.45 | 1.92 | 7.07 | 27.92 | 8.93 | 20.39 | 15.34 |
| 6_04glass | 0.54 | 3.41 | 2.14 | 34.84 | 19.45 | 2.52 | 23.83 | 13.27 |
| 6_05glass | 5.78 | 14.29 | 1.55 | 7.07 | 30.03 | 10.35 | 22.89 | 8.05 |

## 5.2.5 Discussion

### 5.2.5.1 Metals

**5.2.5.1.1 Comparison with previous studies** The polymetallic copper alloys in Fazael adhere to the general characteristics of the Chalcolithic Southern Levantine metallurgy but also show some important deviations. Their pseudo-bulk compositions are within the known range of the main alloying elements Sb, Pb, and As (Fig. 5.26a). The Ag concentration of F203-m1 is practically identical with the highest Ag concentration reported so far (standard 61-253 of the Nahal Mishmar Hoard with 1.2 wt.% Ag: Tadmor et al., 1995). F238 clearly stands out by its very high Pb content, making this crown fragment one of the most heavily alloyed coppers of the Chalcolithic Southern Levant (Tab. 5.6). However, corrosion likely obscured the pseudo-bulk composition of F238-m2 towards the extremely high concentrations. The polymetallic copper alloys in the Fazael assemblage tend to be richer in Sb compared to As than most of the other polymetallic copper alloys (Fig. 5.26b) and the samples containing Pb and As have much higher Pb/As ratios (Fig. 5.26c). The two As-Ni coppers F236 and F502 are dominated by Ni, while As is usually the dominating alloying element in the As-Ni coppers in the Chalcolithic Southern Levant (Fig. 5.27). In summary, the polymetallic copper alloys from Fazael are poorer in As or richer in the other alloying elements than most of the other polymetallic copper alloy assemblages of the Chalcolithic Southern Levant.

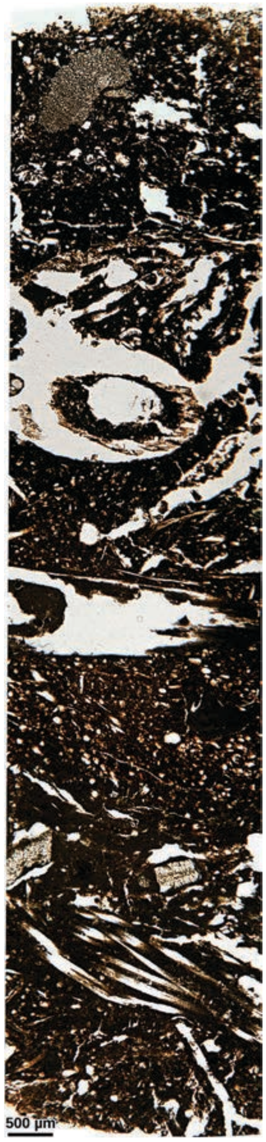


Figure 5.24: Photomicrograph of cross section through F2-Y50, plane-polarised light, composite image.

As was already concluded in previous studies (Notis et al., 1984; Shalev and Northover, 1987; Tadmor et al., 1995), the high concentrations of As and Sb in combination with the presence of sulphide inclusions in six out of the ten polymetallic copper alloys point to fahl ores as the most likely copper ore source. The As-depleted signature could indicate that the Fazael metal items were produced from relatively As-poor fahl ores. Alternatively, As, as the most volatile among the alloying elements, could have become depleted during metallurgical operations. In the latter case, this would imply that the metal of the Fazael objects was subjected to additional or more extensive melting steps than most of the other metal items.

No post-cast treatment of the polymetallic copper alloys is observed, confirming results of previous metallographic studies (Potaszkin and Bar-Avi, 1980; Shalev et al., 1992; Shalev and Northover, 1993).

Other features reported in these studies such as a dendritic structure, extensive porosity, and a gradient from extensive corrosion at the surface to intergranular corrosion deeper in the metal were observed in several of the sections (Chap. 5.2.7). Information about the enrichment of polymetallic phases on the surface ("inverse segregation") is only provided for the mace head in Shiqmim, where it was not observed (Shalev et al., 1992). In the sections under study here, F203-m1 shows such an enrichment on the corrosion-unaffected surfacs (Fig. 5.28).

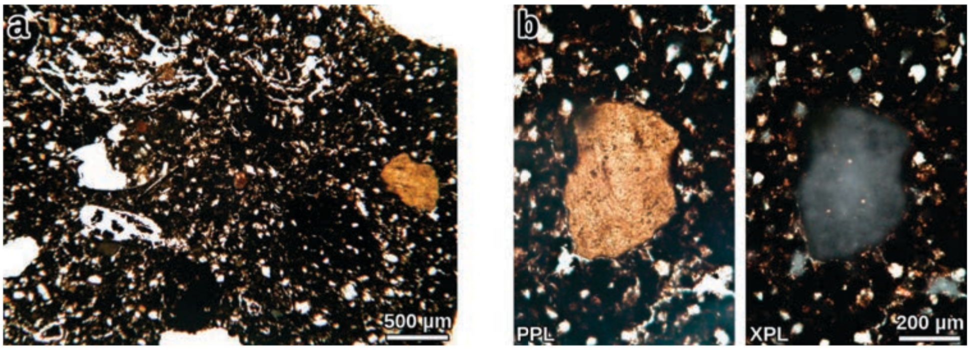


Figure 5.25: Photomicrographs of (a) F2-Y55, plane-polarised light, and (b) example of glassy material in plane (PPL) and crossed-polarised light (XPL).

The chemical composition of the Ni-As copper axe F502 is similar to chisel 97-3484 of Giv'at HaOranim (Namdar et al., 2004) and 61-147 of the Nahal Mishmar Hoard (Key, 1980). The section F502-m was taken from somewhere in the middle of the axe and based on its microstructure remained unworked after casting. A more precise reconstruction of its location is not possible because it is shoved into the standard F-501 and the end outside the standard is broken.

In contrast to the polymetallic copper alloys, unalloyed copper items were usually reworked after casting by a combination of hammering and annealing (Namdar et al., 2004; Potaszkin and Bar-Avi, 1980; Segal, 2002; Segal and Goren, 2013; Segal and Halicz, 2014). In contrast to these observations, the sampled unalloyed copper items of the Fazael assemblage appear as cast. However, it is important to keep in mind that usually blades were sampled while in the Fazael assemblage only middle parts or non-orientated fragments of tool-shaped objects were sampled. An exception is the complete Early Bronze Age axe F4-107, which was sampled at the blade. Neither the very abundant quartz nor cuprite inclusions show any deformation or preferred orientation, indicating that the blade was left in an as-cast state.

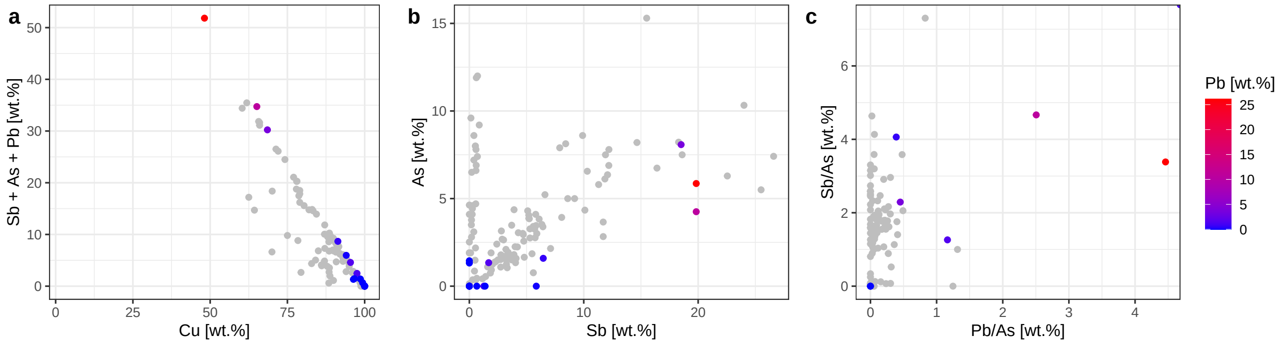


Figure 5.26: Pseudo-bulk compositions of the sections, re-normalised to 100 % after exclusion of eventual quartz inclusions and leftovers of polishing powder (cf. chap. 5.2.7 for raw values), colour-coded for their Pb content. In grey chemical compositions of other polymetallic copper alloys of the Chalcolithic Southern Levant (data taken from Ben-Yosef et al., 2016, Supplementary data). (a) The sum of the main alloying elements plotted against the copper concentration of the samples, (b) As against Sb, and (c) Sb and Pb concentrations normalised to As. Concentrations of 0 wt.% denote elements absent in the pseudo-bulk compositions of the sections.

Section F234-m features the Cu-CuO eutectic towards the surface similar to the copper lump M26 of the Early Bronze Age Camel site (Segal and Rosen, 2005). The gradient in grain size of this sample in combination with the very large and well-crystallised grains in the centre and a dendritic microstructure close to the surface indicates casting in an open mould without any significant post-cast treatment of this middle to rear part fragment of an axe. Cu-CuO eutectic is also present between the large copper grains in some areas of F217-m but is mostly overgrown by corrosion.

Only Notis et al. (1984) mentions silica inclusions, assumed to be quartz, and only for an axe head from Bir es-Safadi. They are restricted to areas close to the surface of the item. Unalloyed copper inclusions in the polymetallic copper objects of the Chalcolithic Southern Levant are a feature not mentioned in any of the studies about such metal items. Both features will be discussed in more detail below.

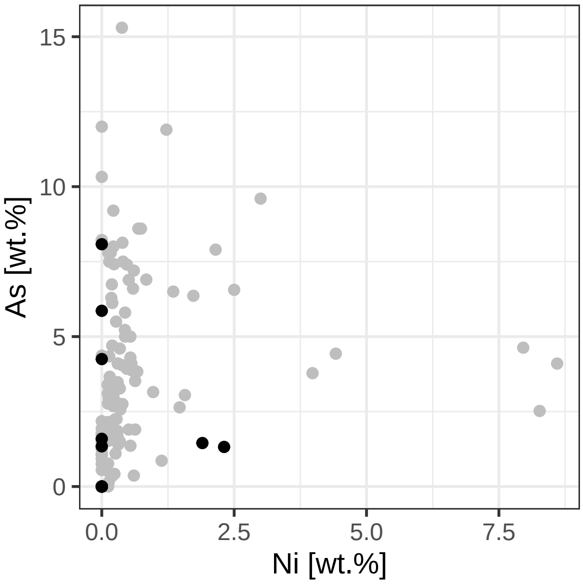


Figure 5.27: Pseudo-bulk As and Ni concentrations of the sections (black), re-normalised to 100 % after exclusion of eventual quartz inclusions and leftovers of polishing powder (cf. chap. 5.2.7 for raw values). Other polymetallic copper alloys of the Chalcolithic Southern Levant in grey (data taken from Ben-Yosef et al., 2016, Supplementary data). Concentrations of 0 wt.% denote elements absent in the pseudo-bulk compositions of the sections.

**5.2.5.1.2 Phase composition** The phase composition of Sb-rich polymetallic copper alloys is widely unknown. Northover (1998b) seems to be the only study that discusses the high alloy phases in the Cu-As-Sb system in some detail. He observed that they can be plain after etching with ferric chloride-based solutions or have a banded or needle like microstructure. Microanalytical investigations of these phases indicate chemical compositions close to $Cu_3(As,Sb)$ and $Cu_2(As,Sb)$, probably as true intermetallic phases $Cu_9AsSb_2$ and $Cu_6As_2Sb$. The determination of the chemical composition was complicated by Ni and Ag impurities, with the latter resulting in white needles. No banded or needle-like structure was observed in the Fazael metal items but the high polymetallic phases do consist of multiple phases and several of them are close in their chemistry to the compositions observed by Northover (1998b) (chap. 5.2.7).

The study by Northover (1998b) is restricted to the Cu-As-Sb system. In addition, only binary phase diagrams are available, leaving insight into the complex interactions of the different alloying elements a desideratum. The binary phase diagrams show that Bi is perfectly soluble in Sb and has a binary phase with Pb but is not soluble with the other metals. Likewise, Pb is not soluble in any of the present metals with exception of Sb. However, only F220-m and F234-m have inclusions that could be Sb-Pb prills, i. e., in samples with a very low concentration of alloying elements. In all other sections Pb seems to be dissolved in the polymetallic phases although Pb prills would be expected based on the phase diagrams. This highlights the complexity of the interactions in the system Cu-As-Sb-Pb-Bi(-Ag), making it impossible to retrieve any reliable information from projections into the binary systems. In addition, higher cooling speeds shift the phase fields towards lower Cu contents. This follows from general thermodynamic considerations and was quantified for the Cu-As system by Mödlinger et al. (2018) with shifts of the phase boundaries of > 5 wt.% towards the Cu-rich side at high cooling speeds. Consequently, a detailed discussion of the phase composition of the Sb-rich polymetallic copper alloys must await studies on the complex interactions of the alloying elements.

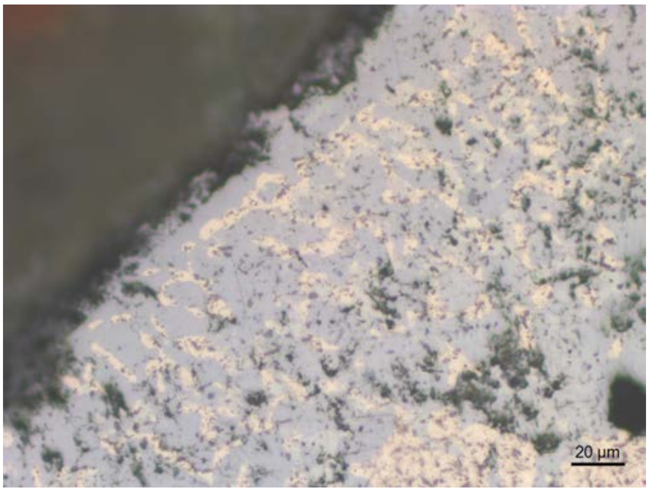


Figure 5.28: Photomicrograph of F203-m1 with a corrosion-unaffected surface layer of the Sb-As-rich polymetallic phase.

For the As-Ni copper items, the phases could only be analytically resolved for F236-m. Plotting them into the Cu-As phase diagram (Mödlinger et al., 2018) suggests the presence of $\alpha$-(Cu,As) and $\gamma$-phase $Cu_3As$ phases, which is in accordance with previous investigations (e. g. Lechtman and Klein, 1999; Mödlinger et al., 2018; Rostoker and Dvorak, 1991).

**5.2.5.1.3 Unalloyed copper inclusions** Unalloyed copper inclusions in tin bronzes and gun metal were investigated by Bosi et al. (2002). They identified three types of unalloyed copper inclusions: (A) precipitation of copper during corrosion, pseudomorphologically replacing other phases, (B) globular inclusions surrounded by a layer of copper sulphides, which are remains of incompletely reacted and slagged Cu-S phases in the smelting process, and (C) large irregular shaped inclusions with a twinned microstructure.

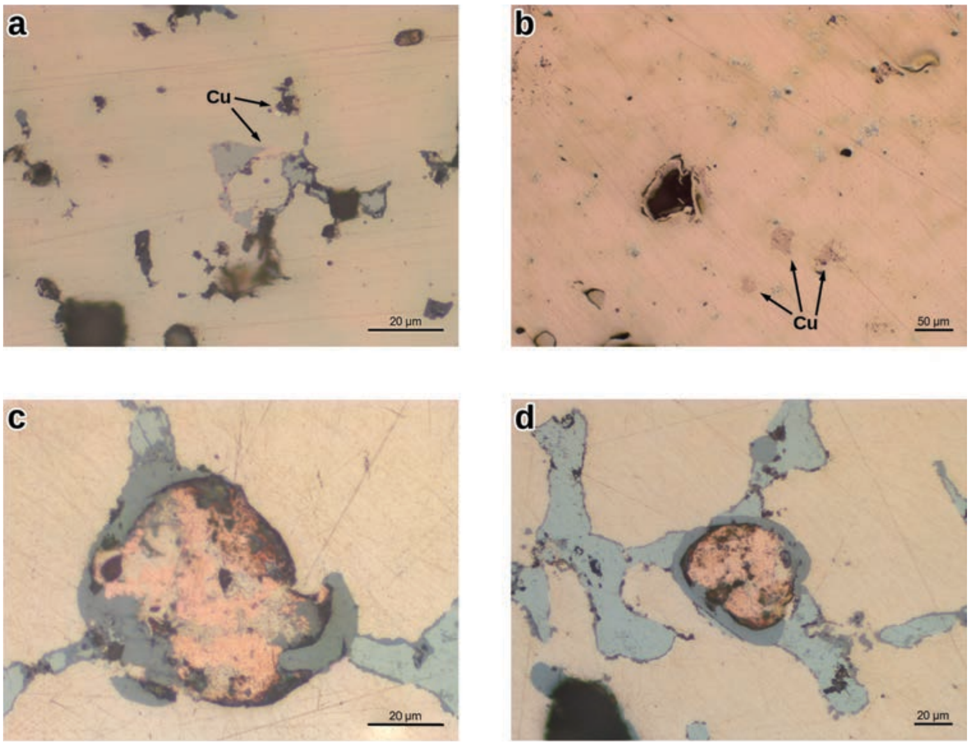


Figure 5.29: Examples for copper inclusions unrelated to corrosion: (a) F204-m, (b) F231-m, and (c, d) type B copper inclusions after Bosi et al. (2002) with more than one phase, F236-m. See also fig. 5.18.

Type A unalloyed copper inclusions are observed in all sections with unalloyed copper inclusions except F236-m (Fig. 5.18d–f). Type B inclusions were exclusively observed in F236-m, where they are not only surrounded by sulphides but also consist of at least one additional whitish phase (Fig. 5.18b, 5.29c,d). Corrosion-unrelated unalloyed copper inclusions occur in F204-m, F231-m, and F236-m (Fig. 5.18a,c, 5.29a,b). They do not correspond to the type C inclusions of Bosi et al. (2002) because they are neither large nor are they irregularly shaped. However, similar unalloyed copper inclusions are reported by Mödlinger and Trebsche (2021) from tin bronze tools in Lower Austria. Mödlinger and Trebsche (2021) interpret them as remains from the addition of unalloyed copper to the tin bronze, most likely added as scrap metal during recycling to balance material loss.

Such copper inclusions can only exist if the metal melt was not (long enough) hot enough to melt the metal completely. To gain a rough estimate of the bulk melting temperature per sample, the pseudo-bulk compositions of the poly-metallic copper alloys with corrosion-unrelated unalloyed copper inclusions can be projected into the Cu-Sb phase diagram. This provides an upper limit of their melting temperatures (Fig. 5.30). The true melting temperature is likely to be considerably lower. It can be as low as 600 °C for As-Sb copper (Northover, 1998b, p. 118) and is probably even lower than this because of the considerably lower melting temperatures of Pb and Bi (cf. chap. 4.3.3). Based on this estimate, it is clear that a metal melt sufficiently liquid for casting but with some unmelted parts could be easily obtained at temperatures below the melting point of unalloyed copper (1085 °C). It must also be kept in mind that even if temperatures beyond the melting point of unalloyed copper were reached, they must be held long enough to melt the unalloyed copper completely.

Furthermore, the features of one copper inclusion in F236-m provides direct evidence for the incompletely melted state of the metal. It is made of unalloyed copper with a dendritic microstructure and no interdendritic phase, most likely because the latter melted completely while temperature was too low to melt the unalloyed copper (Fig. 5.18a). Also the copper prills in the Type B inclusions should be completely melted, leaving rounded sulphide inclusions behind if the metal would have been completely melted before casting. Therefore, it seems highly likely that the (unalloyed) copper inclusions in the Fazael metal items evidence an incompletely melted state of the metal upon casting. In addition, the copper inclusion could be the earliest direct evidence for the deliberate mixing of copper-based metals (cf. chap. 5.2.5.3.2).

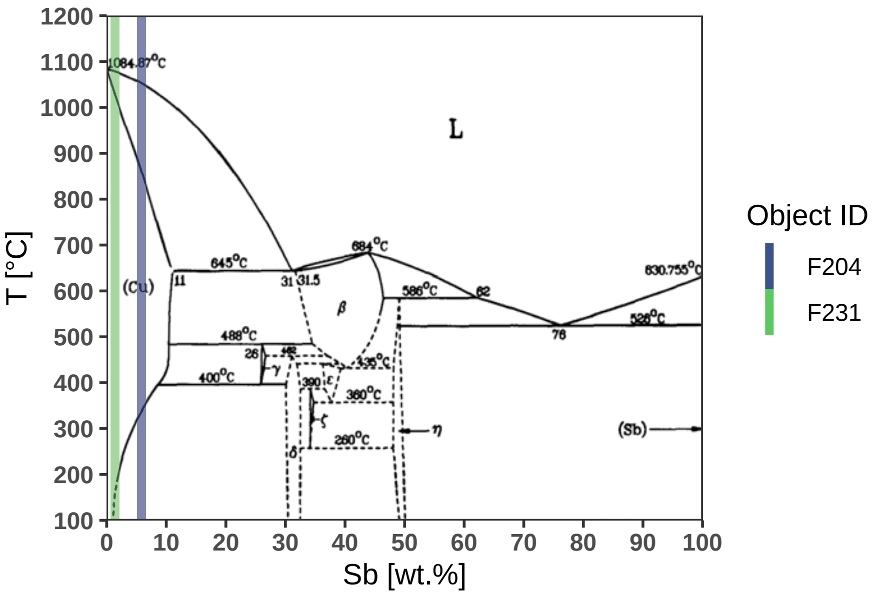


Figure 5.30: Cu-Sb phase diagram with the pseudo-bulk compositions of F204-m and F231-m (cf. Tab. 5.6). Phase diagram redrawn from Massalski (1986).

**5.2.5.1.4 Quartz inclusions** Notis et al. (1984) suggested that the silica inclusions in the axe head from Bir-es Safadi are most likely quartz inclusions, originating from the crucible or mould. Silt-sized quartz is abundant in the Fazael crucible fragments. The extensive bloating of the crucible fragments and the heavily heat-affected rim of F219 suggest that part of the crucibles melted. While the clay was slagged and removed (no slag inclusions were found in the metals), the quartz could have remained in the melt.

This interpretation fits well with the quartz inclusions in F217-m, where they are limited to a certain area of the section, probably one that was closer to the original surface. However, it must be doubted that it explains the large amount of such inclusions throughout the entire section of, e.g., F703-m (Fig. 5.31). Following this interpretation, they would indicate substantial melting of the crucible or mould.

The admittedly very restricted evidence of crucibles in Fazael does not indicate such an extensive melting, neither do the many fragments found in Abu Matar (Shugar, 2000). In addition, it is unlikely that the quartz grains would have been able to penetrate that deeply into the metal melt when slag was removed completely at the same time. The mould as source for the quartz inclusion is even more unlikely because the melt requires heating and stirring after casting in order to distribute the quartz throughout the metal.

Another possibility would be the addition of the quartz to the metal batch either during or before melting. The shape and size of the inclusions is characteristic for loess, i.e. sediment moved by wind, which might have been trapped between stored metal pieces such as prills or was deliberately added to the metal melt to slag off impurities such as iron. In the latter case, stirring of the melt is to be expected to reach also impurities beyond the surface. In any case, the metals should also contain at least some slag inclusions – a perfect removal of the slagged material is extremely unlikely with the equipment available back then. Consequently, additional research is necessary before any definite answers can be provided.

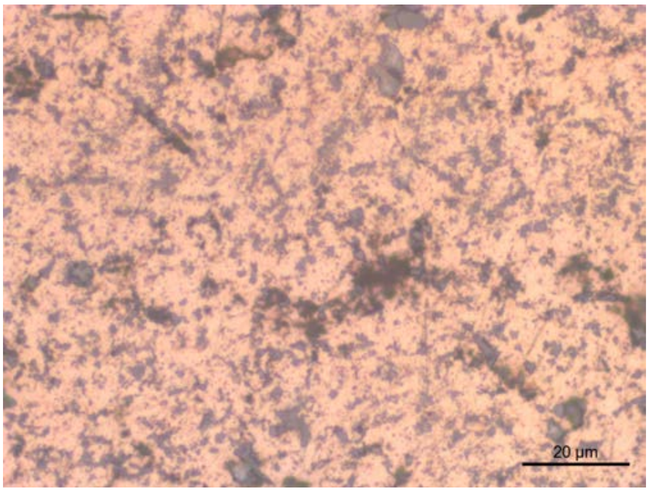


Figure 5.31: Photomicrograph of F703-m with many quartz inclusions.

#### 5.2.5.2 Ceramics

**5.2.5.2.1 Technology** As was shown in chap. 5.1, the pottery of the Chalcolithic Southern Levant was most likely tempered purpose-specific with exclusively chaff temper for metallurgical ceramics, mixed chaff and mineral temper for lost wax casting moulds and exclusive use of mineral temper for non-metallurgical pottery. Following this differentiation, F225 and F229 are not crucibles as suggested by Rosenberg et al. (2020) for F225, but non-metallurgical vessels. The flat base of F225 supports this interpretation because all known crucibles – including the fragments from Fazael – have rounded bases. In addition, these two sherds do not show traces of excessive heating such as slagging or bloating.

The exclusive use of chaff temper in all other sampled vessel fragments indicate that they are crucibles. This includes F219, interpreted by Rosenberg et al. (2020) as burnt glazed sediment. Their bloated state and their black colour are additional proof for metallurgical ceramics. Only crucibles and some furnace wall fragments from the Northern Negev sites show comparable features of excessive heating under reducing conditions. The interpretation as crucible fragments is further supported by the presence of slagged areas on the rim of F219 (Fig. 5.22b) and the copper prill on fragment F223 (Rosenberg et al., 2020, Tab. 4 and Fig. 12.3).

Unfortunately, the sampled fragments are too small for a reconstruction of the crucible shape. Taking into account the crucible fragments not available for petrographic examination, a conical shape with a rounded base similar to crucibles from Abu Matar (Golden, 2014a; Shugar, 2000) is likely. The reconstructed diameter is between 8 and 9 cm (Rosenberg et al., 2020, Tab. 4), considerably smaller than the ~ 12 cm of the Abu Matar crucibles (Shugar, 2000, p. 97). The height of several crucibles in Fazael should be smaller as well considering the substantial curvature of several crucible fragments (Rosenberg et al., 2020, fig. 12). The wall thickness and the smoothness of the surface is comparable with some of the crucibles found at the Northern Negev sites. However, the crucible type with a well-smoothed surface which dominates the assemblages of the 1990s excavation in Abu Matar and of Horvat Beter seems to be absent (Ackerfeld et al., 2020; Golden, 2014a; Hauptmann et al., 1993; Perrot, 1955c; Shugar, 2000). Admittedly, this could easily change when more than the present handful of crucible fragments is found in Fazael.

Following the concept of the purpose-specific temper choices, some of the baked sediment nodules would be fragments of lost wax casting moulds. Although the combination of mineral inclusions and vegetal temper was only observed in F2-YA3 (Fig. 5.23f), both types of non-plastic inclusions are present in F2-Y50 as well, albeit in different parts of the section. Other features unique to them further support an identification of the nodules as remains from lost wax casting moulds. As was shown by Goren (2008) and Goren (2014) and discussed in chap. 5.1, the presence of layers is another characteristic feature of a lost wax casting mould. Such different layers were observed in F2-Y39 (Fig. 5.23c), making it likely that this nodule is a mould fragment despite being devoid of non-plastic inclusions (mineral and vegetal). Subparallel orientation of very coarse vegetal material in F2-Y50 with some inclusion-free areas between them might indicate some kind of layering as well, albeit without a material contrast (Fig. 5.24). F2-Y64 could either be a mould or a crucible fragment, as its only notable petrographic feature is the use of vegetal temper. If it is a crucible fragment, it could derive from an unused crucible because the matrix does not show any typical features of the crucible fragments such as blackening of the clay or charred vegetal material.

The remaining nodules except F2-Y55 are plain clay without any inclusions or other special features. Their connection to metallurgical ceramics can be inferred because the clay is the same as for the other nodules and has strong similarities to the clay used for the crucibles. It is unlikely that they are crucible fragments, though. The crucible fragments have such a high proportion of vegetal matter that the area covered by the sections of the nodules would inevitably have contained some remains of vegetal material. In analogy to the areas void of chaff temper in F2-Y50 and F2-Y39, it seems more likely that they are mould remains.

The colour differences in the nodules, e.g., the orange matrix of F2-Y42 and the darkred-brown colour of F2-Y57, F2-YA3 and the finer layer in F2-Y39, might be correlated with the extent of heating the nodules experienced. A change to darker colours with increasing temperature is caused by the heat-induced removal of water in the iron oxyhydroxides and their transformation to haematite. This transformation occurs between 250 to 300 °C (Palacios et al., 2011). Providing analytical evidence for this hypothesis is very challenging due to the mixture of natural haematite and iron oxyhydroxides in the unfired clay. If this hypothesis holds true, the different fragments could be related to different parts of Chalcolithic lost wax casting moulds. Given that many of them are part of the same finds cluster, some of them could even be from the same mould.

F2-Y55 is also part of this cluster. Although its clay paste and non-plastic inclusions correspond to the overall composition of the other nodules, it is markedly different by its blackened matrix and the glassy inclusions. Analogous to the crucibles, the blackened matrix indicates most likely heating under reducing conditions and the consequent insufficient combustion of organic compounds such as vegetal matter. However, no charred remains were observed in the negatives of the vegetal matter, different from the crucibles. This apparent contradiction could be explained by the handling of lost wax casting moulds: To remove the wax from the mould, they are heated in an oxidising atmosphere, creating porosity for the wax and/or the air in the mould by burning the vegetal material (cf. chap. 5.1). The subsequent casting of the metal will create a reducing atmosphere in the interior of the moulds, which reduces remaining organic material and blackens the matrix of the mould. Following this line of arguments, F2-Y55 would be a mould fragment very close to the metal melt–mould interface.

The clear borders of the vitrified inclusions to the clay matrix in F2-Y55 indicate that these inclusions were already part of the clay paste and were not created during firing of the clay. However, their rounded shape shows that they are not crushed material, rendering the addition of crushed slag unlikely. The absence of copper in their chemical composition excludes their origin from copper slag. Instead, the inclusions could be remains of vitrified ceramic material without direct contact to melted metal or from pottery production. Their true nature must remain open until comparable finds are made and analysed.

F225a seems to be a fragment of a baked sediment nodule by its shape but its clay paste is completely different from the clay of the other nodules and also from the clay used for F225 and F229. Consisting of vegetal and mineral non-plastic inclusions, it would be placed into the lost wax mould category according to the concept of the purpose-specific temper choices. At the same time, it is the only nodule with some kind of smoothed surface. A definite interpretation of this nodule is impossible due to its unique nature but it could indeed be part of a lost wax casting mould. Goren (2008) and Goren (2014) described several mould remains with more than one layer; each made from a different clay paste and concluded that lost wax casting moulds were generally made of two different materials. Accordingly, this nodule might be an example for the use of a different material for lost wax casting moulds in Fazael.

**5.2.5.2.2 Provenance** In addition to the technological interpretation of the ceramic finds, the reconstruction of their provenance is of equal importance. Goren (2008) showed that the clay must not necessarily be local because it was purposefully chosen for its refractory properties and well prepared. Consequently, suitable clay could have been important to the lost wax workshops.

It was already shown that the vessel fragments F225 and F229 are made of clay from the Moza formation. This clay, widely used for domestic pottery and lost wax casting moulds in the Chalcolithic Southern Levant, crops out along the foot of the Judean Plateau (Goren, 2008, 2006, 1995). The features of F225a suggests an origin from Rendzina soils, widely occurring along the Judean Plateau. Like the Moza clay, they are available close to Fazael at the foothills of the Judean Plateau.

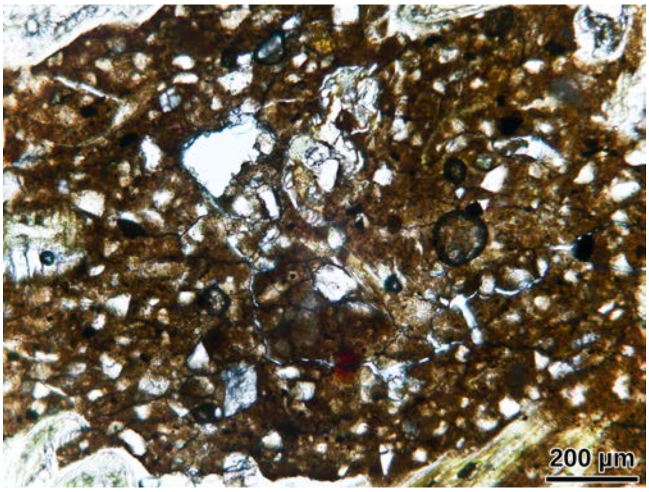


Figure 5.32: Photomicrograph of unfired Fazael clay mixed with vegetal matter.

The clay used for the crucibles and all other nodules is similar to the Negev loess in its amount of silt-sized inclusions of quartz and other minerals but clearly differs in its ferruginous character. A ferruginous loess of similar composition can be found at the banks of the Wadi Fazael close to the site. It has good refractory properties (Rose et al., 2021b). In the archaeological experiment (cf. chap. 5.1), the clay was elutriated to separate it from the carbonate sand. The so prepared clay shows all the features observed in the crucible fragments and nodules: A high proportion of silt-sized angular quartz and other minerals, a high content of iron-rich material, and a very low proportion of non-plastic inclusions (Fig. 5.32). The clay in the nodules and crucible fragments has a higher proportion of the silt-sized fraction and iron-rich aggregates than the clay prepared in the experiment. In addition, its content of non-plastic inclusions is lower. However, a clay paste with these properties could be easily prepared from the ferruginous loess in Fazael by applying a preparation protocol that removes the carbonate sand more efficiently and removes part of the clay fraction. Therefore, the clay for the metallurgical ceramics seems to be extracted directly at the site. Interestingly, none of the pottery fragments found at least during the 2020 excavation season at Fazael has the distinctive features of this clay.

#### 5.2.5.3 The polymetallic copper metallurgy in the Chalcolithic Southern Levant

**5.2.5.3.1 Fazael as production site** While the Fazael assemblage provides important insight into the processing of polymetallic copper alloys, there is little direct evidence that such activities were located at this site because, e.g., furnaces are yet to be found. The slag patches on F219 (Fig. 5.22b) link the crucibles to copper metallurgy in general, as does the vitrification and bloating of F219 and F228. The currently best direct evidence for the processing of polymetallic copper alloys is F236, the casting prill made of As-Ni copper. Admittedly, it cannot be entirely excluded that this presumably valuable material was brought from another site to Fazael.

Nevertheless, the presented results strongly indicate that lost wax casting – and thus processing of polymetallic copper alloys – was carried out in Fazael and probably specifically in Fazael 2. The heated sediment nodules show many features that must be considered specific for lost wax casting moulds, and the clay used for the crucibles and moulds is available close to the site. In contrast to metals, the transport of crucible fragments and mould remains to other sites appear unlikely. In addition, none of the vessel sherds at least from the 2020 excavation season was made of Fazael clay, indicating that it was probably exclusively used for metallurgical purposes. Its intense red-brown colour is very similar to haematite, a material from which many of the stone mace heads were crafted and its seemingly exclusive use in metallurgical operations could be directly related to the symbolic meaning of them and their metallic counterparts (Gošić, 2015; Rowan et al., 2006).

A location of the polymetallic copper alloy processing site(s) in the Jordan valley would fit with the observation that the Jordan valley is more closely related to regions further North, where the polymetallic copper alloys were derived from, than other regions in the Chalcolithic Southern Levant (cf. chap. 3.2.1). It must remain speculative whether the beneficial physical or potential symbolic properties of the ferruginous loess at Fazael were of importance for the location of the lost wax casting workshop(s). In any case, the Fazael area was already populated before the broad room house in Fazael 2 was built and settlement activities in the area continued after the end of the Chalcolithic (Bar et al., 2014; Zutovski and Bar, 2017). Thus, it should be expected that knowledge about the properties of the local clay was already available before the onset of the metallurgical activities.

The location of a lost wax casting workshop at Fazael has important implications for our understanding of the Chalcolithic Southern Levantine metallurgy. Probably most important, metallurgical operations were apparently not restricted to the Northern Negev as the archaeological record suggested so far (e.g., Golden, 2014b) but were also carried out in the Jordan valley. The admittedly scarce evidence further suggests that these activities might have been exclusively related to the processing of polymetallic copper alloys. This could imply a spatial separation of the unalloyed copper technology in the Northern Negev and the polymetallic copper alloys in the Jordan valley. Further, the findings confirm the results of Goren (2008), who localised the production site(s) of the lost wax casted objects somewhere in the Jordan valley or at En Gedi based on the occurrence of the different clays used in the moulds remains he investigated. However, ferruginous loess is not among the clay pastes described by Goren (2008) as mould material for Chalcolithic Southern Levantine lost wax cast objects. Consequently, more than one production site for lost wax casting must be assumed.

**5.2.5.3.2 Mixing, alloying or recycling?** While many of the metallurgical features of the Fazael assemblage confirm or enhance our concepts and notions about the metallurgy of the Chalcolithic Southern Levant, the (unalloyed) copper inclusions allow us to gain access to a previously entirely unknown aspect: mixing and alloying practices related to the polymetallic copper alloys.

Smelting sites for the polymetallic copper alloys are yet to be found (cf. chap. 4.1). It seems likely that they were located close to the fahl ore ore deposits exploited for their production, i.e., somewhere in Anatolia or the Southern Caucasus (Tadmor et al., 1995). Archaeometallurgical remains from these regions indicate that smelting operations were carried out in crucibles and yielded metal prills that needed to be mechanically extracted from the slag (cf. chap. 4.1.1.2, 4.1.1.3). Mixing of the polymetallic copper alloys with unalloyed copper could have happened there, when prills from both metal types were mixed and melted into a larger metal lump. Such prills could even be obtained in the same smelting event (cf. Lorscheider et al., 2003).

However, mixing of the metals in the Southern Levant seems to be more likely. Analyses of the polymetallic copper alloys did not reveal any chemical groups (Fig. 5.26), which could be expected if mixing was carried out in the ore provenance regions to meet certain requirements before exporting it. It seems plausible that the prills were directly exported instead and not combined into some kind of ingot in an additional step. This would not only save extra effort on the producer side, probably more important was that prills represent a smaller unit for exchange and allow on the consumer side a better control over the alloy's properties such as colour or castability, and the amount of metal per batch. In addition, it is in the Southern Levant that we now find evidence for the processing of polymetallic copper alloys such as casting prill F236, while even sites in the ore provenance' regions with suitable ore fragments remained devoid of such remains (cf. chap. 4.1.1.2).

Assuming that mixing happened in the Southern Levant, motivation for it was manifold. As already mentioned, increasing the copper content of the polymetallic copper alloys would change their colour and mechanical properties, turning it from silvery into golden or haematite-like colours. Mixing it with local unalloyed copper could also have been a strategy to extent the available amount of the more exclusive imported material. Alternatively, it was a reaction to a specific shortage in the supply of polymetallic copper. Such a shortage is suggested by Ben-Yosef et al. (2016) as reason why leaded copper was used in the Chalcolithic Southern Levant. This or even a disruption of the supply could have occurred at the end of the Chalcolithic, when the Kura-Araxes phenomenon spread towards the likely source regions of the polymetallic alloys (cf. chap. 3.2.1). Fazael 2 dates exactly into this period (Bar et al., 2013). Beside these more mundane aspects, reasons for mixing could also be related to symbolic practices such as adding local copper to make a foreign material local (cf. chap. 8).

The uniquely large number of fragments from polymetallic copper alloys in Fazael could even point towards recycling as a special case of mixing. Unalloyed copper could be added to the melt of recycled polymetallic copper alloys to balance the loss of material, as was suggested by Mödlinger and Trebsche (2021) for Bronze Age Austria. Motivation for the recycling of polymetallic copper alloys and metal in general might have been similar to the motivations for mixing. In addition, the spiritual connotations of the metals might have limited the possibilities for the disposal of old or damaged metal items and required their recycling. The overall depletion in As of the Fazael metal assemblage seems to support the interpretation as recycling. However, loss of As by repeated melting and casting is only one of three possibilities how such an As-depleted signature can be obtained. Keeping the metal longer in a melted state or a particularly oxidising melting process at Fazael could also result in the observed As-depletion. In addition, this argument assumed that all found metal items were produced in Fazael, an assumption that can currently be neither confirmed nor rejected.

The probably best indication for recycling could be the copper inclusion with a dendritic microstructure in F236. Such a microstructure could be the result of primary smelting but could also indicate that this copper inclusion derives from a previously cast metal object, either a finished object or a failed cast. The latter does not seem to explain the overall As-depleted signature of the metal assemblage, unless Fazael received a particularly high proportion of metal items that were made of recycled (failed) castings; or that the founders of Fazael were particularly untalented if all the metal items were indeed produced locally. If the (unalloyed) copper inclusions and the As-depleted signature of the Fazael metal assemblage indeed evidence recycling in the Chalcolithic Southern Levant, this could indicate a change from depositing metal items (e.g. in the Nahal Mishmar Hoard) to recycling them, probably in response of a supply shortage at the end of the Chalcolithic or regional differences in the deposition behaviour of the Chalcolithic Southern Levant. As intriguing as these thoughts may be, more research is needed before any reliable statements about the nature and motivation for the Southern Levantine mixing of copper alloys can be made.

### 5.2.6 Conclusions

Excavations in Fazael yielded a large number of metal objects, most of them fragments of polymetallic copper alloys, and several crucible fragments. While the archaeological context of the metal items and the crucible fragments was already presented by Rosenberg et al. (2020), its technological aspects remained unstudied. Therefore, their huge potential for a significant progress in our knowledge about the metallurgical practices of the Chalcolithic Southern Levant remained unleashed. In addition to the metal items and crucible fragments, heated sediment nodules were found in a later season and identified as potential remains of lost wax casting moulds. A selection of all three material groups was investigated using metallography, petrography and SEM-EDX in order to gain new insights into the metallurgical practices and to investigate if Fazael can securely be identified as lost wax casting site.

The results of the analyses confirmed the presence of crucibles for copper metallurgy at the site. Further, the heated sediment nodules have many features that are characteristic for lost wax casting moulds. Both are made of the same ferruginous loess, which is available on the riverbanks of the Wadi Fazael. The metal items revealed a wide range in their composition, representing the entire range of metals previously found in the Chalcolithic Southern Levant. In comparison with other assemblages, the metal objects present three important features: (a) their overall composition seems to be depleted in As, (b) the presence of (unalloyed) copper inclusions, and (c) F236, a casting prill made of As-Ni copper.

Based on this evidence it is possible to identify the heated sediment nodules with a very high likelihood as fragments of lost wax casting moulds. In combination with the crucible fragments, the use of local clay for the manufacture of both, and F236, Fazael can be convincingly interpreted as the first identified lost wax casting site of the Chalcolithic Southern Levant. At the same time, the ferruginous loess was not described as mould material in previous studies (Goren, 2014, 2008), indicating the presence of more than one lost wax casting workshop. With these results at hand, it is obvious that metallurgy in the Chalcolithic Southern Levant is not restricted to the confines of the Nahal Beer Sheva.

Furthermore, the (unalloyed) copper inclusions provide the earliest evidence for mixing/alloying in this region and to our knowledge the oldest evidence for alloying after the copper-rich gold objects in the cemetery Varna I (cf. Leusch et al., 2014). Unfortunately, the available information is too limited yet to allow any conclusions beyond the fact of mixing polymetallic copper alloys with unalloyed copper. It seems likely that such mixing happened in the Southern Levant, maybe in an attempt to increase the amount of the limited polymetallic copper alloys by the addition of local unalloyed copper. Indications for recycling could be the overall As-depleted chemistry of the assemblage and a dendritic copper inclusion in F236.

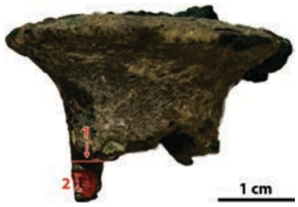
Although the available material is very limited, further studies would allow providing important additional information. Studying more of the nodules and metal objects would help to substantiate the conclusions drawn from this subset. With more sophisticated methods, the provenance of the polymetallic copper alloys and of the (unalloyed) copper inclusions could be reconstructed. An additional severe limitation to a better understanding of the metallurgical practices of the Chalcolithic Southern Levant is the very incomplete knowledge about the behaviour and phase evolution of these alloys. Dedicated studies towards a better understanding of this complex alloying system would allow gaining information about the casting process of these metals. For these reasons, this study can only provide the starting point for an in depth and multi-directional investigation of the metallurgical assemblage of Fazael.

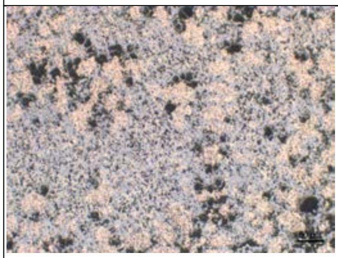
### 5.2.7 Catalogue

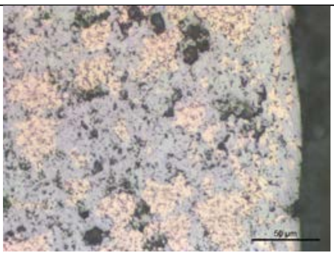
All values are given in at.%. Differences to 100% equals the at.% of O bound in the Oxides; n.o. = not observed.

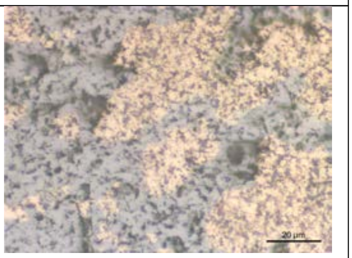
**F203** Rosenberg et al. 2020, fig. 7.1

Site: Fazael 2
Object: Standard (fragment)
Metallographical group: Polymetallic copper alloy with high levels of alloying elements
Microstructure: Dendritic copper with three interdendritic phases
Corrosion: extensive in entire section, preferentially of the polymetallic phases
Porosity: < 10 area%, mostly < 200 µm, shrinkage cavities (< 50 µm)
Pure Cu inclusions: No
Sulphide inclusions: No
Quartz inclusions: Yes

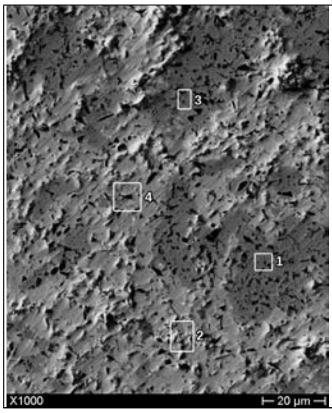








| | Section | Cu | Sb | Pb | As | Ag | $SiO_2$ |
|---|---|---|---|---|---|---|---|
| Bulk | F203-m1 | 68.11 ± 0.88 | 9.60 ± 0.42 | 1.11 ± 0.20 | 6.81 ± 0.87 | 0.73 ± 0.14 | 4.55 ± 0.50 |

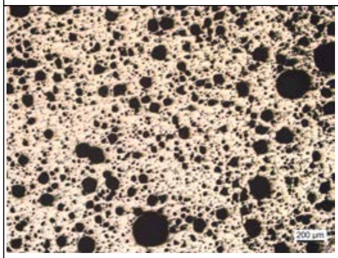


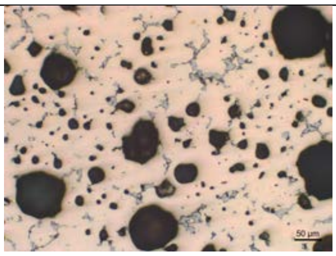
F203-m1 SE image

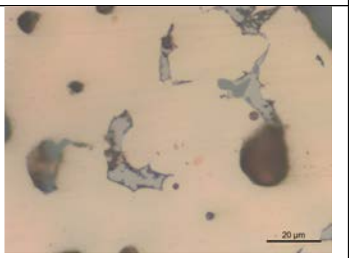
| Point | Cu | Sb | Pb | As | $SiO_2$ |
|---|---|---|---|---|---|
| 1 | 71.98 ± 0.81 | 2.94 ± 0.28 | n.o. | 4.90 ± 0.41 | 6.73 ± 0.47 |
| 2 | 59.29 ± 0.81 | 13.71 ± 0.43 | 0.59 ± 0.10 | 5.40 ± 0.84 | 7.00 ± 0.48 |
| 3 | 71.67 ± 0.80 | 3.00 ± 0.27 | 0.32 ± 0.09 | 4.81 ± 0.90 | 6.73 ± 0.43 |
| 4 | 61.12 ± 0.79 | 11.89 ± 0.4 | 0.36 ± 0.09 | 4.74 ± 0.79 | 7.30 ± 0.48 |

**F204** Rosenberg et al. 2020, fig. 7.2

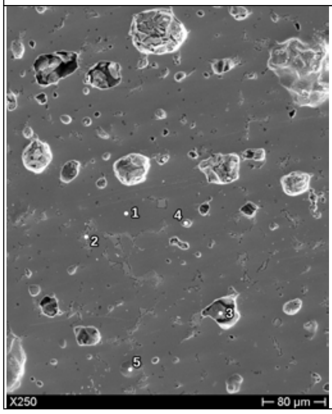
| | |
|---|---|
| Site: | Fazael 2 |
| Object: | Mace head (fragment) |
| Metallographical group: | Polymetallic copper alloy with low levels of alloying elements |
| Microstructure: | Cored dendrites with small amounts of one interdendritic phase and sparse grains of white phase |
| Corrosion: | Extensive on surface, abundant along phase boundaries |
| Porosity: | > 20 area%, often > 200 µm |
| Pure Cu inclusions: | Metal: some, < 10 µm; Corrosion: some, < 50 µm |
| Sulphide inclusions: | Yes |
| Quartz inclusions: | No |





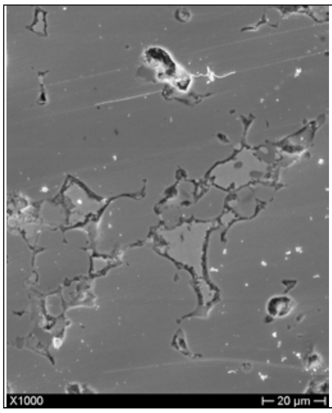


| | Section | Cu | Sb | Pb | $SiO_2$ | $Al_2O_3$ | Comment |
|---|---|---|---|---|---|---|---|
| Bulk | F204-m | 86.13 ± 1.48 | 2.79 ± 0.21 | 0.03 ± 0.16 | 0.25 ± 0.32 | 4.11 ± 0.54 | Remains of polishing powder |



F204-m SE image

| Point | Cu | Sb | Pb | As | Cl | $Al_2O_3$ | Comment |
|---|---|---|---|---|---|---|---|
| 1 | 98.84 ± 1.27 | 1.16 ± 0.19 | n.o. | n.o. | n.o. | n.o. | |
| 2 | 65.62 ± 1.63 | 28.35 ± 1.02 | n.o. | 1.92 ± 0.89 | 4.11 ± 0.79 | n.o. | |
| 3 | 14.43 ± 0.74 | 0.34 ± 0.14 | 0.03 ± 0.45 | n.o. | 0.35 ± 0.16 | 33.94 ± 1.22 | Pore with polishing powder |
| 4 | 97.15 ± 1.63 | 2.85 ± 0.52 | n.o. | n.o. | n.o. | n.o. | |
| 5 | 90.98 ± 1.60 | 4.31 ± 0.54 | 1.42 ± 0.59 | n.o. | n.o. | 1.32 ± 0.48 | |

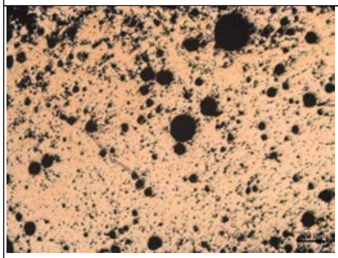


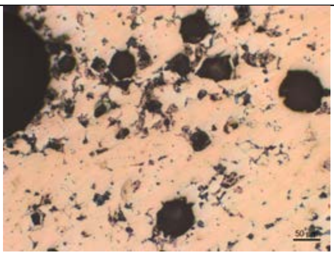
F204-m SE image

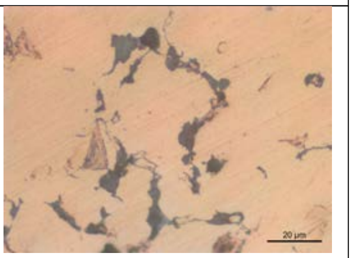
| Feature | Cu | Sb | Pb | S |
|---|---|---|---|---|
| Darkgrey round phase | 65.52 ± 1.00 | 3.61 ± 0.48 | 0.82 ± 0.48 | 30.05 ± 1.31 |
| Lightgrey phase | 74.55 ± 1.24 | 22.69 ± 0.94 | 2.76 ± 0.74 | n.o. |

**F205** Rosenberg et al. 2020, fig. 10.1

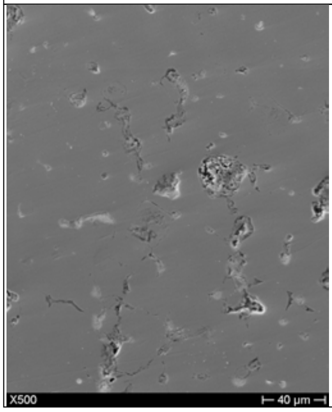
| | |
|---|---|
| Site: | Fazael 2 |
| Object: | Crown (fragment) |
| Metallographical group: | Polymetallic copper alloy with low levels of alloying elements |
| Microstructure: | Cored granular phase with small amounts of one intergranular phase |
| Corrosion: | Extensive on surface, interdendritic phase almost completely corroded, abundant corrosion along copper grain boundaries |
| Porosity: | > 10 area%, some > 200 µm |
| Pure Cu inclusions: | Corrosion: abundant, < 50 µm, some grains with pseudo-hexagonal shape, along corrosion fractures |
| Sulphide inclusions: | No |
| Quartz inclusions: | No |





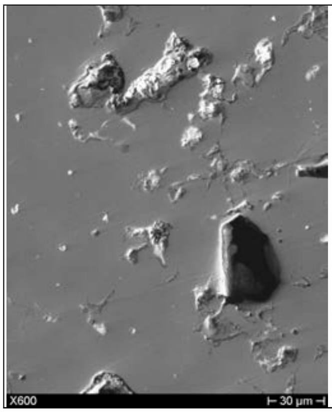


| | Section | Cu | Sb | Pb | As |
|---|---|---|---|---|---|
| Bulk | F205-m | 97.45 ± 1.37 | 0.90 ± 0.17 | 0.49 ± 0.14 | 1.16 ± 0.53 |



F205-m SE image

| Feature | Cu | Sb | Pb | As | Cl | Comment |
|---|---|---|---|---|---|---|
| Phase with rough surface | 69.33 ± 0.46 | 0.48 ± 0.07 | 0.53 ± 0.22 | n.o. | 29.66 ± 0.42 | Corrosion |
| Phase with rough surface | 73.16 ± 0.80 | 0.55 ± 0.12 | 1.08 ± 0.37 | n.o. | 25.20 ± 0.70 | Corrosion |
| Lightgrey phase | 57.83 ± 1.41 | 8.01 ± 0.79 | 17.11 ± 0.69 | 1.94 ± 0.63 | 15.11 ± 1.61 | Metal + Corrosion |

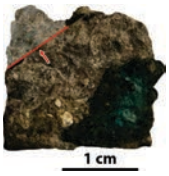


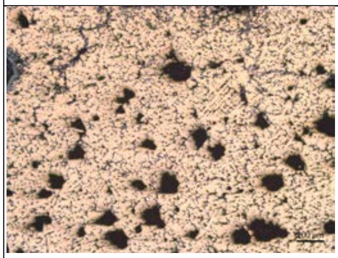
F205-m SE image

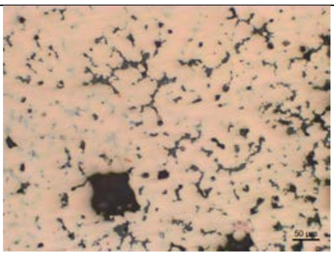
| Feature | Cu | Sb | Pb | $SiO_2$ |
|---|---|---|---|---|
| Phase with rough surface | 91.31 ± 1.21 | 1.16 ± 0.14 | 2.29 ± 0.44 | 1.75 ± 0.26 |

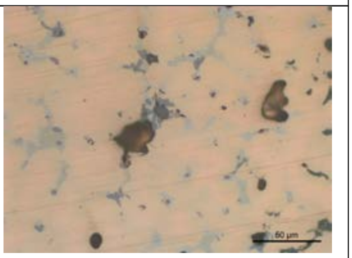
**F206** Rosenberg et al. 2020, fig. 9.1

| | |
|---|---|
| Site: | Fazael 2 |
| Object: | Axe (fragment) |
| Metallographical group: | Polymetallic copper alloy with low levels of alloying elements |
| Microstructure: | Cored granular phase with small amounts of three intergranular phases |
| Corrosion: | Extensive on surface, increasing intensity in interdendritic phase towards surface |
| Porosity: | < 10 area%, mostly < 200 µm |
| Pure Cu inclusions: | Corrosion: moderate, < 50 µm (at least one < 100 µm), some grains with pseudo-hexagonal shape, cluster in one area |
| Sulphide inclusions: | Yes |
| Quartz inclusions: | No |

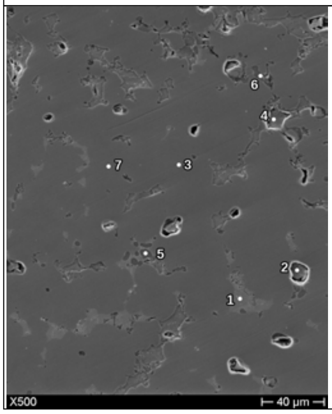






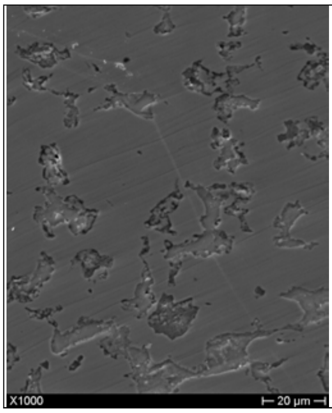


| | Section | Cu | Sb | Pb | As | Cl |
|---|---|---|---|---|---|---|
| Bulk | F206-m | 94.22 ± 1.12 | 3.48 ± 0.16 | 0.20 ± 0.12 | 1.39 ± 0.47 | 0.71 ± 0.20 |



F206-m SE image

| Point | Cu | Sb | Pb | Bi | As | Ag | S | Cl | Comment |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 94.07 ± 1.42 | 4.26 ± 0.61 | 1.67 ± 0.71 | n.o. | n.o. | n.o. | n.o. | n.o. | |
| 2 | 98.39 ± 1.44 | 1.61 ± 0.22 | n.o. | n.o. | n.o. | n.o. | n.o. | n.o. | Pore |
| 3 | 94.69 ± 1.40 | 3.01 ± 0.25 | 2.31 ± 0.70 | n.o. | n.o. | n.o. | n.o. | n.o. | |
| 4 | 88.02 ± 1.75 | 4.52 ± 0.29 | n.o. | n.o. | 6.36 ± 0.92 | n.o. | n.o. | 1.10 ± 0.32 | |
| 5 | 75.90 ± 1.59 | 1.70 ± 0.22 | n.o. | n.o. | n.o. | n.o. | 22.26 ± 1.02 | 0.14 ± 0.30 | |
| 6 | 87.35 ± 1.79 | 6.95 ± 0.72 | 4.08 ± 0.80 | 0.91 ± 0.77 | n.o. | 0.71 ± 0.28 | n.o. | n.o. | |
| 7 | 96.60 ± 1.79 | 1.48 ± 0.22 | 1.91 ± 0.64 | n.o. | n.o. | n.o. | n.o. | n.o. | |

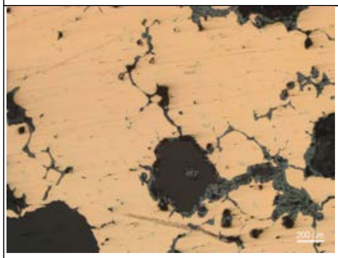


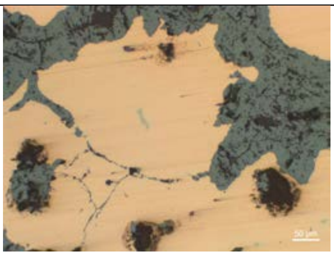
F206-m SE image

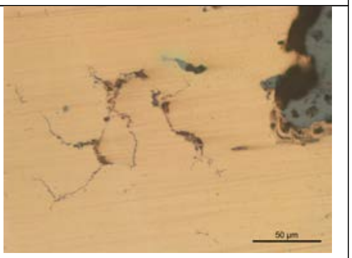
| Feature | Cu | Sb | S | $SiO_2$ | $K_2O$ | CaO | FeO | Cl | $Al_2O_3$ | Comment |
|---|---|---|---|---|---|---|---|---|---|---|
| Phase with rough surface | 9.58 ± 0.35 | 0.52 ± 0.33 | 0.40 ± 0.10 | 16.29 ± 0.39 | 0.45 ± 0.07 | 17.79 ± 0.39 | 0.87 ± 0.09 | 0.07 ± 0.08 | 1.03 ± 0.17 | Corrosion |
| Phase with rough surface | 54.01 ± 2.28 | n.o. | n.o. | 9.49 ± 1.32 | n.o. | 6.02 ± 0.75 | n.o. | 5.47 ± 0.89 | n.o. | Corrosion |

**F208** Rosenberg et al. 2020, fig. 10.2

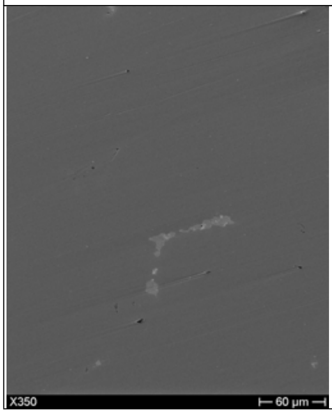
| | |
|---|---|
| Site: | Fazael 2 |
| Object: | Mace head (fragment) |
| Metallographical group: | Polymetallic copper alloy with low levels of alloying elements |
| Microstructure: | Cored granular phase with two intergranular phases |
| Corrosion: | Extensive at surface, along grain boundaries deep into the metal |
| Porosity: | Few pores |
| Pure Cu inclusions: | Corrosion: moderate, > 50 µm, mostly along fractures |
| Sulphide inclusions: | Yes |
| Quartz inclusions: | No |





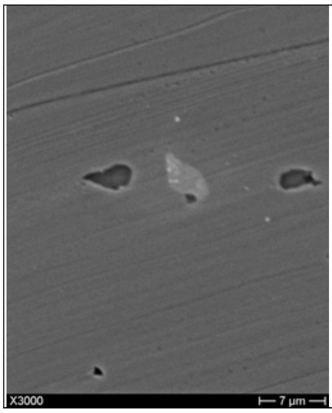


| | Section | Cu |
|---|---|---|
| Bulk | F208-m | 100.00 ± 1.2 |



F208-m SE image

| Feature | Cu | Sb | Pb | As | $SiO_2$ |
|---|---|---|---|---|---|
| Lightgrey phase | 82.16 ± 1.16 | 13.31 ± 0.55 | 0.42 ± 0.15 | 1.94 ± 0.45 | 0.73 ± 0.29 |

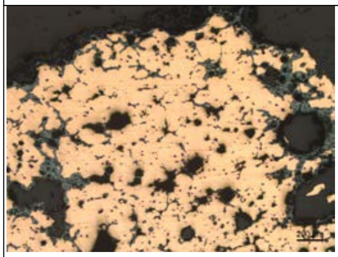


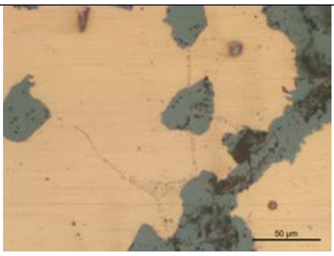
F208-m SE image

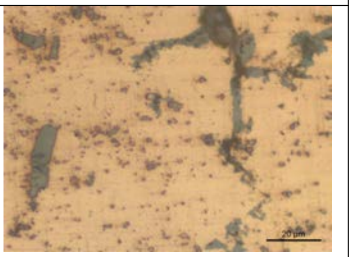
| Feature | Cu | Sb | Pb | $SiO_2$ |
|---|---|---|---|---|
| Lightgrey phase | 86.90 ± 1.00 | 10.73 ± 0.29 | 1.93 ± 0.55 | 0.15 ± 0.31 |

**F217** Rosenberg et al. 2020, fig. 7.5

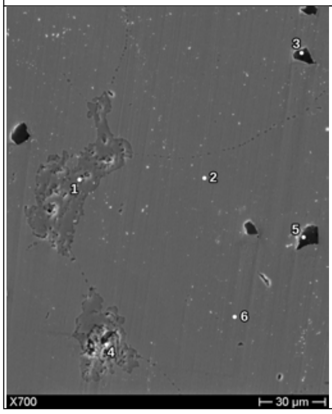
| | |
|---|---|
| Site: | Fazael 2 |
| Object: | Standard (fragment) |
| Metallographical group: | Pure copper |
| Microstructure: | Granular copper matrix with intergranular Cu-CuO eutectic |
| Corrosion: | Extensive at surface and along grain boundaries |
| Porosity: | > 10 area%, some > 200 µm |
| Pure Cu inclusions: | Corrosion: few, < 20 µm |
| Sulphide inclusions: | No |
| Quartz inclusions: | Yes, in some areas |





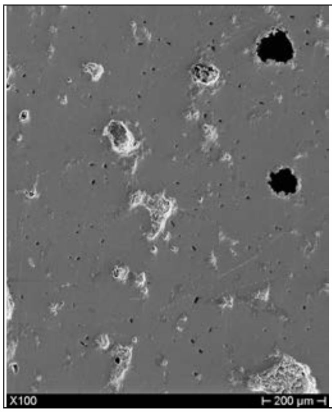


| | Section | Cu | $SiO_2$ |
|---|---|---|---|
| Bulk | F217-m | 95.64 ± 0.99 | 1.45 ± 0.23 |



F217-m SE image

| Point | Cu | $SiO_2$ | $Al_2O_3$ | Comment |
|---|---|---|---|---|
| 1 | 100.00 ± 1.08 | n.o. | n.o. | Corrosion |
| 2 | 100.00 ± 1.01 | n.o. | n.o. | |
| 3 | 100.00 ± 1.00 | n.o. | n.o. | |
| 4 | 89.06 ± 0.99 | 1.52 ± 0.27 | 2.55 ± 0.36 | Corrosion, remains of polishing powder |
| 5 | 100.00 ± 0.99 | n.o. | n.o. | |
| 6 | 100.00 ± 1.00 | n.o. | n.o. | |

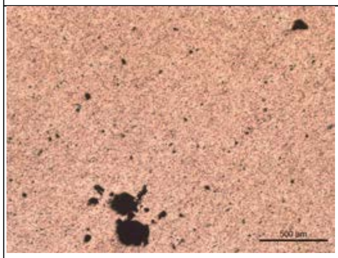


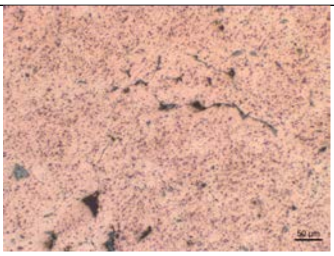
F217-m SE image

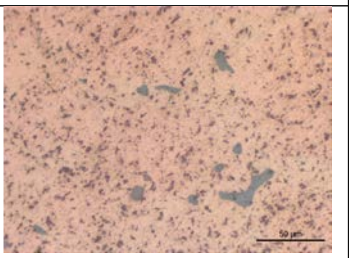
| Feature | Cu | $SiO_2$ | $Al_2O_3$ | Comment |
|---|---|---|---|---|
| Phase with rough surface | 85.89 ± 0.95 | 0.33 ± 0.18 | 5.25 ± 0.52 | Remains of polishing powder |
| Phase with rough surface | 70.99 ± 0.85 | n.o. | 11.60 ± 0.62 | Remains of polishing powder |
| Phase with rough surface | 75.55 ± 1.88 | n.o. | 9.78 ± 1.30 | Remains of polishing powder |

**F220** Rosenberg et al. 2020, fig. 9.4

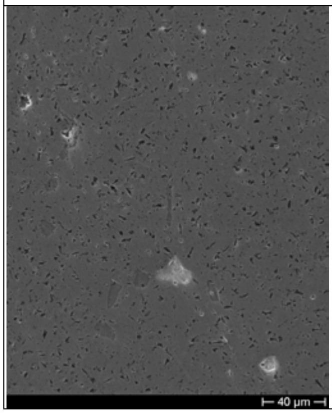
Site: Fazael 2
Object: Mace head (fragment)
Metallographical group: Polymetallic copper alloy with low levels of alloying elements
Microstructure: Granular matrix with very few inclusion of second phase
Corrosion: Extensive on surface, rarely along grain boundaries
Porosity: Very few pores < 200 µm
Pure Cu inclusions: No
Sulphide inclusions: Yes
Quartz inclusions: Yes





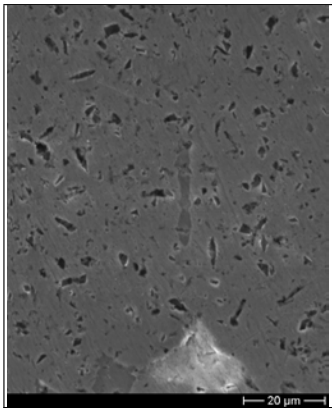


| | Section | Cu | $SiO_2$ |
|---|---|---|---|
| Bulk | F220-m | 79.57 ± 0.84 | 6.81 ± 0.47 |
| Bulk | F220-m | 81.21 ± 0.88 | 6.26 ± 0.48 |



F220-m SE image

| Feature | Cu | Sb | Pb | S |
|---|---|---|---|---|
| Lightgrey phase | 11.40 ± 1.13 | 43.74 ± 1.51 | 44.86 ± 0.79 | n.o. |
| Lightgrey phase | 25.47 ± 2.08 | 29.43 ± 1.91 | 45.11 ± 4.03 | n.o. |
| Elliptical darkgrey phase in centre | 69.01 ± 0.84 | 0.45 ± 0.10 | 1.00 ± 0.33 | 29.54 ± 0.85 |



F220-m SE image

| Feature | Cu | S | $SiO_2$ | Comment |
|---|---|---|---|---|
| Black phase | 47.59 ± 1.03 | n.o. | 17.47 ± 0.68 | With quartz inclusions |
| Black phase | 64.94 ± 1.17 | 35.06 ± 0.91 | n.o. | |

**F231** Rosenberg et al. 2020, fig. 6.4

Site: Fazael 2

Object: Crown (fragment)

Metallographical group: F231

Microstructure: Cored granular phase with three intergranular phases, sometimes present as eutectic

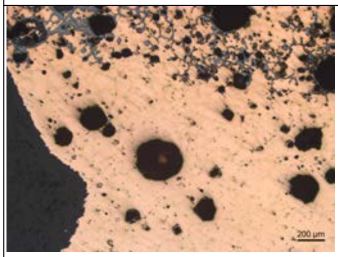
Corrosion: Extensive in one side of section and as replacement of intergranular phases deeper into the metal

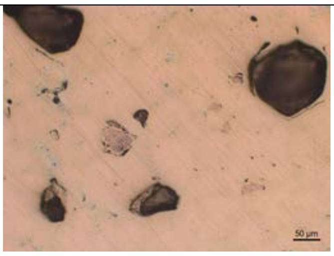
Porosity: 10 to 20 area%, < 500 µm

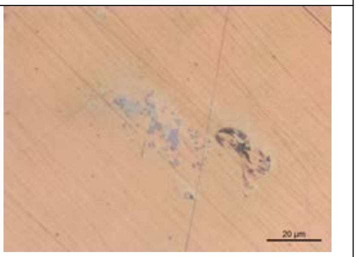
Pure Cu inclusions: Metal: some, < 50 µm, some with resorption-like shape; Corrosion: abundant, < 50 µm (some with hexagonal shape)

Sulphide inclusions: No

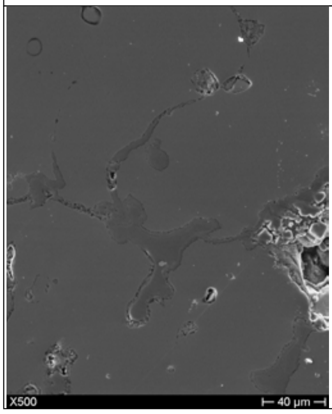
Quartz inclusions: No





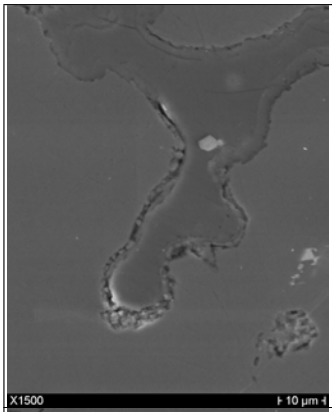


| | Section | Cu | Sb |
|---|---|---|---|
| Bulk | F231-m | 99.28 ± 1.57 | 0.72 ± 0.17 |



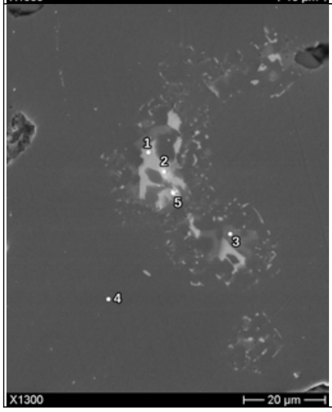
F231-m SE image

| Feature | Cu | Sb | Pb | Bi | Ag |
|---|---|---|---|---|---|
| Darkgrey phase | 92.12 ± 1.24 | 3.17 ± 0.54 | 2.27 ± 0.65 | 2.44 ± 0.70 | n.o. |
| Lightgrey grain in centre | 10.00 ± 1.19 | n.o. | n.o. | n.o. | 90.00 ± 1.66 |
| Matrix | 100.00 ± 1.58 | n.o. | n.o. | n.o. | n.o. |



F231-m SE image

| Feature | Cu | Bi | Ag |
|---|---|---|---|
| Rim between phases | 8.73 ± 0.72 | 20.44 ± 1.54 | 70.84 ± 1.88 |

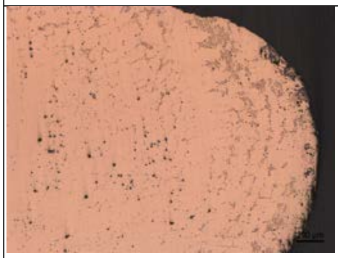


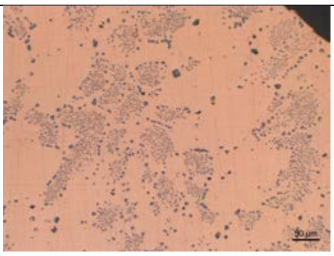
F231-m SE image

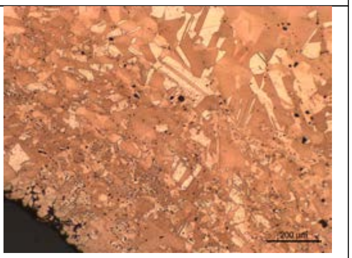
| Point | Cu | Sb | Pb | Bi | Ag |
|---|---|---|---|---|---|
| 1 | 94.50 ± 1.22 | 1.36 ± 0.21 | 2.09 ± 0.59 | 2.05 ± 0.62 | n.o. |
| 2 | 78.03 ± 1.23 | 19.43 ± 0.87 | n.o. | 1.43 ± 0.76 | 1.11 ± 0.26 |
| 3 | 88.23 ± 1.58 | 11.66 ± 0.69 | n.o. | 0.11 ± 0.67 | n.o. |
| 4 | 99.62 ± 1.59 | 0.38 ± 0.17 | n.o. | n.o. | n.o. |
| 5 | 19.41 ± 1.04 | 4.14 ± 0.62 | n.o. | 76.45 ± 4.30 | n.o. |

**F234** Rosenberg et al. 2020, fig. 4.4

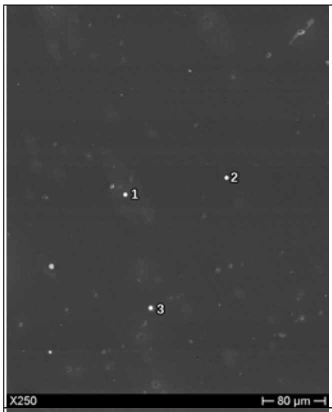
| | |
|---|---|
| Site: | Fazael 2 |
| Object: | Axe (fragment) |
| Metallographical group: | Pure copper |
| Microstructure: | At the surface copper dendrites with interdendritic Cu-CuO eutectic, in centre granular copper matrix (grains up to 800 µm) with some Cu-Oxide inclusions |
| Corrosion: | Only very close to surface |
| Porosity: | No |
| Pure Cu inclusions: | No |
| Sulphide inclusions: | No |
| Quartz inclusions: | No |





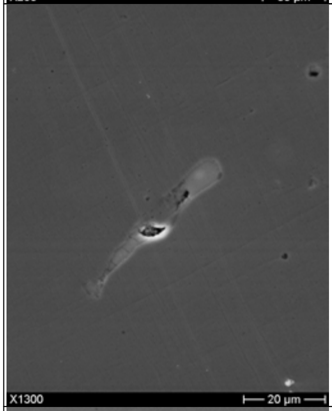


| | Section | Cu | Sb |
|---|---|---|---|
| Bulk | F234-m | 99.66 ± 1.46 | 0.34 ± 0.15 |



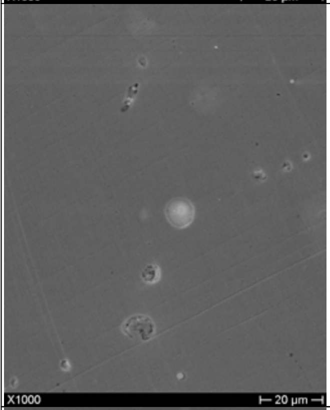
F234-m SE image

| Point | Cu | Sb | Pb | Comment |
|---|---|---|---|---|
| 1 | 99.30 ± 1.20 | 0.31 ± 0.15 | 0.39 ± 0.49 | |
| 2 | 99.78 ± 1.21 | 0.22 ± 0.15 | n.o. | |
| 3 | 100.00 ± 1.21 | n.o. | n.o. | Cuprite |



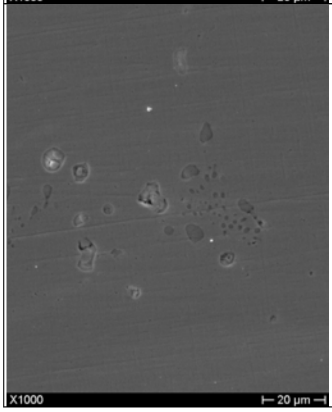
F234-m SE image

| Feature | Cu | Sb | Pb | S | Cl |
|---|---|---|---|---|---|
| Lightgrey phase | 12.50 ± 1.49 | 73.12 ± 2.04 | 9.48 ± 1.35 | 1.72 ± 1.34 | n.o. |
| Lightgrey phase | 10.30 ± 0.87 | 74.26 ± 1.97 | 5.70 ± 1.27 | 2.25 ± 1.37 | 2.35 ± 0.86 |



F234-m SE image

| Feature | Cu | Sb |
|---|---|---|
| Round lightgrey phase | 90.70 ± 1.72 | 9.30 ± 0.70 |



F234-m SE image

| Feature | Cu | Sb | Pb | Bi | Comment |
|---|---|---|---|---|---|
| Darkgrey phase | 99.85 ± 1.86 | 0.15 ± 0.19 | n.o. | n.o. | Cuprite |
| Lightgrey phase | 78.90 ± 1.88 | 19.23 ± 0.98 | 1.87 ± 0.81 | n.o. | |
| Lightgrey phase | 90.65 ± 1.35 | 7.81 ± 0.68 | 1.09 ± 0.63 | 0.46 ± 0.65 | |

**F236** Rosenberg et al. 2020, fig. 10.10

Site: Fazael 2

Object: Metal chunk (casting prill?)

Metallographical group: Polymetallic copper alloy with high levels of alloying elements

Microstructure: Dendritic matrix with abundant inter-dendritic phase

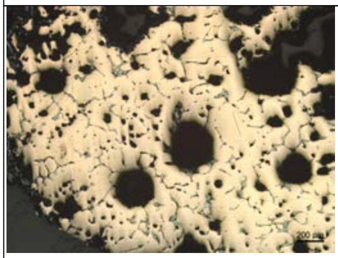
Corrosion: Limited to surface and along pores, sometimes deeper into metal along interdendritic phase

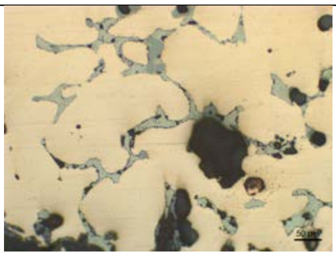
Porosity: > 10 area%, often > 500 µm

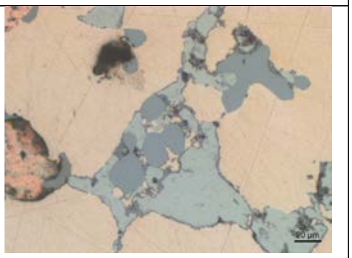
Pure Cu inclusions: Metal: abundant, < 50 µm, many of them multi-phase, sometimes with resorption-like shape or dendrites with removed interdendritic, one two-grained

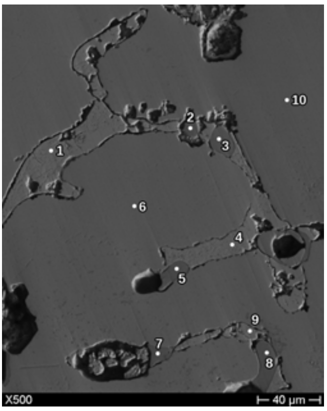
Sulphide inclusions: Yes

Quartz inclusions: No



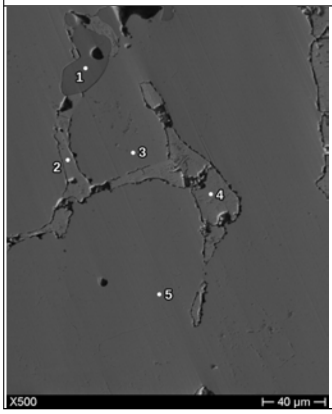






F236-m BSE image

| Point | Cu | As | Ni | S |
|---|---|---|---|---|
| 1 | 68.99 ± 0.67 | 29.82 ± 1.22 | 1.19 ± 0.18 | n.o. |
| 2 | 87.48 ± 0.99 | 8.03 ± 0.92 | 4.49 ± 0.23 | n.o. |
| 3 | 88.97 ± 0.98 | 6.90 ± 0.84 | 4.14 ± 0.22 | n.o. |
| 4 | 70.69 ± 0.87 | 28.42 ± 1.19 | 0.89 ± 0.18 | n.o. |
| 5 | 65.18 ± 0.77 | n.o. | n.o. | 34.82 ± 0.61 |
| 6 | 89.36 ± 0.99 | 5.28 ± 0.48 | 5.36 ± 0.44 | n.o. |
| 7 | 69.19 ± 0.82 | n.o. | n.o. | 30.81 ± 0.62 |
| 8 | 67.47 ± 0.87 | 21.21 ± 1.11 | 2.19 ± 0.36 | 9.13 ± 0.56 |
| 9 | 70.16 ± 0.92 | 22.70 ± 1.18 | 4.71 ± 0.43 | 2.43 ± 0.27 |
| 10 | 90.03 ± 0.99 | 3.33 ± 0.45 | 6.64 ± 0.44 | n.o. |

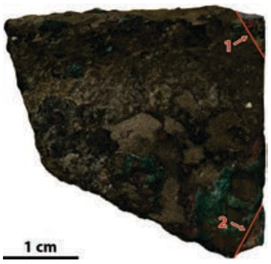


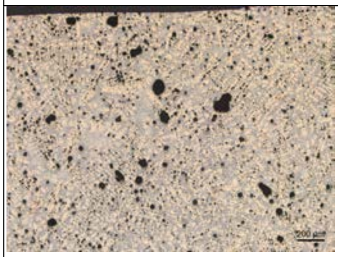
F236-m BSE image

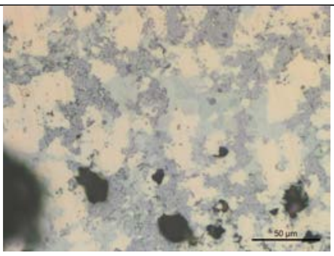
| Point | Cu | As | Ni | S |
|---|---|---|---|---|
| 1 | 65.53 ± 0.77 | n.o. | n.o. | 34.47 ± 0.60 |
| 2 | 71.29 ± 0.90 | 27.63 ± 0.83 | 1.08 ± 0.18 | n.o. |
| 3 | 89.74 ± 0.99 | 4.70 ± 0.48 | 5.56 ± 0.25 | n.o. |
| 4 | 76.73 ± 0.98 | 21.24 ± 1.13 | 1.83 ± 0.21 | 0.20 ± 0.23 |
| 5 | 90.2 ± 1.00 | 3.56 ± 0.46 | 6.24 ± 0.26 | n.o. |

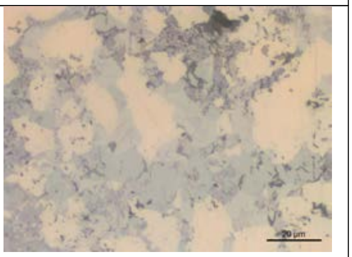
**F238** Rosenberg et al. 2020, fig. 6.5

| | |
|---|---|
| Site: | Fazael 2 |
| Object: | Crown (fragment) |
| Metallographical group: | Polymetallic copper alloy with high levels of alloying elements |
| Microstructure: | Dendritic copper with more than four interdendritic phases and small bright grains |
| Corrosion: | Extensive in interdendritic phase throughout section |
| Porosity: | Few pores < 200 µm, shrinkage cavities (< 50 µm) |
| Pure Cu inclusions: | No |
| Sulphide inclusions: | Yes |
| Quartz inclusions: | No |

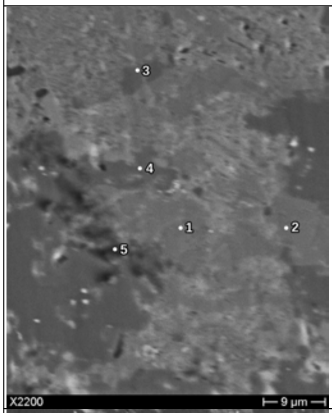






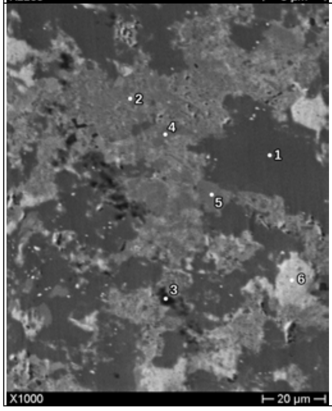


| | Section | Cu | Sb | Pb | Bi | As | $SiO_2$ | Cl |
|---|---|---|---|---|---|---|---|---|
| Bulk | F238-m1 | 79.04 ± 0.85 | 12.56 ± 0.58 | 3.96 ± 0.21 | 0.06 ± 0.53 | 4.38 ± 0.59 | n.o. | n.o. |
| Bulk | F238-m2 | 57.16 ± 1.06 | 12.29 ± 0.84 | 9.52 ± 0.63 | n.o. | 5.90 ± 1.96 | 2.08 ± 0.45 | 8.90 ± 1.40 |



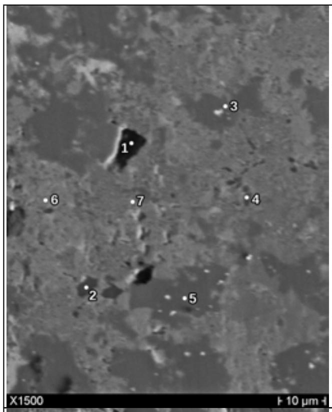
F238-m1 SE image

| Point | Cu | Sb | Pb | As | Cl | Comment |
|---|---|---|---|---|---|---|
| 1 | 69.41 ± 1.45 | 18.12 ± 0.82 | n.o. | 12.47 ± 1.67 | 6.96 ± 1.11 | |
| 2 | 69.27 ± 1.45 | 13.03 ± 0.80 | 4.08 ± 0.56 | 6.67 ± 0.80 | n.o. | Corrosion |
| 3 | 81.21 ± 1.42 | 8.32 ± 0.61 | n.o. | 10.47 ± 1.42 | n.o. | |
| 4 | 89.22 ± 1.47 | 5.26 ± 0.55 | 0.84 ± 0.18 | 4.68 ± 0.69 | n.o. | |
| 5 | 90.75 ± 1.18 | 4.19 ± 0.54 | n.o. | 5.06 ± 0.78 | n.o. | Corrosion |



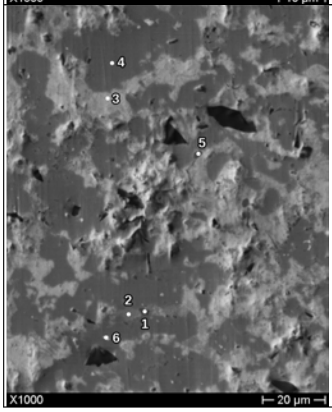
F238-m1 SE image

| Point | Cu | Sb | Pb | As | Ag | Fe | Cl | Comment |
|---|---|---|---|---|---|---|---|---|
| 1 | 94.29 ± 1.54 | 3.32 ± 0.49 | 0.04 ± 0.15 | 2.35 ± 0.71 | n.o. | n.o. | n.o. | |
| 2 | 72.12 ± 1.58 | 14.58 ± 0.82 | 2.37 ± 0.26 | 7.76 ± 0.84 | n.o. | n.o. | 3.17 ± 0.45 | |
| 3 | 65.86 ± 1.57 | 11.71 ± 0.43 | 7.55 ± 0.60 | 8.22 ± 0.92 | n.o. | n.o. | 6.65 ± 0.66 | Corrosion |
| 4 | 69.89 ± 1.18 | 16.88 ± 0.94 | 1.34 ± 0.24 | 8.78 ± 0.94 | 1.34 ± 0.33 | n.o. | 1.77 ± 0.42 | |
| 5 | 75.29 ± 1.58 | 14.96 ± 0.83 | 1.70 ± 0.23 | 5.03 ± 0.79 | 0.90 ± 0.28 | 0.47 ± 0.25 | 1.66 ± 0.4 | |
| 6 | 57.40 ± 2.17 | 12.19 ± 1.57 | 30.41 ± 1.29 | n.o. | n.o. | n.o. | n.o. | |



F238-m1 SE image

| Point | Cu | Sb | Pb | Bi | As | S | Cl | $Al_2O_3$ | Comment |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 27.45 ± 0.64 | 3.77 ± 0.39 | 0.67 ± 0.11 | n.o. | 0.85 ± 0.63 | n.o. | n.o. | 26.9 ± 1.18 | Pore, remains of polishing powder |
| 2 | 62.60 ± 1.18 | 2.51 ± 0.42 | n.o. | n.o. | 2.24 ± 0.53 | 32.64 ± 0.94 | n.o. | n.o. | |
| 3 | 81.83 ± 1.59 | 5.25 ± 0.72 | 9.07 ± 0.60 | n.o. | 3.62 ± 0.73 | n.o. | 0.22 ± 0.64 | n.o. | |
| 4 | 70.76 ± 1.58 | 13.00 ± 0.84 | 2.40 ± 0.26 | n.o. | 12.37 ± 0.97 | n.o. | 1.46 ± 0.42 | n.o. | |
| 5 | 92.47 ± 1.57 | 3.16 ± 0.52 | 0.19 ± 0.17 | n.o. | 3.87 ± 0.72 | n.o. | 0.31 ± 0.28 | n.o. | |
| 6 | 63.18 ± 1.55 | 24.01 ± 1.04 | 2.58 ± 0.28 | 1.53 ± 0.81 | 5.80 ± 0.87 | n.o. | 2.90 ± 0.55 | n.o. | |
| 7 | 69.48 ± 1.49 | 16.29 ± 0.83 | 1.88 ± 0.23 | n.o. | 10.32 ± 0.84 | n.o. | 2.03 ± 0.38 | n.o. | |



F238-m2 BSE image

| Point | Cu | Sb | Pb | As | Ag | $SiO_2$ | Cl | $Al_2O_3$ | Comment |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 82.24 ± 1.18 | 12.74 ± 0.71 | n.o. | 5.02 ± 0.85 | n.o. | n.o. | n.o. | n.o. | |
| 2 | 72.62 ± 1.57 | 19.52 ± 0.94 | 0.38 ± 0.19 | 2.82 ± 0.63 | 4.66 ± 0.58 | n.o. | n.o. | n.o. | |
| 3 | 7.87 ± 1.25 | 27.30 ± 1.62 | 34.68 ± 2.87 | n.o. | n.o. | n.o. | 30.15 | n.o. | n.o. Corrosion |
| 4 | 93.00 ± 1.51 | 2.69 ± 0.20 | n.o. | 4.31 ± 0.76 | n.o. | n.o. | n.o. | n.o. | |
| 5 | 91.13 ± 1.24 | 6.40 ± 0.59 | 0.32 ± 0.15 | 2.15 ± 0.59 | n.o. | n.o. | n.o. | n.o. | |
| 6 | 85.28 ± 1.41 | 3.43 ± 0.44 | 0.01 ± 0.13 | 4.28 ± 1.16 | n.o. | 2.17 ± 0.35 | 0.51 ± 0.22 | n.o. | |

**F241** Rosenberg et al. 2020, fig. 5.2

Site: Fazael 2

Object: Mace head (fragment)

Metallographical group: Polymetallic copper alloy with low levels of alloying elements

Microstructure: Cored granular matrix with some bright, sometimes hexagonal grains

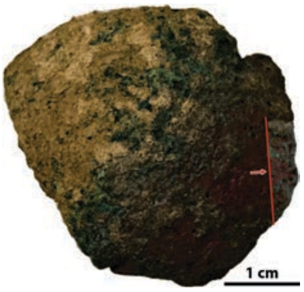
Corrosion: Only small portion of metal left with extensive corrosion probably along previous intergranular phase

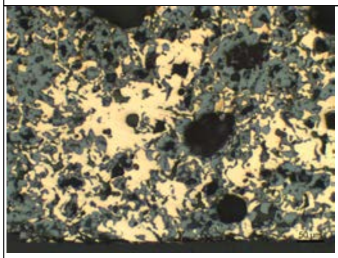
Porosity: Many, < 200 µm

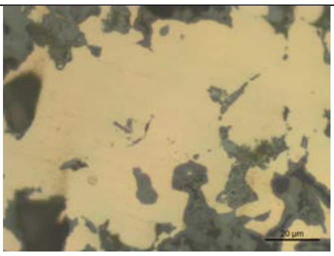
Pure Cu inclusions: No

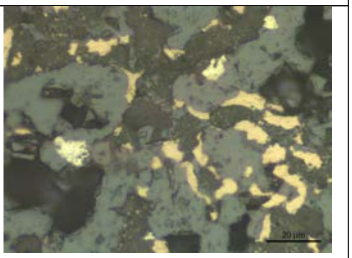
Sulphide inclusions: No

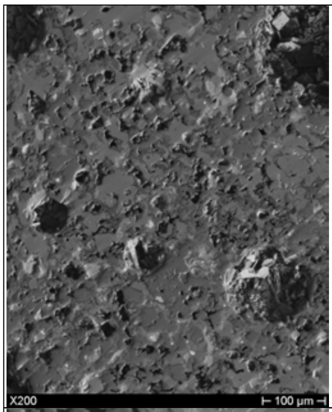
Quartz inclusions: No





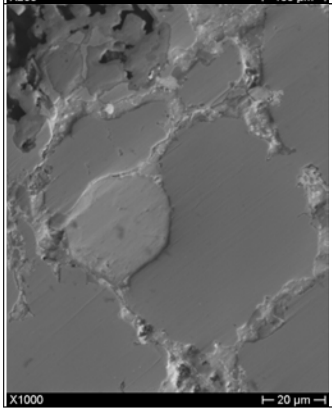






F241-c BSE image

| Feature | Cu | Sb | Pb | Bi | As | $Al_2O_3$ | Comment |
|---|---|---|---|---|---|---|---|
| Lightgrey phase | 14.13 ± 1.00 | 0.76 ± 0.34 | 40.00 ± 0.65 | 2.07 ± 1.04 | 15.19 ± 1.63 | 11.14 ± 0.97 | Corrosion |

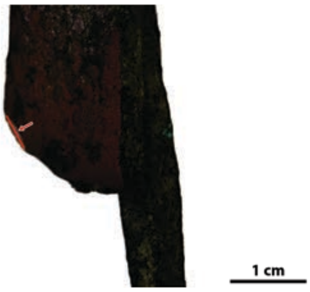


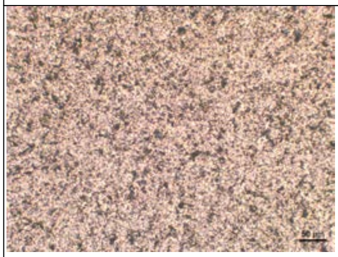
F241-c BSE image

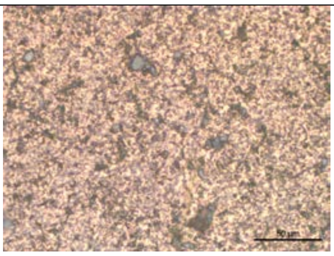
| Feature | Cu | Sb | Pb | As | S | Cl | Comment |
|---|---|---|---|---|---|---|---|
| Lightgrey phase | 97.78 ± 0.85 | 0.83 ± 0.13 | 1.40 ± 0.37 | n.o. | n.o. | n.o. | Corrosion, pore etc. |
| Darkgrey phase adjacent to whitish phase in top centre | 71.58 ± 0.89 | 0.43 ± 0.11 | n.o. | n.o. | 28.00 ± 0.64 | n.o. | |
| Bright phase | 24.66 ± 0.91 | 46.83 ± 0.93 | 0.40 ± 0.19 | 3.19 ± 0.50 | n.o. | 24.93 ± 0.83 | |
| Whitish phase in top centre | 34.18 ± 0.68 | 39.30 ± 0.87 | 0.87 ± 0.21 | 5.85 ± 1.03 | n.o. | 19.80 ± 0.84 | |

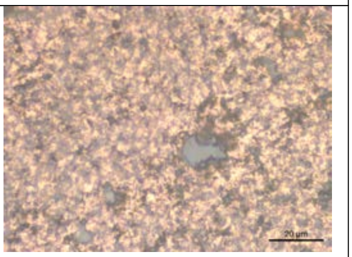
**F502** Rosenberg et al. 2020, fig. 8

Site: Fazael 5
Object: Axe (fragment)
Metallographical group: F502
Microstructure: Matrix of intimately intergrown yellow and grey phase without clear phase boundaries
Corrosion: No
Porosity: No
Pure Cu inclusions: No
Sulphide inclusions: No
Quartz inclusions: Yes

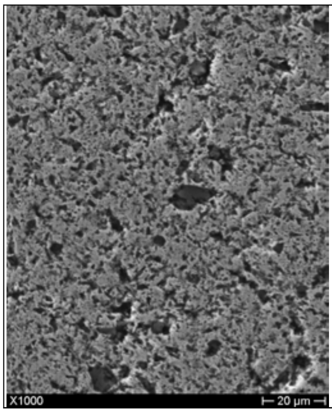








| | Section | Cu | As | Ni | $SiO_2$ |
|---|---|---|---|---|---|
| Bulk | F502-m | 43.83 ± 0.59 | 0.51 ± 0.30 | 1.14 ± 0.16 | 18.17 ± 0.55 |
| Bulk | F502-m | 42.85 ± 0.58 | 0.55 ± 0.29 | 0.91 ± 0.15 | 18.57 ± 0.55 |



F502-m SE image

| Feature | Cu | $SiO_2$ |
|---|---|---|
| Darkgrey inclusion | 1.67 ± 0.16 | 32.78 ± 0.47 |

**F703** Rosenberg et al. 2020, fig. 9.7

Site: Fazael 7

Object: Fragment

Metallographical group: Pure copper

Microstructure: Granular pure copper with extensive fractures

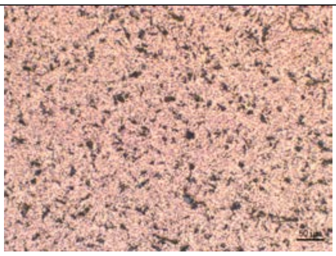
Corrosion: No

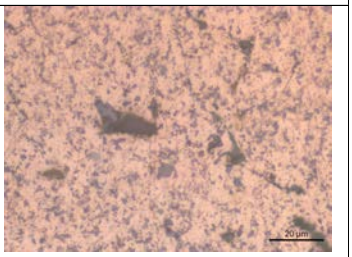
Porosity: No

Pure Cu inclusions: No

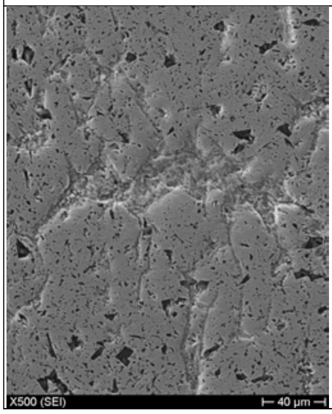
Sulphide inclusions: No

Quartz inclusions: Yes





| | Section | Cu | $SiO_2$ |
|---|---|---|---|
| Bulk | F703-m | 67.80 ± 1.08 | 10.73 ± 0.64 |

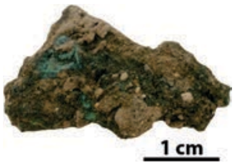


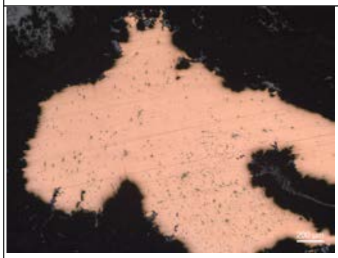
F703-m SE image

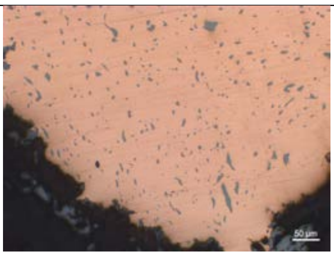
| Feature | Cu | $SiO_2$ | Comment |
|---|---|---|---|
| Matrix | 100.00 ± 1.55 | n.o. | |
| Phase with rough surface | 82.67 ± 1.30 | 5.78 ± 0.63 | Corrosion |
| Dark angular phase | 1.63 ± 0.26 | 32.79 ± 0.75 | |

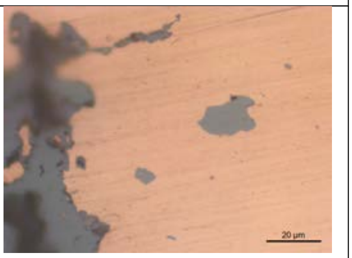
**F709** Rosenberg et al. 2020, fig. 11.2

Site: Fazael 7
Object: Metal chunk
Metallographical group: Pure copper
Microstructure: Granular matrix with elongated (< 100 µm) Cu oxide grains
Corrosion: Only small portion of metal left
Porosity: Very few pores, < 200 µm
Pure Cu inclusions: No
Sulphide inclusions: No
Quartz inclusions: No









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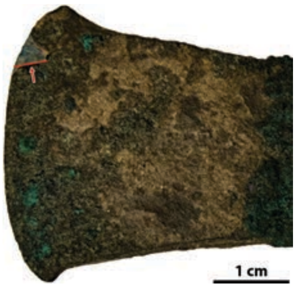
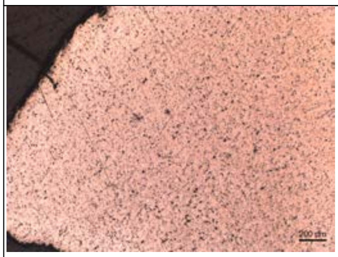
F709-c

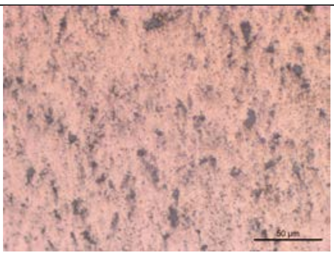
| Feature | Cu | S | Comment |
|---|---|---|---|
| Inclusion | 100.00 ± 2.46 | n.o. | Cuprite |
| Matrix | 98.51 ± 2.24 | 1.49 ± 0.49 | |

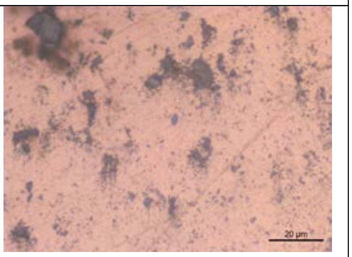
**F4-107**

Site: Fazael 4
Object: Axe
Metallographical group: Pure copper
Microstructure: Granular copper matrix with regularly dispersed cuprite
Corrosion: Limited to surface and along pores, sometimes deeper into metal along intergranular phase
Porosity: No
Pure Cu inclusions: No
Sulphide inclusions: No
Quartz inclusions: Yes

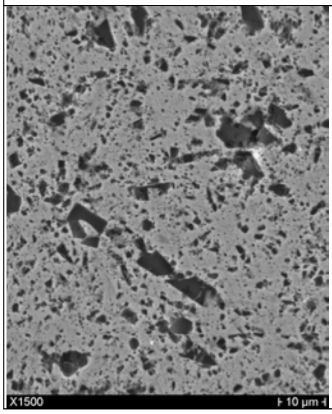








|  | Section | Cu | $SiO_2$ |
|---|---|---|---|
| Bulk | F4-107-m | 49.38 ± 0.56 | 16.87 ± 0.39 |
| Bulk | F4-107-m | 50.33 ± 0.57 | 16.56 ± 0.39 |



F4-107-m SE image

| Feature | Cu | $SiO_2$ |
|---|---|---|
| Dark phase | 2.14 ± 0.17 | 32.62 ± 0.33 |

# Chapter 6

# Pure copper metallurgy: Re-assessing Abu Matar

## 6.1 Introduction

The reconstruction of the pure copper process consists of two main steps: Smelting the ore in a shaft (Shugar, 2000) or pit furnace (Golden et al., 2001), and melting the copper prills into larger pieces of metal in crucibles placed in a pit furnace (Shugar, 2000). While Shugar (2000) leaves it open whether blowpipes or bellows were used for draught, Golden et al. (2001) states that blowpipes were placed in the opening of the pit furnace's collar and the furnace was covered with a ceramic lid to enhance the reducing atmosphere (see discussion in chap. 4.1.1.5.1).

Figure 6.1: Ceramic object 1299b with funnel-shaped feature from Abu Matar.

Building on the experience gained from smelting experiments (Rose et al., 2021b, 2021c) and general technological considerations, several details of these reconstructions seem questionable. As discussed in chap. 4.1.1.5.1, using a shaft furnace for melting should not result in furnace wall heavily slagged up to its rim as is the case for e.g., A-F-26 (Shugar, 2000, fig. 5.08). Using blowpipes as suggested by Golden et al. (2001) would only effectively heat an area about 10 to 15 cm in diameter, much less than the actual size of the pit furnace. In addition, the hot ceramic lid covering the furnace (Golden et al., 2001) would have needed to be moved permanently to add fuel and ore into the furnace and probably would have left visible wear on the rim of the furnace walls. However, such wear is not mentioned (Golden, 2014a; Golden et al., 2001; Shugar, 2000). Melting copper in a crucible in such a pit furnace seems cumbersome as well. The crucible is difficult to access from the side inside the pit furnace. Therefore, pouring the melted copper would require a change in the placement of the extraction tool it was held with (e.g., pliers): from above to take it out the furnace to sideways for pouring. This does not only cost time during which the melt cools down – probably a crucial parameter given that the temperatures in these furnaces were often just above the melting point of copper (Rehder, 2000) – but the round bases of the crucibles also pose a considerable risk of spilling the metal when putting it down, unless precautions are taken such as a suitable depression in the ground or handing the crucible over to another worker.

In order to refine the current reconstruction, the metallurgical assemblage of Abu Matar excavated in the 1990s (Gilead et al., 1992, 1991) was re-assessed. This re-examination led to the discovery of hitherto unnoticed objects which give important new insights into the pure copper metallurgy of the Chalcolithic Southern Levant, especially its draught technique.

## 6.2 Material

### 6.2.1 Metallurgical ceramics

1299b (Fig. 6.1) features on one side a flat funnel-shaped depression. The side next to the smaller end of the funnel is also slightly depressed. The surface of the funnel-shaped depression is red to purple-red while the material is white underneath. The opposite side of the fragment is grey to brown. This side is in its raw state and part of it invokes the impression as if it was placed on unprepared soil.

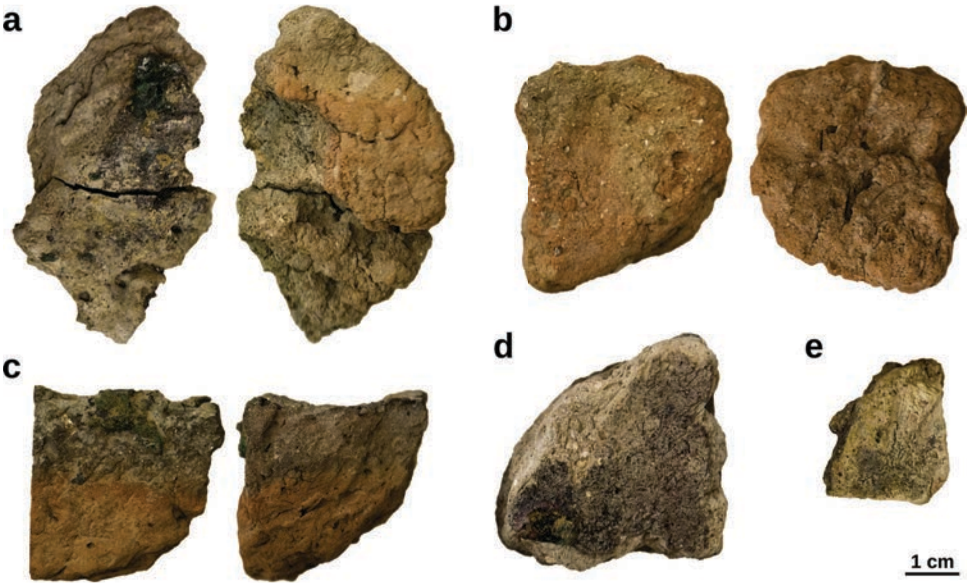


Figure 6.2: Fragments of metallurgical ceramics from Abu Matar with a distinct oblique round side of similar reconstructed diameter: (a) 1320, (b) 1324a, (c) M-F-14, (d) 1317, (e) 1649.

A group of objects (Fig. 6.2) vary in their appearance but have three traits in common: an oblique round side with a reconstructed diameter of around 8 cm, being comparatively thick, and most of them having one fully slagged side with the slag running over an edge to another side of the fragment. Exceptions are M-F-14 with only partial slagging on the two sides and 1324a, which is not slagged. While 1317, 1320, and 1649 have a white colour, 1324a and M-F-14 are red-brown or brick-coloured, indicating more reducing and oxidising heating conditions, respectively.

Fragment 1338 (Fig. 6.3) is a low-fired fragment with a clear channel-like depression. The reconstructed diameter of this feature is 2.5 to 3.0 cm. The fragment is slightly slagged on the side opposite the channel-like depression. It is made of chaff-tempered Negev loess and nearly free of non-mineral sand-sized inclusions, as are all other fragments mentioned so far and the metallurgical ceramics in Abu Matar in general (Shugar, 2000). One end of the channel-like depression has a grey colour while all other sides have the typical yellowish colour of Negev loess.

None of these fragments was further analysed. Objects with similar physical properties were already investigated by Shugar (2000) and it is highly unlikely that additional knowledge about their function or use could be gained through (invasive) analyses. Nevertheless, they are included in the discussion because of their intriguing morphologies.

Figure 6.3: Ceramic object 1338 from Abu Matar with a channel-like feature.

The last group of metallurgical ceramics are the sherds 1331 and A-C-59 (Fig. 6.4). While 1331 is a thin (about 6 mm thickness) rim fragment of a crucible, A-C-59 is an about 1 cm thick fragment with an oblique rim. Both are completely slagged on their interior side, but the slag on A-C-59 flowed over one of the fractures perpendicular to the rim and solidified there in a drop-like shape. Their ceramic paste is deviating from the paste of all other metallurgical ceramics by the regular occurrence of sand-sized carbonate grains and the absence of visible chaff-temper. 1331 was sampled for petrography to verify the difference in the ceramic paste.

### 6.2.2 Slag

A. Shugar exclusively analysed slag adhering to ceramics (Shugar, 2000, p. 184), leaving a large number of slag fragments unconsidered. While re-examining them, five pieces were picked for further investigation by reflected-light microscopy and SEM-EDX because they appeared to be different from the slag reported in Shugar (2000) and Shugar (2003).

Figure 6.4: Metallurgical ceramics from Abu Matar with ceramic pastes deviating from the other metallurgical ceramics: (a) 1331, (b) A-C-59.

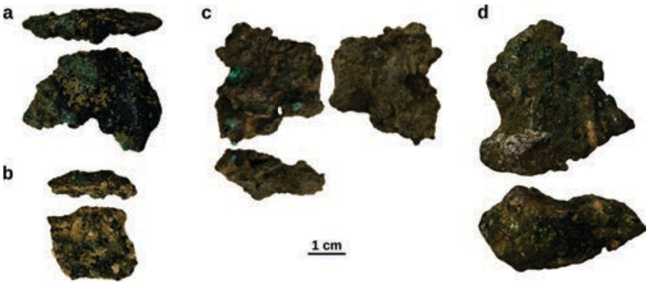


Figure 6.5: Slag pieces from Abu Matar: (a) A-S-1, (b) 1334, (c) A-1018, (d) 220-2242.

A-S-1 and 1334 (Fig. 6.5a,b) have a black-purple to grey surface with a fine-grained texture. This texture, their flat, plate-like shape and a comparatively low density clearly sets them apart from the other slag pieces found in Abu Matar. While 1334 has many yellow patches, green patches prevail on A-S-1. A-1018 (Fig. 6.5c) has a similar surface morphology but is considerably thicker and has a higher density. It was chosen for analysis because of its irregular shape and comparatively large size. Upon cutting, a copper prill was discovered in this fragment but was not part of the section taken for polishing. 220-2242 (Fig. 6.5d) is one of, if not the largest slag piece found in the material of 1990s excavations at Abu Matar. It has a rough but not grainy surface and features a channel-like depression with a reconstructed diameter of about 3.5 cm. This piece has a high density as well. The fifth fragment, 1335a (Fig. 6.6), is different from all other slag fragments. Its surface is smooth and shiny black with large yellow areas on one side and only a couple of small green patches. It has a rugged, complex morphology and a channel-like depression with a reconstructed diameter of 1.5 to 2.0 cm along its longitudinal axis. Breaks in some areas expose an unusually high porosity, which explains its comparatively low density.

## 6.3 Methods

The methods used for investigation of the materials are identical to the ones used for the analysis of the Fazael material (chap. 5.2.3). 1334, 220-2242, A-1018, and A-S-1 were prepared and analysed together with the Fazael metal samples at the Metallography Laboratory of the Dipartimento di Ingegneria Chimica Materiali Ambiente, Sapienza – Universitá di Roma. Unfortunately, many of the features observed in them with reflected light microscopy and under the SEM were smaller than the analytical resolution of the EDX system, often resulting in measuring more than one phase at a spot. Nevertheless, the combination of these analyses and the results of the optical examination provide important information about the phase composition of the slag and in turn the furnace conditions it experienced and the used ore. SEM analyses on 1335a and all other analytical work was carried out at the Ilse-Katz-Institute for Nanoscale Science & Technology, Ben-Gurion University of the Negev, Beer Sheva (Israel).

## 6.4 Results

### 6.4.1 Metallurgical ceramics

Typological comparisons revealed that 1331 and A-C-59 are rim fragments of a V-shaped bowl and a hole-mouth jar, respectively. Both are made of a very silt-rich clay paste. The silt-sized fraction consists of rounded to sub-angular grains, predominantly quartz, sometimes feldspar and rarely heavy minerals such as tourmaline or epidote. The clay paste is completely blackened, masking its optical properties. Darker areas in it could indicate the presence of iron oxide aggregates (Fig. 6.7a). Rare fine sand-sized carbonate and quartz grains are the only non-plastic inclusions of this clay paste in 1331. A-C-59 contains several coarse sand-sized carbonate grains (Fig. 6.7b).

Figure 6.6: Slagged object 1335a with a channel-like feature from Abu Matar.

### 6.4.2 Slag

1334 consists of sand-sized quartz grains, most with resorption rims. Embedded in the vitreous matrix between them is dendritic cuprite and copper together with delafossite needles (Fig. 6.8). Magnetite could not be found and SEM-EDX analyses revealed that iron is only present in glass and/or delafossite (chap. 6.7).

As already expected from the macroscopic examination, A-S-1 is similar to 1334. However, resorption textures are much more restricted and, in some areas, even absent (Fig. 6.9a,b). The material between the quartz grains shows a larger variety in its features than 1334. Some vein-like structures between quartz grains include abundant delafossite but no cuprite or metallic copper, while others include only cuprite dendrites or large amounts of tiny (< 5 µm) copper prills (Fig. 6.9c–f). Larger spaces between quartz grains host clearly delineated aggregates of the copper-rich phases (Fig. 6.9c,d). As in 1334, iron can only be detected in the glass phase and delafossite (chap. 6.7).

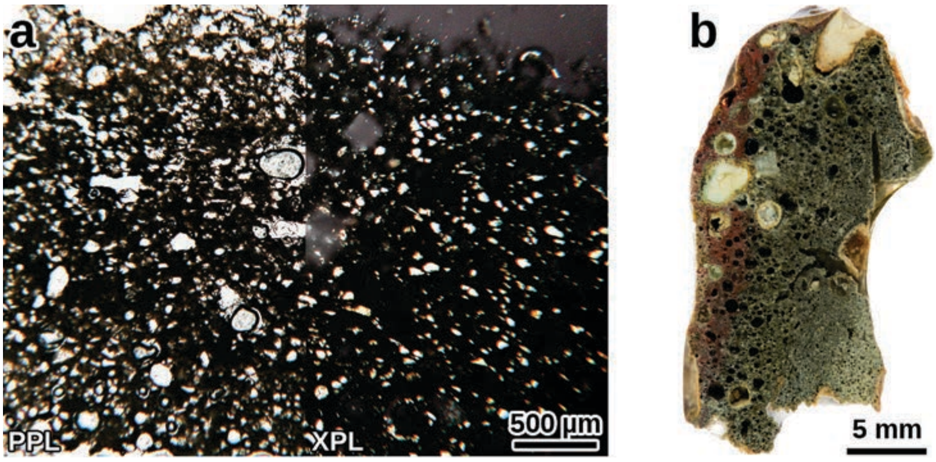


Figure 6.7: Clay paste of (a) 1331 in transmitted light (PPL and XPL) showing the blackened clay matrix and the large proportion of translucent silt-sized minerals and (b) cross-section of A-C-59, highlighting the presence of yellow to white coarse sand-sized carbonate grains.

A-1018 consists of areas with different microstructures (Fig. 6.10, chap. 6.7). While some areas are densely packed with cuprite, sometimes porous, and delafossite needles in the little remaining space between them (Fig. 6.10b), other areas appear to have a more vein-like structure. The microstructure of these areas consists of veins with cuprite dendrites or tiny copper prills and lath-shaped silicates in a vitreous matrix (Fig. 6.10c,d). Other areas seem to combine these two microstructures, consisting of almost massive cuprite with vein-shaped cuprite-rich features and silicates, and cuprite dendrites in between. In addition, patches with skeletal and (hyp)idiomorph magnetite crystals and abundant delafossite needles occur as well. Two other noteworthy features are found at the narrowest part of the section: The remains of what is now copper chloride (probably atacamite) and could be by its position the corroded outer layer of the copper prill, and a comparatively massive rim of slag on the surface of the fragment (Fig. 6.10a). The slag crystals in the latter feature are significantly larger (hyp)idiomorphic plates or lath-shaped crystals than anywhere else in the section and have chemical compositions similar to melilite and pyroxene, respectively. Inbetween sits a glassy matrix with many copper prills of different sizes.

220-2242 (Fig. 6.11, chap. 6.7) consists also of several different areas. Some of them are similar to the quartz-rich features observed in A-S-1, some feature the densely packed cuprite already observed in A-1018. In addition, some areas feature large amounts of cuprite together with skeletal and (hyp)idiomorphic magnetite while others host fan-shaped aggregates of slag minerals (Fig. 6.11a,c–e). Other areas again host large rhomboedric or hexagonal silicates (Fig. 6.11b), sometimes in a fan-like orientation (Fig. 6.11a). Their morphology and chemical composition identify them as melilites and pyroxenes, respectively. Between them occur magnetite crystals. In addition, crystals with the skeletal morphology of fayalite and compatible chemical compositions were observed as well (Fig. 6.11d; chap. 6.7, region 6 of 220-2242big) Other areas again feature (hyp)idiomorphic densely packed magnetite with little glass as the only other phase. Last, chalcocite and bornite are present in this section (Fig. 6.11f; chap. 6.7, region 7 of 220-2242big). The chalcocite always shows some extent of reaction during smelting but many chalcocite grains are still subangular, indicating that temperatures did not become hot enough to melt them. While corrosion was somewhat limited in the other sections, a lot of analyses on this section yielded Cl-rich copper phases (most likely atacamite) of what was by morphology once cuprite or metallic copper.

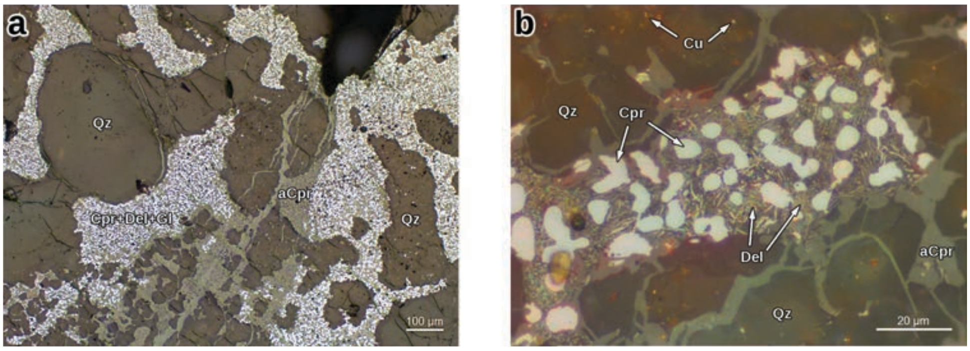


Figure 6.8: Photomicrographs of 1334 in reflected light at different magnifications. (a) Quartz (Qz) with areas of Cl-rich copper phases in between, probably altered cuprite (aCpr) and areas with cuprite and delafossite (Del) in glass (Gl). (b) Close-up of such an area, some quartz contains tiny copper prills (Cu).

1335a (Fig. 6.12) differs significantly from the other slag pieces by its porous yellowish and greyish-black areas. A thin band of this material is also present at the surface of the channel-like feature. Beside these areas, less porous areas with high lustre exist as well, which appear to be similar to the areas densely packed with cuprite in A-1018 and 220-2242. In addition, 1335a contained several copper prills which are now corroded as indicated by their high Cl content (Fig. 6.12a). SEM analyses of this fragment focused on the yellowish and greyish-black areas. They revealed silt-sized quartz (Fig. 6.12c) and vitrified but not slagged areas (Fig. 6.12b) with a consistently high Ca content, clearly distinctive from observations in the other fragments.

## 6.5 Discussion

### 6.5.1 Metallurgical ceramics

A clay paste of Negev loess and carbonate sand is typical for domestic pottery of the Northern Negev while Negev loess with vegetal temper was exclusively used for metallurgical ceramics (cf. chap. 5.1.7.2). Consequently, the petrographical and typological data therefore indicate the secondary use of a V-shaped bowl and a hole-mouth jar in a metallurgical context. The secondary use of domestic vessels was so far reported only for a V-shaped bowl from J. Perrot's excavation in Abu Matar (Golden, 2014a, p. 118). Additionally, Eldar and Baumgarten (1985) suggest the use of a vessel with about 16 cm diameter as furnace in Neve Noy but do not provide any details about the vessel type.

The use of V-shaped bowls as crucibles, indicated by the same slag features as found on genuine crucible fragments (Ackerfeld et al., 2020; Shugar, 2000), could suggest a connection between the rituals in which metallurgical practices (Gošić and Gilead, 2015a) and V-shaped bowls were probably embedded (Roux et al., 2013, p. 64; contra V-shaped bowls as ritual vessels: Kerner, 2010). However, with only two occurrences and both in Abu Matar, the archaeological evidence is yet too limited to reconstruct such a connection. The rare occurrence of this practice in the by far largest metallurgical assemblage of the Northern Negev could equally likely indicate the occasional use of them as substitute for genuine crucibles when the latter were not available.

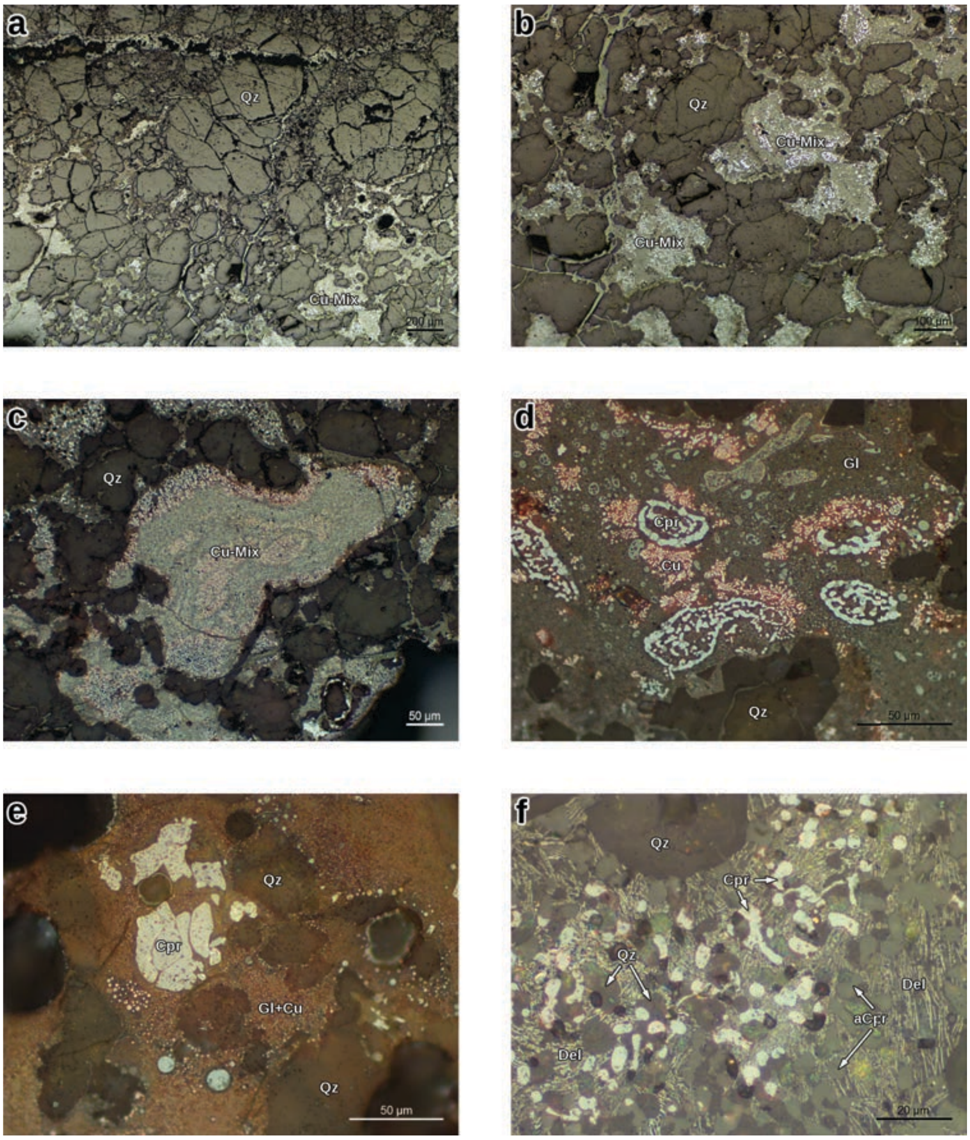


Figure 6.9: Photomicrographs of A-S-1 in reflected light at different magnifications. (a–c) densely and partially reacted quartz (Qz) with a mixture of different copper phases and glass in between (Cu-Mix). (d–e) Higher magnifications of the copper phases: cuprite (Cpr), glass with unidentified phases (Gl) and tiny copper prills (Cu), (f) cuprite, quartz, delafossite (Del, needles), and altered cuprite (aCpr) as indicated by the high Cl content in the SEM-EDX analyses.

A-C-59 is the first evidence for the secondary use of hole-mouth jars in metallurgical contexts in the Chalcolithic Southern Levant. The drop-shaped slag on a break perpendicular to the rim indicates that the vessel was already fragmented before its use and that this vessel fragment was orientated with the rim sideways and the break being at the lowest point but at least partially exposed. One possibility for its metallurgical function could be a placement of the fragment in the furnace wall, partially protruding out of it. The use of pottery fragments in furnace wall is known from roughly contemporary furnaces in Akladi Cheiri (about 4500 to 4300 BCE, cf. 4.1.1.1) at the western coast of the Black Sea (Krauss et al., 2020; Rehren et al.,

2020) and Çamlıbel Tarlası (mid-4th millennium BCE, cf. 4.1.1.2) in Central Anatolia (Rehren and Radivojević, 2010; Schoop, 2011) but evidence for this practice from the Chalcolithic Northern Negev is yet to be found, rendering such a use unlikely.

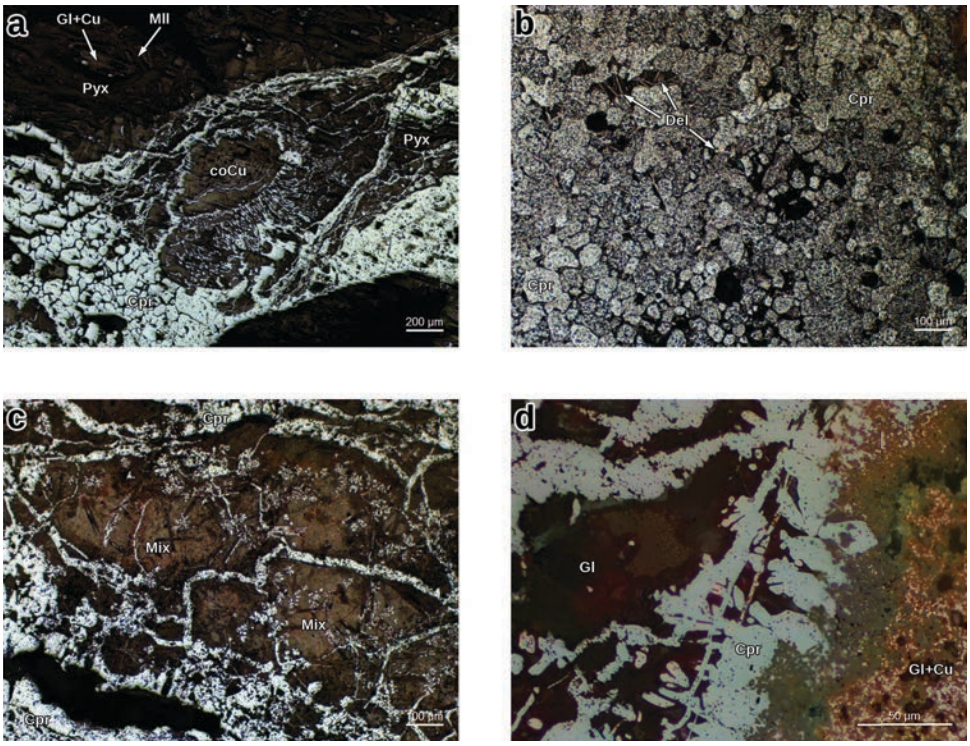


Figure 6.10: Photomicrographs of A-1018 in reflected light at different magnifications: (a) Corroded copper prill (coCu) and slag (Gl+Cu = glass with copper prills; Pyx = pyroxene, sometimes hedenbergite; Mll = melilite). (b) Densely packed cuprite (Cpr) with delafossite needles (Del, yellow needles). (c) Cuprite veins with reacted silicate material (Mix) with cuprite ”flowers” and dark laths of a silicate too small for SEM-EDX analysis. (d) Glass with and without copper prills, cuprite and an unidentified copper-rich phase.

The drop-like shape and black colour of the slag indicate a low viscosity and copper content of the slag, respectively. This is untypical for Chalcolithic copper slag from the Northern Negev but matches the observations made on melted Negev loess in an archaeological experiment (Rose et al., 2021b) and the appearance of 1335a, suggesting that it is rather melted clay than metallurgical slag. Combining these observations, a hole-mouth jar fragment placed with its rim sideways and somehow “hanging” to allow melted clay to flow downwards on it, might be best explained by the secondary use of hole-mouth jar sherds as furnace cover. Covering the furnace with large pottery shards improves the reducing conditions in the furnace by restricting the influx of oxygen and reduces heat loss. Placing the fragments on the fuel would heat the vessel fragments to temperatures high enough to melt Negev loess (cf. Rose et al., 2021b). At the same time, their breaks are partially “hanging” because of the differently sized and shaped fuel pieces, allowing melted clay to flow down and collect on the break. Compared to the use of a clay lid (Golden et al., 2001), using large vessel fragments derived from, e.g., hole-mouth jars allows to partially cover the furnace while they are easier to handle (by weight, and thanks to their curvature), increasing the manageability of the furnace components. Admittedly, the archaeological evidence for this interpretation is extremely limited and other vitrified or unusually highly fired vessel fragments must be identified to add further weight on this hypothesis. A-C-54 might be one of them

(Fig. 6.13); unfortunately, its resemblance was only realised after the end of the analytical work.

## 6.5.2 Slag

All features of the slag pieces except for 1335a are very similar to previous investigations on Chalcolithic copper slag from the Northern Negev and Early Bronze Age slag from Faynan, in particular its heterogeneity and its origin from a solid-state reaction rather than actual liquefaction of the ore (Hauptmann, 2007, 2000, 1989a; Shugar, 2000). Where preserved, the microstructure of the ore corresponds very well with different ore types from Faynan. For instance, 1334 and A-S-1 are in fact pieces of partially reacted cupriferous sandstone (cf. Hauptmann, 1989a, p. 124), and the areas with densely-packed magnetite of 220-2242 were most likely aggregates of haematite or iron (oxy)hydroxides, well-known from , e.g., Faynan "tile ore" (Hauptmann, 2007; Shugar, 2000). The very different parts of A-1018

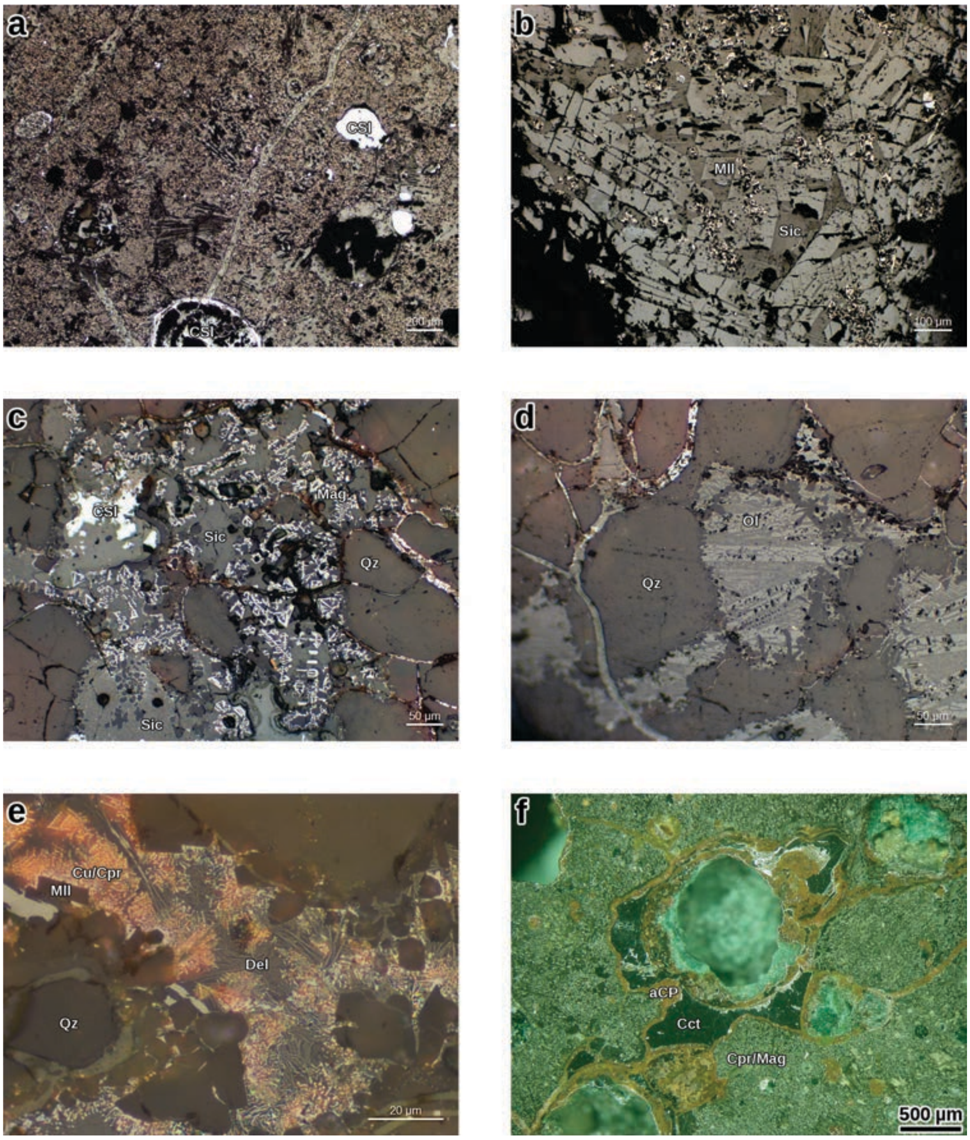


Figure 6.11: Photomicrographs of 220-2242 in (a–e) reflected light and (f) under a stereomicroscope. (a) General impression of the microstructure with inclusions of (reacted) copper sulphides (CSI) and fan-shaped aggregates of silicates (center). (b) Mixture of melilite (Mll) with another silicate phase (Sic), either pyroxene or Ca-Fe-rich olivine. (c) Skeletal magnetite (Mag) in a silicate matrix (Sil) sometimes with darkgrey flowers of pyroxene and remains of copper sulphides surrouned by quartz (Qz). (d) Crystals with olivine chemistry and the morphology of fayalite (Ol) between quartz. (e) Massive amounts of either tiny copper prills or cuprite (Cu/Cpr) and delafossite (Del) in glass. Between the copper phases several (hyp)idiomorphic crystals of melilite occur. (f) Subangular chalcocite (Cct) surrounded by altered copper phases (aCP) in a densely packed matrix of magnetite and cuprite.

and 220-2242, some of them easily recognisable by bare eye in the polished section (Fig. 6.14) are best explained either by a piece containing different ore types or by sintering different ore pieces together. The unmelt chalcocite grains in 220-2242 clearly show that the ore was not heated strong or long enough for melting larger parts of it (Hauptmann, 2000; cf. Hauptmann, 1989a), suggesting the former explanation.

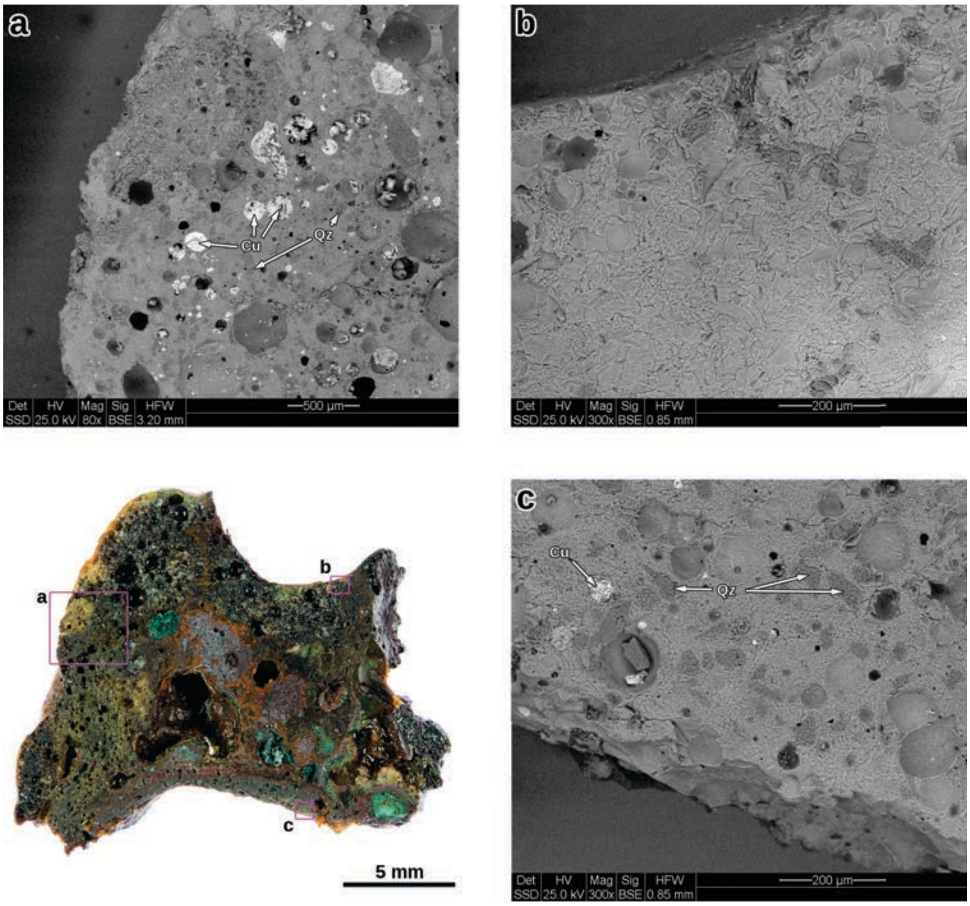


Figure 6.12: Cross section of 1335a with back scatter electron images of different areas of what was clay according to their high Ca and low to absent Cu contents. Note the silt-sized angular quartz (Qz) and corroded copper prills (Cu) in a and c, while the material in b was completely melted. The locations of the BSE images are indicated in the cross section. The channel-like feature is located at the bottom in this figure.

Due to the considerable heterogeneity, bulk chemistry and phase diagrams are not applicable to reconstruct the process conditions. Nevertheless, insight can be gained from the phase composition of the slag pieces, which corresponds to the results of previous investigations (Hauptmann, 2007, 2000, 1989a; Shugar, 2000). The regular presence of delafossite and cuprite shows that the furnace conditions were often only mildly reducing. Especially in 220-2242, but also in A-1018, more reducing conditions are indicated by the presence of magnetite. In addition, 220-2242 contains in some areas, preferentially close to the copper sulphides, Fe-rich olivine, probably fayalite (Fig. 6.11d). This would indicate even stronger reducing conditions, perhaps created by the oxidation of the sulphides. However, based on the available data it must remain open whether these are indeed fayalites or laihunites (cf. discussion in 4.1.1.5.1). In any case, the respective areas are too small to be representative for the entire slag piece. The presence of large pyroxene and melilite crystals in A-1018 and 220-2242 indicates that the furnace became locally hot enough to melt part of the ore (i.e., around 1100 °C). Nevertheless, as pointed out by Hauptmann (1989b), such high temperatures were too localised and did not last long enough for a considerable liquefaction of the ore. Experimental work showed that solid-state reactions of copper ore to metallic copper start already at temperatures as low as 700 °C (Lorenzen, 1966; Pollard et al., 1991a). Taking the melting temperature of Fe-rich olivine (about 1200 °C) as an estimate for the maximum temperature, this wide range emphasises once more the high heterogeneity that must be expected for this process.

In contrast to these objects, 1335a with its silt-sized angular quartz grains, high proportion of Ca-rich glassy material in the yellowish parts of the fragment, and the overall different appearance in colour and lustre is clearly identified as melted Negev loess which became fused to copper slag. The melting point of Negev loess is well below the melting point of copper ore (cf. Rose et al., 2021b). Silt-sized quartz at the channel-like feature and one side of the object while it is absent on the side opposite the channel-like feature points towards a temperature gradient with higher temperatures further away from the channel-like feature.

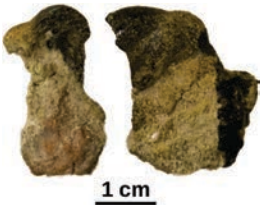


Figure 6.13: A-C-54, a ceramic fragment from Abu Matar with the same black porous slag that is found in 1335a and A-C-59.

### 6.5.3 Draught technique

Figure 6.14: Polished sections of the two fragments comprising 220-2242. The borders between areas with different microstructures are indicated by dotted lines.

Evidence for the draught technique in the Chalcolithic copper metallurgy of the Northern Negev is currently missing (cf. chap. 4.1.1.5.1). Being made of chaff-tempered ceramic, having a distinct channel-like feature of 1.5 to 3 cm diameter and being clearly used in copper metallurgy, 1335a and 1338 can be identified with some confidence as tuyère fragments. While 1335a was almost completely melted, 1338 is only slightly slagged on what was probably the outside. If the original surfaces of 1338 are preserved at the channel-like feature and the slagged area, the ceramic was about 1 cm thick in this area. Combining this information with the about 3 cm long preserved channel-like feature of 1335a, the objects were very likely pipe-shaped. It is hard to imagine the use of pipe-shaped objects involved in early copper (s)melting contexts other than tuyères. Moreover, ceramic objects with a compatible shape are unknown for the pottery of the Chalcolithic Southern Levant.

An explanation for the very different conditions of 1338 and 1335a could be that the former fell or was pushed into the furnace only for a short time and was quickly retrieved, while the latter was either deeply inserted into the furnace and became strongly heated throughout or broke during smelting.

The morphology of 1335a suggests that part of the melted clay flowed down, collecting at the bottom of the fragment, while the channel-shaped surface became soft from partial melting but maintained its structural integrity. An explanation for this behaviour could be the comparatively cold air stream, which kept the inner surface of the tuyère at a relatively colder temperature, preventing it from being completely melted while the outside part of the tuyère did so.

According to Rehder (1994), the diameter of the channel is too large to create a well-focused and sufficiently strong air stream with lung force, i.e., blowpipes. However, it falls nicely into his range of bellow tuyère diameters, suggesting bellowing as draught technique in the Chalcolithic Northern Negev. Rose et al. (2021b) showed that it is possible to achieve temperatures above 1000 °C when such a furnace is operated with bellows. Another tentative evidence for the use of bellows is 220-2242, whose channel-like feature is too regularly shaped to be an accidental product of the smelting process and has a slightly larger diameter than the tuyère fragments. Experimental work (e.g., Rose et al., 2021c) showed that a sufficiently strong air stream can create channel-like features in front of the tuyère, because the air stream chills the material there before the air becomes hot enough. This interpretation is also in accordance with the chilling effect of the air stream assumed for 1335a. Negev loess starts to melt at much lower temperatures than the ore and thus the air from the tuyère could have easily chilled the ore in front of the tuyère while being already heated in the tuyère to temperatures sufficient to keep the clay in a semi-melted state.

Using bellows instead of tuyères comes with several advantages. The area heated with bellows is considerably larger than with blowpipes at a strongly reduced (wo)manpower (Rehder, 1994). This advantage is even more pronounced if the blowpipes were concentrated at the same spot as suggested by Golden et al. (2001). As already mentioned in the introduction, only bellows could heat most of the furnace's interior in the reconstructed operational setup. Using bellows instead of blowpipes would also explain heavily slagged furnace wall fragments such as A-F-10, where considerable amounts of melted furnace wall flowed down until it solidified (Fig. 6.15) – something that should and could be easily avoided with the better focused air stream from blowpipes.

Figure 6.15: Furnace wall fragment A-F-10 with ceramic melt solidified in a flow texture with bulges.

Operating the furnace with bellows could also provide an explanation for the peculiarly shaped fragment 1299b with its funnel-shaped feature. In general, most tuyères have a conical shape. If pressed into a plastic material such as wet clay they would create a funnel-shaped impression. Although the tuyère fragments are too small for a reconstruction of their original shape, a conical design seems sensible and 1299b might have been a support for them, to connect them firmly to the ground and maybe to place them in a downwards angle to direct the air stream deeper into the furnace (cf. Rehder, 2000).

Operating the Chalcolithic furnaces in the Northern Negev with bellows places the metallurgy of the Chalcolithic Southern Levant among the earliest bellow-using metal technologies. Due to the scarcity of archaeological evidence for draught techniques in general and early metallurgy in particular (cf. Bourgarit, 2007), it must remain unclear whether the use of bellows is unique to the metallurgy of the Chalcolithic Southern Levant or was also practised in other areas. Generally spoken, the furnaces of the Northern Negev tend to be among the larger ones in contemporary Western Asia and Southeastern Europe (cf. chap. 4.1), making the use of bellows particularly beneficial for their operation.

### 6.5.4 A refined reconstruction of the pure copper technology in the Chalcolithic Southern Levant

While the overall reconstruction of the furnace as pit furnace with a collar-shaped wall and horizontally inserted draught through the collar opening (Golden, 2014a; Golden et al., 2001) still holds, the presented materials add two important aspects to its operational: Draught via bellows and the potential covering of the furnace with large pottery sherds.

The strong heterogeneity of the slag, or more accurately of the incompletely melted ore pieces, suggests that the furnace conditions were very unstable, the ore too shortly heated for melting and only in moderately reducing conditions. This is characteristic for this type of furnace and practically independent from the type of draught (Rehder, 2000, p. 85). Furnace conditions might have been improved by covering the furnace with fragments of large pottery vessels as is probably indicated by A-C-59. Rehder (2000) describes the operation of such pit furnaces with unidirectional horizontal draught as being based on a principle of rotating material, with the fuel and ore slowly heated on the side opposite of the tuyère. The material is then pushed towards the tuyère, replacing the burnt material there, and finally arrives in the hot zone. When the fuel is burnt, the slag or reacted ore falls deeper into the furnace, below the hot zone, where it accumulates and is retrieved after the end of the furnace campaign. The result is a large number of slag and reacted ore pieces, similar to the finds in Abu Matar. While the conditions in such furnaces with usually up to 1200 °C (Rehder, 2000) are sufficient to slag portions of ore as observed in 220-2242 and

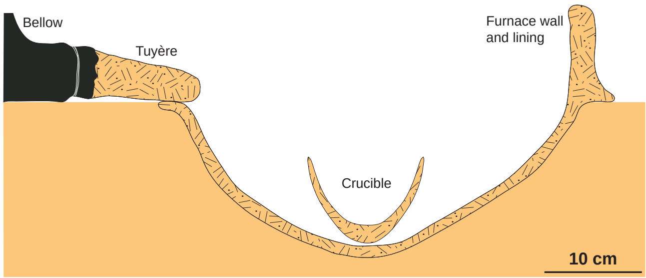


Figure 6.16: Arrangement of the crucible in the pit furnace, true to scale according to the dimensions reconstructed for furnace and crucible by Golden et al. (2001) and Shugar (2000), respectively.

A-1018, especially the high-silica ores such as A-S-1 and 1334 could not be heated or at least not long enough to temperatures close to their melting point, leaving their ore texture widely intact. In a next step, the copper prills were mechanically extracted from this partially melted material (Shugar, 2003).

Practical considerations invoke doubts that this operational set-up, a pit furnace with horizontal draught, was used as installation for the next step, melting the copper prills in a crucible, as suggested by Shugar (2000). Slag on the crucibles clearly shows heating from above. While some features on the crucibles might be compatible with draught from the side and thus a similar operational set-up as for the smelting and melting step (Rose et al., 2021b), such an arrangement does not transfer sufficient heat deep enough into the crucible to ensure a complete melt of the charge (cf. Heeb, 2009). In addition, a horizontal draught might blow away the fuel cover of the crucible which is necessary to prevent the copper from oxidation. Moreover, it would be very challenging to remove it from the pit with the melted copper before casting (Fig. 6.16). This also holds true if some kind of platform is used to place the crucible higher up in the pit unless it is of such a height that it could be argued that the furnace was not used because of being a furnace but because of being a suitable operational area.

For these reasons, a different operational set-up is suggested for the melting step. Perrot (1955c) reports flat clay "cakes" with a depression among the metallurgical material. Unfortunately, he does not provide any details about them. The interpretation by Golden et al. (2001) and Golden (2014a) of a furnace lid might be based on these clay "cakes". The fragments of ~ 8 cm diameter with an oblique outer side might have been related to them as well. Admittedly, the layout of these installations is elusive so far and could be as ephemeral as the one suggested by Frame (2012) for Tal-i Iblis: a crucible placed on such a disc to keep it in place, supported by a small heap of material (e.g., fuel, sediment) around it and covered with fuel (Fig. 6.17). Draught was probably inserted by blowpipes as they are more easily placed to achieve a draught from above and allow a better control of the air stream in direction and intensity. One blowpipe would have been sufficient to heat the entire content in a crucible with the dimensions reconstructed by Shugar (2000) for Abu Matar. The advantage of such an installation is its mobility: The copper can be smelted right next to the moulds. Sand casting is the most likely casting technique for pure copper objects of the Chalcolithic Southern Levant (cf. chap. 4.1.1.5.1) and the moulds might have been placed some distance away from the pit furnaces to maintain a safe plain working area around the latter. Melting the copper directly next to them would ensure that casting is performed at the highest temperature possible.

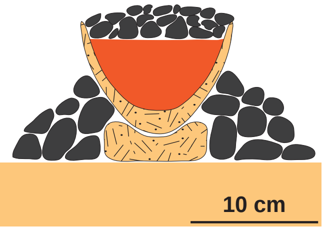


Figure 6.17: Potential setup for melting the copper prills in a crucible. Under the crucible a clay cake with a depression is reconstructed, resembling it is dimensioning the artefacts with about 8 cm diameter. The crucible is filled with melted copper (orange) and a layer of fuel on top (darkgrey). For illustrative purposes, the crucible is supported on its sides by fuel pieces.

## 6.6 Conclusions

Motivated by reservations against the current reconstructions of the furnaces and their operational mode for the pure copper metallurgy of the Chalcolithic Southern Levant, a re-examination of the metallurgical assemblage from the 1990s excavation in Abu Matar led to the discovery of several ceramics and slag pieces with unusual features. Some of the pieces were further analysed using microscopical techniques and SEM-EDX. While none of the analyses brought any major new discoveries on their own, combining them with the morphological features and general technological considerations allowed new insights into three important details of this prehistoric smelting and melting process.

The most important uncovered detail is the draught technique. Two ceramic objects can be confidently identified as tuyère fragments by their morphology, especially their channel-like feature. A slag fragment with a similar feature is best explained as the negative of the air stream leaving the tuyère. Based on Rehder (1994), their reconstructed diameter strongly suggests their use with bellows, making the Chalcolithic Southern Levant potentially one of the earliest bellow-using cultures. Operating the pit furnaces with bellows is further supported by general considerations about how this furnace type was operated (Rehder, 2000) and a previous archaeological experiment (Rose et al., 2021b).

The second detail is the secondary use of domestic pottery. A second case of V-shaped bowls used as crucible could be identified but due to the small number and being restricted to Abu Matar, the reasons for their use must remain unknown. More intriguing is the sherd of a hole-mouth jar, on which melted clay flowed down and solidified in a drop-like shape on a fracture perpendicular to the rim. It was suggested here that this is tentative evidence for covering the furnace with large pottery sherds. Doing so would improve the performance of the furnace but at the same time would be easier to handle than the single piece ceramic lid suggested by Golden et al. (2001).

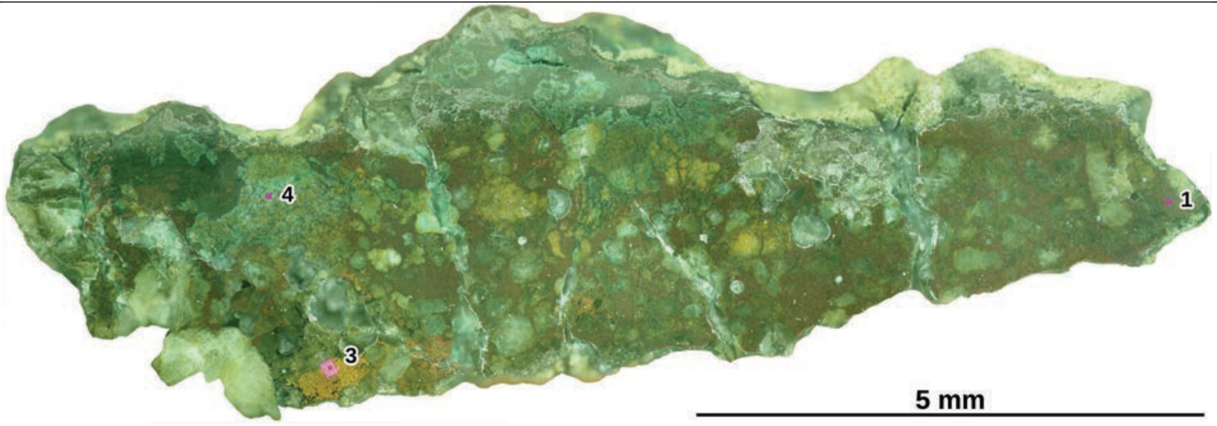
The third detail is the hypothesis that the crucible was not placed in the pit furnace to melt the extracted copper prills but in a more mobile installation. Admittedly, this assumption is purely based on considerations about the arrangement of draught into the crucible, retrieval of the hot crucible from the furnace and how the metallurgical process might have been spatially organised. Nevertheless, clay "cakes" reported by Perrot (1955c), albeit without any details, support the reconstruction of such a mobile installation as they might have been a platform or the round-bottomed crucibles. It is suggested here that a group of objects with oblique rounded edges and a roughly uniform diameter of around 8 cm might be fragments of these clay cakes.

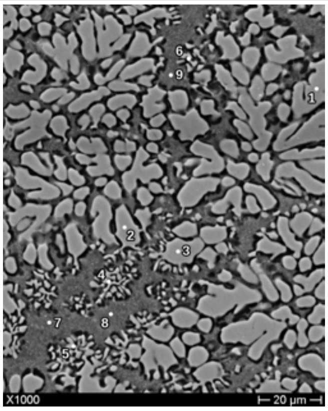
Unequivocally, further archaeological evidence is necessary to support these interpretations. This study showed that the discovery of new evidence does not necessarily requires new excavations but that it could also be found in old material. With the notable exception of Ackerfeld et al. (2020), all major work on the pure copper metallurgy of the Chalcolithic Southern Levant was carried out in the late 1980s to early 2000s. Analytical instrumentation and knowledge about early smelting and melting processes progressed significantly since then, as did the availability of comparative material from archaeological experiments. Therefore, it might be time to return to the shelves and re-assess this material. As this study highlighted, they bear a high potential to better understand the ancient smelting process and through this the role of metallurgy in the Chalcolithic Southern Levant.

## 6.7 SEM analyses

All values are given in wt.%; n.o. = not observed. Pink rectangles in the cross section indicate location and dimension of the respective SEM images, pink dots give the best approximate position of the SEM regions that could not be located exactly.

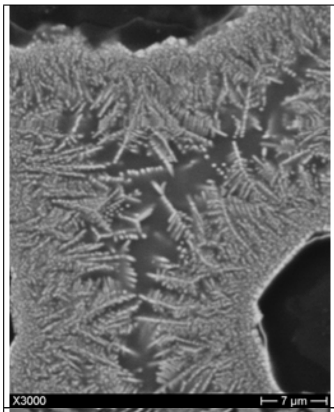
1334





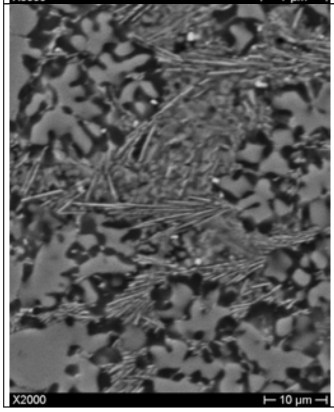
Region 1 SE image

| Point | MgO | CaO | CuO | FeO | $Al_2O_3$ | $SiO_2$ | $TiO_2$ | Cl | Phase |
|---|---|---|---|---|---|---|---|---|---|
| 1 | n.o. | n.o. | 96.31 | 1.45 | n.o. | 2.24 | n.o. | n.o. | Cuprite |
| 2 | n.o. | n.o. | 98.04 | 0.98 | n.o. | 0.98 | n.o. | n.o. | Cuprite |
| 3 | n.o. | 0.19 | 92.80 | 1.42 | n.o. | 5.59 | n.o. | n.o. | Cuprite |
| 4 | 0.45 | 0.58 | 59.85 | 3.71 | 1.73 | 33.22 | 0.46 | n.o. | Cuprite, glass |
| 5 | n.o. | 0.35 | 73.73 | 1.68 | 1.16 | 23.08 | n.o. | n.o. | Cuprite, glass |
| 6 | 0.67 | 1.12 | 45.53 | 12.42 | 1.72 | 37.38 | 1.00 | 0.15 | Cuprite + delafossite (?), glass |
| 7 | n.o. | 0.39 | 69.22 | 2.67 | 0.90 | 26.55 | 0.27 | n.o. | Cuprite dispersed in glass |
| 8 | n.o. | 0.46 | 71.16 | 2.48 | 1.16 | 24.45 | 0.30 | n.o. | Cuprite dispersed in glass |
| 9 | n.o. | n.o. | 98.80 | 1.20 | n.o. | n.o. | n.o. | n.o. | Cuprite |



Region 3 SE image

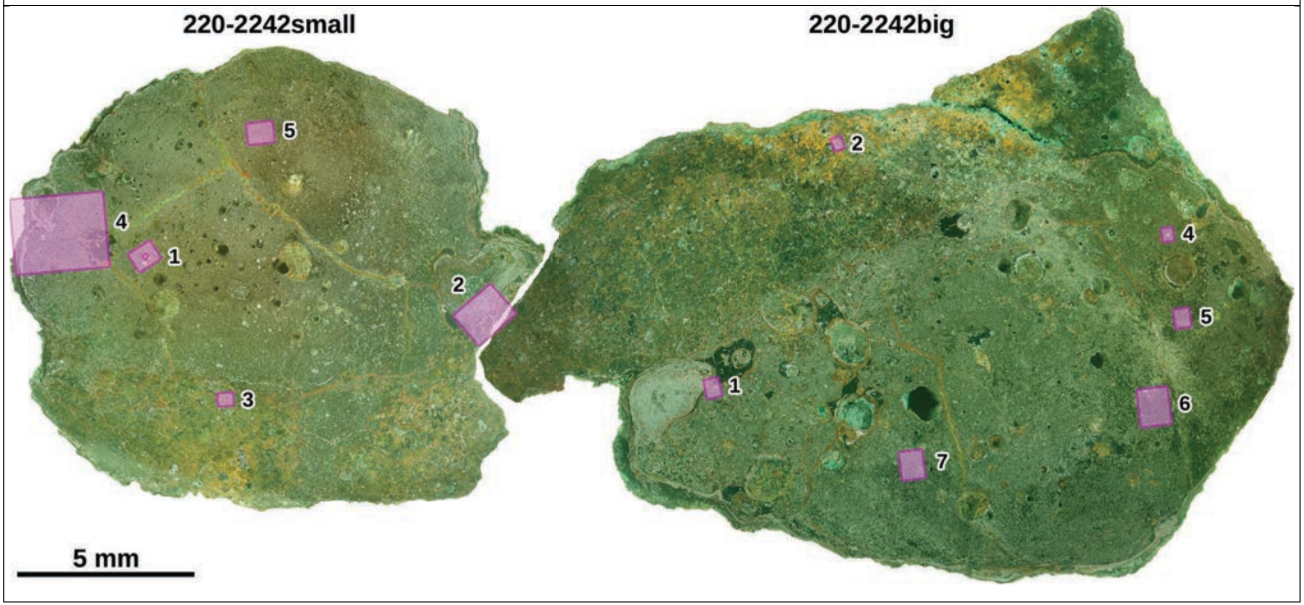
| Feature | CaO | CuO | FeO | $Al_2O_3$ | $SiO_2$ | Cl | Phase |
|---|---|---|---|---|---|---|---|
| Dendrites | 2.17 | 49.87 | 0.76 | 6.60 | 40.59 | n.o. | Cuprite, glass |
| Glass | 3.78 | 35.03 | 1.89 | 8.11 | 51.19 | n.o. | Glass, cuprite |
| Glass | 0.79 | 27.43 | 0.80 | 3.21 | 67.55 | 0.23 | Glass, cuprite |



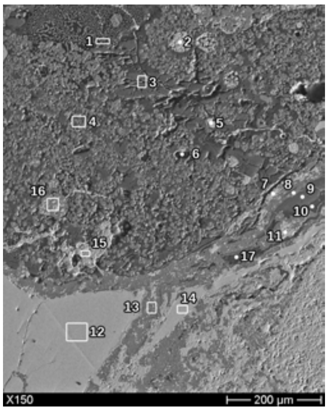
Region 4 SE image

| Feature | CaO | CuO | FeO | $Al_2O_3$ | $SiO_2$ | $TiO_2$ | Cl | Phase |
|---|---|---|---|---|---|---|---|---|
| Dendritic phase | 0.33 | 78.19 | 0.34 | n.o. | n.o. | n.o. | 21.14 | Corroded cuprite |
| Needles + glass | 1.22 | 45.60 | 19.65 | 1.91 | 27.09 | 1.29 | 3.24 | Delafossite, glass |
| Needles + glass | 1.26 | 42.99 | 19.38 | 2.44 | 30.92 | 0.67 | 2.34 | Delafossite, glass |

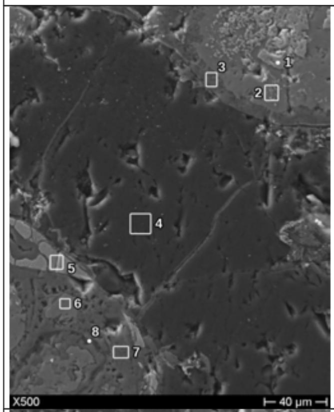
## 220-2242



220-2242big, region 1 SE image

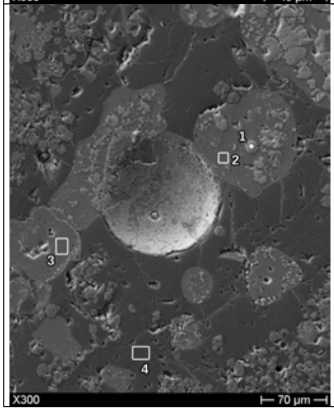


| Point | $K_2O$ | MgO | CaO | CuO | FeO | MnO | $Al_2O_3$ | $SiO_2$ | $TiO_2$ | S | Cl | Phase |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | n.o. | n.o. | n.o. | n.o. | 44.10 | n.o. | 1.06 | 53.67 | 0.60 | 0.47 | 0.09 | Glass, magnetite ? |
| 2 | 0.12 | n.o. | 0.52 | 52.23 | 34.00 | n.o. | 1.06 | 11.55 | 0.29 | n.o. | 0.23 | Cuprospinel, glass |
| 3 | 0.08 | n.o. | 0.47 | 1.92 | 64.95 | n.o. | 1.40 | 31.14 | n.o. | n.o. | 0.03 | Fe-rich olivine/ fayalit. glass |
| 4 | 0.23 | n.o. | 0.59 | 1.05 | 79.36 | n.o. | 0.79 | 17.94 | n.o. | n.o. | 0.03 | Magnetite, Fe-silicates |
| 5 | 0.55 | n.o. | 1.11 | 5.08 | 62.93 | n.o. | 2.47 | 27.86 | n.o. | n.o. | n.o. | silicate/glass |
| 6 | n.o. | n.o. | 0.74 | 1.63 | 66.97 | n.o. | 0.50 | 29.86 | n.o. | n.o. | 0.29 | silicate/glass |
| 7 | 0.49 | 0.77 | 0.73 | 9.97 | 52.74 | n.o. | 1.47 | 33.69 | n.o. | n.o. | 0.14 | Fe-rich silicates |
| 8 | n.o. | n.o. | n.o. | 89.96 | 2.59 | n.o. | n.o. | n.o. | n.o. | n.o. | 7.45 | Corroded cuprite |
| 9 | 0.12 | n.o. | 0.08 | 72.50 | 9.39 | n.o. | n.o. | 2.24 | n.o. | n.o. | 15.66 | Corr. Cu-oxide |
| 10 | n.o. | n.o. | 0.59 | 12.63 | 74.75 | n.o. | n.o. | 10.11 | n.o. | 1.12 | 0.80 | Mixed material |
| 11 | n.o. | n.o. | n.o. | 73.44 | 7.18 | n.o. | n.o. | 2.16 | n.o. | n.o. | 17.23 | Corroded Cu-oxide |
| 12 | n.o. | n.o. | 0.21 | 81.63 | n.o. | n.o. | n.o. | n.o. | n.o. | 18.15 | n.o. | Chalcocite |
| 13 | n.o. | n.o. | n.o. | 87.67 | n.o. | n.o. | 0.78 | n.o. | n.o. | 3.26 | 8.29 | Corroded reacted Cu-Sulphide |
| 14 | n.o. | n.o. | n.o. | 86.13 | n.o. | n.o. | n.o. | n.o. | n.o. | 13.87 | n.o. | Chalcocite |
| 15 | n.o. | n.o. | n.o. | 86.59 | 9.30 | n.o. | 0.74 | 3.38 | n.o. | n.o. | n.o. | Cuprite |
| 16 | n.o. | n.o. | n.o. | 85.89 | 2.67 | n.o. | 0.51 | 1.29 | n.o. | n.o. | 9.64 | Corroded Cuprite |
| 17 | 0.6 | n.o. | 0.62 | 28.85 | 44.01 | 0.77 | 0.81 | 19.23 | n.o. | 0.50 | 4.61 | Mixed material |



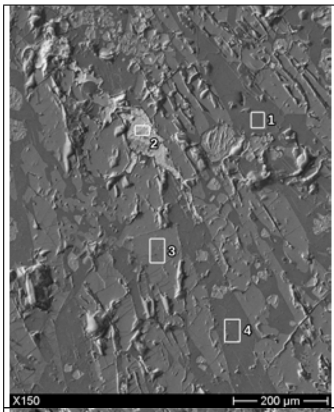
220-2242big, region 3 SE image

| Point | $K_2O$ | MgO | CaO | CuO | FeO | NiO | $Al_2O_3$ | $SiO_2$ | $TiO_2$ | S | Cl | Phase |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | n.o. | n.o. | n.o. | 82.75 | n.o. | n.o. | n.o. | n.o. | n.o. | n.o. | 17.25 | Corroded Cu-oxide |
| 2 | n.o. | n.o. | n.o. | 79.53 | 1.73 | n.o. | n.o. | n.o. | n.o. | n.o. | 18.74 | Corroded Cu-oxide |
| 3 | n.o. | n.o. | 0.60 | 35.98 | 15.33 | 0.71 | 4.25 | 36.53 | n.o. | n.o. | 6.61 | Cu-rich pyroxene |
| 4 | n.o. | n.o. | n.o. | 0.85 | n.o. | n.o. | n.o. | 99.15 | n.o. | n.o. | n.o. | Quartz |
| 5 | n.o. | n.o. | n.o. | 80.59 | 1.24 | n.o. | n.o. | n.o. | n.o. | 17.59 | 0.58 | Chalcocite |
| 6 | n.o. | n.o. | n.o. | 76.35 | 4.71 | n.o. | n.o. | n.o. | n.o. | n.o. | 18.94 | Corroded Cu-oxide |
| 7 | n.o. | n.o. | 1.52 | 10.09 | 66.44 | n.o. | 0.63 | 20.52 | n.o. | 0.66 | 0.14 | Fe-rich silicate |
| 8 | 2.16 | 1.46 | 0.99 | 7.93 | 42.40 | n.o. | 6.64 | 37.04 | 1.11 | n.o. | 0.28 | Fe-rich silicate |



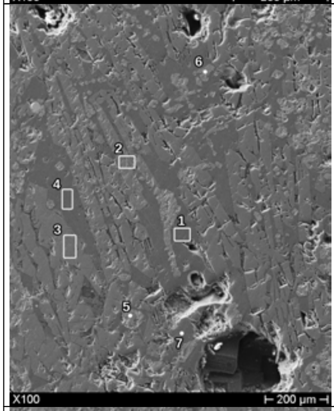
220-2242big, region 4 SE image

| Point | CaO | CuO | FeO | $Al_2O_3$ | $SiO_2$ | Cl | Phase |
|---|---|---|---|---|---|---|---|
| 1 | n.o. | 85.75 | 2.76 | n.o. | n.o. | 11.49 | Corroded Cu-oxide |
| 2 | n.o. | 78.88 | 1.64 | n.o. | n.o. | 19.47 | Corroded Cu-oxide |
| 3 | n.o. | 78.00 | 2.10 | n.o. | n.o. | 19.90 | Corroded Cu-oxide |
| 4 | 10.01 | 0.75 | 49.29 | 1.15 | 38.62 | 0.19 | Fe-rich Silicate (Melilite?) |



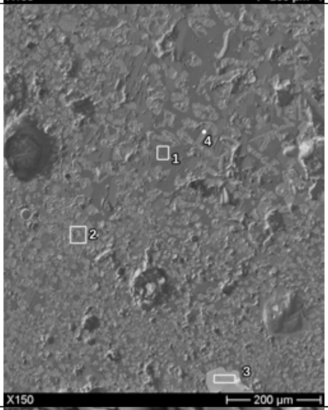
220-2242big, region 5 SE image

| Point | CaO | CuO | FeO | $Al_2O_3$ | $SiO_2$ | $TiO_2$ | Cl | Phase |
|---|---|---|---|---|---|---|---|---|
| 1 | 14.85 | 0.36 | 46.08 | 1.21 | 37.49 | n.o. | n.o. | Melilite |
| 2 | n.o. | 90.98 | 3.06 | n.o. | n.o. | n.o. | 5.97 | Corroded Cu-oxide |
| 3 | 1.47 | 0.37 | 71.99 | n.o. | 26.04 | n.o. | 0.13 | Fe-rich silicate |
| 4 | 7.59 | 1.65 | 54.71 | 1.91 | 33.50 | 0.28 | 0.37 | Melilite |



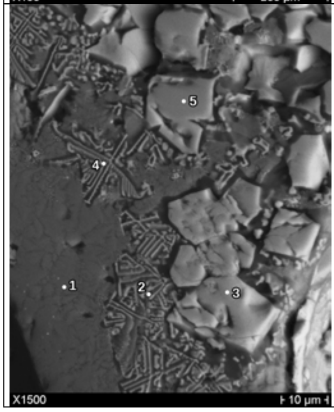
220-2242big, region 6 SE image

| Point | $K_2O$ | CaO | CuO | FeO | $Al_2O_3$ | $SiO_2$ | Cl | Phase |
|---|---|---|---|---|---|---|---|---|
| 1 | n.o. | 8.02 | 0.63 | 63.66 | 1.97 | 25.72 | n.o. | Fe-Ca-olivine? |
| 2 | n.o. | 1.73 | 0.52 | 70.45 | 1.57 | 25.74 | n.o. | Fe-rich olivine? |
| 3 | n.o. | 1.03 | 0.79 | 73.09 | n.o. | 25.09 | n.o. | Fe-rich olivine? |
| 4 | n.o. | 15.20 | 0.49 | 45.21 | 1.97 | 37.13 | n.o. | Melilite |
| 5 | n.o. | 15.67 | 1.22 | 40.67 | 2.63 | 39.52 | 0.29 | Melilite |
| 6 | n.o. | n.o. | n.o. | 98.27 | n.o. | 1.73 | n.o. | Magnetite |
| 7 | 0.57 | 15.88 | n.o. | 42.36 | 3.19 | 38.00 | n.o. | Melilite |



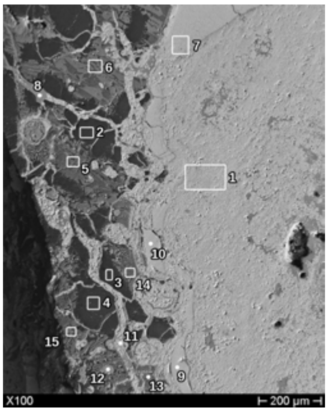
220-2242big, region 7 SE image

| Point | $K_2O$ | CaO | CuO | FeO | $Al_2O_3$ | $Cr_2O_3$ | $SiO_2$ | $TiO_2$ | S | $P_2O_5$ | Phase |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.64 | 1.92 | 0.82 | 63.49 | 1.22 | 0.11 | 31.80 | n.o. | n.o. | n.o. | Fe-rich glass |
| 2 | n.o. | 0.56 | 0.78 | 85.87 | 1.71 | n.o. | 11.08 | n.o. | n.o. | n.o. | Magnetite |
| 3 | n.o. | 0.64 | 65.64 | 14.13 | 0.70 | n.o. | 3.76 | n.o. | 14.84 | 0.29 | Bornite |
| 4 | 0.33 | 15.48 | n.o. | 40.25 | 2.13 | n.o. | 41.28 | 0.53 | n.o. | n.o. | Magnetite, Ca-Fe-Silicate |



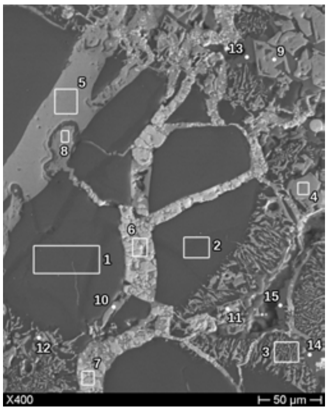
220-2242small, region 1 SE image

| Point | CaO | CuO | FeO | $Al_2O_3$ | $SiO_2$ | Cl | Phase |
|---|---|---|---|---|---|---|---|
| 1 | 13.83 | 1.41 | 41.63 | 1.92 | 41.04 | 0.17 | Glass |
| 2 | 0.49 | 0.49 | 59.39 | 0.82 | 38.82 | n.o. | Magnetite, glass |
| 3 | n.o. | n.o. | 100.00 | n.o. | n.o. | n.o. | Magnetite |
| 4 | 0.70 | n.o. | 52.00 | n.o. | 47.08 | 0.22 | Magnetite, glass |
| 5 | n.o. | n.o. | 98.50 | n.o. | 1.50 | n.o. | Magnetite |



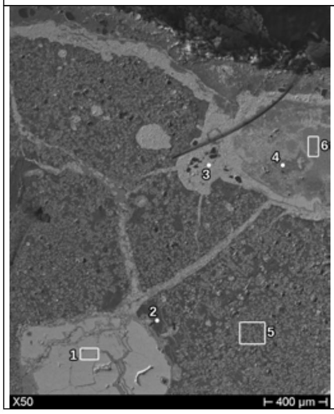
220-2242small, region 2 SE image

| Point | $K_2O$ | CaO | CuO | FeO | $Al_2O_3$ | $Cr_2O_3$ | $SiO_2$ | $TiO_2$ | S | Cl | Phase |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | n.o. | n.o. | 96.33 | n.o. | n.o. | n.o. | n.o. | n.o. | 3.09 | 0.57 | Cu-oxide/Reacted Cu-suplhide |
| 2 | n.o. | n.o. | 2.51 | n.o. | n.o. | n.o. | 97.49 | n.o. | n.o. | n.o. | Quartz |
| 3 | n.o. | n.o. | 9.64 | n.o. | n.o. | n.o. | 89.29 | n.o. | n.o. | 1.07 | Quartz |
| 4 | n.o. | n.o. | 1.57 | n.o. | n.o. | n.o. | 98.43 | n.o. | n.o. | n.o. | Quartz |
| 5 | n.o. | 8.71 | 2.18 | 50.60 | 1.96 | n.o. | 35.89 | 0.66 | n.o. | n.o. | Melilite |
| 6 | n.o. | 6.17 | 1.02 | 56.67 | 2.57 | n.o. | 33.58 | n.o. | n.o. | n.o. | Melilite |
| 7 | n.o. | n.o. | 98.56 | n.o. | n.o. | n.o. | n.o. | n.o. | 0.90 | 0.55 | Cuprite |
| 8 | n.o. | n.o. | 81.51 | 0.81 | n.o. | n.o. | n.o. | n.o. | n.o. | 17.67 | Corroded Cu-oxide |
| 9 | n.o. | n.o. | 97.49 | 2.07 | n.o. | n.o. | n.o. | n.o. | n.o. | 0.45 | Cuprite |
| 10 | n.o. | n.o. | 82.13 | 7.41 | n.o. | n.o. | 4.81 | n.o. | n.o. | 5.64 | Corroded Cu-oxide |
| 11 | n.o. | 0.63 | 78.43 | 5.79 | 1.10 | n.o. | 4.90 | n.o. | n.o. | 9.16 | Corroded Cu-oxide |
| 12 | n.o. | 0.51 | 4.82 | 66.13 | 0.88 | n.o. | 27.59 | n.o. | n.o. | 0.08 | Magnetite, silicates |
| 13 | 0.09 | 0.71 | 69.47 | 12.91 | n.o. | n.o. | 15.19 | n.o. | n.o. | 1.63 | Cuprite, silicates |
| 14 | n.o. | 0.50 | 3.16 | 28.14 | n.o. | n.o. | 68.04 | n.o. | n.o. | 0.16 | Fe-rich silicates |
| 15 | n.o. | 0.92 | 11.09 | 60.05 | 0.23 | 0.33 | 26.99 | n.o. | n.o. | 0.40 | Fe-rich siilicates (fayalite?) |



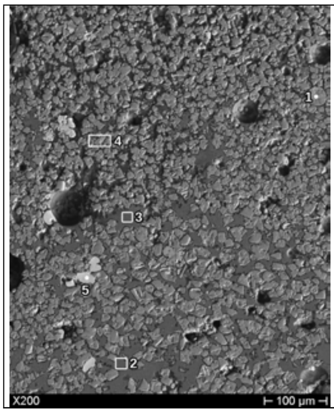
220-2242small, region 3 SE image

| Point | MgO | CaO | CuO | FeO | $Al_2O_3$ | $SiO_2$ | S | Cl | Phase |
|---|---|---|---|---|---|---|---|---|---|
| 1 | n.o. | n.o. | 2.22 | n.o. | n.o. | 97.68 | n.o. | 0.10 | Quartz |
| 2 | n.o. | n.o. | 1.22 | n.o. | n.o. | 98.78 | n.o. | n.o. | Quartz |
| 3 | n.o. | n.o. | 5.31 | 51.80 | n.o. | 42.62 | n.o. | 0.28 | Pyroxenitic composition, magnetite + quartz? |
| 4 | n.o. | 0.53 | 49.13 | 15.37 | n.o. | 32.80 | n.o. | 2.17 | Cuprite, Fe-rich silicate |
| 5 | n.o. | n.o. | 79.03 | 0.82 | n.o. | n.o. | 0.19 | 19.96 | Corroded Cu-oxide |
| 6 | n.o. | n.o. | 63.58 | 0.99 | n.o. | 33.38 | n.o. | 2.04 | Cuprite, glass |
| 7 | n.o. | n.o. | 73.04 | 5.71 | 0.56 | 18.57 | n.o. | 2.12 | Cuprite, glass |
| 8 | n.o. | n.o. | 83.44 | 1.06 | n.o. | n.o. | n.o. | 15.50 | Corroded Cu-oxide |
| 9 | n.o. | 2.47 | 4.90 | 14.52 | n.o. | 77.67 | n.o. | 0.44 | Magnetite, glass |
| 10 | n.o. | n.o. | 3.15 | n.o. | n.o. | 95.91 | n.o. | 0.93 | Quartz |
| 11 | 0.78 | 0.70 | 35.15 | 9.40 | 1.96 | 52.02 | n.o. | n.o. | Magnetite/Cuprospinel, glass |
| 12 | n.o. | 0.53 | 1.48 | 44.08 | n.o. | 53.90 | n.o. | n.o. | Magnetite, glass |
| 13 | n.o. | n.o. | 70.42 | 2.80 | 0.59 | 11.33 | n.o. | 14.86 | Corroded Cu-oxide |
| 14 | n.o. | n.o. | 1.85 | 52.28 | n.o. | 45.66 | n.o. | 0.22 | Fe-Pyroxene (Ferrosilite?) |
| 15 | n.o. | 18.06 | 13.49 | 24.50 | 3.71 | 39.52 | 0.38 | 0.34 | Melilite |



220-2242small, region 4 SE image

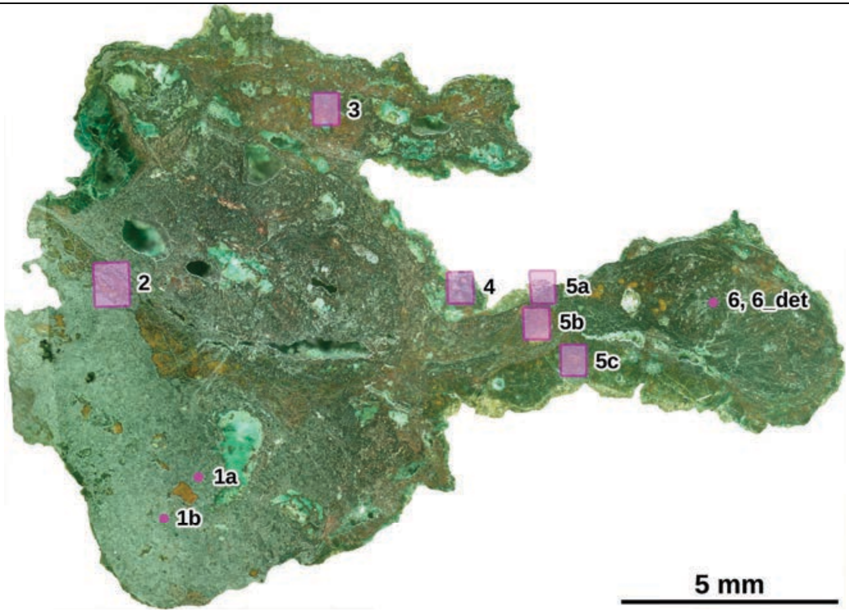
| Point | CaO | CuO | FeO | $Al_2O_3$ | $SiO_2$ | $TiO_2$ | S | Cl | Phase |
|---|---|---|---|---|---|---|---|---|---|
| 1 | n.o. | 81.69 | n.o. | n.o. | n.o. | n.o. | 17.93 | 0.37 | Chalcocite |
| 2 | n.o. | 85.37 | 1.67 | n.o. | n.o. | n.o. | n.o. | 12.96 | Corroded Cu-oxide |
| 3 | 1.22 | 56.70 | 17.09 | n.o. | 24.44 | 0.38 | n.o. | 0.17 | Cu-Fe-Silicate |
| 4 | n.o. | 39.20 | 47.91 | n.o. | 6.77 | n.o. | 5.57 | 0.55 | Reacted Cu-sulphide |
| 5 | 0.71 | 5.14 | 71.60 | 1.75 | 20.38 | n.o. | n.o. | 0.42 | Magnetite, silicates |
| 6 | n.o. | 85.03 | 3.72 | n.o. | n.o. | n.o. | 1.30 | 9.95 | Reacted Cu-sulphide |

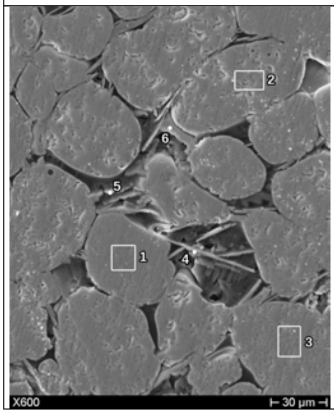


220-2242small, region 5 SE image

| Point | $K_2O$ | CaO | CuO | FeO | $Al_2O_3$ | $SiO_2$ | $TiO_2$ | Cl | Phase |
|---|---|---|---|---|---|---|---|---|---|
| 1 | n.o. | n.o. | n.o. | 41.98 | 0.41 | 57.61 | n.o. | n.o. | Magnetite, glass |
| 2 | n.o. | 1.41 | 1.01 | 52.51 | 2.48 | 41.82 | 0.44 | 0.33 | Glass, magnetite |
| 3 | 0.37 | 3.13 | 0.36 | 52.25 | 3.80 | 39.51 | 0.45 | 0.13 | Glass |
| 4 | n.o. | n.o. | 1.18 | 84.80 | n.o. | 14.02 | n.o. | n.o. | Magnetite, glass |
| 5 | n.o. | n.o. | 94.95 | 5.05 | n.o. | n.o. | n.o. | n.o. | Cuprite |

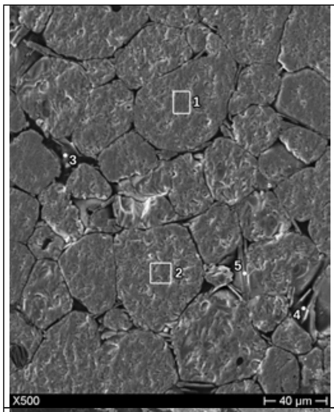
### A-1018





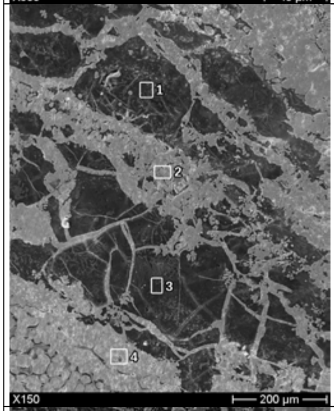
Region 1a SE image

| Point | $K_2O$ | CaO | CuO | FeO | $Al_2O_3$ | $SiO_2$ | $TiO_2$ | Cl | Phase |
|---|---|---|---|---|---|---|---|---|---|
| 1 | n.o. | n.o. | 100.00 | n.o. | n.o. | n.o. | n.o. | n.o. | Cuprite |
| 2 | n.o. | n.o. | 100.00 | n.o. | n.o. | n.o. | n.o. | n.o. | Cuprite |
| 3 | n.o. | n.o. | 100.00 | n.o. | n.o. | n.o. | n.o. | n.o. | Cuprite |
| 4 | 1.39 | 5.32 | 27.41 | 23.33 | 5.70 | 35.55 | 1.30 | n.o. | Delafossite, glass |
| 5 | 0.61 | 3.32 | 33.16 | 27.35 | 3.75 | 30.50 | 1.19 | 0.11 | Delafossite, glass |
| 6 | n.o. | 1.13 | 43.52 | 30.80 | 3.61 | 20.32 | 0.62 | n.o. | Delafossite, glass |



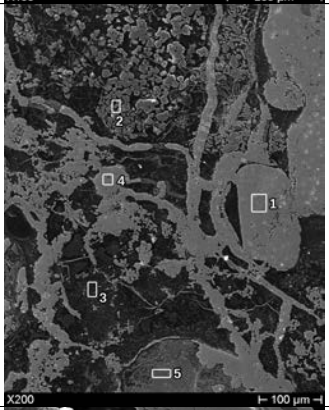
Region 1b SE image

| Point | CuO | FeO | $Al_2O_3$ | $SiO_2$ | Cl | Phase |
|---|---|---|---|---|---|---|
| 1 | 100.00 | n.o. | n.o. | n.o. | n.o. | Cuprite |
| 2 | 100.00 | n.o. | n.o. | n.o. | n.o. | Cuprite |
| 3 | 73.92 | 1.66 | 1.20 | 19.3 | 3.92 | Cuprite, glass |
| 4 | 97.39 | 2.61 | n.o. | n.o. | n.o. | Cuprite, delafossite |
| 5 | 81.06 | 1.85 | 2.93 | 11.38 | 2.77 | Cuprite, delafossite, glass |



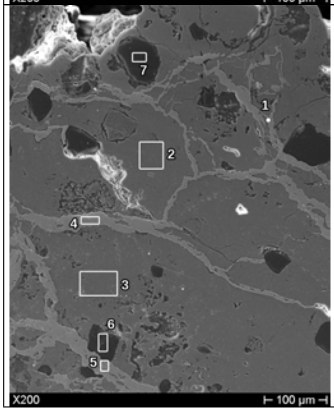
Region 2 SE image

| Point | $K_2O$ | CaO | CuO | FeO | $Al_2O_3$ | $SiO_2$ | $TiO_2$ | Cl | Phase |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.49 | 5.31 | 21.88 | 6.03 | 4.89 | 61.23 | n.o. | 0.17 | Mixed material |
| 2 | n.o. | 0.55 | 81.92 | 8.85 | 1.41 | 6.94 | n.o. | 0.32 | Cuprite, glass |
| 3 | 0.85 | 1.76 | 12.32 | 3.15 | 6.69 | 73.17 | 1.40 | 0.66 | Mixed material |
| 4 | n.o. | n.o. | 98.76 | 1.24 | n.o. | n.o. | n.o. | n.o. | Cuprite |



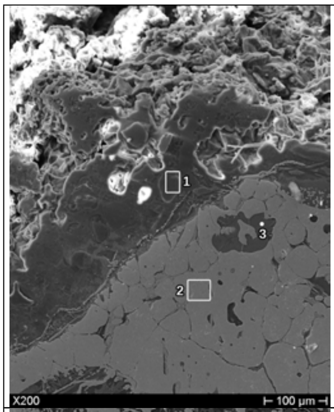
Region 3 SE image

| Point | $K_2O$ | CaO | CuO | FeO | $Al_2O_3$ | $SiO_2$ | $TiO_2$ | Cl | Phase |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.13 | n.o. | 80.70 | 0.62 | n.o. | 18.02 | 0.38 | 0.15 | Cuprite, glass |
| 2 | 0.68 | 1.38 | 27.67 | 58.18 | n.o. | 11.56 | n.o. | 0.52 | Magnetite/cuprospinel, glass |
| 3 | 1.72 | 8.88 | 34.99 | 6.53 | 3.18 | 43.46 | 0.70 | 0.55 | Cu-rich silicate |
| 4 | n.o. | n.o. | 99.22 | n.o. | n.o. | n.o. | n.o. | 0.78 | Cuprite |
| 5 | n.o. | n.o. | 74.57 | 2.28 | n.o. | 8.52 | n.o. | 14.63 | Corroded Cu-oxide |



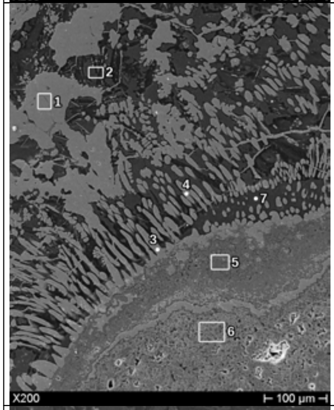
Region 4 SE image

| Point | $Na_2O$ | CuO | FeO | $Al_2O_3$ | $SiO_2$ | Cl | Phase |
|---|---|---|---|---|---|---|---|
| 1 | n.o. | 81.10 | 0.37 | n.o. | n.o. | 18.53 | Altered Cu-oxide |
| 2 | n.o. | 82.13 | n.o. | n.o. | n.o. | 17.87 | Altered Cu-oxide |
| 3 | n.o. | 80.81 | n.o. | n.o. | n.o. | 19.19 | Altered Cu-oxide |
| 4 | n.o. | 100.00 | n.o. | n.o. | n.o. | n.o. | Cuprite |
| 5 | n.o. | 99.16 | n.o. | n.o. | n.o. | 0.84 | Cuprite |
| 6 | n.o. | 4.79 | 0.58 | n.o. | 94.64 | n.o. | Quartz |
| 7 | 7.16 | 2.89 | n.o. | 17.39 | 72.56 | n.o. | Na-Feldspar |



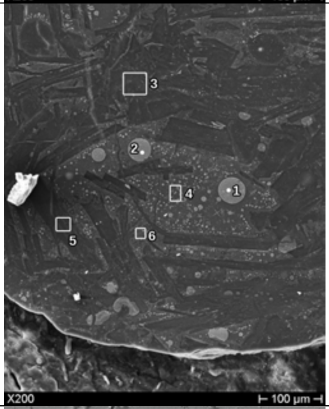
Region 5a SE image

| Point | $K_2O$ | CaO | CuO | FeO | $Al_2O_3$ | $SiO_2$ | Phase |
|---|---|---|---|---|---|---|---|
| 1 | 1.51 | 35.14 | 16.89 | 14.72 | 2.04 | 29.7 | Fayalitic glass |
| 2 | n.o. | n.o. | 100.00 | n.o. | n.o. | n.o. | Cuprite |
| 3 | n.o. | 0.95 | 97.68 | 1.37 | n.o. | n.o. | Cuprite |



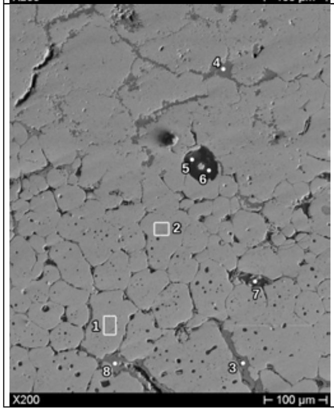
Region 5b SE image

| Point | $K_2O$ | CaO | CuO | FeO | $Al_2O_3$ | $SiO_2$ | $TiO_2$ | Cl | Phase |
|---|---|---|---|---|---|---|---|---|---|
| 1 | n.o. | n.o. | 100.00 | n.o. | n.o. | n.o. | n.o. | n.o. | Cuprite |
| 2 | 1.71 | 20.35 | 19.45 | 14.73 | 2.68 | 40.41 | 0.68 | n.o. | Hedenbergite |
| 3 | n.o. | n.o. | 100.00 | n.o. | n.o. | n.o. | n.o. | n.o. | Cuprite |
| 4 | 0.65 | 1.43 | 66.83 | 0.65 | 1.82 | 27.80 | n.o. | 0.82 | Cuprite, glass |
| 5 | n.o. | n.o. | 81.40 | 1.93 | n.o. | 2.17 | n.o. | 14.51 | Altered Cu-oxide |
| 6 | n.o. | n.o. | 91.12 | 1.18 | n.o. | n.o. | n.o. | 7.70 | Altered Cu-oxide |
| 7 | 4.74 | 15.98 | 23.91 | 6.60 | 1.46 | 47.3 | n.o. | n.o. | Pyroxenitic glass |



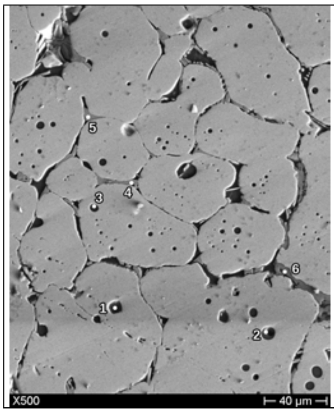
Region 5c SE image

| Point | $K_2O$ | MgO | CaO | CuO | FeO | $Al_2O_3$ | $SiO_2$ | Phase |
|---|---|---|---|---|---|---|---|---|
| 1 | 2.38 | n.o. | 34.42 | 16.07 | 9.67 | 3.70 | 33.76 | Melilite |
| 2 | n.o. | n.o. | n.o. | 90.21 | 9.79 | n.o. | n.o. | Copper |
| 3 | n.o. | n.o. | 6.18 | 38.72 | 7.01 | n.o. | 48.08 | Pyroxene |
| 4 | 2.70 | n.o. | 29.98 | 23.50 | 8.29 | 3.41 | 32.11 | Glass |
| 5 | n.o. | 6.46 | 25.03 | 28.53 | 1.73 | n.o. | 38.24 | Melilite |
| 6 | 1.43 | n.o. | 26.29 | 25.17 | 12.79 | n.o. | 34.32 | Melilite |



Region 6 SE image

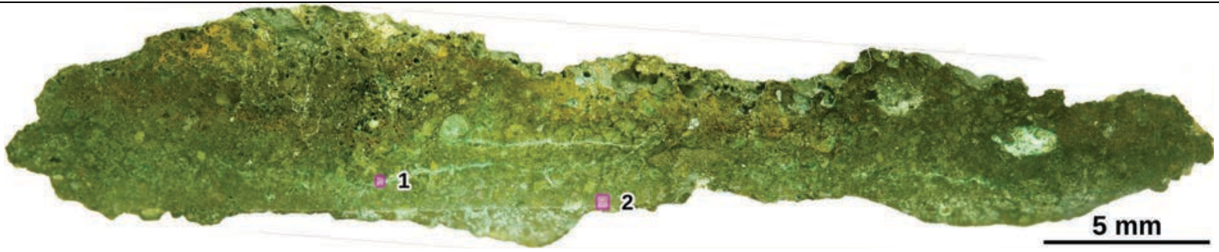
| Point | CaO | CuO | FeO | $Al_2O_3$ | $SiO_2$ | Cl | Phase |
|---|---|---|---|---|---|---|---|
| 1 | n.o. | 100.00 | n.o. | n.o. | n.o. | n.o. | Cuprite |
| 2 | n.o. | 99.57 | n.o. | n.o. | n.o. | 0.43 | Cuprite |
| 3 | n.o. | 100.00 | n.o. | n.o. | n.o. | n.o. | Cuprite |
| 4 | n.o. | 85.44 | n.o. | n.o. | n.o. | 14.56 | Altered Cu-oxide |
| 5 | n.o. | 100.00 | n.o. | n.o. | n.o. | n.o. | Cuprite |
| 6 | 0.99 | 5.69 | 3.77 | 11.23 | 77.95 | 0.36 | Glass |
| 7 | n.o. | 98.29 | 0.49 | n.o. | n.o. | 1.23 | Cuprite |
| 8 | n.o. | 100.00 | n.o. | n.o. | n.o. | n.o. | Cuprite |

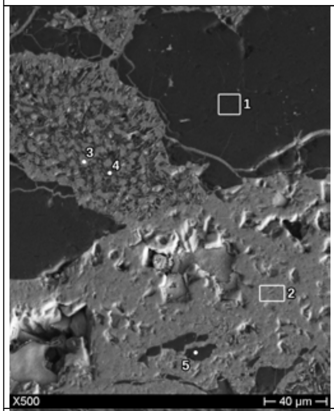


Region 6_det SE image

| Point | CaO | CuO | FeO | $SiO_2$ | Cl | Phase |
|---|---|---|---|---|---|---|
| 1 | n.o. | 89.91 | n.o. | 9.23 | 0.86 | Cuprite |
| 2 | n.o. | 100.00 | n.o. | n.o. | n.o. | Cuprite |
| 3 | 2.27 | 91.55 | 1.85 | 4.32 | n.o. | Cuprite |
| 4 | n.o. | 91.39 | 8.61 | n.o. | n.o. | Cuprite |
| 5 | n.o. | 84.95 | 10.48 | 3.80 | 0.77 | Cuprite |
| 6 | n.o. | 92.69 | 0.99 | 3.029 | 3.03 | Cuprite |

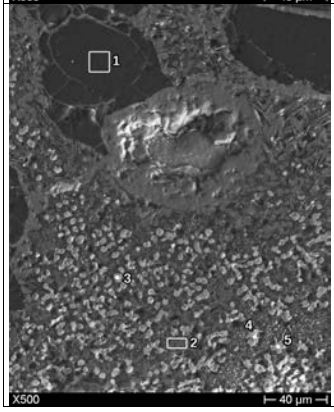
## A-S-1





Region 1 SE image

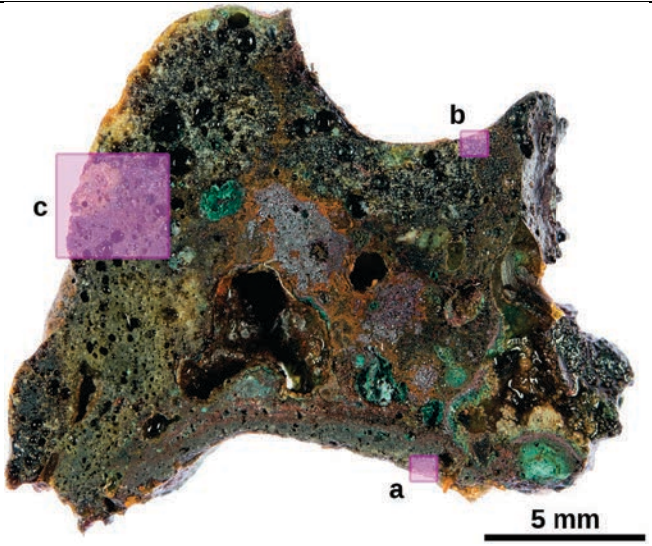
| Point | $K_2O$ | CaO | CuO | FeO | $Al_2O_3$ | $SiO_2$ | $TiO_2$ | Cl | Phase |
|---|---|---|---|---|---|---|---|---|---|
| 1 | n.o. | n.o. | 0.37 | n.o. | n.o. | 99.51 | n.o. | 0.13 | Quartz |
| 2 | n.o. | n.o. | 80.16 | n.o. | n.o. | n.o. | n.o. | 19.84 | Altered Cu-oxide |
| 3 | 0.82 | 0.32 | 49.66 | 8.98 | 1.91 | 25.30 | 1.48 | 11.54 | Cuprite, delafossite, glass |
| 4 | n.o. | 0.79 | 24.3 | 26.87 | 5.52 | 36.42 | 2.38 | 3.72 | Cuprite, delafossite, glass |
| 5 | n.o. | n.o. | 54.32 | n.o. | n.o. | 32.38 | n.o. | 13.29 | Cuprite, quartz |

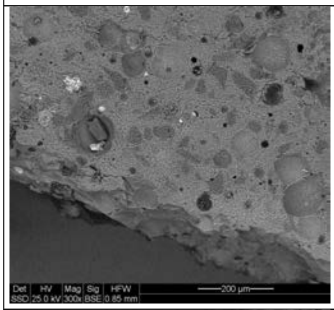


Region 2 SE image

| Point | MgO | CaO | CuO | FeO | $Al_2O_3$ | $SiO_2$ | $TiO_2$ | Cl | Phase |
|---|---|---|---|---|---|---|---|---|---|
| 1 | n.o. | n.o. | 2.58 | n.o. | n.o. | 97.42 | n.o. | n.o. | Quartz |
| 2 | n.o. | 0.50 | 53.22 | 10.25 | 3.79 | 31.42 | 0.82 | n.o. | Cuprite, delafossite, glass |
| 3 | 0.97 | 0.98 | 46.11 | 5.00 | 4.35 | 41.87 | 0.56 | 0.18 | Cuprite, glass |
| 4 | n.o. | 0.67 | 54.58 | 9.91 | 2.90 | 30.40 | 1.25 | 0.29 | Cuprite, glass |
| 5 | n.o. | 0.89 | 39.47 | 12.08 | 4.50 | 41.28 | 1.78 | n.o. | Cuprite, glass |

1335a

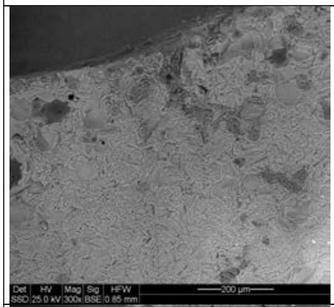




Region a

BSE image

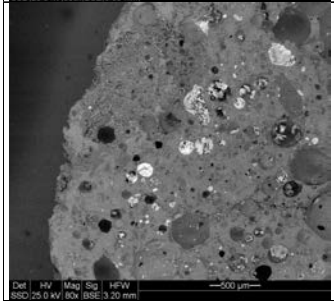
| Feature | K | Mg | Ca | Cu | Fe | Al | Si | Cl | C | O | Phase |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Light grey matrix | 2.98 | 1.86 | 17.93 | n.o. | 12.41 | 7.08 | 32.70 | n.o. | 1.27 | 23.77 | vitrified loess |
| Whitish round phase | n.o. | n.o. | n.o. | 75.35 | 1.31 | n.o. | 1.38 | 15.56 | n.o. | 6.40 | corroded copper prill |
| Dark grey angular phase | n.o. | n.o. | n.o. | n.o. | n.o. | n.o. | 67.61 | n.o. | n.o. | 32.39 | quartz |
| Light grey matrix | 2.32 | 1.35 | 18.45 | n.o. | 10.42 | 9.20 | 32.22 | n.o. | n.o. | 26.04 | vitrifies loess |



Region b

BSE image

| Feature | K | Mg | Ca | Fe | Al | Si | O | Phase |
|---|---|---|---|---|---|---|---|---|
| Light grey matrix | 2.02 | 2.12 | 15.19 | 10.70 | 6.48 | 29.87 | 33.61 | vitrified loess |



Region c

BSE image

| Feature | K | Mg | Ca | Cu | Fe | Al | Si | Cl | O | Phase |
|---|---|---|---|---|---|---|---|---|---|---|
| Grey phase with rough surface (upper left) | 2.72 | 0.90 | 13.29 | 15.52 | 10.53 | 6.65 | 29.75 | n.o. | 20.64 | vitrified loess |
| Whitish round phase | 0.37 | n.o. | 0.87 | 79.29 | 1.68 | n.o. | 3.67 | 8.72 | 5.39 | corroded copper prill |
| Light grey matrix | 3.52 | n.o. | 20.74 | 2.22 | 14.95 | n.o. | 32.50 | 0.35 | 25.62 | Mix vitrified loess + copper slag |

# Chapter 7

# Spread of the lost wax casting technology

The archaeological record is too limited for a full-fledged reconstruction of the when and how the lost wax casting technology spread. Nevertheless, the evidence presented in chap. 3 and 4 allows to develop a hypothesis for the spread of the lost wax casting technology to the Chalcolithic Southern Levant. It is likely to be re-assessed as soon as new archaeological and archaeometallurgical evidence becomes available. In the meanwhile, it hopefully stimulates future research about the spread of the lost wax casting technology in West Asia.

First, was there any spread at all or was the lost wax casting technology in the Chalcolithic Southern Levant locally invented? The isolated occurrence of this technique here, the unique polymetallic copper alloys almost exclusively used for such casts, the design and iconography of the objects (cf. chap. 3.1.1), all point towards a local innovation. However, the absence of suitable ore sources for the polymetallic copper alloys in the Southern Levant clearly identifies them as imports (e.g. Tadmor et al., 1995). Moreover, this complex technology is among the earliest evidences for metallurgy in the Late Chalcolithic Southern Levant. Obviously, this does not preclude a local origin for this technology, but it seems highly unlikely that it was invented practically from scratch while relying on a non-local and previously unused (unknown?) raw material. Although the iconography of the objects made by lost wax casting is clearly local (Beck, 1989; Shalem, 2015), this cannot be taken as an argument for or against a local origin of the innovation because lost wax casting puts almost no constraints on the shape and design of the objects made with it. Consequently, the appropriation of a non-local technology seems more likely.

The origin of the lost wax casting technology is most likely located in Southeast Europe. The Varna I cemetery, dating to the mid-5$^{th}$ millennium BCE (Higham et al., 2018), yielded a couple of gold artefacts cast in this technique (Leusch et al., 2015). A technological connection between this region and the Late Chalcolithic Southern Levant seems to be indicated by smelting copper directly in the furnace, while crucible smelting was performed in the other regions (cf. chap. 4.1). Further, Klimscha (2013b, pp. 97–98) notes strong similarities in the social organisation of Southeast Europe and the Southern Levant. Burials in both regions often contain metal items but neither them nor other aspects of their material culture seen to indicate a vertical stratification of the society (cf. chap. 3.1.1 and 3.1.5). Nevertheless, indicators for direct contacts between the two regions remain absent (cf. chap. 3.2.1). Therefore, if the lost wax casting technology of the Late Chalcolithic Southern Levant is indeed adopted from Southeast Europe, contacts between the two regions were indirect and should have left traces in the regions between them, particularly Southeastern Anatolia/Northern Mesopotamia and the (Southern) Caucasus. Contemporary far-reaching networks already existed between, e.g., Southeast Europe, Western Europe, and Northern Europe (e.g., Klassen, 2004). The existence of comparable networks covering West Asia and neighbouring regions should not be surprising considering the close connections between the West Asian regions in previous periods (cf. chap. 3.2).

Widening the scope to these regions reveals an interesting pattern. Apart from the Southern Levant, metal burial items are found in Iran, the Southern Caucasus and, in exceptional cases, Northern Mesopotamia. Like Southeast Europe and the Southern Levant, they do not seem to indicate status differences in a vertically stratified society in Iran (Helwing, 2021). A notable exception is Susa, where such stratification is suggested by elite residences (Matthews and Fazeli Nashli, 2022, p. 150). The currently only known burial with metal items of the Sioni culture in the Southern Caucasus is an infant burial in Ovçular Tepesi (Gailhard et al., 2017). The situation in Northern Mesopotamia is more complex. A vertically stratified society existed and was expressed through staple finance and monumental architecture. The social organisation of Southeastern Anatolia seems to correspond to the staple finance system as well (cf. chap. 3.1.2). No metal items were found in burials from these two regions except for three children burials in Tepe Gawra, Grai Resh and Hacınebi, which contained small gold and silver objects. All of them belong to the North Mesopotamian or Eastern group (cf. chap. 3.1.2). Admittedly, this pattern could be the result of the limited archaeological record: Only subadult burials were excavated at Susa in the level dating to the early 4th millennium BCE (Tallon, 1987, p. 315), and the total number of burials from the Sioni culture and in Southeastern Anatolia is small. The three burials from Northern Mesopotamia are exceptional in many ways, not only because they have metal items (cf. chap. 3.1.2). Therefore, it seems likely that burials in this region usually did not have metal.

Although the archaeological record might hint to a connection between subadult burials and metal items at the turn of the 5th to the 4th millennium BCE, it is yet too limited for such an interpretation. Important in the context of this study is the perceivable difference between regions with monumental buildings and staple finance and regions with metal-containing burials. The Southern Caucasus cannot be safely assigned to one of the two groups due to the singular nature of the burial in Ovçular Tepesi. The earliest evidence for monumental architecture in the Southern Caucasus dates only to the very end of the period under study here (cf. chap. 3.1.3), providing tentative evidence for an assignment to the group without monumental buildings but with metal-bearing burials. The situation in Iran is more complex but it seems that except for Khuzestan monumental buildings and metal-bearing burials are mutually exclusive. Unfortunately, the social organisation of the Iranian regions is still too poorly understood for reliable statements about whether a staple finance system like the Southeastern Anatolian-Northern Mesopotamian system existed in the regions with monumental architecture (cf. chap. 3.1.4). Despite all these uncertainties, two general ways of communicating status seem to prevail at the turn of the 5th to the 4th millennium BCE in West Asia. Metal objects (and other exotic materials) in burials to display types of status not related to a vertically stratified society in Southeast Europe, the Southern Levant, parts of Iran and probably the Southern Caucasus, and monumental architecture in Southeastern Anatolia, Northwestern Mesopotamia and the remaining parts of Iran, at least in the former two regions associated with control over staples.

Regardless of this apparent difference in the communication of status, the material culture of the Southern Caucasus, Southeastern Anatolia, Northern Mesopotamia, and Iran with their respective neighbouring regions has many shared traits such as shaft hole axes or chaff faced ware (cf. chap. 3.2.3). This suggests a close interaction between these regions and consequently the existence of one large interaction sphere. As Matthews and Fazeli Nashli (2022, p. 187) suggested, this network might build upon earlier cultural phenomena such as the Ubaid, during which far-reaching contacts were established. They further suggest that not only goods and related technologies but also immaterial features such as symbolic meanings and ideologies spread through this network.

If the lost wax casting technology spread from Southeast Europe to the Southern Levant, it must have entered this network. One potential entry point could have been (South)eastern Anatolia. However, chap. 3.2.4 showed that elements of Southeast European material culture can be traced as far East as the region of İkiztepe but are not found in Eastern Anatolia, indicating a cultural barrier between these regions. The other possible route is along the north coast of the Black Sea. There is little archaeological evidence that connects Southeast Europe with the Caucasus and specifically the Southern Caucasus (cf. chap. 3.2.3) but this could be the result of the very limited archaeological record from this period at the Black Sea's north coast and in the Northern Caucasus. The most striking indicators for such contacts are shaft hole axes, which appear first in Southeast Europe and a couple centuries later in the Southern Caucasus and Iran (Rosenstock et al., 2016). Unfortunately, the contexts of the Southern Caucasian and Iranian shaft hole axes cannot be dated precisely enough to elucidate if these objects spread from Iran to the Southern Caucasus (e.g., Helwing, 2012b) or in the opposite direction (Stöllner, 2021). Considering the West Asian interaction sphere and the comparatively short distances between the Caucasian and Iranian sites as well as the earlier occurrence of these objects in Southeast Europe, an adoption of the Southeast European shaft hole axes to the Southern Caucasus followed by a fast spread towards Iran seems more likely.

Another indicator for a connection between Southeast Europe and the Caucasus might be the lost wax cast bull figurines in the Maikop kurgan (Reinhold, 2019). Although dated to the second quarter of the 4th millennium BCE, i.e., slightly after the end of the period under study, they are the earliest evidence for this technology in this region (cf. chap. 4.1.4). Like in the Southeast European tradition, two of them are made of gold. The other two are made of silver, whose production was discovered during the early 4th millennium BCE in the mountainous regions of Western Asia (Pernicka, 2020).

At some point, the lost wax casting technology had to leave this West Asian interaction sphere towards the Southern Levant. The archaeological evidence presented in chap. 3.2.1 shows that contacts between the Southern Levant and Anatolia were established the latest during the Ubaid. These contacts are not that easily traceable because of the very fragmented archaeological record in the Northern Levant, the likely contact region between the West Asian interaction sphere and the Chalcolithic Southern Levant. Nevertheless, the archaeological remains are sufficient to reconstruct a steady flow of materials, technologies and ideas between the two regions. In addition, archaeogenetic studies revealed that Anatolian and Iranian groups arrived independently in the Southern Levant at some point before or during the Late Chalcolithic (Harney et al., 2018). Assumedly, they brought their symbolic concepts and technologies with them.

While the reconstruction of the route along which the lost wax casting technology spread is important, the more intriguing aspect is the motivation for this spread and why it was seemingly ignored in the mountainous regions of the fertile crescent, but readily adopted in the Southern Levant. Lost wax cast objects are found only in regions where status is communicated with metals and other exotic materials. Broadly dated to the first half of the 4th millennium BCE, a golden lost wax cast bead in Tepe Hissar (Jansen and Benati, 2020, p. 319) seems to complement this picture for the North Central Iranian Plateau. Furthermore, except for the Chalcolithic Southern Levant on the other side of the regions expressing status through monumental buildings and staple finance, all lost wax cast objects except two of the Maikop bulls are made of gold, all are massive casts, and the spread of gold as new metal seems to parallel the spread of the lost wax casting technology (cf. chap. 4.1.2). It seems as if the two were components of the same technological package, probably embedded in a concept of shininess (see below). Another component of this package might have been the shaft hole axes. To understand the spread of the lost wax casting technology, the spread of the entire technological package and its interaction with the two status-communicating systems must be understood.

Concepts of the acceptance and appropriation of innovations are essential to understand these processes and will be shortly summarised here (see Erb-Satullo, 2020 for a recent archaeological review on this topic). Principally spoken, any new element in a group/society (e.g., custom, technology, material) is an invention. This also holds true if this element is already fully established in a group and discovered by a member of another group where it is still unknown – it is an invention in the latter group then (Shortland, 2004, pp. 2–3). If this invention is considered useful, it becomes an innovation (Shortland, 2004, p. 2), which means that it enters a process of being accepted or not within a defined group such as a society (Burmeister and Müller-Scheeßel, 2013; Erb-Satullo, 2020; Roberts and Radivojević, 2015). This process is often described with the S-curve model established by Rogers (2003). Although it has its limitations, this model offers a simple and easy concept for diffusion of innovations within the group. The S-curve is derived from performance of a successful innovation over time, measured, e.g., by the number of adopters. At the beginning, only a few persons (the innovators and early adopters) use the innovation but with time it will be adopted by more and more people until it is firmly established within the group. At this point, only the "laggards" will adopt the invention and the curve will flatten again (Fig. 7.1).

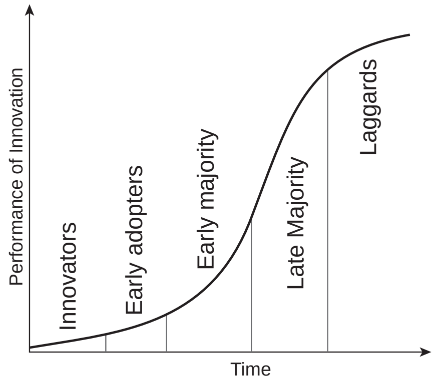


Figure 7.1: The S-curve model for the diffusion of innovations after Rogers (2003).

The success of an innovation depends on whether it fits sufficiently well into the existing social system of the group, i.e., whether the members of the group can build a connection between their socio-cultural background and the innovation and if they perceive the innovation as something advantageous (Burmeister and Müller-Scheeßel, 2013; Kuijpers, 2015; Schubert, 2017; Shortland, 2004). Especially pre-modern societies are usually not very open to novelties, and innovation as something new always means opposition and criticism on the existing society. Consequently, the acceptance of innovations is always a process of social differentiation, a positioning of "them" against "us" (Burmeister and Müller-Scheeßel, 2013). Therefore, a successful innovation succeeded in modifying existing social codes, e.g., by loading new materials with symbolic meaning. For the same reasons, the more radical the innovation is, the further away from the society's majority are the people adopting and promoting it first. They might be outsiders, which have nothing to lose by adopting it, or elites, which are powerful enough to modify or even create said social codes. Additionally, the chance of becoming a failed innovation increases because it might not spread beyond this group (Burmeister and Müller-Scheeßel, 2013; Schubert, 2017). In turn, chances to become a successful innovation increase by an active exchange of knowledge (Burmeister and Müller-Scheeßel, 2013) and "open channels of cultural transmission"

(Henrich, 2010, p. 106). These are a large number of role models that uses the innovation and convinces other members of its use by their prestige, obtained either by status or on an individual level, such a teacher-pupil or parent-child relations (Radivojević, 2015). Success chances increase also with the openness and flexibility of an innovation (Schubert, 2017).

In summary, the innovation process is primarily a social process (Bernbeck and Burmeister, 2017; Henrich, 2010; Renfrew, 1986) and its outcome is controlled by the reaction of a population to an innovation, which again follows a path of dependencies resulting from previous decisions and developments. There is no automatism in the incorporation of "better" technologies or "beneficial" innovations because it depends on the society and its background (social, economic, technological, etc.) what is perceived as "better" and "beneficial". "Lock-in" states are possible when the established system is too strong to allow the inclusion of innovations even if their advantages are acknowledged (Schubert, 2017). Therefore, an innovation can be (a) directly adopted by copying, i.e., learning how it is made, or reproduction, i.e. imitating the invention without knowledge of the original process, (b) adapted to local particularities but remaining mostly unchanged, (c) domesticated, i.e., transformed to make it fit with the respective social system, or (d) actively rejected (Burmeister and Müller-Scheeßel, 2013; Schubert, 2017).

Applying those concepts to the technological package "lost wax casting with gold" suggests that the role of metals is the most important parameter in the interaction between the technological package and the different status-communicating systems. Only small unalloyed copper items are reported from Southeastern Anatolia and Northern Mesopotamia (cf. chap. 3.1.2). Moreover, they seem to have belonged to the community and not individuals (Stork, 2015). Lost wax cast decorative items do not fit at all into this setting. Because prestige was already communicated through monumental buildings and staple finance, the elite controlling the access to and distribution of staples had assumingly ample interest in keeping the associated concept of individually assigned status away from their dominions. Consequently, the lost wax casting technology was rejected because it was not compatible with the social codes of these groups. However, gold as new material was successfully adapted at least in Northern Mesopotamia as is evidenced by the exceptional burials in Tepe Gawra and Grai Resh. Perhaps it was compatible with the existing social codes because of the other new shiny metal silver. The earliest production remains for silver are located in this region, suggesting that it was discovered here (cf. chap. 4.1.3). Of course the finds in these burials can also be the harbingers of the changes in the status-communicating system unfolding during the second quarter of the 4th millennium BCE in the entire interaction sphere, when the local elites begin to use shiny and exotic materials in addition to control over staples (cf. chap. 3).

The status-communicating system based on metal exotic items in the other West Asian regions seems to have been more open for the new technological package with its associated symbolic concepts; most likely, because the social codes related to the technological package were compatible with already existing ones. This also holds true to the apparent contradiction between individual burials in Southeast Europe and the secondary burials in the Chalcolithic Southern Levant, where burial goods cannot be assigned to individuals (cf. chap. 3.1.1). In Varna, some of the richest are cenotaphs at it was suggested that they were part of rites defining and expression group identities (Radivojević and Rehren, 2016). Likewise, Chalcolithic burial caves in the Southern Levant seems to be used by specific groups (Nativ and Gopher, 2011). Consequently, burials and burial rites, albeit very different, might have had a played a similar role in the social organisation of both cultures.

Arsenic copper was used from early on in the Southern Caucasus and Iran (Courcier, 2014; Thornton, 2009a). Copper with a certain amount of arsenic has a gold-like colour, making the objects also by their colour compatible with gold. The very few lost wax cast items from the two regions seem to indicate that the technological package was adopted practically unchanged. Because of the very limited archaeological record it must remain open if an adoption did not happen before the second quarter of the 4th millennium BCE, or if remains are yet to be found. In any case, gold (and silver) becomes widespread in the Caucasus only with the first kurgans around 3800 to 3700 BCE (Lyonnet et al., 2008).

Dynamics in the Late Chalcolithic Southern Levant were very different although some general commonalities exist. Lost wax technology was adopted here readily with objects clearly pre-dating the ones from the Southern Caucasus and Iran. Besides the general compatibility of the status-communicating system with the technological package, an advantageous circumstance was surely that this period is characterised by a generally high innovativeness and creativity (e.g. Yekutieli, 2022). Moreover, the technological package was heavily modified ("domesticated"): polymetallic copper alloys were used instead of gold, and instead of small personal ornaments, large objects such as mace heads, standards and crowns were produced. What is more, new components seem to have been added to it, most importantly the use of ceramic cores instead of the massive casts in the other regions. The motivation for the use of ceramic cores, making the casting process more complex, remains unclear. The probably most obvious is to save on metal. Other reasons could be the (in)stability of the modelling material in thick layers (Anfinset, 2011; Levy et al., 2008), or, analogous to the use of grog temper by the emigrated groups from the northern Southern Levant (Roux, 2022), to include something local in this foreign process. Other potential genuine Southern Levantine components related to the lost wax casting technology are the repair of casting errors with a cast-on technique (Tadmor et al., 1995) and mixing/recycling (chap. 5.2.5.3.2).

The reasons for the apparent enthusiasm for this new technology – the number of objects found in the Southern Levant is magnitudes larger than the number of contemporary items from the other West

Asian regions and Southeast Europe combined – are deeply rooted in the ideology of the Chalcolithic Southern Levant and will be discussed in chap. 8. For this discussion, it may suffice to point out that the lost wax cast objects are skeuomorphs or imitations of already existing items. So are the unalloyed copper objects, whose technology was introduced to the Southern Levant at the same time (Gošić, 2015). It seems as if the main incentive for the adoption of metallurgy in this region was the creation of a new, metallic, representation of existing objects, especially of so-called prestige items.

The modifications of the technological package can be explained by technological and aesthetic reasons. The Chalcolithic Southern Levant knew gold, as is evidenced by the gold rings found in Nahal Qanah cave (Gopher and Tsuk, 1996a). From the technological perspective, only the significantly lower melting temperatures of the polymetallic copper alloys (compared to gold) and their very good castability (cf. chap. 4.3.3) made single-piece casts of large and/or detailed objects such as standards and crowns possible. Access to the metal was surely another decisive factor. The Southern Levant is devoid of gold deposits and at this time the material is very rare in the other West Asian regions (cf. chap. 4.1.2). Polymetallic copper alloys, itself a singular innovation, were probably more readily available and, equally important, in the necessary quantities. The whereabouts of these metals remain obscure (cf. chap. 4.1.1.5.2). It seems possible that they are by-products from unalloyed copper smelting (cf. chap. 4.3.2), discarded in their source regions due to their poor mechanical properties (cf. chap. 4.3.3) but brought (traded?) to the Southern Levant. Hauptmann (2000) suggested that these by-products, technically speiss, were used as master alloy that was mixed with local unalloyed copper. The metal items found in Fazael might support such an interpretation (cf. chap. 5.2.5.3.2), although the nature of the mixing remains unclear.

From an aesthetic perspective, polymetallic copper alloys imitate all the assumedly important materials depending on their alloy composition: gold, silver (cf. chap. 4.3.3), and haematite (Craddock, 1995, p. 291; Shalev and Northover, 1993). The former two were newly available metals and became the next big thing in metallurgy during this time in the North (cf. Sherratt, 2019), while the Southern Levant does not have direct access to them. The latter was the preferred material for stone mace heads, and red decorations are an important element on a range of special objects such as the clay vessel figurines and ossuaries (e.g., Alon, 1977; Shalem et al., 2013).

The technological package seems to be embedded in an aesthetic concept of shininess (chap. 4.4), which might have included beads made of glazed steatite or artificial enstatite (Bar-Yosef Mayer et al., 2014; e.g., Bar-Yosef Mayer and Porat, 2009; Klimscha, 2011; Nezafati, 28.01.2022) and exotic stones such as lapis lazuli (e.g., Bar-Yosef Mayer et al., 2014; Helwing, 2012a; Kepinski et al., 2011; Lyonnet et al., 2008; Schmidt, 2002). The origins of this concept remain obscure and its apparent linkage to the status-communicating system through shiny materials (metals, exotic stones) makes it difficult to differentiate between autochthonous developments linked to the inherent fascination that shiny materials trigger at humans, or allochthonous concepts brought from elsewhere, perhaps together with the technological package.

In any case, the arrival of technologies in the Southern Levant that allow creating complex shapes of practically any kind in a shiny material with variable colour, including a direct connection to the important colour red and thus enhancing their compatibility, seem to have sparked the interest of the Late Chalcolithic society in metallurgy while being open enough to fit (easily?) into its social codes. As C. S. Smith observed,

> "[…] the first appearance of almost all artificial materials and of treatments to adjust their properties or shapes to specific uses appear first in objects of art, or at least in objects of ceremony in which utility resides in their aesthetic overtones." (Smith, 1975, p. 606)

It is difficult to reconstruct to which extent the social and symbolic meanings associated with the technological package and the aesthetic concept were included into the ideology of the Late Chalcolithic Southern Levant. There seems to be no significant change in the burial rites with the advent of metallurgy. Moreover, burial goods, including metal objects, cannot be assigned to individual burials (cf. chap. 3.1.1), contrasting burial rites in the other West Asian regions with a similar status-communicating system. The social meaning of the burial rites for the respective social groups might have been similar, though (see above).

If shaft hole axes were a component of the technological package as well, they were apparently rejected, as they were in Southeastern Anatolia and Northern Mesopotamia but not in the Southern Caucasus and Iran. This comes as no surprise with regards to the discussion above. Large copper tools were already used in the latter two regions, making shaft hole axes generally compatible with the respective social system. They maybe also provided a technological advantage over the existing metal axes. In contrast, large copper items disappeared in Southeastern Anatolia and Northern Mesopotamia until the second half of the 5th millennium BCE (cf. chap. 3.1.2) and it seems extremely unlikely that they would be incorporated again because of a widely incompatible technological package. The Chalcolithic Southern Levant again used the new technologies to create representations of already existing items; also the tool-shaped metal items were not used as tools (Golden, 2009, p. 295; Namdar et al., 2004). Consequently, the inclusion of a new object type was not compatible with the ideology in which the Chalcolithic Southern Levantine metallurgy was embedded.

It is tempting to assign the technological package to one of the two groups immigrating into the Southern Levant (Harney et al., 2018). Being a period with many innovations, could other traits of the Southern Levantine Chalcolithic be identified as "Anatolian" or "Iranian"? The probably best attempt is the V-shaped bowls, which are very similar to the slightly earlier dating North-Mesopotamian Coba bowls (Fig. 3.3) and were like them produced in large quantities (Baldi, 2018; Kerner, 2001). However, Gilead (2011) identified precursors of them in the Besorian, pointing towards either a local origin or an immigration of one of the groups before the Chalcolithic. In addition, it must not be forgotten that the Iranian group most likely arrived in the Southern Levant through Northern Mesopotamia, potentially obscuring a distinction of the material culture related to both groups. The decreasing import of Anatolian obsidian with the onset of the Southern Levantine Chalcolithic (Yellin et al., 1996) might even point towards a reduction of contacts between the two regions; perhaps because of the different status-communicating systems. And another important innovation, unalloyed copper metallurgy, appears to be Southeast European as well: smelting directly in a pit furnace and not in a crucible placed in a pit furnace was only observed there as well, as is a potential tuyère fragment whose interior diameter would suggest the use of bellows (cf. chap. 4.1.1.1, 4.1.1.5.1, 6). Consequently, a correlation of the archaeogenetic evidence with Chalcolithic innovations is not possible or requires in-depth studies of other aspects in the material culture such as pottery.

Admittedly and already hinted to at the beginning of this chapter, this model has several constraints. The visibility of metal in the archaeological record is a matter of deposition practices. While metal items were deposited in one of the status-communicating systems, their absence in the other does not mean they did not exist or had no role in them. However, the relatively paucity of metal items and the complete absence of large items in these regions renders it unlikely that this difference is the exclusive result of a skewed archaeological record. Closely related is the small number of burials in some of the regions (see above). Nevertheless, it seems unlikely that finds of more burials would turn the picture completely because the more extensively investigated and studied archaeological record in Southeastern Anatolia and Northern Mesopotamia compared to the neighbouring regions suggests that burials are indeed rare at this time. Last but definitely not least, new important results about the high level of metalworking in the regions under study here are already lurking on the horizon. An example is the finds from Chega Sofla in Khuzestan (Moghaddam and Miri, 2021; Nezafati and Moghaddam, 2021), whose outstandingly high level of metalworking is currently under study (Nezafati, 28.01.2022). They might require revision of the proposed model not too far into the future. Nevertheless, the proposed model shows the potential of large-scale comparative approaches and the inclusion of concepts about the spread and appropriation of innovations in West Asia in the second half of the 5th and early 4th millennium BCE. It further shows that a good grasp of these long-distance interactions is essential for understanding the processes within a single region, and how elaborate contact networks already were during this time.

# Chapter 8

# The role of metal in the Chalcolithic Southern Levant

As was shown in chap. 3.1.1, the adoption of metallurgy in the Southern Levant was paralleled by several other changes in the material culture, most notably the disappearance of the “temples”, marking the transition to the Late Chalcolithic. At the same time, chap. 7 indicates that the two metallurgical traditions prevailing in the Chalcolithic Southern Levant are probably best discussed together and were deeply embedded in an already existing ideology. It remains to be discussed which ideological meaning metal objects had in the Late Chalcolithic Southern Levant and why the lost wax casting with polymetallic copper alloys went extinct at the end of the Chalcolithic while the unalloyed copper metallurgy survived.

A closer look must be taken first on the notion that all metal objects are skeuomorphs or imitations as suggested in chap. 7. This is pivotal to understand the role of metal in the ideology of the Chalcolithic Southern Levant. Gošić (2015) probably developed this hypothesis the furthest, but it was previously suggested that the different decorated mace heads could represent bulbs or seeds (Merhav, 1993 cit. in Ilan and Rowan, 2011), and the parallels between stone mace heads and axes and their metallic counterparts were obvious from early on and made particularly obvious by the lost wax cast axe with imitated mounting strings in the Nahal Mishmar Hoard. In addition, some objects in the Nahal Mishmar Hoard seem to resemble, e.g., a shepherds crook or a reed cane (Bar-Adon, 1980; Gošić and Gilead, 2015a). Taken a step further, the horizontal incisions or protrusions on many shafts of the standards might be a reminiscence of the nodes on reed canes or corn stalks, on which the mace heads and, e.g., the bird-shaped standard were probably shafted. Moreover, the hollow cast mace heads might be in fact skeuomorphs of miniature hole-mouth jars. Admittedly, these would miss the bottom, but this might have been a necessary compromise to reliably attach the inner part of the mould to the outer part and might have been negligible for the purpose of the object because they were always standing on something, like many of the hole-mouth jars are dug into the floor. Likewise, the crowns resemble the stands on which the “Gilat woman” sits (Alon, 1977) and which were found, among others, in Peqi’in cave (Shalem et al., 2013). Fish hooks have unalloyed copper equivalents, although unalloyed copper has rather problematic properties for their use as such (Rosenberg and Chasan, 2020). Proving these interpretations is hard but it seems not too far-flung to assume that most or even all of the metal objects might be imitations or skeuomorphs of objects made of perishable materials such as wood, when many of the items made of non-perishable materials have metal analogues (cf. Gošić, 2015). It is important to note that this practice seems to exclude some object types such as V-shaped bowls or basalt bowls, interpreted by some researchers as ritual items (cf. Roux, 2019b), but also, e.g., churns.

Following these lines of thought supports the notion of metal objects as boundary objects, but rather than between new and old technologies as suggested by Gošić (2015), between mundane and ritual items. It is suggested here that metallurgy was a transformative act to create ritual versions of non-ritual objects, seemingly fulfilling the need for a new, shiny, representation of these objects. A mediating role of rituals between the new material metal, the associated technologies, and the existing Chalcolithic ideology does not seem necessary. The apparent readiness and open mindset (cf. Yekutieli, 2022) of the Chalcolithic people enabled the quick modification, incorporation, and extension (ceramic cores, polymetallic alloys, possibly tuyères and direct smelting in pits, cf. chap. 7) – not necessarily in that order – of the metal technologies (cf. Roberts and Radivojević, 2015). The large-scale metal production at the Aqaba-sites (Klimscha, 2011; Pfeiffer, 2009) might be an echo of this seeming enthusiasm for metal, although cultural and also metallurgical parallels between these sites and the Chalcolithic Southern Levant are weak (Joffe, 2022; Klimscha, 2011). This innovativeness of the Chalcolithic Southern Levant certainly extended to other crafts, such as the tournette in the Early Southern Levantine Chalcolithic (Baldi and Roux, 2016; Gabrieli, 2016), used almost exclusively for the production of V-shaped bowls (Commenge and Alon, 2002; Kerner, 2001).

If the metal objects are indeed ritual representations of mundane objects, the role of the objects without metallic representations must be discussed as well. Basalt bowls and V-shaped bowls were interpreted previously as ritual objects (cf. Roux, 2019b) and if they already were, no metallic representation of them would have been necessary. The function of churns is unclear but usually related to the processing of dairy products (Rowan and Golden, 2009). While some of them have enormous sizes, miniature versions exist as well (Kerner, 2001, p. 126). Moreover, they are featured in the ceramic figurines: the “Gilat woman” and the ram from En Gedi are carrying them on their head and back, respectively (Alon, 1977; Ussishkin, 1980). Therefore, it seems possible that they were ritual items, too.

There are two other possible mutually non-exclusive interpretations, why these objects were considered as ritual objects. The ritual element might have been not the object or material itself but the technology associated with it (cf. Roux and Harush, 2022 for a similar line of thought based on V-shaped bowls). As is the case with metallurgy, all of them represent a special technology: basalt bowls are the only stone vessels, V-shaped bowls were wheel-shaped, and churns were used for dairy products. While wheel-shaping seems to be genuine to the Chalcolithic Southern Levant (Baldi and Roux, 2016; Gabrieli, 2016), the use of secondary products and the production of basalt bowls is attested earlier but fully unfolds only then (cf. chap. 3.1.1). The second interpretation focusses on the foreign origin of the respective technologies as criterion for their ritual significance. This can be shown relatively well for metallurgy (cf. chap. 7). The V-shaped bowls might be locally modified versions (in the same sense the lost wax casting technology was modified) of the Northern Mesopotamian Coba bowls (Kerner, 2001). The same might be true for secondary products, although the respective contacts would date to the Late Neolithic Wadi Rabah culture (Rosenberg, 2009), which was in close contact with the Halaf culture (cf. chap. 3.2.1). Admittedly quite a stretch, the basalt vessels could be the localised version of the concept “stone vessel”, which was derived from imported chlorite vessels (Rosenberg et al., 2010), or their region of origin (most likely Golan Heights) was considered to be already foreign. It must remain open whether the import of these innovations were driven by the exchange of technologies and ideas, i.e., without the movement of people, or if groups bearing one or another innovation arrived in the Southern Levant from the North (cf. Harney et al., 2018).

In contrast to metallurgy, all of these potential ritual objects were already available with the onset of the Chalcolithic. Being the latest innovation that arrived in the Southern Levant, metallurgy was quickly turned into a genuinely Southern Levantine technology and included in the Chalcolithic ideology. As mentioned above, the social system of the Chalcolithic Southern Levant changes from the Early to the Late Chalcolithic. While many aspects of the material culture continue, the probably most important change is the relinquishment of the “temples” or “shrines” and the onset of metallurgy. Chap. 7 showed that a new technology does not automatically has the power to initiate such a change as suggested by, e.g., Gošić and Gilead (2015a). Instead, the social system must be already susceptible for it. Based on our current knowledge, it is possible that either the arrival of metallurgy opened up possibilities for this process because the ideological role of the “temples” could (finally?) be replaced with something of equal ritual value but more mobile, or that the arrival of metallurgy initiated social dynamics and added a facet to the prevailing ideology that quickly outcompeted the raison d’être of the “temples”.

Although usually identified as religious buildings, the purpose of these “temples” remains obscure and other theories exist (cf. chap. 3.1.1). The difference might have been marginal anyway if the Chalcolithic ideology interlinked the ritual sphere and daily life as closely as suggested by Joffe (2022). However, if their purpose was indeed mundane as suggested by, e.g., Guyot (2014), and metallurgy indeed entirely ritualistic as suggested above, the change from the Early to the Late Chalcolithic might also indicate an increase in the ritualisation of the Chalcolithic ideology.

If the people in charge of these buildings initiated the replacement of the special buildings by metallurgy, their motivation could have been to reinforce the already weakening Chalcolithic ideology. As suggested by Joffe (2022), the decline of the Chalcolithic ideology (see below) began several centuries before its end and might have required new concepts to keep the ideology compatible with the changing world or at least to re-assure the people that the divine entities (e.g., gods, ancestors) were still with them. Adopting metallurgy might have been a very welcomed opportunity to do so and not only stabilised the Chalcolithic ideology but also the power of the ritual-conducting persons. If metallurgy outcompeted the ideological aspects related to the special buildings, we might see the replacement of a weakened ritual group with one that perhaps offered better explanations and spiritual service to the people.

Whether these changes happened in a heterarchical or hierarchical society is difficult to decide and although the discussion in chap. 7 suggests a heterarchical system build on individually obtained status, both will be discussed. In a hierarchical society, inter-personal violence would be expected for the second option if the elite was toppled over. Because the overall ideology remained unchanged and such evidence is sparse, although not completely absent (Dawson et al., 2003), it is unclear how significantly the hierarchy was actually changed. In a heterarchical society, both processes are expected to unfold without any major disruptions. Although it can be expected that also in this society people with power want to keep it, loosing this power by losing the support of the remaining parts of the society should result in a much smoother transition than in a hierarchical society.

Regardless of the social organisation, what made metal that attractive for the Chalcolithic ideology? The fascination of metallurgy was probably threefold: a new shiny material with various colours, a spectacular process to manipulate it, which can be easily turned into one or a series of rituals, and the transformative character aspect of the process. The colours of the material were assumedly closely linked to the ritual sphere. Haematite and red as colour can be assumed to be important for the ideology of the Chalcolithic Southern Levant well before the arrival of metallurgy, with the red-banded decorations on ossuaries, clay figurines, and other ceramic objects (e.g., Alon, 1977; Shalem et al., 2013), and the haematite mace heads (Rosenberg, 2013). If the ancestors were indeed a central component of the spiritual life (Ilan and Rowan, 2011; Joffe, 2022; Roux, 2022), they might have been associated with this blood-like colour. We know from other cultures that golden colours are often associated with the sun, and silver colours with the moon, both often important divine entities for early farming societies (Ilan and Rowan, 2011; Jones, 2004). It must also kept in mind that specular haematite has a shiny dark-silvery surface. Metal melting and smelting allowed to modify and even create such potentially divine materials. They might be divine with a meaning ranging from being symbolical connectors, like in the pre-colonial Americas (cf. chap. 4.4), up to being literally part of gods, like gold was the flesh of the gods for ancient Egyptians (Lichtheim, 1976). Metal smelting and melting are audio-visually spectacular (Molloy and Mödlinger, 2020) and require a high degree of ritualisation, with many actions having sensory triggers to achieve optimal results, such as flame colour. It is quite easy to turn these operations into impressive rituals and spiritual gatherings (Gošić and Gilead, 2015a). The transformative aspect must also not be underestimated. It is the first time in this regions that humans can produce shiny rock-like materials, make them liquid, and bring them into any shape they want (Hansen, 2013) – and the metallurgists of the Chalcolithic Southern Levant were masters in it. Lastly, creating the models and moulds might have been another important ritual component (cf. chap. 4.4).

The preferentially mined and technologically beneficial haematite-rich “tile ore” in Faynan (Hauptmann et al., 1992) might have symbolised the ancestors, with the green colour of the copper ores being probably the seeds of new life and connecting the use of these ores with the use of green stone in the Neolithic (e.g., Bar-Yosef Mayer and Porat, 2008). Through the smelters, they were reborn or the smelters helped the gods with their rebirth (see Gošić, 2013 for an extensive account of myths related to metallurgy), linking metallurgy closely to the ideological concept of death and rebirth (Ilan and Rowan, 2011). Similarly, the polymetallic copper alloys could represent the ancestral bearers of the lost wax casting technology or other divine entities. In analogy to the addition of grog temper as symbol for the ancestors (Roux, 2022), polymetallic copper alloys were turned into a local material, incorporating foreign ancestors in the local community, by adding unalloyed copper or already localised polymetallic copper alloys (cf. chap. 5.2.5.3.2). Consequently, metallurgy could have been the perfect way of re-assuring the people that the ritual-performing person was still in contact with the ancestors and had their support.

In a society under fear that the ancestors could turn their back on them or even turn against them, such rituals might have been part of the burial customs (cf. chap. 3.1.1) and important events to reinforce group identities (Gošić and Gilead, 2015a). Creating a metallic representation of an object symbolising an important or powerful deceased might have manifested its presence in the world of the living, probably providing the living with some sort of power over him. In this notion, it could be that not the metallurgical act was the focus of the ritual but the transformation of a mundane object into a ritual one, i.e., switching from the non-metallic to its metallic form. Such a notion is supported by the involvement of the metal objects into the exchange networks of the Chalcolithic Southern Levant alongside the other ritual and so-called prestige items (cf. chap. 3.1.1). The distribution of the unalloyed copper objects suggest their association to the southern exchange network, which overlies the Ghassulian interaction sphere encompassing the entire Chalcolithic Southern Levant (Rosenberg et al., 2017a; Rosenberg and Shimelmitz, 2017; Roux, 2019b). Fazael, the first identified production site for lost wax cast items (cf. chap. 5.2), lies at the contact point of the two networks (Rosenberg and Shimelmitz, 2017). The petrographical results from this study (chap. 5.2.5.2) and Goren (2008) show that more than one production site for these items existed. Although they are yet to be found, they are most likely located somewhere in the Jordan valley, tentatively linking them to the northern exchange network. This seems to be further supported by the circumstance that such objects are mostly found in burial caves, but this pattern could also be the result of geographical factors (cf. chap. 3.1.1). Alternatively, the modelling and the moulding step could have been carried out as part of the ritual that created a representation of the deceased in the world of the living. Subsequently, the moulds were sent to some kind of central facility to turn the models into metal. In this case, Fazael might have been some sort of central foundry for polymetallic copper alloys and its position at the contact point of the two networks deliberate. However, all mould remains analysed so far are local (cf. chap. 5.2.5.2), speaking against this interpretation.

Keeping a representation of an ancestor in the world of the living might have been beneficial not only for the living. This practice could be an echo of the metamorphosis or waiting period the deceased had to endure for the period of their primary burial, probably locked in a sphere between the living and the nether world. The metal items might have been the focal points for rituals helping the deceased in this process and/or preventing the living from his wrath. The metal objects then might have accompanied the deceased on their last journey to the secondary burial. The hoards in Fazael 5 (Bar et al., 2015; Rosenberg et al., 2020) and Neve Noy (Baumgarten and Eldar, 1984) might represent primary burials of deceased whose body was not found, analogous to the cenotaphs of Varna I (Leusch et al., 2017) in the potential origin region of the lost wax casting technology (cf. chap. 7). Moreover, could the Nahal Mishmar Hoard be some kind of secondary burial for them, maybe specifically for the deceased in the Judean desert with its predominantly primary burials (Ilan and Rowan, 2016)?

At the end of the Chalcolithic, the lost wax casting technology, V-shaped bowls and most of the other so-called prestige items disappear (Genz, 2000; Kerner, 2011; Milevski, 2013; Roux et al., 2013). Moreover, the ones surviving undergo a significant simplification. For example, Early Bronze I stone mace heads are made exclusively from white-coloured stones such as limestone (Rowan and Levy, 2011). Also many other, but not all, aspects of the material culture change; perhaps most prominently the architecture (Braun, 2022). It seems as if the Chalcolithic ideology as such finally collapses, leaving traits unrelated to status or ritual often unchanged. The exact reasons for this prolonged breakdown, resulting in the transition horizon defined by Braun (2022), are not completely understood, yet. It seems likely that changes in the environmental conditions over time in combination with some sudden changes such as earthquakes created a situation, where the Chalcolithic ideology ultimately failed to provide the necessary narratives to explain the world (Joffe, 2022; Joffe, 2003). Beside environmental factors, internal political factors might have been important, too. Following the hypothesis above that metal objects were ritual representations of the deceased, and even if they were “only” ritualised representations of mundane objects, it seems possible that the religious authorities used their exclusive ritual knowledge to extent their power too far beyond their areas of responsibilities; maybe in a desperate attempt to preserve the influence of the Chalcolithic ideology and their owns. Especially in a heterachial system, this must have led to tensions with the remaining members of the society, resulting in an accelerated demise of the ritual system and perhaps in violent outbursts against them, their facilities, and symbols. The many scattered fragments of lost wax cast item in Fazael 2 (Rosenberg et al., 2020), might be the remains of such an event. In addition to these internal processes, polymetallic copper alloys might have become inaccessible due to the contemporary rise of the Kura-Araxes phenomenon (Badalyan, 2014; Kavtaradze, 2017; Manning et al., 2018), which seems to have split-up the West Asian interaction sphere. Consequently, the religious authorities would have been deprived of their most important material base for the creation of ritual objects, undermining their already weakening power.

Whatever the exact reasons, the collapse of the Chalcolithic ideology results in a complete change of the mindset (Yekutieli, 2022) and many Chalcolithic groups at least temporarily emigrate to neighbouring regions such as Egypt (Hartung, 2013; Oren and Gilead, 1981) and Southern Lebanon/Syria (Roux, 2022). If the Chalcolithic ideology really linked that closely landscape and ancestors as it is reconstructed (Ilan and Rowan, 2011; Joffe, 2022; Nativ and Gopher, 2011; Winter-Livneh et al., 2012), the living must have felt as if their ancestors turned away from them. If the colour red and secondary burials were closely interlinked with them, their disappearance at the end of the Chalcolithic (Rowan and Levy, 2011, pp. 207–208) would not be surprising. As another consequence, there was hardly any reason to continue with the lost wax casting, even if suitable raw materials were available and the respective knowledge not exclusive to the now-toppled religious authorities (cf. Roux, 2010): the link to the ancestors was broken, liberating the metal objects of their ritual purpose. The non-utilitarian polymetallic copper alloys, only usable for casting ritual or decorative items (cf. chap. 4.3.3), stand in strong contrast to the new goal-orientated and efficiency-focussed mindset (cf. Yekutieli, 2022). As a result, no reason was left for a continuation of this technology. The innovation lost wax casting (and the wheel-throwing practice of the V-shaped bowls) was too intimately interwoven with a certain ideology, that it could have outlived its demise (Roux, 2010). In contrast, unalloyed copper and the tool-shaped objects have indeed utilitarian value and this might be the reason why their production continues and, perhaps inspired by the Aqaba sites (Kerner, 2011, 2008; Klimscha, 2011), increased and why they later began to replace stone tools in the Southern Levant (Manclossi et al., 2019).

Of course, many of the outlined interpretations remain hypothetical, as it is often the case when attempts are made to reconstruct past belief systems. Moreover, the aim of this chapter was to present some associations that came into mind while reading about the reconstructions of the Southern Levantine Chalcolithic ideology and not to present a full-fledged theory of the Chalcolithic ideology and the place of metals in it. Consequently, many aspects are not discussed, such as the iconography of the objects. The decorations on, e.g., the standards and crowns, likely had organic counterparts and they had a certain meaning, too. In addition, there are certainly many aspects that could (and should) be linked to ethnographical and ethno-archaeological investigations. In this sense, the ideas presented in this chapter hopefully outline potential paths for further investigations by researchers much more proficient in the study of the immaterial aspects inherent to the material culture of the Chalcolithic Southern Levant.

# Chapter 9

# Conclusions

Although still limited, we now have the archaeological evidence that enables us to better appreciate the high technological level of the metallurgical knowledge and the associated innovativeness of the Chalcolithic Levant. The investigation on the technological aspects of the Chalcolithic Southern Levantine metallurgy and especially the lost wax casting technique yielded exciting insights into how lost wax casting sites could be recognised. A lost wax casting workshop of the Chalcolithic Southern Levant was identified for the first time. For the pure copper technology, the re-examination of the Abu Matar material provided important new insights into details of the smelting process, including the currently earliest evidence for the use of bellows in metallurgical operations. Research on other materials and innovations, such as pottery (e.g. Baldi and Roux, 2016; Gabrieli, 2016; Roux, 2022), helps to complement the picture. They show that the innovativeness of the Chalcolithic Southern Levant was not restricted to metallurgy but that metallurgy was only one of the many crafts they mastered – maybe the one they mastered the fastest.

However, this study is by no means exhaustive. The re-examination of the metallurgical assemblages from Abu Matar highlights the huge potential that can be gained from old excavations. At the same time, the new finds from Fazael showed that a lot of new information is still waiting in the ground to be uncovered with targeted excavation methodologies. Further investigations on the Fazael metal assemblage – the second largest by number after the Nahal Mishmar Hoard – opens new pathways to gain a better understanding of the provenance of these metals. For example, the only larger-scale provenance study on polymetallic copper alloys from the Chalcolithic Southern Levant was carried out on the Nahal Mishmar Hoard almost 30 years ago (Tadmor et al., 1995). Instrumentation and the number of reference data from the potential source regions improved significantly since then. A re-assessment of the old data in combination with new data promises a better understanding about the whereabouts of this material and how it was distributed in the Late Chalcolithic Southern Levant. Furthermore, the inclusion of new methods, such as the reconstruction of firing temperatures with minimally invasive FTIR spectroscopy (e.g., Yan et al., 2021), promises exciting insights into previously inaccessible aspects of the pure copper and lost wax casting technology. It might not only help to reveal additional details about the heating of the moulds but could also help to identify the assumedly ephemeral furnaces used for lost wax casting.

As exciting as the high innovativeness of the Chalcolithic Southern Levant metallurgists might be, it must not be forgotten that metallurgy might have arrived already at a high technological level in the Chalcolithic Southern Levant. The discovery of silver and the outburst of new metallurgical practices just after the end of the Southern Levantine Chalcolithic in entire West Asia (cf. chap. 4) clearly show that the Southern Levant was maybe the region with the most favourable conditions for metallurgical innovations at this time, but that it was not the only one. Inventions are mostly visible in the archaeological record only after they became successful innovations and this process can take decades and even considerably longer (Burmeister and Müller-Scheeßel, 2013; Lienhard, 2006). Therefore, it must be expected that what we perceive as innovations of the Late Chalcolithic Southern Levant does not imply the absence of comparable developments in the other regions. Except for the implementation of ceramic cores in the lost wax casting process, at least tentative earlier or contemporary evidence exists in the other regions as well.

The inter-regional approach for tracing the spread and evolution of the technological package "lost wax casting with gold" shows how close contacts between the different regions already were. Admittedly, they are not always readily discernible from the archaeological record, may it be of differences in the extent of archaeological research in the different regions or because they are badly preserved. As Anfinset (2010), Gailhard et al. (2021), Marro (2007), and Alizadeh (2004), among others, pointed out for each of the regions under study here except Southeast Europe, mobile groups, may they be pastoralists or nomads, are an important part of Chalcolithic societies and are decisive agents for exchange and mediators between different cultures. Unfortunately, their lifestyle leaves only minor traces in the archaeological record. Nevertheless, the current evidences suffice to identify a West Asian interaction sphere in which technologies can spread easily, and became modified according to the regional social systems. Applying theoretical and sociological approaches on innovations to this network was rarely done before but turned out to be powerful in uncovering differences between the social dynamics in the different regions.

While the technological package "lost wax casting with gold" might be an impressive example because of its material and the high technological level attested in it, it is only one among many and one that left only minor traces in the centre of the West Asian interaction sphere. Comparative studies on other technological packages such as artificial enstatite beads or Canaanean Blades, and more in-depth studies on the West Asian interaction sphere along this approach would add an additional dimension to our understanding of the dynamics within this interaction sphere and between the interaction sphere and its neighbours. They might necessitate at some point to widen the scope and include other regions as well. For example, fan scrapers indicate a network extending from Northern Mesopotamia as far South as Egypt (Klimscha, 2013b). Additionally, the Levant was a corridor between Africa and Arabia in the South and the northern parts of West Asia since the first humans left Africa. The recently published olivine beads from Tel Tsaf (Rosenberg et al., 2022a) provide a first glimpse for such even further-reaching contacts in the Late Neolithic and likely also the Chalcolithic.

The Southern Levantine metallurgy, and especially the lost wax casting with polymetallic copper alloys provided a perfect example on how deeply embedded in the ideologies of societies innovations and technologies can be, and how changes to the latter decide about the fate of the former. Like most aspects of the Southern Levantine Chalcolithic, metallurgy was deeply embedded into a ritual concept, which we just start to understand. Even more than the remarks made on the evolution of the technological package “lost wax casting with gold” and its associated ideologies, the remarks about the importance and ritual function of metallurgy for the society of the Southern Levantine Late Chalcolithic are meant as a starting point for future research. The presented hypotheses clearly require embedding into a concept that includes the entire material culture, which would have been beyond the scope of this study. In conclusion, it is as it is so often: a number of questions about the how, why, and wherefrom of the Chalcolithic metallurgy in the Southern Levant can now be answered, but other turned out to be more complex or just opened up. This thesis hopefully provided some inspiration on how they could be approached in the future.

# Chapter 10

# Appendix: Two mace head collections from the IMJ

## 10.1 Material

In the 1990's, two mace head collections arrived to the Israel Museum, Jerusalem (IMJ). Prof. Dan Barag donated 15 mace heads (Inv. 96.99.158 – 96.99.172), and soon after the museum purchased 14 more in London (C. J. Martin collection, Inv. 97.71.1 – 97.71.14). Museum records note provenience from the Southern Levant and based on their overall features date them to the Ghassulian (Late Chalcolithic), but their true archaeological context and date are essentially unknown.

The shapes of the mace heads are mostly (elongated) piriform, with four mace heads from the C. J. Martin collection and two from the Dan Barag collection being more barrel shaped. Additionally, the shapes of four mace heads in the Dan Barag collection are best described as drop-shaped (Fig. 10.1a–c). The size of most mace heads is comparable to genuine Chalcolithic ones, but some decorated ones are considerably larger.

The mace heads from the Dan Barag collection are all but three undecorated, while all in the C. J. Martin collection are. Decorations are either knobs (Fig. 10.1d,e) or spikes (Fig. 10.1f–i), usually with a round base. In some objects, the base of the spikes appears rectangular due to their narrow spacing. The arrangement of the spikes and knobs can be best described as an irregular crosshatched pattern. On some mace heads, the knobs/spikes are arranged in a horizontal linear pattern but never in a vertical linear one. In general, the shapes of the knobs/spikes and their arrangement on the mace heads are showing a wide degree of variability. The mace heads are mostly decorated only in their central part. Just a few are decorated up to the shaft hole opening on the wider side (Fig. 10.1f,h,i) .

The casting quality varies between the two collections. In the Dan Barag collection, eight mace heads do not have visible casting errors (Fig. 10.1c) , while four have a few and three have a lot of them (Fig. 10.1a,b,d). With casting errors visible on only three mace heads, the overall quality in the C. J. Martin collection is higher, although incrustations cover large parts of three mace heads and might hide casting errors. A similar difference can be seen in the degree of damage the objects suffered from: Most of the mace heads in the Dan Barag collection are damaged, sometimes heavily (Fig. 10.1d) and several of them show the same pattern of heavy damage around the shaft hole opening on the wider part (Fig. 10.1b,f). In contrast, the mace heads in the C. J. Martin collection suffered only from minor damages and many of them are entirely undamaged.

After their arrival at the museum, some of the items were cleaned and all treated with $AgNO_3$ to prevent bronze disease.

## 10.2 Aim

The typological features and the enormous size of some of the mace heads in combination with the unclear provenience gave rise to doubts about their dating to the Late Chalcolithic Southern Levant. Therefore, the mould and soil remains were analysed with petrography and the chemical composition analysed with pXRF to determine whether the petrographic features and the chemical composition support a Southern Levantine provenance of the objects.

## 10.3 Methods

In the museum, all objects were examined for ceramic remains from the mould. Where present, parts of these remains were removed in the shaft hole with a steel chisel for petrography. Additionally, all mace heads were screened with a pXRF on the corroded surface for their metals' elemental composition.

Ceramic remains were visible and sampled on 24 of the 29 objects. Additionally, sediment kept during the conservation treatment was sampled from 2 objects of each collection. All samples were embedded in epoxy resin. Petrographic thin sections were prepared according to standard procedures and analysed with a petrographic microscope.

Chemical analyses of all mace heads were determined with a ThermoScientific Niton XL3t GOLDD+. Analyses were carried out on one spot per mace head without additional preparation of the items' surface. The spot size was 8 mm, and acquisition time was set to 90 s. The instrument was operated in Mining mode using the factory calibration for quantification.

## 10.4 Results

### 10.4.1 Petrography

Figure 10.1: Selection of the mace heads in the two collections. Images: IMJ

Petrographic investigation revealed that the two same fabrics are present in both collections. Fabric 1 (Fig. 10.2a) represents the ceramic material and is a brown to dark brown opaque paste very rich (~ 50 area%) in well sorted angular silt, almost purely quartz. The opaqueness of the paste indicates extensive heating. Only a few inclusions were observed, mostly vegetal matter and occasionally carbonaceous rocks. Charred remains of the vegetal matter are often preserved and sometimes the voids are partially filled with secondary calcite. Most of the vegetal matter was located at the outside of the fragments, indicating preferential breakage of the fragments along these voids. Hence, it cannot be excluded that they exceeded the observed maximum length of 1.8 mm. No porosity was observed.

Fabric 2 (Fig. 10.2b) corresponds to the soil that adhered to the mace heads. It is made of a marly orange to brown paste. The inclusions consist of sand-sized rounded mikritic limestone, ooliths and iron oxide particles with subordinate angular quartz grains. With sizes < 150 µm, the ooliths and iron oxides are smaller than the limestone and quartz grains (700 to 1000 μm). No porosity was observed.

Fragments with a direct contact between the two fabrics exist in some sections (Fig. 10.2c–e). Both fabrics show no difference in the contact area, although one of them bears traces of extensive heating, suggesting the attachment of fabric 2 at some point after the ceramic cooled down.

Corrosion products were found in all samples. Corrosion seems to have affected fabric 2 more severely than fabric 1, where it was found mostly in the voids of the vegetal matter (Fig. 10.2f). However, this impression might be invoked because soil material left after cleaning was probably adhering to the mace heads because of its intergrowth with corrosion minerals (Fig. 10.2c,d).

### 10.4.2 Elemental analysis

Mace heads in the Dan Barag collection are predominantly copper enriched in As and Ni (As > 1 wt%, Ni > 1 wt%), while items in the C. J. Martin collection are predominantly made of unalloyed copper (As < 1 wt%, Ni < 1 wt%, Fig. 10.3). In addition, Ca was regularly detected and sometimes also Ag (Tab. 10.1). All other elements are either below the detection limit or below 0.5 wt% in all analyses and thus regarded negligible. Ca is likely derived from the calcareous soil. The Ag signals likely originate from remaining $AgNO_3$ rather than the metal. In general, the results might be affected by enrichment or depletion of elements due to corrosion and the treatment with $AgNO_3$. Additionally, it was shown that pXRF analyses can be strongly affected by matrix effects and the use of a factory calibration instead of a matrix-matched calibration (Conrey et al., 2014; Hall et al., 2014). Consequently, the results should be interpreted qualitatively rather than quantitatively.

## 10.5 Discussion

The mace heads' metal compositions show an unexpectedly high degree of homogeneity within the different collections and deviate in many aspects significantly from the genuine Chalcolithic lost wax cast items. Fig. 10.3 indicates that the mace heads of both collections are relatively depleted in As (or enriched in Ni) when compared to the chemical composition of Chalcolithic lost wax cast items compiled by Ben-Yosef et al. (2016). Moreover, the number of lost wax cast items made of unalloyed copper is extremely high in one assemblage. Another striking difference is the absence of significant Sb concentrations in combination with the overall high purity of the metal in all mace heads. While especially the latter might be due to the limitations of the used analytical method, the absence of significant levels of Sb in all mace heads as well as the large homogeneity in combination with overall low concentrations of the usual alloying elements is not.

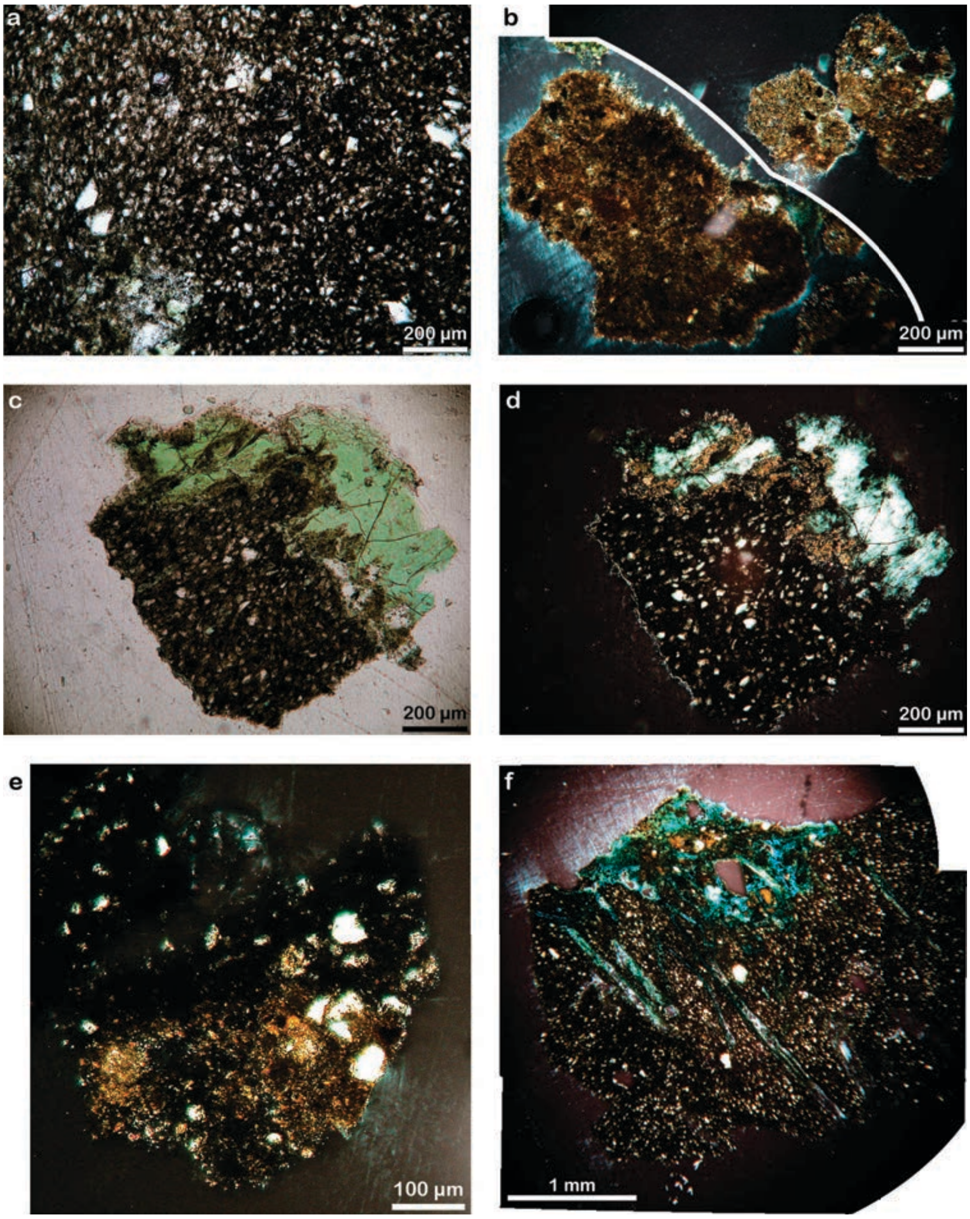


Figure 10.2: Photomicrographs of thin sections of (a) fabric 1, (b) fabric 2, (c, d) fabric 1 with fabric 2 overgrown by corrosion, (e) both fabrics, and (f) fabric 1 with corrosion and vegetal matter; a, c: plane-polarised light; b, d–f: crossed-polarised light.

Comparing fabric 1, used for the mould, with clay used in the Chalcolithic Southern Levant shows that only Negev loess or Fazael clay contain considerable amounts of silt-sized angular quartz and are otherwise sufficiently pure in non-plastic inclusions (e.g., Goren, 1995). Fabric 1 differs clearly from the pastes of mould remains associated with Chalcolithic lost wax casts (Goren, 2008). A closer comparison with Negev loess reveals that fabric 1 contains a too low proportion of heavy minerals to be comparable with Negev loess. Compared to Fazael clay (Fig. 5.32, 5.23), the silt-sized fraction of fabric 1 has a generally smaller grain size and a generally higher proportion in the clay. Consequently, a Southern Levantine origin of the mould material can be excluded with a high degree of certainty. Similarly, fabric 2, i.e., the soil adhering to the mace heads, does not have any equivalents in modern day Israel. The closest potential region with a comparable oolithic soil would be Southern Lebanon, outside the confines of the Chalcolithic Southern Levant.

The stylistic features of the mace heads from the two collections deviate significantly from genuine Southern Levantine Chalcolithic mace heads (e.g., Bar-Adon, 1980). While all Chalcolithic objects with spike decoration found so far have spikes with a rectangular base arranged in vertical rows, spikes of the collections' mace heads are rounded and arranged in some kind of cross-hatched pattern (Fig.

10.1g–i). The shape of some mace heads does not fit to the Chalcolithic mace heads, especially shapes such as Fig. 10.1a and 10.1c are practically absent among the latter. Lastly, a few of the mace heads in the two collections are almost twice the height of the Chalcolithic mace heads.

In summary, the two analysed mace head collections of the IMJ deviate significantly in the three important aspects chemical composition, mould fabric, and style from their genuinely Chalcolithic Southern Levantine counterparts. In addition, the adhering soil implies a find location outside the Southern Levant. The two collections are remarkably homogeneous concerning their composition, stylistic features and the petrographic fabrics, invoking the impression that two different metal batches were used to produce one assemblage, which was then buried in one spot.

## 10.6 Conclusions

The mace head collection donated by Prof. Dan Barag to the Israel Museum in Jerusalem, and the mace heads of the C. J. Martin collection purchased by the museum shortly after were investigated with portable XRF and petrography (mould remains, adhering soil). In addition, their stylistic features were compared. The aim of the study was to assess whether the mace heads could have been produced in the Chalcolithic Southern Levant.

Results show that the same mould material was used for the two collections and both were buried in the same soil. Moreover, the objects in each collection have a remarkably homogeneous and pure metal composition when compared to genuine Chalcolithic mace heads. They also differ significantly in their stylistic features from the Chalcolithic mace meads.

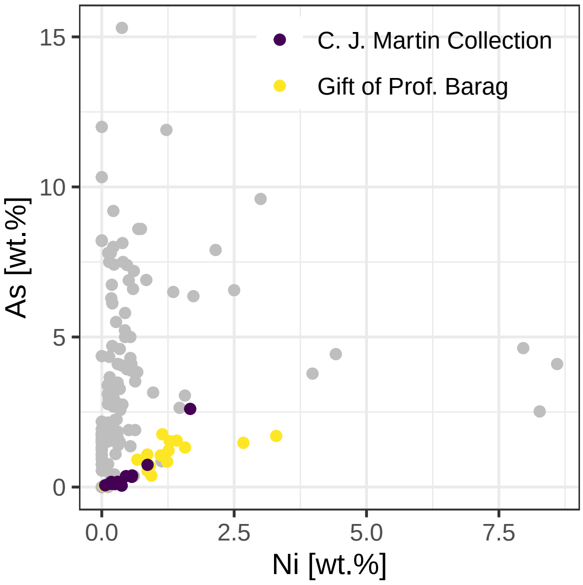


Figure 10.3: As and Ni concentrations of the mace heads in the two collections. Polymetallic copper alloys of the Chalcolithic Southern Levant are plotted in grey for comparison (data taken from Ben-Yosef et al., 2016, Supplementary data).

It is concluded with a high degree of confidence that they do not belong to the Chalcolithic Southern Levant. This certainly does not preclude that they are archaeological objects. Neither a definitive origin nor a date of the objects can be reconstructed with the applied methodology. To reach this aim, the soil and clay of the mace heads but also their stylistic features must be compared with references outside the Chalcolithic Southern Levant. Such an endeavour would be extremely challenging due to the unconstrained geographical origin and age.

Table 10.1: Results of the pXRF analyses on the mace heads. All values in wt.%, Bal = Balance. Only elements with at least one analysis > 0.5 wt.% are listed.

| Inv. | Cu | As | Ni | Ag | Ca | Bal |
|---|---|---|---|---|---|---|
| **Gift of Prof. Barag** | | | | | | |
| 96.99.158 | 59.25 | 0.38 | 0.94 | | 1.01 | 38.04 |
| 96.99.159 | 67.58 | 0.03 | 0.05 | | 1.57 | 30.14 |
| 96.99.160 | 71.77 | 0.91 | 0.67 | | 1.06 | 25.22 |
| 96.99.161 | 61.79 | 1.22 | 1.26 | | 0.77 | 34.46 |
| 96.99.162 | 70.59 | 0.71 | 0.91 | | 3.35 | 23.47 |
| 96.99.163 | 55.82 | 0.85 | 1.23 | 0.31 | 0.96 | 40.62 |
| 96.99.164 | 60.71 | 1.32 | 1.57 | | 0.78 | 35.12 |
| 96.99.165 | 47.18 | 1.55 | 1.42 | 1.46 | 0.87 | 46.66 |
| 96.99.166 | 77.47 | 1.08 | 0.86 | | 0.82 | 19.45 |
| 96.99.167 | 47.17 | 1.48 | 2.67 | | 1.10 | 47.14 |
| 96.99.168 | 71.92 | 1.06 | 1.11 | | 1.02 | 23.75 |
| 96.99.169 | 53.98 | 1.70 | 3.29 | 0.16 | 2.53 | 37.42 |
| 96.99.170 | 65.10 | 0.54 | 0.87 | | 0.67 | 32.30 |
| 96.99.171 | 73.79 | 1.76 | 1.14 | | 1.13 | 21.78 |
| 96.99.172 | 65.15 | 1.53 | 1.29 | | 0.91 | 30.52 |
| **C. J. Martin Collection** | | | | | | |
| 97.71.1 | 68.13 | 0.39 | 0.57 | | 0.95 | 29.08 |
| 97.71.10 | 69.92 | 0.11 | 0.17 | | 0.65 | 28.71 |
| 97.71.11 | 63.44 | 0.12 | 0.15 | | 1.46 | 34.22 |
| 97.71.12 | 71.78 | 0.36 | 0.46 | | 0.65 | 26.50 |
| 97.71.13 | 50.61 | 0.14 | 0.27 | | 0.89 | 47.73 |
| 97.71.14 | 54.15 | 2.60 | 1.67 | | 0.82 | 40.16 |
| 97.71.2 | 68.90 | 0.74 | 0.86 | | 0.69 | 28.39 |
| 97.71.3 | 73.25 | 0.11 | 0.19 | 0.14 | 0.94 | 24.86 |
| 97.71.4 | 75.32 | 0.06 | 0.06 | 0.13 | 0.55 | 23.48 |
| 97.71.5 | 59.13 | 0.17 | 0.18 | | 1.38 | 38.51 |
| 97.71.6 | 63.86 | 0.10 | 0.25 | | 2.85 | 32.27 |
| 97.71.7 | 65.85 | 0.34 | 0.57 | | 0.76 | 31.97 |

Table 10.1: Results of the pXRF analyses on the mace heads. All values in wt.%, Bal = Balance. Only elements with at least one analysis > 0.5 wt.% are listed. *(continued)*

| Inv. | Cu | As | Ni | Ag | Ca | Bal |
|---|---|---|---|---|---|---|
| 97.71.8 | 68.26 | 0.17 | 0.30 | | 0.75 | 30.04 |
| 97.71.9 | 72.17 | 0.05 | 0.38 | | 2.05 | 25.01 |

# Chapter 11

# References

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יותר, מה שהוביל לכישלון פולחני. בנוסף, ייתכן שסכסוכים פנימיים מקורם בתפקיד הטקסי החשוב של המתכת ועשויים היו לתרום לדעיכת המסגרת הטקסית של האידיאולוגיה הכלקוליתית. עם קריסת האידיאולוגיה הכלקוליתית, פריטי יציקת השעווה האבודה והסגסוגות הפולי-מתכתיות מאבדים את ייעודם, בעוד שהערך התועלתני של נחושת טהורה הוכר, אולי בהשראת אתרי עקבה. כתוצאה מכך, מטלורגיית יציקת השעווה האבודה נזנחה בעוד שמטלורגיית הנחושת הטהורה שולבה בהלך הרוח ממוקד היעילות והמטרה של תקופת הברונזה הקדומה.

מילות מפתח: כלקוליתית ,גאסוליאן ,דרום הלבנט ,אבו מטר ,פאזאל, מטלורגיה ,נחושת ,התכה, יציקת שעווה אבודה, סגסוגות נחושת פולי מתכתיות, חדשנות

השעווה האבודה בפרט לא מילאו רק את הצורך של האוכלוסייה המקומית למוצגים הנוצצים הללו. יחד עם זאת, השינוי החזק של החבילות הטכנולוגיות גורם לסבירות, שתקשורת מעמדית באמצעות פריטים מיוחדים ושימוש בחומרים נוצצים, שהיא נשללה מהיבטיה האידיאולוגיים למעט המושגים הבסיסיים ביותר ונכללה במלואה באידיאולוגיה המקומית.

# תפקיד המתכת דרום הלבנט הכלקוליתי

מחקרים קודמים כבר הצביעו על כך שהן חפצי הנחושת הבלתי-מסגסוגים והן החפצים יצוקי השעווה האבודה, היו פריטים שנועדו לתקשורת מעמדית. לכן, יש לדון בתפקידם בלבנט הדרומי הכלקוליתי כמקשה אחת. במקום השערה מלאה, מוצגים כאן כמה רעיונות.

ניתן לשער כי כל חפצי המתכת מבוססי הנחושת בלבנט הדרומי הכלקוליתי הם ייצוגים (סקאומורפים, חיקויים) של עצמים עשויים מחומרים אחרים. למרות שמצב זה ברור למדי בהקשר לחפצים בצורת כלי וראשי שרביט, חפצים אחרים היו עשויים מחומרים מתכלים. לדוגמא, מחקרים קודמים העלו כי ראשי השרביט המעוטרים עשויים לייצג זרעים או פקעות ולחלק מהחפצים במטמון נחל משמר יש דמיון לקני חיזרן.

אם האידיאולוגיה של הלבנט הדרומי הכלקוליתי זוכה למעמד כה כבד משקל, כפי ששיערו חוקרים מסוימים, חפצי המתכת עשויים להיות ייצוגים פולחניים של חפצים ארציים. עם זאת, לחלק מהאובייקטים האיקוניים של דרום הלבנט הכלקולית אין ייצוגים מתכתיים, כגון קערות בצורת V וקערות בזלת. הסבר סביר הוא שהם כבר היו חפצים פולחניים, ולכן לא נזקקו לייצוגים מתכתיים.

המעבר שבין התקופה הכלקוליתית הקדומה למאוחרת והשינוי הנלווה מארכיטקטורה לפריטי מתכת לשם הפגנת מעמד, עשויים להצביע על שינוי במערכת הפולחנית של הלבנט הדרומי הכלקוליתי. משוער כי שינוי זה עשוי להיות קשור לירידתה של האידיאולוגיה הכלקוליתית עקב ירידה בעוצמתה בהסברת הסביבה המשתנה. אולי חפצי מתכת היו ההזדמנות לחזק את העוצמה הזו.

עוד עולה, כי אחד המרכיבים המרכזיים להבנת תפקידן של מתכות בדרום הלבנט הכלקוליתי הוא הגוון שלהן. אנו יודעים מתרבויות אחרות שהזהב מקושר לעתים קרובות לשמש, בעוד שכסף קשור לירח. שניהם היו ישויות אלוהיות חשובות בחברות חקלאות מוקדמות. באידיאולוגיה הכלקוליתית, גוונים דמויי המטיט או אדום באופן כללי עשויים להיות מקושרים לאבות הקדמונים. לפיכך, שיטות המטלורגיה עשויות להיות דרך להתחבר לספירה האלוהית ולהפוך אובייקטים מהספירה הארצית לספירה הפולחנית. התכה והמסה יכולות להפוך בקלות לטקסים מרשימים מבחינה אודיו-ויזואלית, שבאמצעותם ניתן היה לבצע תקשורת זו.

מחקרים קודמים העלו כי היבטים רבים של האידיאולוגיה הכלקוליתית קשורים למעגל של מוות ולידה מחדש. המטלורגיה כנראה הייתה משובצת בו היטב. המסת עפרות נחושת עשירות בהמטייט למתכת עשויה לסמל את לידתם מחדש של אבות קדמונים. הפיכת פריטים המסמלים אותם למקבילות המתכת שלהם עשויה להיות חלק מטקסים סביב מעבר הנפטרים לעולם התחתון.

אם הם אכן היו ייצוגים סמליים של הנפטר, ייתכן שההיבט המרכזי של המטלורגיה היה ההפיכה הטקסית של הפריט הארצי לייצוג הטקסי שלו. זה לא חייב להיות קשור בהכרח לתהליכים מתכתיים, כלומר לייצור שלהם. זה יכול להסביר מדוע פריטי מתכת היו חלק מרשתות חליפין יחד עם חפצים פולחניים אחרים.

בסוף התקופה הכלקוליתית, האידיאולוגיה קורסת לחלוטין ורוב פריטי היוקרה נעלמים. תנאי הסביבה כנראה השתנו עד כדי כך שהאידיאולוגיה הכלקוליתית לא יכלה לספק להם הסברים מתאימים

מכן חולצו טיפות הנחושת (sllirp) באופן מכאני מהשברים המעוותים, כפי ששוחזר קודם לכן, ולאחר מכן אלו הומסו בכורית. מכיוון שהטיפול בכור ההיתוך בתוך כבשן הבור קשה, סביר להניח שהם הונחו על פלטפורמות ניידות קטנות ליד התבניות, שם כוסו בערימות קטנות של דלק. צינורות נשיפה כנראה סיפקו משב אויר מספק לשלב זה מכיוון שהם מאפשרים הרבה יותר שליטה על עוצמת וכיוון זרם האוויר.

## האבולוציה של המצאת "היציקת בשעווה האבודה"

בהתבסס על סקירת הספרות הנרחבת, ניתן לשחזר תחום אינטראקציה גדול ממערב אסיה המורכב מדרום מזרח אנטוליה, צפון מסופוטמיה, דרום הקווקז ואיראן. בתוך תחום האינטראקציה הזה, חומרים, כמו גם רעיונות, יכלו להתפשט בקלות יחסית, אבל אלו לא אומצו בהכרח בכל מקום. יתרה מזאת, ניתן היה לזהות שתי מערכות שונות באופן מהותי של מדרג מעמדי. בדרום הלבנט, חלקים מאיראן ודרום מזרח אירופה, התקשורת המעמדית בוצעה באמצעות חפצי מתכת ופריטי יוקרה אחרים. מאפיין של מערכת זו הוא השימוש בפריטי מתכת ומוצרים בלעדיים אחרים כפרטי קבורה. לעומת זאת, בצפון מסופוטמיה וסחלקים אחרים של איראן השתמשו בארכיטקטורה מונומנטלית ומשאבים בסיסיים לצורך תקשורת מעמדית. מערכת התקשורת המעמדית של דרום הקווקז אינה ברורה, אך היעדר ארכיטקטורה מונומנטלית ונוכחותם של פריטי מתכת בחלק מהקבורות מצביעים על כך שהיא שייכת לסוג הראשון.

השערה אחרת היא, שלמעט דרום הלבנט, פריטי מתכת מיציקת השעווה האבודה במערב אסיה בתקופה זו עשויים תמיד מזהב וייצוקים בצורה מאסיבית. לפיכך מוצע כי החבילה הטכנולוגית "יציקת השעווה אבודה עם זהב" התפשטה מדרום-מזרח אירופה דרך הקווקז אל תחום האינטראקציה של מערב אסיה, כנראה יחד עם צירי הנקב. בהתאם לתאימות למערכת התקשורת המעמדית, חבילה טכנולוגית זו שונתה. בעוד שצירי הנקב אומצו בקלות בדרום הקווקז ובאיראן, החבילה הטכנולוגית הופכת לגלויה בתיעוד הארכיאולוגי רק לאחר עיכוב מסוים, לכאורה ללא שינוי, אך במסגרת אידיאולוגית שונה מאוד של חברה ההיררכית. בצפון מסופוטמיה ובדרום מזרח אנטוליה, נראה שרק החומר החדש - הזהב, אומץ. ההסבר יכול להיות שההיבטים האידיאולוגיים של החבילה הטכנולוגית - התקשורת המעמדית באמצעות חפצי מתכת - לא היה תואם לתקשורת המעמדית באמצעות משאבים בסיסיים וארכיטקטורה מונומנטלית בעוד זהב כחומר חדש היה תואם לכסף שהתגלה לאחרונה.

דרום הלבנט אימץ ושינה מאוד את החבילה הטכנולוגית. במקום זהב, נעשה שימוש בסגסוגות נחושת פולי-מתכתיות, החפצים המיוצרים גדולים בהרבה מכל דבר אחר שיוצר בטכניקה זו בעבר, וליבות קרמיות שימשו במקום יציקות מסיביות. נראה כי הסיבות לשינויים אלו הן טכנולוגיות ואסתטיות. זהב אינו זמין בדרום הלבנט והכמויות הגדולות הנחוצות לחפצים המיוצרים כנראה חרגו בהרבה ממה שהיה זמין במקומות אחרים - אם באמת היה זמין שם. בנוסף, לסגסוגות נחושת פולי-מתכתיות יש נקודת התכה נמוכה בהרבה, ונראה שסביר שרק מסיבה זו ניתן היה לייצר חפצים גדולים כל כך בטכניקת יציקת השעווה האבודה. המרכיב האסתטי היה כנראה חשוב באותה מידה: בהתאם להרכב סגסוגות הנחושת הפולי-מתכתיות, ניתן היה לחקות לא רק את החומרים החדשים של זהב וכסף אלא גם המטיט. ראשי אלה מהמטיט יוצרו הרבה לפני הופעת המטלורגיה בדרום הלבנט הכלקוליתי, ועיטורים על צלמיות הכלים, גלוסקמאות וחפצים קרמיים אחרים הם לרוב פסים אדומים שנעשו ממינרל ברזל זה. ליבות הקרמיקה שבחפצי הנחושת שימשו ככל הנראה לחסוך במתכת.

גורם מפתח לאימוץ מהיר זה בדרום הלבנט הכלקוליתי הוא התאימות של החבילה הטכנולוגית למערכת החברתית הקיימת. נטען כאן שפריטי מתכת בלבנט הדרומי הכלקוליתי הם ייצוג של חפצים העשויים מחומרים אחרים (למשל, אבן, כלי חרס, עץ). הגעת המטלורגיה בכלל וטכנולוגיית יציקת

לסיכום, מחקר המכלול המטלורגי של פצאל מאפשר לזהות את פצאל כאתר ייצור עבור חפצי יציקת השעווה האבודה באמצעות זיהויים של שברי תבניות יציקה בשיטת השעווה האבודה הראשונים במקום. בנוסף, הוא סיפק לראשונה ראיות ישירות לערבוב של סגסוגות פולי-מתכתיות עם נחושת טהורה ובאופן טנטטיבי גם עם סגסוגות פולי-מתכתיות אחרות.

# הערכה מחדש של המכלול המטלורגי של אבו מטר

בהתבסס על הניסיון מניסויי ההתכה בעבר, כמה היבטים של השחזור הנוכחי של תהליך הנחושת הכלקוליתית בדרום הלבנט נראו בלתי מעשיים, במיוחד השימוש בצינורות נשיפה דרך פתח הצוואר, וכיסוי הכבשן במכסה קרמי גדול, כפי שהציע ג'ונתן גולדן. בניסיון לחדד את השחזור הזה, חלקי הקרמיקה המטלורגית מממצאי חפירות אבו מטר בשנות ה-90 הוערכו מחדש והובילו לזיהוי של כמה מרכיבים חשובים שעד כה לא זכו לתשומת לב. החשובים שבהם לדעתי, הם שני חלקים עם פרופיל ברור של נקב גלילי דמוי תעלה בקוטר של כ-2.5 עד 3.0 ס"מ. בעוד שהאחד עשוי מקרמיקה מחוממת ומכוסה רק מעט בכמה כתמים ירקרקים, השני מזוגג לחלוטין. בנוסף, שבר מעוות גדול כולל תעלה דומה בקוטר גדול יותר. יתר על כן, נמצאה קבוצה של כמה חפצי קרמיקה עבים במיוחד, מעוגלים בצד אחד ובצדדים האחרים מכוסים בגובה פני הקצה אל משטח אחר. שני שברי שפה קרמיים אחרים חורגים בעליל במרקמם מן הקרמיקה המטלורגית האחרת כיון שהם מכילים חול קרבונטי ונעדרים חסמי חומר צמחי. הפריטים המעוותים וחלק מן הקרמיקה נדגמו לצורך ניתוחים פטרוגרפיים ובדיקה במיקרוסקופ אלקטרונים סורק (SEM-EDX). עבור הפריטים הנותרים, המאפיינים המקרוסקופיים הספיקו והדגימה לא סיפקה תובנות נוספות.

תוצאות הניתוחים מראות ששברי הכלים עם חסמי החול הם מקטעים של קערה בצורת V ופערור שהיו בשימוש משני. בעוד ששימוש משני בקערות בצורת V כיוריות כבר תועד בעבר, זוהי העדות הראשונה לשימוש משני של סוגי מיכלים אחרים בתהליך המטלורגי. שבר הפערור המעוות בצדו האחד מרמז על שימוש בשברי פערורים ככיסוי לכבשן. שימוש כזה יאפשר גם לכסות את הכבשן בחפצים שקל יותר לטפל בהם מאשר במכסה קרמי אחד גדול.

השבר המזוגג לחלוטין בעל השקע דמוי התעלה התברר כשריד קרמי בצורתו המקורית ולא שבר מעוות. יחד עם שבר הקרמיקה האחר בעל השקע דמוי התעלה, ניתן לזהות בהם שברי פיות מפוח (tuyère) הודות להיעדרם של אובייקטים אחרים בתהליך המטלורגי שיש בהם תעלה כה צרה. הקטרים שלהם מרמזים על שימוש במפוח. הפעלת הכבשן עם מפוח במקום צינורות נשיפה דרך פתח הצוואר נראית הרבה יותר הגיונית, כיוון שהיא מאפשרת חימום של שטח גדול יותר בכבשן תוך הפעלתו בצורה יעילה יותר ובפחות מאמץ. בנוסף, הניסוי הארכיאולוגי הראה שכבשן המופעל באמצעות מפוח יכול לייצר טמפרטורות גבוהות די הצורך להתכת נחושת.

שחזור של השימוש בשברי הקרמיקה המעוגלים לא היה אפשרי לחלוטין. נראה שהם אינם חלק מקיר הכבשן וגם מאתרים אחרים לא מדווח על פריטים דומים. מוצע כאן כי ייתכן שאלה היוו סוג של פלטפורמה ניידת כורית, שמטרתם להמיס את טיפות הנחושת ליד התבנית, ושברי "עוגות החומר" שז'אן פרו הזכיר במאמרו אך תואר בצורה גרועה.

בהתבסס על תוצאות ופרשנויות אלה, ניתן לשפר את שחזורו של תהליך הפקת ויציקת הנחושת הטהורה: התכה של עפרות הנחושת בכבשן מכוסה בשברי פערורים שנועדו לשמר את הטמפרטורה ולהגביר את תנאי החיזור בכבשן. המפוחים שימשו לדיבוי הלהבה. הכבשן הופעל באופן סיבובי, שמו פחם טרי ועפרות בצד הנגדי לפית המפוח ודחפו אותו קרוב יותר אליה כשהחומר החל להגיב. לאחר

בשל מצבם השבור ממילא של חפצי המתכת הרבים, ניתן היה להקריב דגימות ממבחר מייצג שלהם למחקר מטלוגרפי כולל אנליזות SEM-EDX במיקרוסקופ אלקטרונים סורק. בנוסף, נחתכו מספר שברי כורית וגושי חומר מחוממים עם חסמי חומר צמחי לצורך בדיקות פטרוגרפיות. המטרה הייתה לבדוק האם השרידים מאפשרים לזהות את פצאל 2 כאתר ליציקת השעווה האבודה ולקבל תובנות חדשות לגבי תהליך יציקה זה.

ההרכב הכימי של חפצי המתכת שנדגמו עולה בקנה אחד עם ניתוחים קודמים מאתרים אחרים, אם כי לסגסוגות הנחושת הפולי-מתכתיות יש ריכוז ארסן מדולדל מעט, והן מועשרות מעט בשאר יסודות הסגסוגת. ניתן לחלק את הפריטים לשלוש קבוצות על סמך המבנה המטלוגרפי שלהם: חפצי נחושת טהוריה, חפצים עם רמות נמוכות של סגסוגת וחפצים עם רמות גבוהות של סגסוגת. קבוצות אלו מתאימות לטיפולוגיה של הפריטים. הן מאשרות ידע קודם שנצבר על המטלורגיה הכלקוליתית אך מוסיפות שתי תצפיות חשובות: המתכת של פריטים מסוימים מכילה כמויות גדולות של קוורץ זוויתי בגודל סילטי, וחלק מסגסוגות הנחושת הפולי-מתכתיות מכילות תכלילים של נחושת טהורה, ובמקרה אחד, של סגסוגת נחושת רב-שלבית.

תכלילי הנחושת מראים כי סגסוגות הנחושת הפולי-מתכתיות לא נמסו לחלוטין בעת היציקה. בעוד שהערכה מהימנה של טמפרטורת ההיתוך היא בפועל בלתי אפשרית בשל משחק הגומלין המורכב של יסודות הסגסוגת, כולם מורידים את נקודת ההיתוך של הסגסוגות בהשוואה לנחושת טהורה. כתוצאה מכך, המתכת יכולה להיות נוזלית מספיק ליציקה הרבה מתחת לנקודת ההיתוך של נחושת טהורה. יחד עם זאת, נוכחותם של תכלילי נחושת טהורה בסגסוגות הנחושת הפולי-מתכתיות מעידה על איזשהו ערבוב של שני סוגי המתכות. בנוסף, הכללות של סגסוגות נחושת רב-שלביות במדגם אחד מצביעות על כך שערבוב כזה אינו כרוך בהכרח רק בנחושת טהורה. זוהי העדות הראשונה לערבוב של סגסוגות נחושת פולי-מתכתיות. המוטיבציה והמיקום של פעולת הערבוב נותרו לא ידועים. זה יכול להיות קשור, למשל, לסגסוגות של ספייס (תערובת ארסנית של מתכות) כסוג של סגסוגת אב עם נחושת טהורה או למיחזור.

מקום הימצאם של תכלילי הקוורץ חייב להישאר לא ידוע גם כן. בניגוד לדגימה בודדת מביר א-ספאדי, הם מתרחשים בכל הקטע ולא רק על פני השטח. זה לא כולל את מקורם כזיהום, למשל, מתבנית היציקה. האפשרויות מוצגות אך אף אחת מהן לא יכולה לספק השערה משכנעת מדוע קוורץ בגודל סילטי מתפזר בכל הפריט.

ניתן להפריד את שברי הכוריות לשלוש קבוצות פטרוגרפיות. הקבוצה הראשונה אינה מורכבת מכורית אלא שברי כלי העשויים מחוואר מוצא (Moza). הקבוצה השנייה מורכבת מהפריט F225a בעל צריפה נמוכה עם חומר עשיר בפורמיניפרות וחול קרבונטי. רק הקבוצה השלישית מכילה כורית אמיתית, כפי שמעידה התערובת הקרמית עם חומר צמחי שפני השטח שלה מזוגגים ונפוחים, בהתאמה טובה עם הקרמיקה המטלורגית מאתרי נחל באר שבע.

נראה שגושי הסדימנטים המחוממים עשויים מאותו חומר כמו כור ההיתוך, אך חוממו לטמפרטורות נמוכות בהרבה. בעוד שחלקם אינם מכילים חימום כלל, אחרים מכילים חימום צמחי, חול קרבונטי או שניהם. גוש אחד כולל שתי שכבות של שברים בגדלים שונים של אותו חומר.F2-Y55 נבדל מכל הגושים הללו מכיוון שהוא מושחר לחלוטין ומכיל תכלילים מעוגלים של חומר נטול נחושת מזוגגת, יחד עם חימום צמחי ומינרלים.

השוואה עם דגימות של סדימנטים מוואדי פצאל הראתה כי מחומר זה נוצרו כורית וגושי סדימנטים מחוממים. על פי הקריטריונים שנקבעו לעיל, ניתן לפרש בצורה מהימנה את רוב גושי הסדימנטים המחוממים כשרידים של תבניות יציקת השעווה האבודה. בהיותו ממצא בודד, תפקידו של F225a חייב להישאר לא ברור.

שלמים של שתי תבניות וכן חתכים חלקיים של התבניות האחרות. ניסויי דריכה והטבלה מתועדים עם חלקי תבנית וקרמיקה מטלורגית אחרת בוצעו כדי לדמות מתח מכני ואינטראקציה שלהם עם מים.

מכיוון שאף אחת מהתבניות הארכיאולוגיות לא הראתה אינטראקציה עם המתכת המותכת והתערובות הקרמיות הארכיאולוגיות והניסיוניות ניתנים להשוואה בסך הכל, תבניות הניסוי הן אנלוגים בני קיימא לאלו הארכיאולוגיים. העלייה בשבריריות של התבניתים מוסברת בצורה הטובה ביותר על ידי הרטבתו של החול הקרבונטי לאחר החימום ועליית הנפח הנלווית לכך. ריסוק התבניות וחיתוכן לצורך פטרוגרפיה גילה שניתן להפריד בקלות את השכבה הפנימית והחיצונית, מה שמסווה את העיצוב הרב-שכבתי המקורי שלהן. ניתוחים פטרוגרפיים הראו שניתן לזהות את השכבות השונות רק על ידי תערובות החימום השונות של תערובות החומר והחסמים. מבחני השינוי חשפו כי שברי התבנית יציבים כאשר הם שקועים במשך מספר שעות, אך לעיתים קרובות מספיק צעד אחד כדי לרסק אותם לפירורים זעירים, שאינם ניתנים לזיהוי בתיעוד הארכיאולוגי יותר. כתוצאה מכך, יש לצפות ששרידי תבנית באתרים ארכיאולוגיים יהיו נדירים. אם הם נשמרים, הם חלקים שבריריים (פריכים) ועשויים להיות מעוגלים ועשויים מקרמיקה בצריפה נמוכה, ולכן, הם עלולים להיחשב בקלות לפירורי אדמה מחוממים.

יתר על כן, מאפיין נוסף בעל תחולה אוניברסלית של תבניות יציקת השעווה האבודה מוצע: התערובת של חימום צמחים ומינרלים. תוקפו של קריטריון זה מבוסס על שיקולים טכנולוגיים כלליים. ייצור כלי חרס בדרום הלבנט הכלקוליתי המאוחר נעשה אך ורק עם חסמים מינרליים, לרוב בצורת חול מנופה, וקרמיקות מטלורגיות נצרפו במהלך היציקה אך ורק בטמפרטורה נמוכה בגלל המשך הקצר מאוד של השוק התרמי והקירור המיידי. במקרה של חרס, בחירת צריפה בטמפרטורה גבוהה ולמשך זמן ניכר ממקסמת את החוזק המכני ומפחיתה את הנקבוביות של הכלים. עבור קרמיקות מטלורגיות רצויה נקבוביות גבוהה לצורך הגברת בידוד החום ולמניעת התפשטות סדקים. תבניות יציקת השעווה האבודה היו צריכות לשלב את שתי התכונות: התבניות העבות באופן יחסי היו צריכות להיות יציבות מספיק כדי להתחמם מבחוץ לצורך הגעה לטמפרטורות מספקות בפנים. יחד עם זאת, הנקבוביות הגבוהה במיוחד בשכבה הפנימית מונעת התפשטות סדקים תוך מתן אפשרות לאוויר בתבנית לברוח במהלך היציקה. עם קריטריון זה בהישג יד, ניתן לזהות באופן אמין שברי תבנית ללא קשר לעיצובם הרב-שכבתי, כל עוד ארכיאולוגים מודעים לאיסוף פיסות בלתי בולטות לכאורה של סדימנטים מחוממים או קרמיקה באש נמוכה.

## המכלול המטלורגי של פצאל

האתר פצאל ממוקם לאורך גדת הערוץ של ואדי פצאל ומורכב מפיזור של כמה בתי חדרים כלקוליתיים ומאפיינים ארכיאולוגיים נוספים. בחפירות החדר הרחב של הבית פצאל 2 נחשפו שברים רבים של פריטי נחושת יצוקים בטכניקת השעווה האבודה יחד עם מספר שברים של כוריות וגושי סדימנטים מחוממים ולפיכך, הוצע כי הוא היה אתר יציקת השעווה האבודה. עם זאת, עדיין לא נמצאו מתקנים מטלורגיים כגון כבשנים. תת האתר פצאל 5 הניב מטמון קטן, המורכב מקנה בצורת ראש אדם שאליו נדחסו אזמל, מרצע וחפץ בצורת ספירלה. בתת האתר פצאל 7 מבנה רוחבי ובו קירות שהשתמרו לגובה של יותר ממטר אחד ובו נמצאו שברי מתכת רבים וכן פריטי מתכת שלמים. תת האתר פצאל 2 סיפק תאריך פחמן-14 של 4000 עד 3900 לפני הספירה, כלומר, שלהי הרצף הע'סולי של התקופה הכלקוליתית בדרום הלבנט. תאריך זה נתמך על ידי תרבות חומרית כלקוליתית חלקית והופעת אלמנטים אופייניים לתקופת הברונזה הקדומה כגון להבים כנעניים.

ישירה של עפרות פאהל עם בלייה כבדה או סיגוג של נחושת טהורה עם ספייס. ארסן ואנטימון מורידים את נקודת ההיתוך של נחושת באופן משמעותי, ומגדילים את יכולת היציקה שלה. ארסן גם מגביר את הקשיות והפלסטיות של הנחושת באופן משמעותי, בעוד ריכוזים גבוהים של אנטימון הופכים את הנחושת לשבירה עד כדי כך שלא ניתן לעבד אותה יותר מכנית. כתוצאה מכך, סגסוגות הנחושת הפולי-מתכתיות המשמשות בדרום הלבנט הכלקוליתי יכלו לשמש רק ליציקת פריטים דקורטיביים וכאלו המשדרים מעמד.

בהתאם לרמות השונות של יסודות הסגסוג במתכת, הגוון שלה משתנה. לדוגמה, בהתאם לרמות האנטימון והארסן בנחושת, הגוונים של סגסוגות נחושת פולי-מתכתיות נעים בין נחושתי אדמדם לגווני זהב דמויי המטיט, זהוב וכסוף. הגוונים השונים של סגסוגות מתכת לא שימשו רק מטלורגים בעבר כאינדיקטור להרכב המתכות, אלא נוצלו בכוונה גם למטרות אסתטיות, למשל, על ידי סידור חרוזי זהב בגוונים שונים בשרשרת בבית הקברות הראשון בוורנה. C. S. Smith הגיע למסקנה שמאפיינים אסתטיים של חומרים חדשים נוצלו תמיד לפני השימוש שלהם לכלים. מתכות אינן שונות מחומרים אחרים בהקשר זה. כתוצאה מכך, יש לחקור את תפקידם של חפצי מתכת בחברות קדומות כחומר אחד מני רבים ולא כעדיף על פני כלי חרס או אבן. מספר דוגמאות מתרבויות ארכיאולוגיות שונות בדגש על

תכונות של מתכות מוצגות. פריטי המתכת המוקדמים בדרום מזרח אירופה הם דוגמאות טובות. הם הוטמעו בקונספט אסתטי של ברק יחד עם השחרה והברקה של כלי חרס בגרפיטציה. נראה כי הימצאותם של סוגי מתכת רבים ושונים עם גוונים מבריקים שונים (כגון כסף) במהלך האלף הרביעי לפני הספירה במערב אסיה נבעה מאותה רדיפה אחר חומרים מבריקים. הדוגמה של acsiuM הדרום אמריקאית מראה שלא בהכרח פריטי המתכת הם בעלי חשיבות, אלא זה יכול להיות גם תהליך הייצור (במקרה זה יציקת שעווה אבודה) כמוקד של טקס.

## יציקת שעווה אבודה

## נראות בתיעוד הארכיאולוגי

למרות ריבוי האתרים הכלקוליתיים בדרום הלבנט, כל שרידי התבניות שהובחנו עד כה נמצאו מחוברים לחפצי מתכת במקומות מוגנים כמו מערות קבורה. כתוצאה מכך, עדיין לא ברור אם שרידי תבניות באתרי הייצור נשמרו, נמצאו אך לא הוכרו ככאלה או שעדיין לא נמצאו. למרות שמחקרים קודמים זיהו עיצוב רב-שכבתי, שימוש בחסמים צמחיים ושימוש מזדמן בטיח כמאפיינים מרכזיים של התבניות, ניתן לזהות את רוב המאפיינים הללו רק בשיטות פטרוגרפיות ולא בקלות בשטח. לכן, בוצע ניסוי ארכיאולוגי בהתבסס על ידע ממחקרים קודמים והושלם על ידי תיעוד אתנוגרפי כדי לחקור את זיהויין של תבניות יציקת שעווה אבודה בממצא הארכיאולוגי. מכיוון שניתן לזהות בקלות שכבות העשויות מחומר שונה בשקפים, נבדקה זיהוין של שכבות עם אותו חומר אך עם כמויות ופרופורציות שונות של חימום.

הניסוי הארכיאולוגי היה רב תכליתי. חומרי גלם דומים לחומרים ששימשו בתקופה הכלקוליתית שימשו ליצירה מחדש של תבניות יציקת השעווה האבודה. לאחר מכן חיממנו את התבניות כדי להסיר את השעווה. במקביל, נבנו כורית וכבשן לפי הכבשנים המשוחזרים של תהליך הנחושת הטהורה שנמצאו באבו מטר, כדי לבחון את יכולת הפעולה שלהם עם מפוח (ראה להלן) ולהמיס את הנחושת והאנטימון ליציקה.

בוצעו ארבע הרצות, באף אחת מהן לא הומסה מספיק מתכת ליציקה מוצלחת. התבניות היו שבירות מיד לאחר היציקה ושבריריותן עלתה משמעותית ביומיים הבאים. לבדיקה פטרוגרפית הוכנו חתכים

במערב אסיה, פריטי זהב מופיעים מעט מאוחר יותר כחפצים קטנים בודדים כגון חוטים או חרוזים, לרוב בשילוב עם פריטים עשויים מחומרים אקזוטיים אחרים. בהשוואה להיקף המרחבי הגדול באזור, הם נדירים מאוד. דוגמאות חשובות הן חרוז הזהב בקבורה בטפה גאורה ועוד אחד בקבורה בגראי רש (Grai Resh), שניהם מתוארכים לקראת סוף האלף החמישי לפני הספירה. בערך לאותו זמן מתוארכים פריטי הזהב המעטים שנמצאו בצ׳גה סופלה. חרוז יצוק שעווה אבודה מוזהב בטפה היסאר (Hissar Tepe) מתוארך למחצית הראשונה של האלף הרביעי לפני הספירה. פריטי הזהב היחידים בדרום הלבנט הכלקוליתי הם שתי טבעות הזהב ושש טבעות האלקטרום ממערת הקבורה של נחל קנה. הזהב הקדום ביותר בדרום הקווקז מתוארך לרבע השני של האלף הרביעי לפני הספירה, ביניהם שני שורים מסיביים יצוקים בשעווה אבודה במאיקופ קורגן (Maikop kurgan). עם מכרה הזהב בסאקדריסי (Sakdrisi) וכורית באתר דז׳דזווּבי (Dzedzvebi) הסמוך (שניהם מאמצע האלף הרביעי לפני הספירה), אזור זה הניב את העדויות הקדומות ביותר לכרייה והיתוך של עפרות זהב.

חפצי כסף מדווחים מאתרים בדרום מזרח אירופה שהכילו את ממצאי הזהב הקדומים ביותר. עם זאת, ההקשרים שלהם אינם ברורים ופריטי הכסף המוקדמים ביותר הניתנים לתיארוך בטוח מאזור זה מתוארכים למחצית השנייה של האלף הרביעי לפני הספירה. הם מתוארכים מראש על ידי ממצאים מדרום מזרח אנטוליה, צפון מסופוטמיה ואיראן. עגילי כסף שנמצאו בקבורה בהאצ׳ינבי (Hacınebi) מתוארכים למחצית הראשונה של האלף הרביעי לפני הספירה, וכך גם העדות הראשונה לריקוע שנמצאה בדרום מזרח אנטוליה. מאמצע האלף הרביעי ואילך, ניתן למצוא עדויות לריקוע במספר אתרים בצפון מסופוטמיה ובאיראן. ממצאי הכסף הקדומים ביותר של דרום הקווקז נמצאו בקורגנים, ביניהם שתי מקבילות כסף לשורים המוזהבים היצוקים בשעווה האבודה במאיקופ קורגן. בדרום הלבנט, כסף לא נמצא לפני תקופת הברונזה הקדומה.

בנוסף לרקע הארכיאומטלורגי, נדונים בתזה זו היבטים מרכזיים של תהליכי ההיתוך עם עפרות נחושת טהורות ועפרות פאהל (fahl-ore), כמו גם התכונות של סגסוגות נחושת פולי-מתכתיות. טכניקת המפוחים, נושא מרכזי בהערכה מחדש של תהליך הפקת ויציקת הנחושת הטהורה בתקופה הכלקוליתית בדרום הלבנט, ניתנת לשיחזור על פי הקטרים הפנימיים של פיות המפוח (tuyères). עבודה ניסיונית וחישובים תרמו-דינמיים הראו כי קוטר של 5 עד 01מ״מ הוא אופטימלי עבור צינורות נשיפה, בעוד שחרירים עם קוטר פנימי של 20 עד 30 מ״מ הם האופטימליים עבור מפוח.

מודגש כי עם הטכנולוגיה והכבשנים הזמינים בעת הזו, לעתים רחוקות ניתן היה להשיג אווירה מחזרת והמסה מלאה של העפרה. במקום זאת, התרחשה תגובה במצב מוצק של מינרלי הנחושת לנחושת מתכתית. השימוש בעפרות גופרית שעברו בליה מועיל לתהליך מכיוון שהתגובה האקזותרמית של גופרית עם חמצן מגבירה את הטמפרטורה ואת האווירה המחזרת בכבשן לפחות באופן מקומי. מחקרים ניסיוניים הראו כי התכה של עפרות פאהל (שעברו בלייה) ללא קלייה מוקדמת יכולה לגרום לייצור של נחושת טהורה לצד ספייס (תערובת ארסנית של מתכות) בהרכב דומה לסגסוגות הנחושת הפולי-מתכתיות שנמצאות בדרום הלבנט הכלקוליתי. דוגמאות מאזורים גיאוגרפיים אחרים הראו כי סגסוגות פולי-מתכתיות עם רמות כה גבוהות של אנטימון וארסן הן בלעדיות לדרום הלבנט הכלקוליתי. יוצאי דופן הם מטילי האלפים המזרחיים מתקופת הברונזה. יש להם הרכב כימי דומה, אך הם סוגסגו עם נחושת טהורה והותכו בתנאי חמצון לפני יציקת המתכת, מה שהפחית משמעותית את כמות הארסן והאנטימון בפריטים היצוקים. לכל שאר הממצאים בעלי הרכב כימי דומה יש פחות מ-Sb 10% או רמות ארסן נמוכות מאוד.

ארסן, ובמידה מסוימת אנטימון, הם נדיפים ביותר בתנאי חמצון. תכונה זו הופכת את ייצורה של נחושת ארסן וסגסוגות פולי-מתכתיות ללא פשוט. מוצגות מספר גישות תיאורטיות וניסיוניות, אך נראה שהשיטה הטובה ביותר עם הידע הטכנולוגי של התקופה הזו היא ייצור של נחושת ארסן באמצעות התכה

השעווה האבודה, ומטלורגיית נחושת טהורה עם יציקת תבנית פתוחה. עדויות למטלורגיית נחושת טהורה מוגבלות לנחל באר שבע. רובן המכריע של העפרות נכרה בפינאן והובאו ליישובים לצורך התכה. כמה חתיכות עפרה הובאו מתמנע. סדני אבן ואבני ריסוק עם עקבות של מינרלים של נחושת שנמצאו באבו מטר מעידים על טיוב עפרות. עפרת הנחושת הותכה ישירות בכבשן בור בקוטר של כ-30 עד 40 ס"מ ובעומק של כ-20 עד 30 ס"מ עם דופן דמויית צווארון בגובה של כ-10 ס"מ. רוחב הפתח בקיר הכבשן היה כ-10 ס"מ. רק לעתים נדירות הפכו העפרות במלואן לנוזל בכבשן זה, ומוצרי ההיתוך מתויגים בצורה הטובה ביותר כעפרות שהגיבו במקום עיוותים. התופעה הנרחבת של דלאפוסייט וקופרייט (delafossite and cuprite) מעידה על תנאים מחמצנים למדי, בדומה לאזורים אחרים במערב אסיה מלבד איראן. בשל ההמסה הקצרה והלא מלאה של העפרה, נחושת מתכתית הייתה נוכחת כגלילי נחושת בתוך חלקי העפרה שהגיבו. בשלב הבא הם הם חולצו מכנית, הותכו בכורית ונוצקו לחפצים. כורי ההיתוך הם בדרך כלל קערות אליפטיות בקוטר של כ-10 ס"מ ועומק פנימי של כ-7 ס"מ. עדיין לא נמצאו תבניות יציקה, מה שמצביע על שימוש בתבניות חול (כנראה בקרקע הלס המקומית). מוזכרים מספר שברי פיות מפוח (tuyère), אך מלבד אחד מאבו מטר לא התפרסמו פרטים עליהם וזיהויו של החלק מאבו מטר כשבר מפית מפוח זכה לביקורת מוצדקת.

עדיין לא קיים ממצא ארכיאולוגי הנוגע לייצור בטגניקת היציקת בשעווה האבודה עם סגסוגות נחושת פולי-מתכתיות. בהתבסס על הכימיה (עד 25% Sb ו 15% As , לפעמים כמה אחוזים מ-Pb, Ag או Ni) הוצעו עפרות פאהל (fahl-ore) עשירות באנטימון כמקור לעפרות. ניתוח הרכבי איזוטופים של עופרת מצביע על דרום הקווקז ודרום מזרח אנטוליה כאזורי המקור. מחקרים טכנולוגיים, בעיקרד של חפצי המתכת במטמון נחל משמר, העלו כי חלקם נוצקו על ליבות העשויות בדרך כלל מקרמיקה אך לפחות במקרה אחד גם מאבן. יתרה מכך, הם חשפו איכות יציקה הטרוגנית מאוד של חפצים אלה ותיקון מדי פעם של שגיאות במהלך היציקה, כנראה מיד לאחר הסרת התבנית. שאריות תבנית שנצמדו לחפצי המתכת אפשרו לשחזר עיצוב תבנית רב-שכבתי עם לפחות שתי שכבות. השכבה הפנימית עשויה לרוב מחרסית עדינה העשויה מחוואר מתצורות מוצא (Moza), ולעיתים גם מתצורת טקיה, המעורב בחומר צמחי עשבוני ובחול קרבונטי (קלציטי) עדין. השכבה החיצונית עשויה מפצלים חרסיתיים עתירי ברזל מתצורת חתירה, או טיח סיד. מחשופים של התצורות האלה ששימשו כחומרי הגלם המתאימים לתבניות מופיעים בקרבה זה לזה בדרום עמק הירדן ובאזור ים המלח ומרמזים על מיקומם של בית או בתי המלאכה ליציקות השעווה האבודה אי שם בעמק הירדן התחתון. בשלב התכנון של פרויקט זה הוצעה פצאל בבקעת הירדן כאתר ייצור פוטנציאלי עקב הימצאות משותפת של שברי כורית - הראשונים מחוץ לאתרי נחל באר שבע - ומספר רב של שברי פריטים שנוצרו בטכניקת השעווה האבודה באתר המשנה פצאל 2.

תל חוג'יראת אל-גוזלן ותל אל-מגאס במפרץ עקבה חשפו קנה מידה פרוטו-תעשייתי של ייצור נחושת עם עפרות מתמנע. אתרים אלו אינם חלק מהיישות התרבותית הכלקוליתית של דרום הלבנט, כפי שהוזכר לעיל. הם נבדלים במטלורגיית הנחושת שלהם על ידי שימוש בכורית ולא בכבשנים להתכה. בנוסף, נראה כי מטילי נחושת תקניים (סטנדרטיים) היו המוצר העיקרי באתרים אלו והם, בניגוד לגושי מתכת, נעדרים מדרום הלבנט הכלקוליתי.

בדומה למטרולוגיית הנחושת, העדויות הקדומות ביותר לשימוש בזהב נמצאות בדרום מזרח אירופה. למרות שאינו האתר העתיק ביותר, בית הקברות הראשון של ורנה (אמצע האלף החמישי לפני הספירה) הוא המפורסם ביותר בגלל הכמות הגדולה של פריטי זהב שנמצאו בו. זהב יוצר לקישוטים אישיים, צלמיות בצורת טבעת, כלים מיניאטוריים ומטות/שרביטים. רוב החפצים נוצקו, אך רק מעטים מהם בטכניקת השעווה האבודה. כתוצאה מכך, אתר זה מספק גם את העדויות המוקדמות ביותר כיום לטכנולוגיית היציקה הזו.

בערך לאותו זמן. צירים אלו מופיעים כבר מעט מוקדם יותר בדרום מזרח אירופה ולכן הם מהווים אינדיקטור חזק למגעים עם אזור זה.

גם דרום-מזרח אירופה הייתה בקשר הדוק עם אנטוליה, אם כי בעיקר עם אנטוליה המערבית. התפוצה של צלמיות בצורת טבעת מעידה על רשת חילופין המשתרעת מדרום מזרח אירופה לצפון אנטוליה. עם זאת, נראה שההרים בין מזרח וצפון אנטוליה היוו גבול תרבותי. עדויות למגעים עם דרום מזרח אירופה חסרות במזרח אנטוליה ולהיפך, אין ראיות למגעים עם דרום הקווקז בצפון אנטוליה.

# רקע ארכיאומטלורגי

העדות המוקדמת ביותר הידועות לפירו-מטלורגיה נמצאה בדרום מזרח אירופה, שם נחושת טהורה הומסה ושמשה לייצור מרצעים, גרזנים, פטישים וחפצים אחרים מאז תחילת האלף החמישי לפני הספירה. כבר באמצע האלף החמישי לפני הספירה, פעילויות ההתכה היו נרחבות וניכרות כיום בכמויות הגדולות של כלים כבדים כגון גרזנים ופטישים (בסביבות 4.7 טון נחושת בסך הכל). בהשוואה לכמות עצומה זו של מתכת, מספר אתרי ההתכה הידועים קטן להדהים. תערובות של מינרלים ירוקים ושחורים או סגולים שימשו כעפרה. העפרות הותכו בתנאי חמצון יחסיים בכבשני בור מדופנים בשברי חרס, והתהליך כמעט ולא הניב עיוותים. לתקופה קצרה הותך גם סטאניט, וכתוצאה מכך נוצרה ברונזה של בדיל. לאחר מכן יצקו את המתכת בתנאי חמצון.

הנחושת המותכת הקדומה ביותר המוכרת באנטוליה היא של האזמלים הגדולים, הגרזנים והמחטים של מרסין-יומוקטפה (Mersin-Yumuktepe) (בסביבות 5000 לפנה"ס), בעוד שאתרי ההיתוך הקדומים ביותר מתוארכים רק למחצית הראשונה של האלף החמישי לפנה"ס. לאורך כל התקופה הנחקרת כאן, כמעט ואין שינוי בתהליך ההיתוך. עפרת נחושת, בדרך כלל עפרה גופרתית שעברה בליה, מותכת בכוריות, שלעתים קרובות הונחו בבור. כתוצאה מכך, הותכו טיפות הנחושת (prills) בכורית ונוצקו בתבניות פתוחות. מלבד נחושת טהורה, הופקה נחושת עם רמות גבוהות של ארסן ולפעמים ניקל.

בדרום הקווקז, ממצא המתכת המוכר ביותר הוא חרוזים עשויים מנחושת ארסן מהאלף השישי לפני הספירה. עם זאת, העדויות הבטוחות המוקדמות ביותר לפעילות התכה מתוארכות רק למחצית השנייה של האלף החמישי לפני הספירה. ערימת עפרות שנמצאה במנטש טפה (Mentesh Tepe) מצביעה על התכה של מטילי נחושת גופרתית שעברו בליה ממרבצי עפרות ששכנו באופיולייטים. ממצאי עיוותים מצביעים על תנאים מחמצנים יחסית. שרידי Tuyère מ-Ovçular Tepesi מצביעים על שימוש בצינורות נשיפה. כבשנים עדיין לא נמצאו בזמן שכן נחשפו שברי כורית, מה שמעיד על כך שהתכה והיתוך בוצעו בכורית. יש רק שינוי מינורי במטלורגיה של דרום הקווקז במהלך התקופה הנחקרת.

העדויות המוקדמות ביותר להתכת נחושת באיראן מתוארכות למחצית הראשונה של האלף החמישי לפני הספירה. ב-Tal i-Iblis הותכו עפרות פולי-מתכתיות שעברו בליה בכוריות. תהליך ההיתוך היה מצמצם יותר מאשר בכל שאר האזורים הנבחנים. משלב מוקדם, נחושת ארסן מופקת לצד טהורה. פריטי נחושת גדולים יותר נמצאים מהאלף החמישי לפני הספירה ואילך, במיוחד בהרי זגרוס (Zagros) ובאזורי איראן הסמוכים. טכניקות יציקה מתקדמות מוכחות על ידי התבניות לצירי נקב ב-Tepe Ghabristan, הכוללות ליבות קרמיקה ניתנות להזזה ליצירת חורי פיר. כפי שהוזכר לעיל, מכלול המתכת הגדולים ביותר נמצאו בסוסה ובצ'וגה סופלה שבח'וזסטן. עם זאת, עדיין לא נמצאו אתרי התכה בח'וזסטן ונראה סביר יותר שנחושת יובאה מהאזורים הצפוניים יותר, למשל, הרמה הצפונית של איראן.

בהיותה אחד הנושאים המרכזיים במחקר זה, המטלורגיה של דרום הלבנט הכלקוליתי נדונה בהרחבה. כפי שכבר צוין, קיימות שתי מסורות מתכתיות: סגסוגות נחושת פולי-מתכתיות שנוצקו בטכניקת

ומקודשות בצ׳וגה (Choga) מיש (Mish) ובסוסה (Susa), ומגורי עילית בסוסה מצביעים על התפתחות לעבר חברה היראכית בתקופת הכלקוליתית. בתי הקברות של סוסה וצ׳גה סופלה (Chega Sofla) הניבו כמויות גדולות של פריטי מתכת. הממצאים בצ׳גה סופלה מצביעים על מיומנות גבוהה של עיבוד מתכת שאין שני לה בשאר האזורים באיראן בשלב זה.

דרום מזרח אירופה כלולה כאן בשל העדויות המוקדמות ביותר להתכת נחושת, המתוארכות לתרבות הווינצ׳ה (Vinča) (אלף 6 לפני הספירה) בסרביה של ימינו. באמצע האלף החמישי לפני הספירה התרבות הזאת קורסת. פעילויות ההתנחלות והמטלורגיה עוברות לחוף המערבי של הים השחור, כאשר בית הקברות של ורנה 1 הוא כנראה האתר הבולט ביותר. מטלורגיה באזור זה מאופיינת במספר רב של כלי נחושת כבדים (יותר מ-4300 פריטים) ובחדשנות גבוהה עם ממצאי הזהב הקדומים ביותר, פרק קצר של ייצור ברונזה ״טבעי״ מסטאניט, עדויות לסגסוגת נחושת וזהב , ויציקת שעווה אבודה עם זהב באמצע האלף החמישי לפני הספירה. בדומה לדרום הלבנט הכלקוליתי, אין אינדיקציה לריבוד חברתי בהתיישבויות ובקבורות, למרות כמויות זהב ונחושת גדולות בקבורות ובמטמונים.

כל האזורים הללו היו בקשר זה עם זה. ניתן לאתר עדויות ארכיאולוגיות למגעים בין דרום הלבנט לצפונו כבר בשלב הנאטופי (13 עד 9.6 אלפי שנים לפני הספירה) בצורת אובסידיאן מאנטוליה המתפשט עד לדרום הלבנט. לתרבות החומרית של תרבות ואדי רבה (מחצית ראשונה של האלף החמישי לפני הספירה) תכונות רבות שניתן לקשר לאזור התרבותי של חלאף בצפון. בדומה לכך, תל צף (המחצית הראשונה של האלף החמישי לפני הספירה) הניב אינדיקטורים רבים למגעים עם המרחב של תרבות עוביד. בתקופה הכלקוליתית, העדויות למגעים ממשיכות, למשל, בצורת אובסידיאן אנטולי המופיע לפעמים באתרים בדרום הלבנט. מגרדי מניפה מצביעים על אופק טכנולוגי המשתרע ממצרים דרך דרום הלבנט ועד לצפון מסופוטמיה. הגיוון ואולי עוצמת החליפין גדלים עם הגעת התקופה הכלקוליתית המאוחרת: סגסוגות הנחושת הפולי-מתכתיות והלהבים הכנענים מצביעים על קשרים רעיוניים, ובמקרים מסוימים חליפין ממש, עם דרום מזרח אנטוליה/צפון מסופוטמיה או דרום הקווקז, בעוד שאובני הקדרים האיטיות (tournette) הן חידוש דרום לבנטיני שהתפשט לעבר הצפון. על מגעים עם אזורים רחוקים אף יותר מעידים, למשל, חרוזי לאפיס לזולי (lapis lazuli) באתרי מערות בדרום הלבנט. יתרה מכך, צוינו קווי דמיון חזקים בארגון החברתי של דרום מזרח אירופה ודרום הלבנט.

צדפות מהנילוס באתרים בדרום הלבנט מעידות על מגעים עם מצרים. בנוסף, נוכחות של אוכלוסייה דרום לבנטינית במצרים מוכחת על ידי כלים שיוצרו מחומר מקומי במסורת הכלקוליתית של דרום הלבנט בבוטו (Buto) ובבית תת קרקעי במאדי (Maadi). ממצאים כלקוליתיים מהלבנט וממצריים נמצאים גם באתרים שנסקרו ונחפרו בצפון סיני, שהוא הגשר בין האזורים. עם זאת, חליפין נרחבים בין מצרים לדרום הלבנט מוכחים בצורה הטובה ביותר בתל חוג׳יראת אל-גוזלן במפרץ עקבה. אתר זה שאינו קשור תרבותית לתקופה הכלקוליתית של דרום הלבנט, הניב עדויות לייצור נרחב של נחושת ומשלוח של מטילי נחושת למצרים.

הקשרים בין דרום הקווקז והאזורים שמדרום לו קרובים מאז התקופה הנאוליתית, כפי שמעידים האובסידיאן הקווקזי באתרים אנטוליים וכלי חרס מחלאף באתרים קווקזיים. במהלך התקופה הנחקרת כאן, דרום הקווקז, צפון מסופוטמיה ודרום מזרח אנטוליה הם חלק מהאופק הטכנולוגי של כלי מוץ. נרמז, כי הבדלים בתרבות החומרית מצביעים על הבדלים בין קהילות הרריות ניידות עם תרבות חומרית ״קווקזית״ לבין מתיישבים ״מסופוטמיים״ בשפלה ולא בין אזורים גיאוגרפיים נפרדים. נראה כי הופעתה של תופעת הקורה-ארקסס (Kura-Araxes) במהלך המחצית הראשונה של האלף הרביעי לפני הספירה היא גורם משבש עיקרי למגעים בין שלושת האזורים. מה שמכונה קרמיקת דלמה (Dalma) מעיד על קשרים של דרום הקווקז עם איראן. בנוסף, יוצרו צירי נקב בשני האזורים והתרחשותם מתוארכת

בנוסף, מחקרים ארכיאו-גנטיים מצביעים על שני גלי הגירה עצמאיים מהצפון לפני או במהלך התקופה הכלקוליתית.

אזור דרום מזרח אנטוליה וצפון מסופוטמיה מתפצל למספר קבוצות בסוף שלב עובייד (אמצע האלף החמישי לפני הספירה), אשר שוב ניתן לחלקן לקבוצות לפי כלי החרס שלהם לקבוצה מזרחית ומערבית, המופרדות על ידי נהר הפרת. בסוף האלף הרביעי לפני הספירה, הקבוצה המערבית מתפצלת לקבוצה צפונית וקבוצה דרומית, והאחרונה מכוונת את עצמה קרוב יותר לקבוצה המזרחית. מרכיב מאחד של כל הקבוצות הוא ייצור כלי מוץ וייצור סדרתי של מה שנקרא קערות קובה. בעוד שבאתרים בקבוצה המזרחית כמו טפה גאורה יש ארכיטקטורה מונומנטלית, חברה היררכית ואינדיקטורים לעירוניות מוקדמת, התפתחויות דומות מופיעות בקבוצה המערבית, המיוצגות בארלסנטפה שהוא האתר החשוב ביותר שלה, רק מאמצע האלף הרביעי לפני הספירה ואילך. ברצף הזמן הנחקר כאן, לא ניתן לספק ראיות ברורות לחברה ריבודית בקבוצה המערבית. החברות ההיררכיות בקבוצה המזרחית ולאחר מכן גם בקבוצה המערבית מבוססות על חלוקה מחדש, כלומר, השליטה על הגישה והחלוקה של משאבים, ובעיקר המזון. בהשוואה לאזורים אחרים, פריטי מתכת נדירים בצפון מסופוטמיה ובדרום מזרח אנטוליה. מהמחצית השנייה של האלף החמישי לפני הספירה ואילך, ככל הנראה יוצרו רק כלי נחושת קטנים וכנראה היו אלה פריטים קהילתיים. פרט לשלוש קבורות עם פריטי זהב וכסף קטנים, קברים מהתקופה הנחקרת אינם מכילים מתכת באזור זה.

קשה עדיין לשחזר תהליכים תרבותיים בדרום הקווקז. רוב חלקי התרבות הסיונית היו ככל הנראה קבוצות נוודיות שהותירו שרידים ארעיים מדי מכדי שניתן יהיה לזהותם ללא קושי בממצא הארכיאולוגי, ורק היישובים Mentesh Tepe ו-Ovçular Tepesi נחקרו בפירוט, עדיין. ככלל, נראה שדרום הקווקז מושפע מאוד מהאזורים שמדרום לו; כלי חרס עם פני מוץ נמצאים לעתים קרובות יחד עם כלי חרס מקומיים. התכת נחושת מוכחת כבר מאז האלף ה-6 לפנה"ס, אך עדויות ברורות למטלורגיה יכולות להיות מתוארכות רק למחצית השנייה של האלף החמישי לפנה"ס. חלק מהקברים המעטים שנחפרו הכילו פריטי מתכת. שחזור הארגון החברתי אינו אפשרי עדיין, אך הוצע מבנה התארגנות בקבוצות משפחתיות גדולות. המצב משתנה במידה ניכרת במהלך הרבע השני של האלף הרביעי לפני הספירה; תרבות Leilatepe-Berikldeebi כוללת סדנאות מתכת וארכיטקטורה מונומנטלית. בנוסף, מוקמים הקורגנים (תל שנבנה מעל קבר) הראשונים. הם מכילים הרבה מתכת ופריטי יוקרה אחרים, דבר המצביע על חברה היררכית בשלב זה.

איראן מאופיינת בהתיישבויות קטנות ומפוזרות ללא ריבוד חברתי, ואי שוויון חברתי-כלכלי מינורי בסוף התקופה הנאוליתית. התהליכים החלים במהלך התקופה הכלקוליתית דומים בכל האזורים אך מתרחשים בקצב שונה. צפון מערב איראן מהווה חלק מאזור התרבות של דרום הקווקז - צפון מסופוטמיה וההתפתחויות התרבותיות נמנות לפי התהליכים שם. הרמה הצפונית-מרכזית של איראן עדה לעלייה חזקה בהתמחות המקצועית, כולל בתי מלאכה עם מרחבים ייעודיים, למשל, למטלורגיה וקדרות. מבנים מרכזיים מצביעים על ישות מתאמת כלשהי אך נראה שלא מתקיימת היררכיה ברורה בתוך החברה. דוגמאות לחליפין למרחקים ארוכים הן תבניות לצירי נקב והצירים עצמם שנמצאו בבית הקברות של Susa בדרום מערב איראן, או השימוש בלאפיס לזולי שיובא ממרחק. עדויות ראשונות באיראן למטלורגיה, שימוש בכבשן דו-חדרי לצריפת כלי חרס וייצור טקסטיל נמצאות בדרום מזרח איראן, משם הן התפשטו לאזורים האחרים במהלך המחצית השנייה של האלף החמישי לפני הספירה. מלבד החידושים הללו, אזור זה נצמד לדגם היישוב ולארגון החברתי הניאוליתיים. נראה שהרי הזגרוס מאוכלסים בשלב זה בקבוצות נוודיות עם בתי קברות מרכזיים גדולים. חלק מהקבורות מכילות פריטי מתכת. בכל האזורים הללו, נראה כי פריטים העשויים ממתכת ואבנים אקזוטיות משמשים לציון מעמד פרטני. ניגוד חזק מספקת ח'וזסטן (Khuzestan) בדרום מערב איראן, שם ארכיטקטורה מונומנטלית למטרות ציבוריות

נסוב גם סביב תפקידם של חפצי המתכת בחברה זו והיעלמותם הפתאומית בסוף התקופה הכלקוליתית. למרות שמספר מחקרים כבר התמודדו עם נושא זה, הוא עדיין שנוי במחלוקת, לא מעט משום שהארגון החברתי הכללי של דרום הלבנט הכלקוליתי נותר שנוי במחלוקת.

מסיבות אלה, פרויקט מחקר זה מתייחס לשלוש מטרות עיקריות: (א) איפיון מדוייק ברזולוציה גבוהה של התהליכים המטלורגיים בדרום הלבנט הכלקוליתי על ידי שילוב הניתוח (מחדש) של המכלולים המטלורגיים מאבו-מטר ופצאל, מתוך עם גישה ניסויית; (ב) התחקות אחר התפתחותה של ההמצאה "יציקה בטכניקת השעווה האבודה" בפרספקטיבה בין-אזורית. (ג) גיבוש רעיונות חדשים על תפקידם התרבותי של חפצי המתכת במערכת החברתית-כלכלית של דרום הלבנט הכלקוליתי. לצד העבודה הניסויית והאנליטית בחלק הראשון, מוצגת כאן לראשונה סקירת ספרות נרחבת ומקיפה שהיא הבסיס להשגת כל שלושת המטרות.

## רקע ארכיאולוגי

בדרום הלבנט מהווה התקופה הכלקוליתית המשך של התקופה הניאוליתית המאוחרת שתפוצתה בישראל של היום מדרום הנגב, הגדה המערבית ובקעת הירדן ועד לגליל התחתון. ניתן לחלק אותה לשני שלבים, המכונים כאן כלקוליתית קדומה ומאוחרת. התקופה הכלקוליתית הקדומה מאופיינת, בין היתר, בגביעי קרן (cornet), צלמיות חרס ובמבנים ארכיטקטוניים ("מקדשים") גדולים בגילת, עין גדי ותולילאת ע׳סול. התקופה הכלקוליתית המאוחרת מאופיינת, בין היתר, בהעלמות התכונות הללו ובהופעת המטלורגיה. שינויים אלה בתרבות החומרית מקבילים לשינוי בתקשורת-הסטטוס מארכיטקטורה לפריטי יוקרה כביכול. עם זאת, היבטים רבים בתרבות החומרית נותרו ללא שינוי, כגון קבורה משנית (לעיתים קרובות בגלוסקמאות ובשימוש במערות), היעדר פריטי קבורה הניתנים להגדרה נפרדת, ראשי אלה מאבן, קערות בצורת V וקערות בזלת. נראה שרבים מפריטי המתכת הם סקאומורפים או חיקויים של חפצים שאינם מתכתיים, כך שנוצר קשר הדוק בין החומר החדש הזה לחומרים שהיו בשימוש ארוך יותר. שחזור הארגון החברתי של דרום הלבנט הכלקוליתי הוא מאתגר, מכיוון שהן אופי ההתיישבויות והן הקבורות אינם מספקים אינדיקטורים ברורים להבדלי המעמדות. לכן, קיימים מודלים של מנהיגות היררכית כמו גם מודלים הטרארכיים של ראשי משקי בית. בסופו של דבר, נראה שהאידיאולוגיה הכלקוליתית ואיתה המערכת החברתית כולה קורסות בתום התקופה ורוב הפריטים היוקרתיים ובהם יציקות בטכניקת השעווה האבודה מסגסוגות הנחושת הפולי-מתכתיות נעלמו עם תחילתה של תקופת הברונזה הקדומה.

התקופה הכלקוליתית בדרום הלבנט היא תקופה עם חידושים רבים. מלבד העמקת החקלאות והפסטורליזם וההתבססות המלאה של מוצרים משניים, האובניים האיטיים לייצור קרמיקה והמטלורגיה הם כנראה החשובים שבהם. במקביל לחידושים אלו הייתה עלייה משמעותית בהתמחות המקצועית עם סדנאות ייעודיות, למשל, לכלי צור, קערות בזלת ופריטי מתכת, וכן עלייה בסטנדרטיזציה של כלי החרס, בעיקר של הקערות בצורת V. חליפין אורגן כמערכת דו-שכבתית. רשת (network) המחברת את האזור כולו ובאה לידי ביטוי, למשל, בשרשרת הפעולות של הייצור (chaîne opératoire) האחיד בייצור כלי החרס, תוגברה על ידי רשתות שהתקיימו באזורי התפוצה הצפוני והדרומי של התרבות, על ידי התמחויות אזוריות בייצור דסקיות צור מחוררות ופריטי נחושת טהורה, וכן גם פיסול בשנהב, בהתאמה. כמו כן, התקיימו מגעים עם גורמי התרבות השכנים כמו התרבות התמנעית (Timnian) בנגב ובערבה ועם אזורים שמעבר לשכנים המיידיים הללו. קשרים אלה נשמרו ככל הנראה על ידי מרכיבם נוודיים למחצה של האוכלוסייה, או קבוצות נוודים מוחלטות כמו התימנאנים או רועים נוודים מהקבוצות המשניות.

# תקציר

התקופה הכלקוליתית המאוחרת בדרום הלבנט (4500 עד 3800 לפני הספירה) ידועה במיוחד בזכות חפצי הנחושת יוצאי הדופן שלה, למשל, הכתרים, הקנים המעוטרים, ראשי האלות ומגוון צורות אחר שנמצאו, בין היתר, במטמון נחל משמר כמכלול הגדול והבולט ביותר. הם יוצרו בטכניקת יציקת השעווה האבודה מסגסוגות נחושת פולי-מתכתיות, שמקורות העפרה שלהן נמצאים בהרי אנטוליה או דרום הקווקז. השילוב של סוג מתכת זה, הנמצאת בשימוש בלעדי בדרום הלבנט הכלקוליתי, והעדויות המוקדמות ביותר במערב אסיה לתהליך הטכנולוגי המורכב הזה של ימיקת מתכת, מעידים על התפתחות מטלורגית (חקר תכונות של מתכות) ייחודית בדרום הלבנט הכלקוליתי. בהתבסס על ממצאים ארכיאולוגיים משמעותיים שהתגלו לאחרונה בפצאל (עמק הירדן התחתון), הוצע אתר זה כמקום ייצור אפשרי לתעשייה הזאת. מסורת זו של עיבוד מתכת הייתה מקבילה למטלורגיית הנחושת הטהורה שמופיעה באזור מוגבל של אתרי ייצור בנחל באר שבע, שם הותכו עפרות נחושת בעיקר מפינאן (פונון המקראית) והנחושת הנקיה נוצקה בתבניות פתוחות לחפצים בצורת כלי עבודה פשוטים.

ההיבטים העיקריים של תהליך יציקת השעווה האבודה ועיצוב התבנית שלה מובנים זה זמן רב מן המחקר של שרידי תבניות שנשארו צמודים לחפצי המתכת, ושל סגסוגות הנחושת הפולי-מתכתיות עצמן. עם זאת, היעדר שרידי ייצור במקום (למשל, כבשנים, שברי תבנית) יצר מצב שלא אפשר לרכוש ידע נוסף על רצף הפעולות הטכנולוגי. בנוסף, נותר עדין לאתר עדויות ארכיאולוגיות לייצור ולעיבוד של סגסוגות הנחושת הפולי- מתכתיות. זאת לאחר שהוכח כי ממצאי העפרות הספורים בעלי כימיה תואמת שהתגלו באתרי Arslantepe ו- Norşuntepe בדרום מזרח אנטוליה, לא שימשו ככל הנראה בפעילויות התכה. יתר על כן, העדרם הכמעט מוחלט של שרידי הייצור בשתי שיטות היציקה המטלורגית בדרום הלבנט נראית מוזרה לאור ריבוי ממצאי המתכת (בעיקר במטמון נחל משמא אבל גם באתרים אחרים), אם כי כבר צויין במחקר כי הניראות הארכיאולוגית של טכנולוגיית היציקה בשעווה האבודה היא בדרך כלל נמוכה מבחינת השאריות שהיא מותירה אחריה בשטח.

בניגוד לתהליך יציקת השעווה האבודה, ניתן לשחזר ביתר פירוט את תהליכי הייצור של הנחושת הטהורה. שרידי כבשנים מאבו-מטר ושקמים מעידים על שימוש בתנורי בור, שבהם הותכה העפרה. בשלב שני חולצו מכנית טיפות הנחושת (prills), הותכו בכורית ונוצקו ממנה לתבניות פתוחות. עם זאת, פרטים חשובים נותרו לא ברורים, בהם למשל טכניקת השימוש במפוחים ובפיות המפוח (tuyère), ובהתאם, מספר היבטים של שחזור התהליך ונסיונות הסימולציה שלו נראים כיום מאוד בלתי מעשיים ולכן מוטלים בספק.

מלבד היבטים טכנולוגיים אלה של המטלורגיה הכלקוליתית בדרום הלבנט, המקור וההתפתחות של "טכניקת השעווה האבודה" לא נחקרו עדיין בפירוט. אמנם קיימים מחקרים רבים על ההתפתחויות התרבותיות והמטלורגיות בדרום הלבנט הכלקוליתי ובאזורים אחרים של מערב אסיה, אך לעתים רחוקות הובאה בחשבון הפרספקטיבה הבין-אזורית, למרות הקשר הברור שהתקיים עם האזורים המרוחקים של אנטוליה, הקווקז או איראן (בהתאם להשקפת החוקר) הנובע ממקורן של סגסוגות הנחושת הפולי-מתכתיות ועדויות אחרות. חלק מהדיון על המטלורגיה של דרום הלבנט הכלקוליתי

# **הצהרת תלמיד המחקר עם הגשת עבודת הדוקטור לשיפוט**

אני החתום מטה מצהיר/ה בזאת : (אנא סמן) :

X חיברתי את חיבורי בעצמי, להוציא עזרת ההדרכה שקיבלתי מאת מנחה/ים.

X החומר המדעי הנכלל בעבודה זו הינו פרי מחקרי מתקופת היותי תלמיד/ת מחקר.

___ בעבודה נכלל חומר מחקרי שהוא פרי שיתוף עם אחרים, למעט עזרה טכנית הנהוגה בעבודה ניסיונית. לפי כך מצורפת בזאת הצהרה על תרומתי ותרומת שותפי למחקר, שאושרה על ידם ומוגשת בהסכמתם.

תאריך : 30.09.2022 שם התלמיד/ה : תומס רוז חתימה ___________

העבודה נעשתה בהדרכת

Prof. Yuval Goren

Prof. Francesca Balossi-Restelli

Dr. Peter Fabian

במחלקה Bible, Archeology & Ancient Near Eastern Studies - Archeology

בפקולטה Humanities and Social Sciences

# הופעת פירוטכנולוגיית הנחושת במערב אסיה

מחקר לשם מילוי חלקי של הדרישות לקבלת תואר "דוקטור לפילוסופיה"

מאת

**תומס רוז**

הוגש לסינאט אוניברסיטת בן גוריון בנגב

פרופ' יובל גורן
המחלקה לארכיאולוגיה
המגמה למדעי החומרים הארכיאולוגיים והשימור
אוניברסיטת בן גוריון בנגב

**אישור המנחה** ____________________ Francesca Balossi Restelli

**אישור דיקן בית הספר ללימודי מחקר מתקדמים ע"ש קרייטמן** ________________________

ה' תשרי תשפ"ג 30.09.2022

באר שבע

# הופעת פירוטכנולוגיית הנחושת במערב אסיה

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מאת

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הוגש לסינאט אוניברסיטת בן גוריון בנגב

ד' תשרי תשפ"ג 30.09.2022

באר שבע