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Fine metalworking tools and workshops in Western and Northern Europe. A diachronic consideration

Barbara Armbruster¹

Abstract

This paper deals with late prehistoric fine metalworking tools and workshops in Western and Northern Europe. From the beginning of metallurgy in the third Millennium BC up to the end of the Iron Age in the first centuries BC, tools and manufacturing techniques for gold and silver develop with ongoing technological improvement. An interdisciplinary approach to fine metalworking tools combining archaeology, ethnoarchaeology, experimental archaeology, iconography, and ancient written sources with archaeometry is demonstrated. Case studies illustrate specialised tools and their handling as well as the raw materials they are made of.

Keywords

FINE METAL WORKING; TOOLS; WORKSHOPS; BRONZE AGE; IRON AGE; HISTORY OF TECHNOLOGY

Résumé

Cet article traite des outils et des ateliers spécialisés dans le travail des métaux précieux de l'âge des métaux en Europe de l'Ouest et du Nord. Depuis le début de la métallurgie, au troisième millénaire avant notre ère, jusqu'à la fin de l'âge du fer, aux premiers siècles avant notre ère, les outils et les techniques de fabrication de l'or et de l'argent se développent avec une amélioration technologique continue. Une approche interdisciplinaire des outils de travail des métaux fins combinant l'archéologie, l'ethnoarchéologie, l'archéologie expérimentale, l'iconographie et les sources écrites anciennes avec l'archéométrie est démontrée. Des études de cas illustrent des outils spécialisés et leur maniement ainsi que les matières premières qui les composent.

Mots clés

TRAVAIL DES MÉTAUX PRÉCIEUX ; OUTILS ; ATELIERS ; ÂGE DU BRONZE, ÂGE DU FER, HISTOIRE DES TECHNIQUES

The focus of this paper is the ancient fine metal working technology, in particular the tools and workshops in Western and Northern Europe, dating from the Copper and Early Bronze Ages in the third Millennium BC to the end of the Iron Age in the first centuries BC. What did ancient metal workshops and specialised tools look like and which materials were used? How can archaeologists' approach ancient metalworking tools, workshops, and craftspeople? An interdisciplinary methodology to approach fine metal working tools presented here links archaeology, ethnoarchaeology, experimental archaeology, iconographic and ancient written sources with chemical analyses and imaging from material science.

The development of the goldsmith's craft and equipment is not straightforward, neither in geographic nor chronological terms. During the Metal Ages, the function, form, and decoration of goldwork changed, as do the materials used to produce ornaments, tableware, votives and decorative objects (Eluère 1990; Perea, Armbruster 2008; Armbruster 2013). This is directly linked to the development of the techniques, the tools and their handling. The technology of precious metals is complex and includes many specialized *modus operandi*, instruments, chemical agents, and materials (Maryon 1912; Untracht 1982). Furthermore, it requires a long training, to develop both technical and artistic skills.

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The European goldsmith's art, as well as the workshops and tools accompanying it, encompass a long development through the millennia (Armbruster 2012a; 2012c). Accordingly, the present study provides a broad overview of the archaeological and technological background of late prehistoric fine metalworking workshops. We will begin by discussing the different research methods applied in the study of the technological aspects of metal artefacts and metal working tools. Several case studies from Western, Central and Northern Europe outline the complexity of tools used in the processing of precious metals as part of the history of technology. They exemplify specialised tools, the raw materials they are made of, as well as the tool's usage and handling. They also illustrate that tool mark analyses with microscopic examination reveal much about the instruments that did not survive in the archaeological record. Our diachronic perspective allows the tracing of traditions and advances in early metallurgist's workshops.

Therefore, special attention is given to workshop equipment. However, since architectural remains of workshops are generally lacking and few complete tool kits have survived from the Bronze and Iron Ages, an attempt is made to sketch a picture of ancient workshops via tool finds as well as from indirect information from tool marks left on gold artefacts. Functional analogies and finding contexts are also discussed using case studies.

Short note on the history of research

The beginning of detailed studies of late prehistoric tools applied in European early metalworking dates to the late 19th century. One of the first to observe casting moulds, hammers, and anvils, made of stone and of bronze was J. Evans. He considered these specialized tools in two fundamental works on ancient instruments of Great Britain and Ireland, one volume dedicated to stone (Evans 1872) and the other to bronze instruments (Evans 1881). To give an example from the latter he illustrates the Bronze Age anvil from Fresné-la-Mère, Calvados, France, fixed in a wooden stump in two different working positions, to underline its technical multi-functionality (Evans 1881: 182). Other examples of early publications on Bronze Age metal working tools made of bronze are of artefacts found at the Bronze Age settlement of Velem-Szentvid in Hungary (Miske 1899), on lake dwellings in Switzerland (Gross 1883: fig. 27), or tool finds from Bohemia (Richly 1896). In the first half of the 20th century, German and Swedish scholars investigated ancient metal worker's tools (Ohlaver 1939; Oldeberg 1942-43). From the second half of the twentieth century onwards studies of ancient metal worker's tools become more frequent (Armbruster 2000: 34-127; 2021: 29-94).

Gold technology as an active element of material culture

Studies of ancient metalwork deal with manifold questions of the production of material culture, such as the "*chaîne opératoire*" from the procurement of the raw material to the finished product, as well as recycling, repair, or intentional damage to metal objects. In general, physical properties and technological aspects of archaeological artefacts are key factors in understanding the production context, since hardly any object can really be understood if the manufacturing process remains unknown (Armbruster 2011b). Therefore, metal technology can be seen as an active element of material culture and subsequently a mirror of social conditions (Inker 2000: 26; Armbruster 2012b). In archaeological research, technology has been for a long time regarded merely as the bearer of typological information and thus seen as implicitly passive. In this context, technology was a purely functional assessment, typological studies and theoretical considerations were thought superior to technological studies.

Technology was predominantly considered as part of the natural sciences and therefore left to archaeometry, while archaeology was assigned to humanities. In the archaeology of the Metal ages, technology was usually viewed from a purely positivistic perspective, a concept that strongly contrasts with the cognitive technological studies in research on the Neolithic. In a sense, a divide has been drawn between artefact and art, technology, and implicitly of the craft and between artist

and craftsman. However, this dichotomy established in our society since the industrial revolution was unknown during the Bronze and Iron Ages. The term technology (Greek “τεχνολογία” - *technología*) refers to the systematic treatment of art, technology and science within its social context (Knauss 2004: 33). The concept of technique (Greek “τέχνη” - *technē*) stands for a specific knowledge and a particular ability both in the field of art and craftsmanship. “Τεχνίτες” is the Greek term that equally names artists and craftsmen without distinction.

The technical knowledge and the resulting artefacts constitute the material prerequisites of a culture. It is the object produced according to the technical and stylistic knowledge that is the visible and archaeologically comprehensible expression of this culture (Armbruster 2011a). This principle also applies to the products of gold working. The production of material culture would be a mirror of society according to which artefacts are designed and produced (Appadurai 1986; Pfaffengerger 1992). Each product appears in a twofold way: it is technologically determined and thus part of the technical system that has produced it (Nobelet 1981: 10-20). The artefact is also clearly associated with the cultural and ideological milieu from which it emerges and in which it is incorporated. Its integration into the appropriate social setting depends on whether its function, form, and style display recognizable information carriers.

Approaches to fine metalworking and tools

Recent archaeological studies of ancient gold working are interdisciplinary and link several research areas (Armbruster, Guerra 2003; Perea, Armbruster 2008). In addition to the artistic and stylistic characteristics as well as the practical function of gold artefacts, the symbolic and religious meanings as well as the economic and social values are considered. Issues of exchange, trade, and the circumstances of the final deposition of the end product also play a role. An understanding of the technical processes involved in their production plays an essential part in assessing gold work. In order to answer technology-related questions, research methods and information from various disciplines interact: archaeology and art history, ancient depictions and historic written sources, ethnology, experimental archaeology, macro- and microscopy, material analyses, metallography, radiography, history of technology and craft-expert knowledge about gold working. Typology, function, and discovery context of metal artefacts are explored with methods from archaeology and art history to determine dating and cultural historical classification (Armbruster 2011a). The optical studies on precious metal objects and tools, as well as the scientific material analyses, are carried out directly on the original artefacts. Also, methods from different scientific fields that are not based on the direct study of the original object assist likewise to draw conclusions and contribute decisively to the gain of knowledge through functional analogy and explanatory models.

Various methods of archaeometallurgy are of relevance for the investigation of the technical production processes and tools. When examining the artefact under the microscope, attention is focused on tool marks and processing characteristics which can be observed directly on the piece (Benner Larsen 1987). Each tool leaves unmistakable traces on the metal surface like a fingerprint. These tool marks can be identified with optical instruments of macro- and microscopy and documented with macro- and microphotography or imaging from the scanning electron microscope (SEM) (Meeks 1987; Mortimer, Stoney 1997; Meek *et al.* 2012). Tool mark analysis can therefore indirectly access information on the tools used. Tool marks can be eliminated by scraping, grinding, or polishing, but under special circumstances, X-ray images show hidden traces of hammering as a cloudy structure in sheet objects (Figure 1a-b) or connecting elements and the internal structure of hollow or assembled pieces (Figure 1c) (Oddy 1996).

Material analyses are used to determine the exact composition of the metal alloy (Guerra, Calligaro 2004; Schlosser *et al.* 2009). When studying gold, the alloy components of the base metal on the one hand, on the other hand, the solder alloy used to join several gold elements are of interest. For example, when studying technological aspects of Late Bronze Age composite rings from France and



Fig. 1a-b Tool marks from hammering on the gold vessel from Gönnebek, Germany. a) Sheet vessel from the early Nordic Bronze Age (© B. Armbruster/Archäologisches Landesmuseum Schleswig); b) X-ray radiography illustrating the hammering marks (© R. Aniol, Archäologisches Landesmuseum, Schleswig)

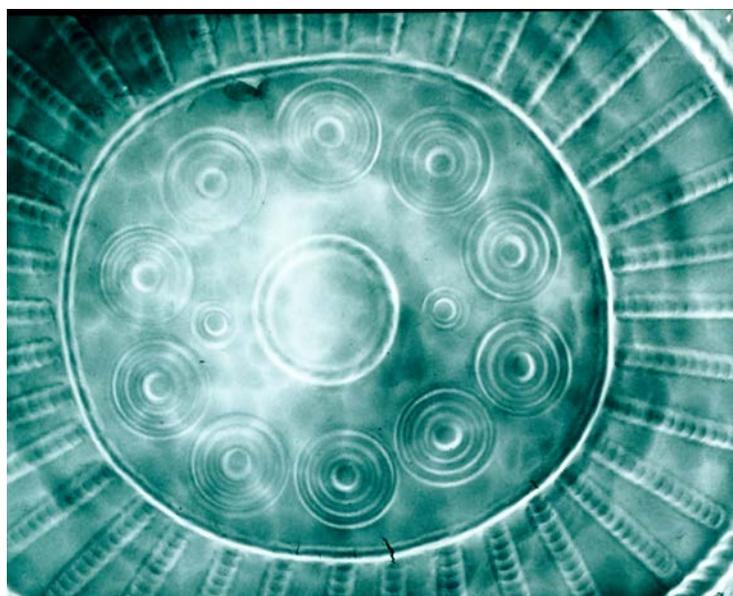


Fig. 1c X-ray radiography with hammering marks and thicknesses of various parts of an Iron Age gold torc from North-West Iberia (© S. La Niece, British Museum, London)

Great Britain, material analyses have shown that gold wires were not joined by copper salt solder as previously claimed. A metallic solder of a ternary gold alloy containing a higher percentage of silver and copper was used with the advantage of having a lower melting point than the base metal (Armbruster *et al.* 2010; Cowie *et al.* 2011).

In ancient and early medieval literary sources, fine metal working is rarely described in detail. The comprehensive treatise “*diversarum artium schedula*” by the Benedictine monk Theophilus constitutes one of the first detailed descriptions of preindustrial metalworking (Hawthorne, Smith 1963; Brepohl 1987). This work, probably written in Cologne in the first half of the twelfth century, offers an insight into technical knowledge, the workshop equipment, tools, auxiliary means, and the materials used by ancient goldsmiths. Works of Italian artists and goldsmiths such as Vannoccio Biringuccio (Biringuccio 1977) and Benvenuto Cellini (16th century) provide further information (Fröhlich, Fröhlich 1974). They cannot be used directly as sources of information for Bronze and Iron Age metalwork but serve as analogies for interpretative models.

The subject of the artisan and his tools is also rarely touched on in fine arts. As a result, iconographic evidence of early gold working and more generally of metalworking in Europe is rare. For the Bronze Age, depictions of fine metal working of the 3rd and 2nd millennium BC from low reliefs and wall paintings in Egyptian tombs provide ample information about workshop organisation, tools, their handling, and the applied techniques (Figure 2a-b; Figure 22) (Garenne-Marot 1985; Scheel 1989). In addition, conclusions can be drawn by analogy. For example, Roman and Medieval representations such as the wall painting from the “*Casa dei Vetii*” in 1st century Pompeii (Figure 23) (Ogden 1982: 66 fig. 4:58) or noteworthy depictions of craftsmen practicing their profession in the *Handbuch der Mendelschen Zwölfbrüderstiftung zu Nürnberg* from the 15th and 16th centuries allow insights into ancient metal working crafts, tools, and workshops (Figure 3) (Treue *et al.* 1965).

Ethnoarchaeology and experimental archaeology play a very important role in reconstructing old methods of production. They serve as comparative bases for explanatory models that are drawn from functional analogies. Most techniques used by metal workers during the Metal ages are still used by today’s goldsmiths. Ethnological investigations can be helpful in scrutinizing late prehistoric metal techniques, and they provide valuable information on traditional tools and their handling. To give an example, ethnographic fieldwork in Mali was decisive for a better understanding of Bronze Age flange and bar twisted gold torcs made by plastic shaping techniques (Armbruster 1995). Iron Age gold working techniques such as wire preparation, filigree and granulation, or sheet making as carried out in Algeria are another example of functional analogy (Camps-Fabrer 1990).

Experiments check the feasibility of hypothetically accepted methods of metal working (Armbruster 2005). The research issues in experimental archaeology require a well-thought-out preparation and detailed documentation. The experimental issues should be taken directly in relation to the archaeological artefacts and the technical preconditions of the period they belong to. Numerous experimental investigations are based on information from ancient sources, such as the above-mentioned work of Theophilus. Experiments on fine metalworking technology of the Bronze and Iron Ages are still rare in comparison with antique and medieval gold working, or moreover compared to experimental archaeology concerned with ancient bronze working. Some experimental work has been carried out on the techniques of filigree and granulation typical in the Iron Age and antique gold jewellery (Nestler, Formigli 1993; Binggeli 2003). Experimental work on the Bronze Age lathe and the Early Iron Age spinning lathe demonstrate the employment of rotary motion tools in the manufacturing of annular gold ornaments (Armbruster 2000: 146-151 fig. 81; 2018). Recently, the making of the enigmatic Late Bronze Age to Iron Age ribbon torcs from Ireland and Great Britain has also been elucidated by experiments (Clarke 2014).

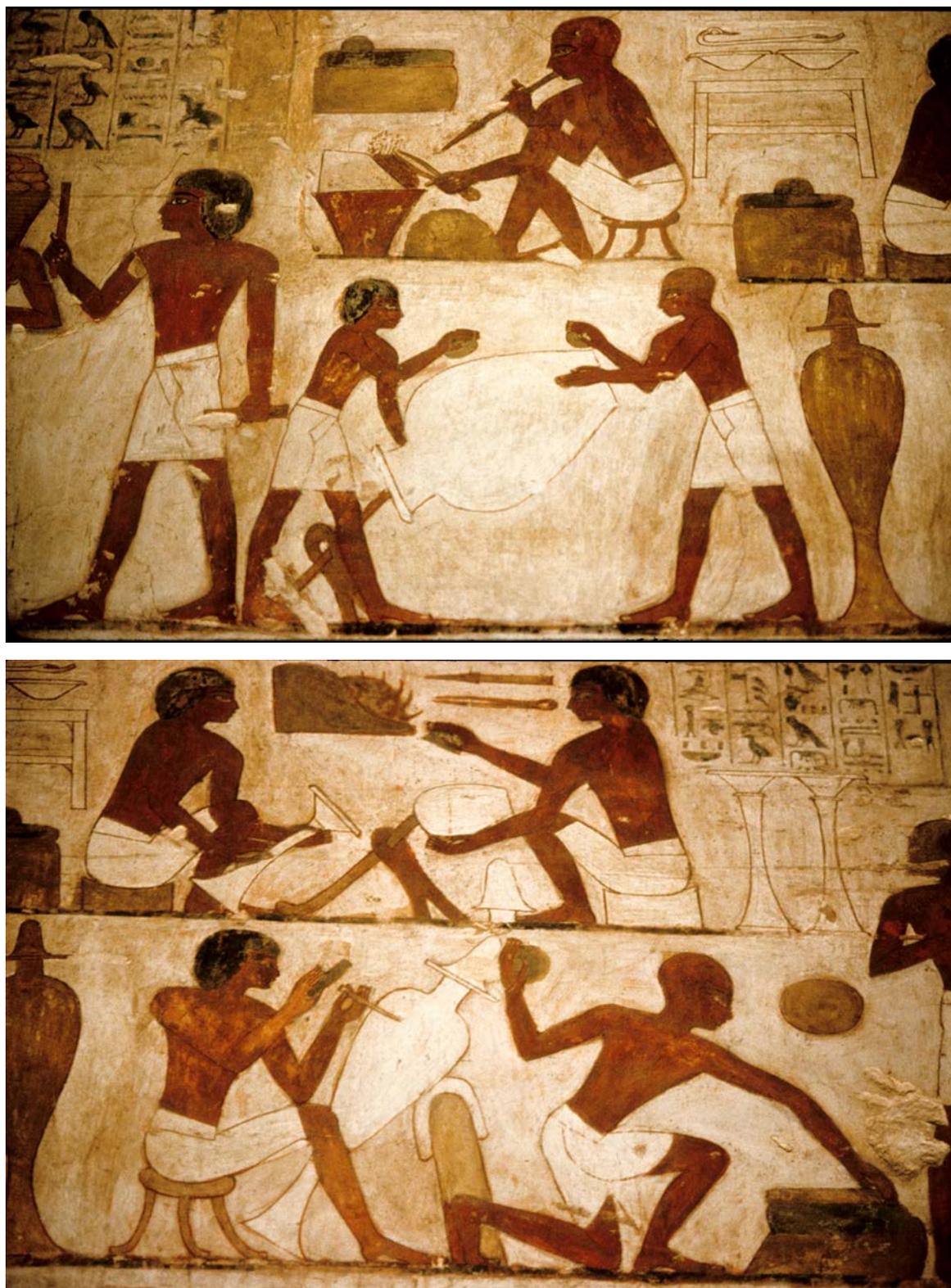


Figure 2a-b. Scenes of an Egyptian goldsmith's workshop on wall paintings in the tomb of Rekmire near Thebes, Bronze Age, c. 1450 BC, showing tools and their handling: furnace, blowpipe, tweezers, snarling iron, stone anvils and round and flat hammers, bronze punch. Techniques: a) up: a sitting artisan uses of a blow pipe and tweezers on a hearth for annealing or soldering; below: two standing artisans are hammering a metal vessel with stone hammers and a snarling iron; b) up: polishing, hammering a metal vessel; below: chasing, hammering sheet metal (© B. Armbruster)

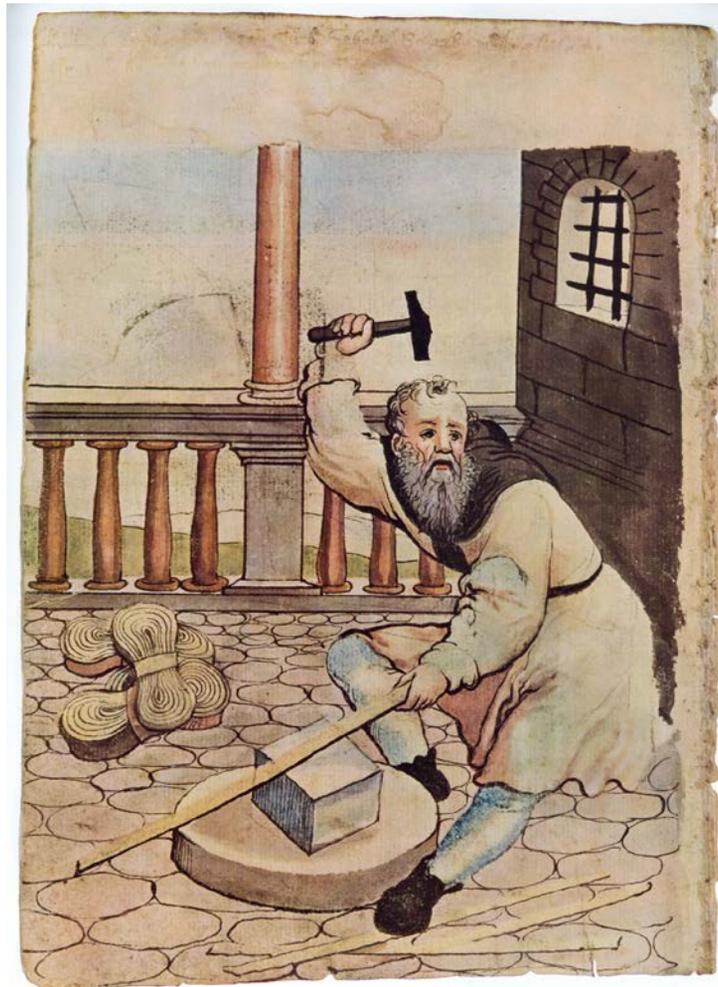


Figure 3. Hammering sheet metal. Medieval representation in the „Hausbuch der Mendelschen Zwölfbrüderstiftung zu Nürnberg“ (Treue et al. 1965)

Misunderstandings in interpreting the practice and tradition of ancient goldsmith's workshops were often the result of a lack of technological expertise and practical experience, as H. Maryon remarked: *“Therein lies the root of trouble. Archaeologists, relying on their acquaintance with modern methods, or misunderstanding the ancient methods, have attributed to the ancient workers power which, with their primitive furnaces, they could never have attained”* (Maryon 1949: 103). A proper assessment of the technological aspects of archaeological metal finds needs a detailed investigation with cooperation between different experts in arts and crafts, humanities, and material science. This also applies when comparing information and analogies cited here. It is important to determine whether representations in an image or in a text correctly describe a technical situation as the artist or writer may not be familiar with the technical details. Even in the case of correct representation in pictorial or written work, the interpretation of technical details requires a technical professional background (Jüngst 1982).

Fine metal working tools

The development of manufacturing processes and the required tools goes hand in hand with a change in materials and object morphology although there are very basic procedures and equipment that remain in use to this day (Maryon 1912; Untracht 1982). This is due to the function of the tools.

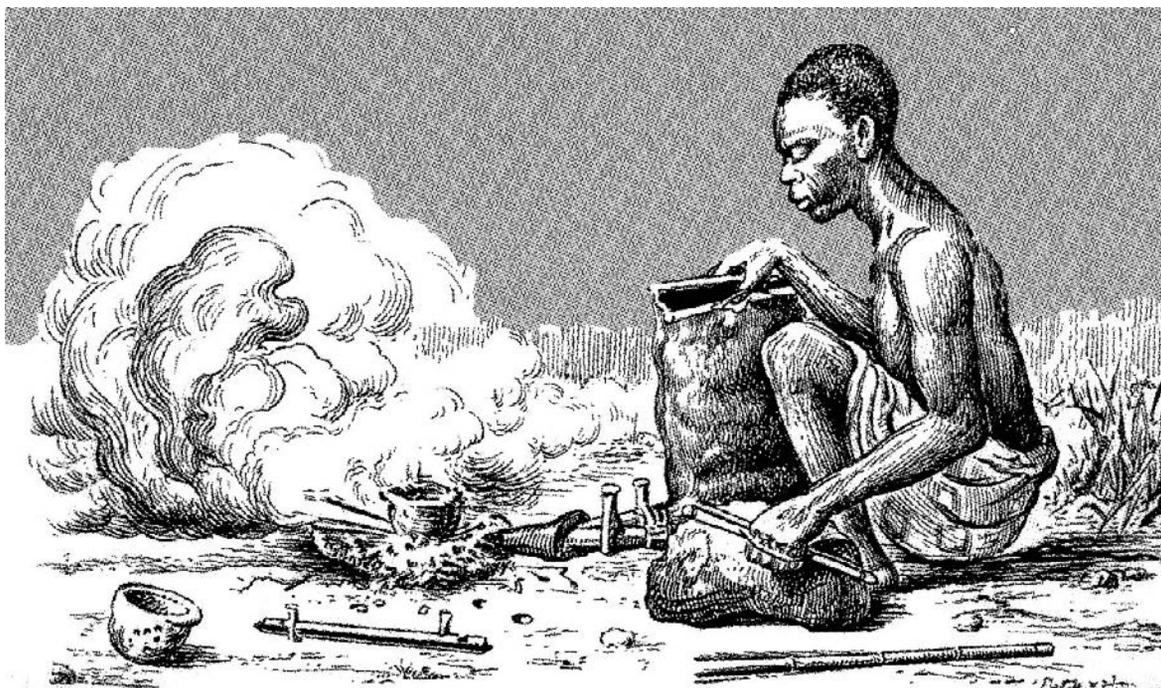


Figure 4. Double skin bellow and its handling in East Africa (Weule 1908: pl. 20, 2)

The creation process is the start of any metalwork, when the concept and design consider the function, shape, and decoration of the object to be manufactured, as well as the physical properties of the materials to be used. The object's concept can be an idea, a sketch, or a model none of which leave any archaeological evidence. To facilitate the realisation of the design the material quality is first checked, and quantities weighed. This is followed by techniques that require a heat source such as melting, alloying and casting. To reach the melting temperature for gold alloys (around 1000°C) constant ventilation of the charcoal fire is necessary. Furnaces were equipped with bellows, or several craftsmen blew with blowpipes. Complete blowpipes or bellows are not found in the archaeological record; however, they can be deduced from clay nozzles and tuyeres. Information about the shape and construction of bellows comes from ancient Egyptian, Greek, and Roman pictorial representations (Weisgerber, Roden 1985; 1986). In addition, ethnographic observations clearly show the handling of double skin as well as of double pot bellows (Weule 1908: plates 20, 2; Cline 1937: 103 fig. 11 a-c; Armbruster 1995: 122-124) (Figure 4). Soldering and annealing are pyrotechnical processes that also require a heat source. The charcoal hearth whether it is a simple pit furnace or a complex-constructed specimen is always a central point in a metal workshop (Figure 24).

The archaeological finds of specialised metalworking tools can be grouped into several categories. They are listed here according to their use in the "*chaîne opératoire*" of specialised working processes: 1) instruments of measurement and testing techniques, 2) pyrotechnical devices, 3) plastic shaping tools, 4) holding tools, and 5) abrasive tools. Stone, ceramics, and metals (bronze, or iron since the Iron Age) are the basic materials of fine metal working tools known from archaeological contexts, as they are preserved due to their good conservation conditions. In addition, goldsmiths were always equipped with tools or materials that left little trace in the archaeological record. These include grinding and polishing agents, acids for pickling, or organic materials, such as leather, bone, antler, wood, and fibres.

Refractory materials such as technical ceramics are used in workshops in the form of clay nozzles and tuyeres, crucibles, moulds, or furnace lining residues. Stone is represented as a raw material for moulds, touchstones, grinding stones, anvils, and hammers (so-called "cushion stones")

Table 1. Categories of artefacts expected during excavations

1	Measuring, weighing, testing	Beam balances, pair of scales, weights, touchstones
2	Pyrotechnical techniques	Furnace remains, tuyeres, nozzles, crucibles, casting moulds
3	Plastic shaping	Hammers, anvils, stakes, punches, chisels, dies, doming blocks
4	Holding	Tweezers, pliers, vices
5	Abrasive techniques	Scrapers, grinding and polishing stones, abrasive materials

(Armbruster 2006; 2010b; Boutoille 2019; 2020; Armbruster 2021, 44-50; Crellin *et al.* 2023). According to figurative representations of Bronze Age casting workshops in Egypt, there were also stones that were used to manipulate hot crucibles or moulds (Figure 24). Stone remains a material for casting moulds, touchstones and grinding stones up to the Early Medieval period. Equipment made of copper alloys (bronze) can be found as weighing panes, weights, moulds, anvils, stakes, hammers, chisels, punches, dies, mandrels, pliers, compasses, and terminals of blowpipes. During the Iron Age, iron begins to replace certain copper alloy tools, mainly anvils, hammers, chisels, punches, and tongs. However, many bronze tools used for plastic shaping techniques are also known from Iron Age contexts (Figure 22). Bronze continues to be the preferred material for casting moulds, scales, weights or dies until the early medieval period (Armbruster 2012c).

Often only a small part of the wide tool repertoire can be detected. What might remain of the equipment from fine metal working workshops for archaeological research? During excavations, the following five categories of artefacts can be expected (Table 1):

Further devices that are not detected directly can be indirectly recognised and reconstructed using tool mark analysis. These include, for example, the drill with a vertical axis or the lathe with a horizontal axis of rotation used to produce wax models for gold processing since the Late Bronze Age in Iberia or in the Early Iron Age Hallstatt period (Armbruster 2004; 2018).

Specific tool findings will be briefly presented below with characteristic case studies. To simplify the complex technical history of fine metal working tools, three major chronological groups are distinguished here. For the Chalcolithic and Early Bronze Age, the Bronze Age, and the Iron Age, examples from Western and Northern Europe are mainly considered.

Copper and Early Bronze Age

Material evidence is rare from the beginning of the gold working craft. Moulds for casting and crucibles for melting are not preserved, although gold has been melted and poured into something. Possibly bars were just cast into a hollowed-out piece of charcoal or wood. From the Chalcolithic and Early Bronze Age, stone tools for plastic shaping refer to early metallurgy (Figure 5). The



Figure 5a-b. Stone hammers from France (© B. Armbruster/Musée d'Archéologie Nationale)



Figure 6. Goldsmiths in Peru working with stone tools and blow pipes (Benzoni 1565: 251)



Figure 7. Experimental use of astone anvil fixed in a wooden stump and hammer without shaft (© M. Weber)



Figure 8. Ensemble of cushion stones, gold work, bell beaker pottery, and prestige objects. Artificial cave of São Pedro do Estoril, Lisbon, Portugal (© P. Witte - DAI Madrid)

stone implements used as percussion tools such as hammers as well as anvils have one or more flat surfaces (Butler, van der Waals 1967; Armbruster 2010b). They appear as stone axes with the edge cut off and smoothed, and as parallelepiped blocks, the so-called cushion stones (Boutoille 2019; Armbruster 2021: 44–50; Crellin *et al.* 2023). The handling of stone hammers without a handle is demonstrated not only by pictorial representations from ancient Egyptian wall paintings and low reliefs but also by ethnographic depictions in historical chronicles (Figure 6) information from ethnological sources and experiments (Figure 7) (Freudenberg 2009; Armbruster 2010b). Cushion stones are found in rich male burials such as the tomb of the so-called Amesbury archer in Southern England or the princely grave from Leubingen in Eastern Germany (Fitzpatrick 2011; Bertemes 2004). Gold ornaments, flint, and copper weapons as well as prestige objects like stone wrist guards, boar teeth or bell-beaker vessels were also deposited in these rich burials. Another well-known example from the Chalcolithic period with cushion stones, gold ornaments, bell-beaker pottery and other high-status artefacts comes from the cave of São Pedro do Estoril, Lisbon, in Portugal (Figure 8) (Gonçalves 2005: 106). Such rich funerary contexts are interpreted as early metallurgist's tombs. Despite several comparable findings, however, the social status of the early fine metal worker has not yet been clarified.

Small wire helices and ornamental sheet objects made by hammering with stone tools are among the earliest gold ornaments. During the Chalcolithic and Early Bronze Age in Atlantic Europe thin decorative sheet ornaments, lunulae, disc shaped appliquéés and neck pieces, the so-called “*gargantillas de tiras*”, appear (Armbruster, Comendador Rey 2015; Cahill 2015; Needham, Sheridan 2014). The ornamentation of these pieces remains linear and has hardly any relief. The sheet metal work gradually developed into three-dimensional shaped ornaments, vessels, and sacred objects from the Early Bronze Age, with the manufacture of gold cups, cylindrical arm rings and the exceptional Mold Cape, Wales (Hughes 2000; Needham 2000; 2006; Armbruster 2010a). The

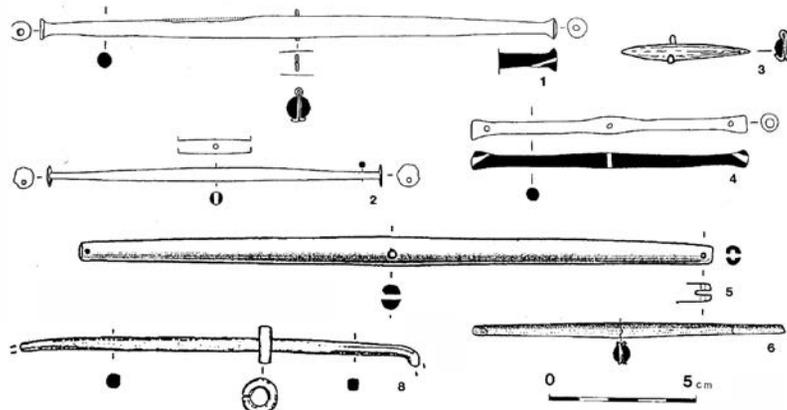


Figure 9. Weighing and testing tools; 10a touch stone Choisy-au-Bac, Oise (© B. Armbruster); 10b balance beams in bone and antler, no. 8 in bronze (1 Cave Chaude au Bois du Roc; 2 Marolles-sur-Seine, Seine-et-Marne; 3 Monéteau, Yonne; 4 Parrat à Agris, Charente; 5 Bordjos, Banat; 6 Gours aux Lions à Marolles-sur-Seine, Seine-et-Marne; 8 Richemont-Pépinville, Moselle (Gomez de Soto 2001: 119 fig. 5, 1-8).

ornamental motifs on these complex gold objects often consist of chased geometric patterns and dotted lines as shallow relief.

Bronze Age

Middle and Late Bronze Age fine metalworking tools are mainly known from hoards. There are still no crucibles or moulds for precious metal processing, however, bronze tool assemblages testify to the variety of instruments used mainly for plastic shaping (Armbruster 2000: 34-65; 2001; Armbruster *et al.* 2003; Armbruster 2021). About 300 hammers and 70 anvils or stakes made of bronze are preserved from the European Bronze Age whereas other types of tools are rarely found in the archaeological record (Jantzen 2008: 379-389).

Early scale pans and weights made of copper alloys and used to control the quantity and quality of the metal alloys are identified from Late Bronze Age contexts (Pare 1999; Vilaça 2011; Ialongo *et al.* 2021; Mordant *et al.* 2021; Rahmstorf *et al.* 2021). Balance beams are made of bone and bronze (Figure 9) (Gomez de Soto 2001; Mordant *et al.* 2021). Weights come in various shapes and sizes. They are usually made of bronze and frequently follow a weight standard of about 9.3 g (Vilaça 2003; 2011). The category of testing and measurement instruments also includes touchstones for

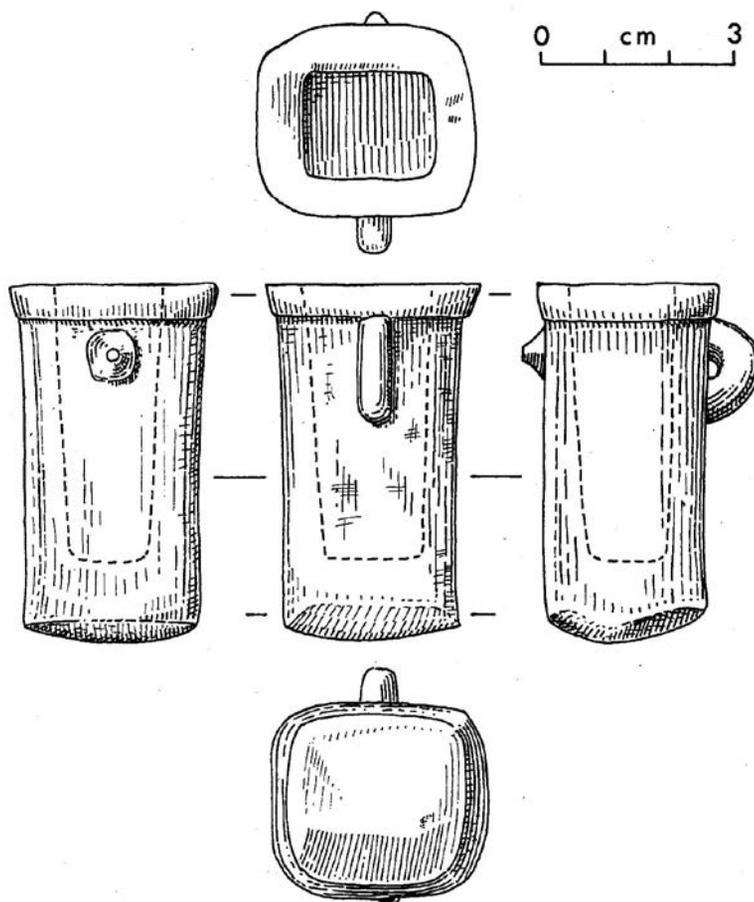


Figure 10. Schematic drawing of a socketed hammer (Nicolardot, Gaucher 1975)

the colorimetric test of gold alloy's composition and quality (Figure 9). Touchstones have been used since the Late Bronze Age (Eluère 1985; Oddy 1986; Armbruster 2006: 178-180).

Passive hammering supports and active percussion instruments of the Middle and Late Bronze Age such as hammers, anvils, stakes, swages and doming blocks, punches and chisels, are mainly cast in copper alloys (Armbruster 2001). Bronze hammers and anvils can be subdivided into functional categories (Ohlhaber 1939; Jockenhövel 1982; Ehrenberg 1981; Armbruster *et al.* 2019; Armbruster 2021: 42-69). Socketed hammers form the main part of active percussion tools in the Bronze Age (Figure 10). The cast socketed bronze hammers were provided with a wooden handle made from knee-timber that had to be fixed into the bronze socket (Wyss 1967: fig. 1).

Covering a wide range of tools, the French tool ensembles of Larnaud, Jura, and of G nelard, Sa ne-et-Loire, the Irish Bishopsland's hoard and the Southern German finding from Murnau, Garmisch-Partenkirchen, Bavaria, are outstanding examples of Bronze Age fine metal working tool assemblages made of bronze. Most of them are plastic shaping tools used for hammering, chasing, and punching. The G nelard hoard contains among other objects a cross-shaped stake (Figure 11a-b), several socketed hammers perhaps also used as small stakes (Figure 11a), a swage block (Figure 11c-d), several decorative punches including punches with concentric circles (Figure 11e), a casting mould for rings (Figure 11a left), and a stone hammer (Figure 11f) (Thevenot 1998; Thouvenin, Thevenot 1998). While the G nelard hoard with its 50 bronze objects, half of which are tools for



Figure 11a-d. Gévelard tool hoard, Late Bronze Age; 11b cross shaped stake; 11c-d swage block and detail (© B. Armbruster/MuséeDenon, Chalon-sur-Saône)



Figure 11e. decorative punches with concentric circles; 11f stone hammer (© B. Armbruster/MuséeDenon, Chalon-sur-Saône)



metalworking, can clearly be designated as a fine metal worker's hoard (Figure 11a-f), the large bronze hoard of Larnaud contains only a few metalworking tools within an assemblage of about 1800 other bronze finds (Figure 12a-b) (Armbruster 2008). Nevertheless, Larnaud is of great interest, as it includes an extremely rare tool, a small doming block in addition to a socketed hammer, six chisels and decorative punches. Another French find, the Fresné-la-Mère hoard, Calvados, must be included in this overview as it contains a socketed hammer and a multifunctional anvil with swages (Figure 13) and two gold items, torcs and an arm ring, as well as several bronze objects (Marcigny *et al.* 2005: 90). The Irish Bishopsland hoard comprises three socketed hammers, a small multifunctional anvil (Figure 14), and perhaps a vice (Eogan 1983: 234). The Bavarian "tool-kit" found in the area around Murnau combines about 20 fine metal working tools, including a small stake, two small plain hammers and several decorative punches (Nessel 2009). Finally, the rich tool ensembles found in the Late Bronze Age Lake dwellings of Switzerland must be mentioned (Figure 15a-c). Published at the end of the 19th century, these bronze tools are exemplary for their large range of fine metal working implements (Gross 1883; Wyss 1967).

For a long time, scholars have assumed that during the Bronze Age in Southern Scandinavia cast artefacts were predominantly produced locally, while hammered products, such as gold or bronze vessels, were imported. However, a considerable number of socketed bronze hammers from Denmark and Northern Germany show a local knowledge of plastic shaping techniques of gold and bronze (Jantzen 2008: 236-252). The collections of the Danish National Museum house numerous hammers with very different working surfaces that suggest specialized hammering techniques (Figure 14). However, bronze anvils have so far only been found in the north as miniature tools



Figure 12. Specialised bronze tools; a-b socketed hammer, chisels, decorative punches, dapping block, Larnaud hoard; detail of punches
 (© B. Armbruster/ Musée d'Archéologie Nationale)

or as special equipment made of scrap material (Fabian 2006; Jantzen 2008: 253–259). Presumably, stone implements were used as a hammering support (anvil) in connection with bronze tools. Even today, stone anvils and metal hammers are used together in Africa (Armbruster 1993: 289; Brown 1995).

In the Late Bronze Age tool set of G nelard, S one-et-Loire, a stone hammer was found along with bronze tools. This indicates that occasionally percussion tools made of stone were used in metal processing until the Late Bronze Age, when bronze was largely the material of metal worker's tools (Figure 11f). So far, there is only one Bronze Age context known where a stone anvil block was found associated with and fixed in a wooden stump. This exceptional find comes from the Lac Neuch tel near M ringen, Switzerland (Gross 1883: fig. 27). Like the numerous bronze hammers, anvils and moulds from the Swiss lake settlements already mentioned, this stone anvil is also dated to the Late Bronze Age (Wyss 1967).

Since bronze can be cast in complex shapes and is easily recycled it has two advantages in comparison to stone. In this perspective, the small bronze anvil from Lachen-Speyerdorf, Neustadt an der Weinstrasse, Germany, is of particular interest (Sperber 2000). It can be used in a variety of positions on a wooden stump and since it is made of a tin-rich bronze alloy it offers a considerable

Figure 13a. Two working positions of the stake with swages from the Fresné-la-Mère, Calvados, hoard, France (Evans 1881: 182); 13b fragmented stake from Kyle of Oykel, Scotland (© B. Armbruster/National Museum of Scotland); 13c small stake from Lichfield, Staffordshire (Needham, Meeks 1993)

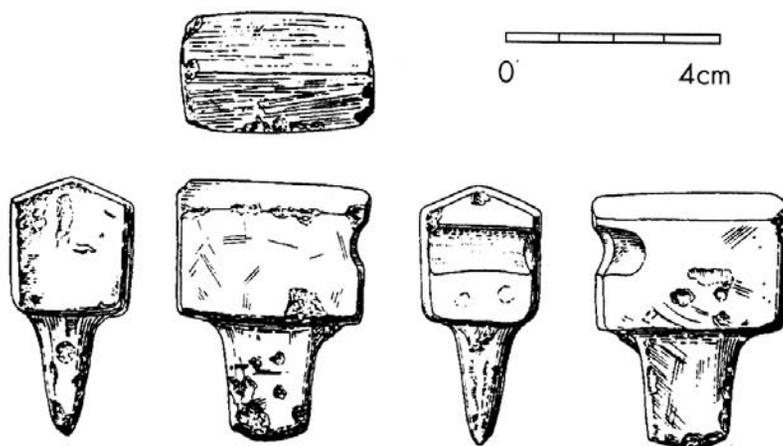
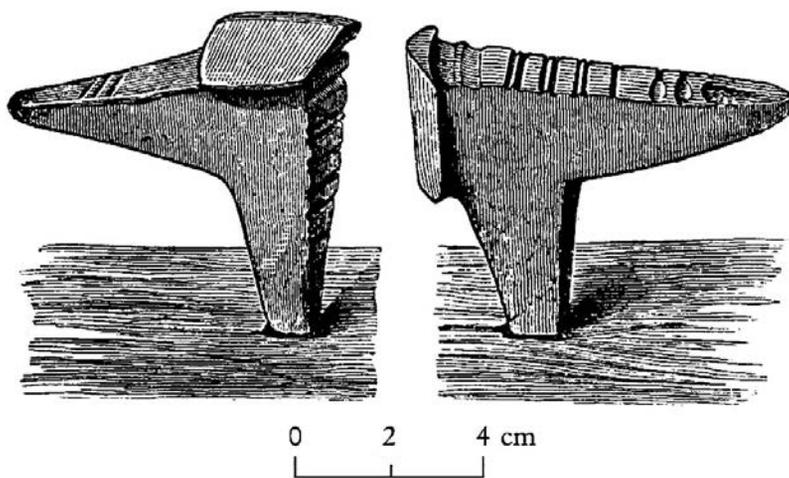




Figure 14. Irish Bishopsland hoard (© B. Armbruster/National Museum of Ireland, Dublin)



Figure 16. Bronze Age socketed hammers, Denmark (© B. Armbruster/National Museum of Denmark)

hardness. By alloying copper with a high proportion of tin the artisans were able to deliberately determine the material properties of the tools and to produce a hard bronze that could compete with stone anvils and hammers.

A few other important single finds must be highlighted here. The small stake from Lichfield, Staffordshire, Great Britain, is a rare example of a bronze tool on which gold particles still adhere (Figure 13c), they relate this small bronze tool directly to gold working (Needham, Meeks 1993). This stake has the shape of a gable-roofed block with a tang underneath for fixation in a stump. There are also rare finds of unusual tools such as a bronze stake for producing vessels from Crete (Hundt

Figure 15a-c. Bronze Age bronze tools from Swiss lake dwellings; 16a two anvils; 16a-b one hammer with a hafting hole, two socketed hammers, and one hammer made from an ailed axe head. (© B. Armbruster/National Museum of Switzerland, Zurich)



1986) or a small ball punch from Petit-Villatte, Neuvy-sur-Barangeon, France (Nicolardot, Gaucher 1975: 36 fig. 1; Eluère, Mohen 1993: 15). Other rare devices appear in two already mentioned hoards: the doming block in the Larnaud hoard (Figure 12a), and a swage block in the G nelard assemblage (Figure 11c-d) (Nicolardot, Gaucher 1975: 35 fig. 1). While a swage block is provided with grooves, a doming block bears small hemispherical depressions. It was used to produce hemispherical sheet elements for beads or appliqu s, with a ball-shaped punch with a rounded head in combination with the doming block. Even today, the goldsmith manufactures sheet metal hemispheres with the help of a doming block, a ball punch, and a hammer (Brepohl 1980: 233).

There are tools in prehistoric fine metal working workshops that have not survived in the archaeological record but are attested by tool marks. For example, the finishing of metal objects by grinding or polishing can only be deduced from the traces left on the object surfaces. The use of the drill and the lathe has been hypothetically reconstructed based on tool mark analyses, object shapes of rotational symmetry, and perfectly concentric ornamental motifs. Rotary motion tools are evident for the manufacturing of heavy gold arm rings from Late Bronze Age Iberia (Figure 17) (Armbruster 2004). Information from iconography, experimental archaeology, and ethnoarchaeology facilitate the development of explanatory models of rotary instruments, their construction, and handling (Figure 18a). Both, the drill, and the lathe belong to the first devices with a rotary motion and thus an early form of machine. We must assume that during the Late Bronze Age and the Iron Age, the lathe was made entirely of wood, as it is also known from ethnographic contexts. With the help of a hand-held cutting tool on a tool rest, shapes and ornamental reliefs can be cut into wax models. These wax models shaped on a lathe are intended for casting in the lost wax process. An Egyptian representation from the tomb of Petosiris around 300 BC (Figure 18b) and a Japanese drawing from the 18th century both show a very similar construction of a lathe turning with a cord (Figure 18c) (Lefebvre 1924: plate 10; Mutz 1972: fig. 13). These images served as the basis for the reconstruction of an experimental lathe (Figure 18a).

Iron Age

Due to a lack of written or iconographic sources, the Bronze and Iron Age gold technology and the implied tools are mainly investigated by means of rare tool finds and tool marks left on the gold objects. However, there is considerably less archaeological evidence of fine metal working technology from Iron Age contexts than is the case for the Bronze Age presumably because



Figure 17. Golden armrings from the Villena hoard, Spain, with cylindrical shape, decorated with grooves, spikes, and series of perforations (  B. Armbruster/Museo de Villena)

Figure 18a. Reconstruction of a lathe to produce wax models of the Villena/ Estremoz type (© B. Armbruster); 18b Egyptian (Lefebvre 1924: plate 10) and 18c Japanese depiction of lathes (Mutz 1972: fig. 13).

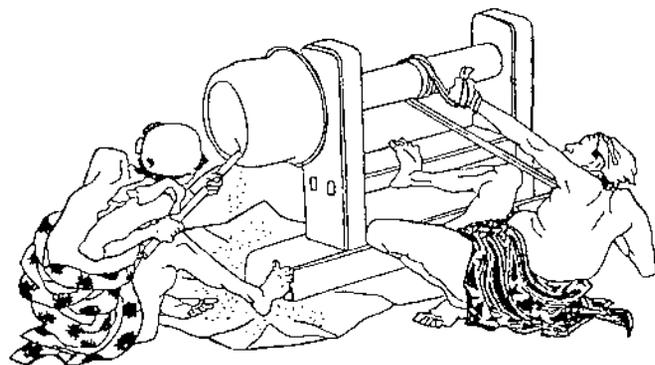
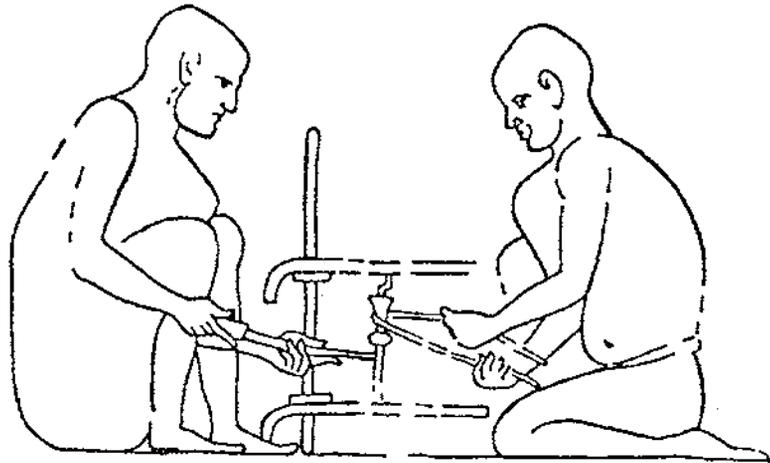
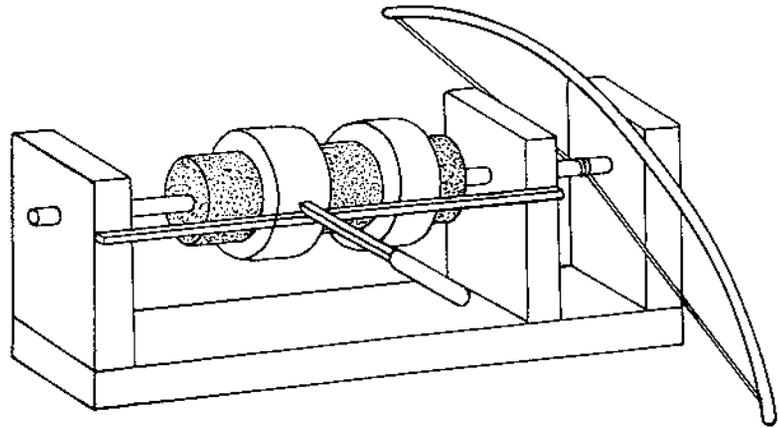




Figure 19. Suggestion of a Late Bronze Age goldsmith's workshop (Maryon 1938, 132 fig. 1).

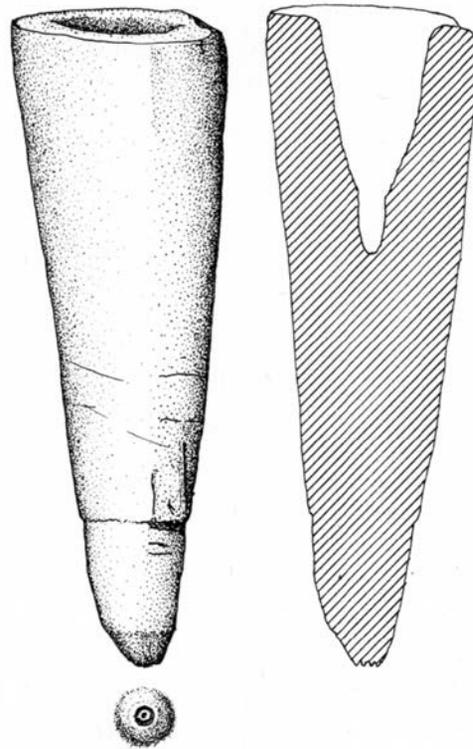
deposition habits changed (Armbruster *et al.* 2003). Only some rare specialised fine metal working tools are preserved, in most cases as single objects. The Iron Age goldsmith, however, had well-equipped workshops as can be deduced by the product shapes, construction, and tool marks.

Reconstruction models have shown during the exhibition “Gold of the Helvetians” give a good insight into a hypothetical Iron Age fine metal workshop. A differentiated spatial distribution shows specialized activities: melting and casting, hammering, chasing, wire preparation, soldering, and finishing by grinding and polishing (Furger, Müller 1991: 150–151). Compared to this quite truthful reconstruction of Iron Age workshops, fancy ideas of a Late Bronze Age goldsmith's workshop as imagined in the 1930s, with two goldsmiths standing on a megalithic stonework table while manufacturing an Irish gold gorget seem to be rather anecdotic (Figure 19) (Maryon 1938: 132 fig. 1).

During the Iron Age, iron is supposed to be the material used for making tools such as anvils, hammers, or tongs. However, there are also references to the preservation of bronze as a material for plastic deformation tools such as hammers, anvils, punches, chisels, and dies for precious metal processing. Antler was apparently used to make decorative punches for Early Iron Age gold ornament decoration. A rare example of an antler punch with concentric circles was found at the Early Iron Age hill site of the Heuneburg, Germany (Figure 20a) (Sievers 1984). The practical use of such kind of decorative punches made of organic material was tested by experiment (Figure 20b-c).

Another extraordinary find of a goldsmith's tool is a casting mould, as moulds for precious metal casting are extremely rare. This mould made of stone and allotted for the serial production of precious metal jewellery was discovered in the Iron Age shipwreck of Cala Sant Vicenç, Mallorca, Spain, dating to the 4th century BC (Figure 21) (Perea, Armbruster 2009). This one-half of a two-piece mould is provided with several negatives for small jewellery elements. Iron Age finds of dies point towards the increased serialised production of ornaments in the Iberian Peninsula compared to previous periods (Lorrio, Sánchez de Prado 2000–2001; Perea, Armbruster 2011).

Figure 20a-c. Antler punch from the Early Iron Age settlement Heuneburg, Germany; 17a drawing (Sievers 1984); 17b original punch and experimental punch side by side, 17c details of the concentric pattern (© B. Armbruster/Museum Württemberg Stuttgart)



1567



Finds that involve several instruments from a goldsmith workshop are exceptionally rare, such as an ensemble of a clay crucible, stone moulds, and several metal punches from a grave in Pecica, Arad (1st century AD Romania) (Meier-Arendt 1980: fig. 24).

The tomb of an Iron Age goldsmith and warrior dating back to the 4th century BC was excavated in 1986 in the Iberian necropolis of Cabezo Lucero, Alicante (Spain) (Aranegui *et al.* 1993). During the Late Iron Age, specialised tools may well appear again not only in hoards or settlements but also in funerary contexts. This discovery can be regarded as extraordinary for the study of goldsmiths. Tomb 100 contained the standard equipment of iron weapons of an adult Iberian warrior and about 50 gold working tools (Uroz 1992). This tool assemblage includes scales, a weight, a hammer, a stake, punches, chisels, a decorative punch, tweezers and two blowpipe tips, as well as an ensemble of 31 dies (Perea, Armbruster 2011). The Cabezo Lucero burial testifies to several important steps within the “*chaîne opératoire*” of jewellery production: control of the raw material, shaping, ornamentation and joining techniques such as soldering. The only objects missing in this tool repertoire are tools for pyrotechnic processes such as melting, alloying and casting, i.e. crucibles, moulds, tuyères, furnaces and pliers. This tool set reflects the techniques of sheet and wire production that are characteristic of Iberian gold work including sheet elements decorated with filigree and granulation (Perea 1991: 238–253). Interestingly, the tools from Cabezo Lucero are all made of bronze.

Two circular panes of a beam balance made of a thin bronze sheet and a perforated disc-shaped weight (9.36 g) indicate specialised knowledge of weighing and the control of raw materials (Figure 22a). A socketed anvil and a socketed hammer are representatives of the production of rods, wire, and sheet metal by hammering (Figure 22b-c). Due to the strong corrosion of the bronze hammer, it is hard to see that its shape corresponds to socketed bronze hammers well known from the Late

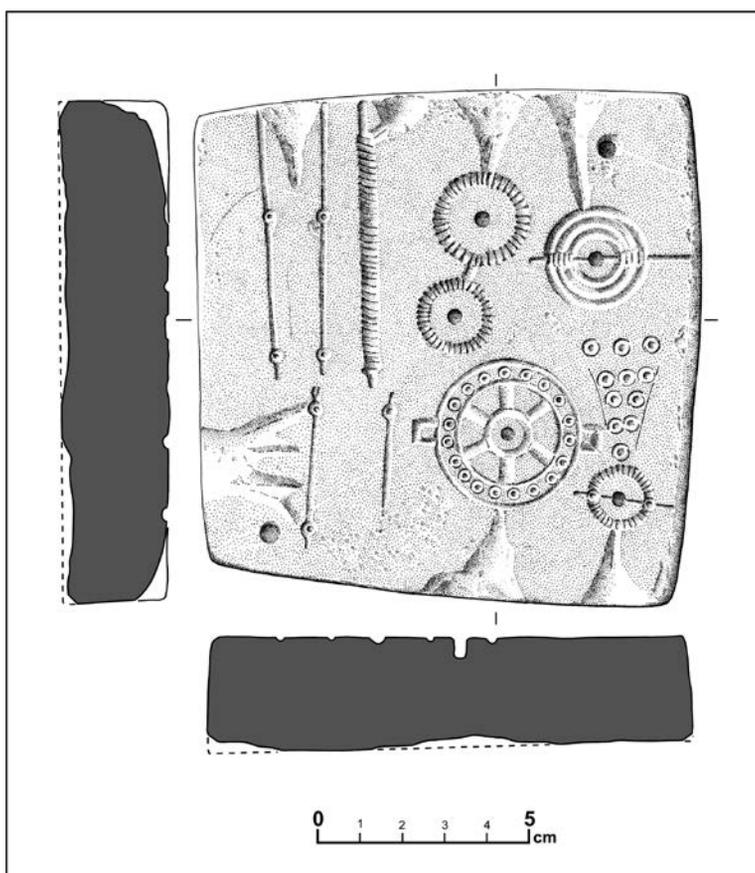


Figure 21. One part of a two piece casting mould from Cala Sant Vicenç, Mallorca, Spain (Perea, Armbruster 2009)

Bronze Age (Nicolardot, Gaucher 1975: 11 fig. 5). The stake is also provided with a socket that serves to fix the tool on a wooden rod.

The grave of Cabezo Lucero comprises a series of 31 dies whose Iberian culture iconography has been thoroughly investigated (Uroz Rodriguez 2006). They served the shaping of thin sheet elements by pressing a decorative relief. The bronze dies are a clear indication that the Iberian gold jewellery craft was accompanied by a certain standardisation and serial ornament production. The tool kit also includes punches and chisels with various shapes for chasing and punching. Findings of decorative punches and dies that bear a motif as a relief are extremely rare in Iron Age contexts.

The bronze tweezers with tapered ends presumably served the filigree and granulation work. Both decorative techniques are characteristic of Iberian goldwork and in combination with pressed sheet elements. This is the very first proof of such specialised bronze tweezers with tapered tips used for bending and manipulating wire elements for filigree decoration. The pointed tweezers could also be used to arrange granules for the granulation patterns on a metal sheet. Another completely novel object type unknown either for the Bronze Age or for the Iron Age appears in this tomb: two conical, hollow end pieces of blowpipes, both cast in bronze. Ancient goldsmiths used blow pipes for annealing, soldering and the control and alignment of the flame (Perea, Armbruster 2011). During the Iberian Iron Age soldering was carried out with metallic solder. This means that an artificial gold alloy with a higher copper and sometimes an increased silver content than the base metal was produced. This gold-based alloy was then applied in small particles to the parts to be joined and melted by heating in the furnace or with a flame and a soldering blowpipe. Since the solder alloy has a lower melting point than the base metal it melts earlier and connects the individual parts. In the case of ornaments with granulation and filigree, the solder material can be crushed into very small particles by means of coarse grinding stones. The tiny solder particles can then be scattered like salt onto the workpiece together with the small ornamental elements.

Unfortunately, none of the very numerous traditional Iberian gold jewellery items directly correspond to the bronze dies found in Cabezo Lucero. This fact suggests that one can expect a significant production of pressed gold sheet ornaments of which only a small fraction continues to exist archaeologically. Gold sheet jewellery, such as the diadem made from numerous pressed gold sheet elements from La Puebla de los Infantes, Seville, or the Aliseda ensemble, Cáceres, clearly testify to the work with dies (Figure 23a-c).

Ancient Egyptian and Roman goldsmith's workshops

At the beginning of this contribution, Egyptian studios from the 3rd and 2nd millennium BC were briefly mentioned as analogies for illustrating fine metal working in the Bronze Age. The basic techniques and the “*chaîne opératoire*” of weighing, melting, and casting, the hammering of sheets, the manufacturing of vessels, and the decoration of metal objects are shown. The workshop depicted in the tomb of Mereruka, near Saqqara and dated to circa 2500 BC, shows metal working with a pair of scales and weights, a furnace, blowpipes, crucibles, as well as anvils and hammers made of stone (Figure 24) (Garenne-Marot 1985: 86, fig. 1, 1, 96; fig. 5, 1-3). Similar activities are revealed by wall paintings from the mid of the 2nd millennium BC, e.g. in the tomb of Rekmire, close to Thebes (Figure 2a-b) (Davies 1943; Scheel 1989). These depictions demonstrate several scenes of metal vessel making in a well-organised Egyptian goldsmith's workshop. They illustrate in detail the following tools and their handling: furnace, blowpipe, tweezers, stone anvils, and round and flat hammers, as well as punch and snarling iron presumably made in bronze. The left part of the panel shows two different scenes: in the upper part an artisan is sitting on a chair and uses a blowpipe and tweezers for annealing or soldering something in a hearth, while below two upstanding artisans are hammering a large metal vessel with stone hammers and a snarling iron (Figure 2a). The right part of the panel depicts two facing goldsmiths, both sitting on cushions or blocks, one is polishing a conical vessel, whilst the other one is planishing small, egg-shaped

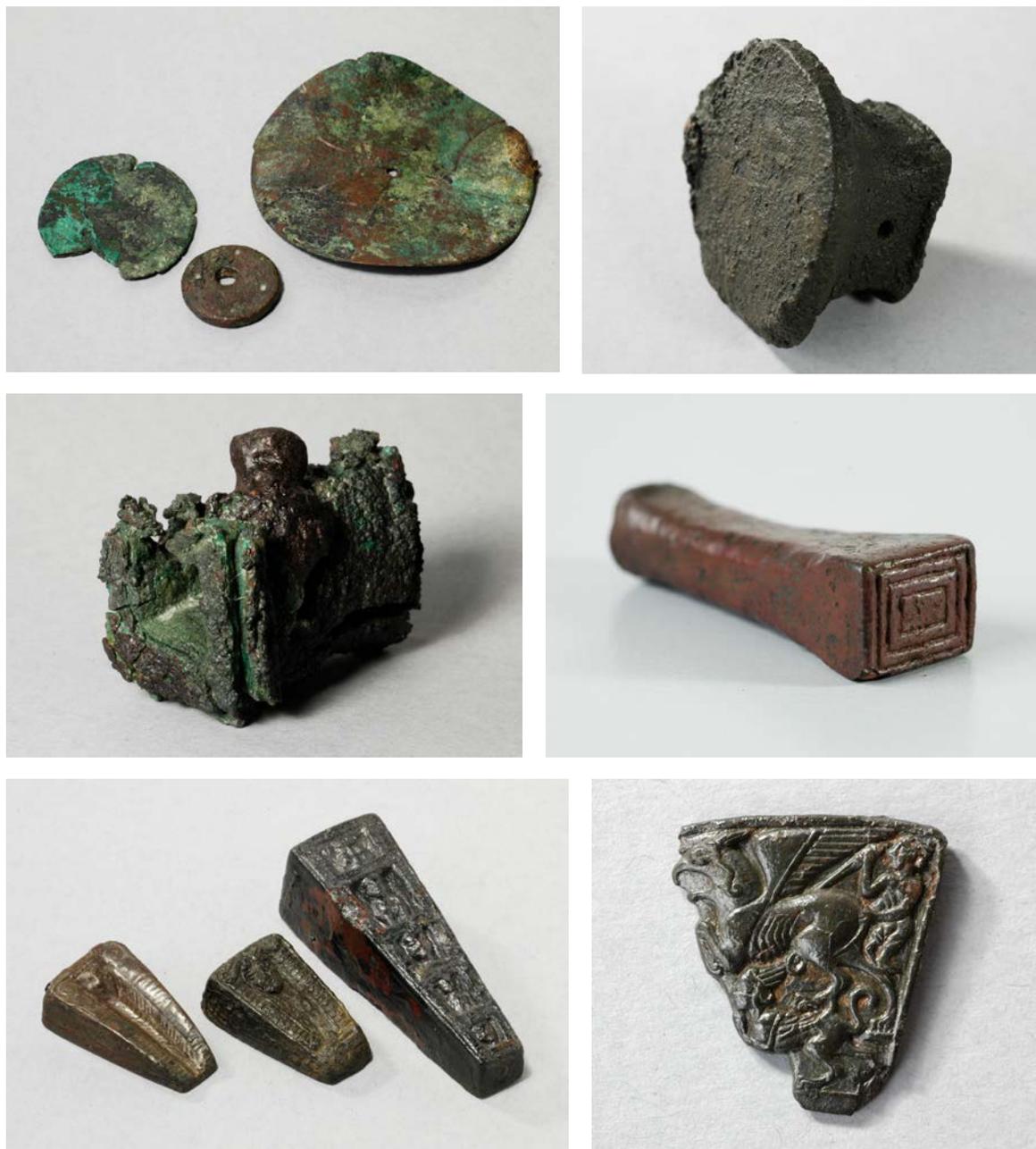


Figure 22a-k. Bronze tools of an Iron Age goldsmith and warrior, tomb 100 from Cabezo Lucero, Alicante, Spain. 22a two weighing pans and a weight; 22b socketed stake; 22c socketed hammer, 22d punches and chisels; 22e decorative punch/die; 22f-h selection of dies (© B. Armbruster/Museo Arqueológico Alicante)

vessels using a flat stone hammer and a snarling iron. The lower part shows the decoration of a large vessel by chasing from the outside, using a metal punch and a flat stone as percussion tools. The vessel must have been filled with a sort of chaser's pitch during the chasing process. Next to the chaser, a kneeling artisan is hammering sheet metal on a large, block-shaped stone anvil with a round stone hammer.

In comparison, the representation of a Roman goldsmith's workshop on a wall painting from Pompei gives an idea about the workshop equipment of the 1st century AD (Figure 25) (Ogden 1982: 66 fig. 4:58). The "amorini orefici" workshop from the Pompeian "Casa dei Vettii" is equipped with three beam balances and weights as the central activity of checking the quantity and quality of the precious metal. A grand built-up furnace with bellows as well as the use of a blowpipe demonstrates

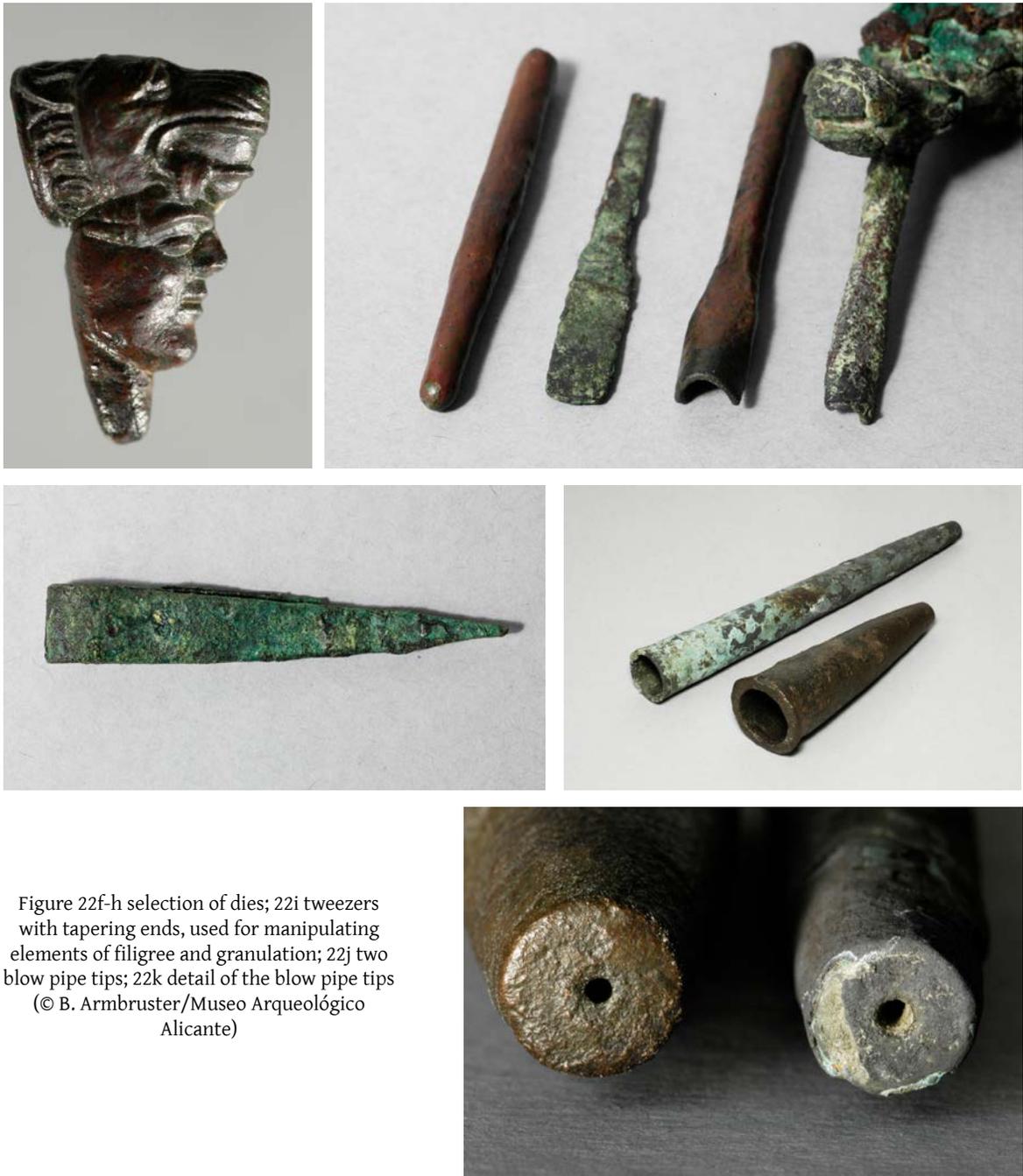


Figure 22f-h selection of dies; 22i tweezers with tapering ends, used for manipulating elements of filigree and granulation; 22j two blow pipe tips; 22k detail of the blow pipe tips
(© B. Armbruster/Museo Arqueológico Alicante)

the implementation, control, and employment of the charcoal heat source for alloying, melting, annealing, and soldering. Both goldsmiths at the furnace carry out their activities standing. One of them operates the bellows behind the furnace while the other works with tongs and a blowpipe directly at the charcoal fire at an opening on the front. Furthermore, there are two scenes of plastic shaping. One scene shows two goldsmiths who apparently are hammering together as a team, one holding the workpiece with a pair of tongs while the other one works with a heavy hammer. Both craftsmen work standing. Two different-sized anvils are lodged in a wooden stump. Two pliers and two hammers are shown of which only one device of each is actively used. The second scene reveals a seated craftsman performing delicate work on a small stake with a hammer. This stake is also fixed on a wooden stump. The goldsmith sits on a stool with a pillow and his feet rest on a bench. Presumably, the hammers, anvils, and pliers shown on this wall painting are made of iron.

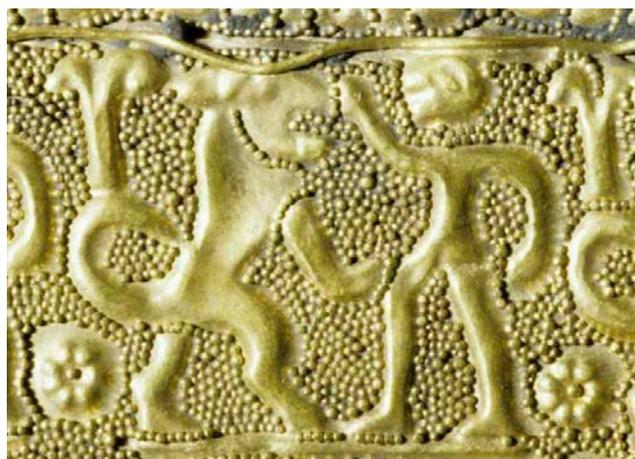


Figure 23a. Early Iron Age gold work from Aliseda, Caceres, Spain; 23b Detail of the belt made with pressed sheet and decorated with granulation; 23c Ear pendants constituted of several pressed sheet elements
(© B. Armbruster/Museo Arqueológico Nacional, Madrid)

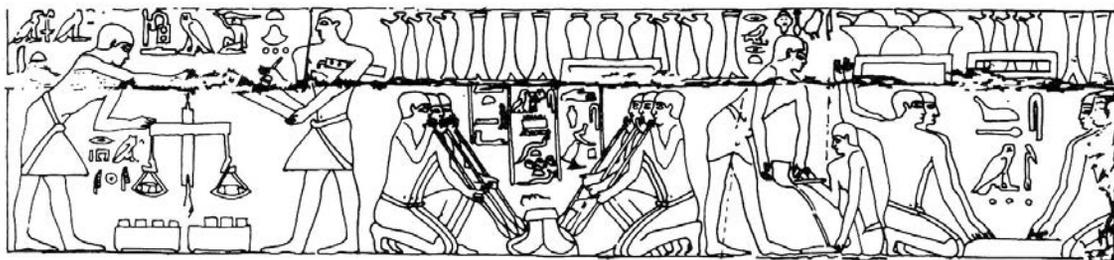


Figure 24. Tomb of Ti, Saqqara: Egyptian metalworking workshop, about 2500 BC, represented tools: scales, weights, furnace, crucible, blowpipes, stones to hold and transport the crucible to cast metal, anvil, and hammer stones (Garenne-Marot 1985: 86 fig. 1, 1)



Figure 25. Roman fine metal working workshop, wall painting from Pompeii, first century AD, tools represented: scales, weights, furnace, crucibles, blowpipes, bellow, tongues, anvils and hammers (Ogden 1982: 66 fig. 4:58)

These scenes from a Roman gold working workshop draw a picture of several techniques, tools, and their handling. However, the techniques of melting, alloying, and casting are missing here. This wall painting also conveys an impression of the workshop organisation where several goldsmiths have defined tasks. Comparing these images with scenes from ancient Egyptian workshops show that tools such as furnace, pliers, hammers, and anvils undergo changes in form and material. Nevertheless, the activities described have largely remained the same.

Outlook

The brief overview of the development of fine metal working tools, with respect to their material, shape, and function shows a gradual improvement and diversification of the equipment and technical possibilities in ancient gold production. This development is closely linked to the progress of the gold artefact's typology. The direct connection between technology, aesthetics, and function of both the products as well as the means of production was argued in this context.

While the use of lithic materials for grinding stones, touch stones and casting moulds continues from the beginning of metallurgy up to the Roman period, the material choices for plastic shaping tools changed through time. Although bronze replaces stone as a raw material for hammers, stakes, and anvils during the Bronze Age, they exist in bronze and in iron during the Iron Age.

Metallic pliers with an articulated joint, suitable for metal working, are only identified from Iron Age contexts. Before pliers were most probably made of wood. Only a few simple pincers in the shape of large tweezers are found in Bronze Age contexts, such as a tool from the bronze hoard from Freixiada (Vilaça *et al.* 2012). During the Iron Age, iron does not completely replace copper-based alloys from the stock of materials for making tools as hammers, stakes, dies, decorative punches, and tweezers could still be made of bronze (Perea, Armbruster 2011).

A certain similarity of the tool equipment from Roman workshops with those of the Bronze Age shows that astonishing coincidences exist due to functional characteristics. It becomes clear that

metalworking tools are subjected to much less typological change than other artefacts such as ornaments. The different traditions of ancient metalworking workshops shown here as well as the goldsmith's production witness a specialized and organized craft worked by skilled and trained craftspeople since the beginning of metallurgy.

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