

# Technological Aspects of Selected Gold Objects from Ur - Preliminary Results and Perspectives

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## Introduction

Gold is a rare metal, whose magical power derives from its shining, sun-like color and its resistance to corrosion. The noble metal played an important role in all cultures of the ancient Near East in art, religion, trade, and society (Boese and Rüß, 1971). Works concerned with Mesopotamian jewelry or Ancient Near Eastern gold often focus on style and iconography whereas technological matters are rarely considered. However, technical knowledge, and the goods produced with it, form the material conventions of a culture and, consequently, manufactured objects are especially able to transmit a visible and archaeologically comprehensible expression of that specific culture (Armbruster, 2011a, p.419). The craft of goldworking was anchored religiously, socially and economically in Bronze Age society. The objects produced testify to a specialized craft knowledge with a high technical and aesthetic standard. The goldsmith, who knew how to work with valuable materials and whose task was to make important prestige goods and ritual objects, can therefore be seen as a prominent figure in Bronze Age society.

Excavations at Ur in the 20<sup>th</sup> century brought to light extraordinarily rich funerary evidence of mid-third millennium BC goldwork from Mesopotamia (Maxwell-Hyslop, 1960; Maxwell-Hyslop, 1974; Reade, 2003; Woolley, 1934). The treasures from Ur are suggestive of the lavishness of Sumerian art and craft. These masterpieces in precious materials mirror the sophisticated design and technological knowledge of craftspeople from Bronze Age Mesopotamia. As it is common for the Near East in general, the main functional categories of Bronze Age gold at Ur are: jewelry, decorative elements, and ritual objects, which include tableware, sculptures and weapons. This panoply, with exception of sculpture, is also relevant for Bronze Age Europe (Armbruster, 2013).

Parts of the artifacts from the royal Ur cemetery are housed in the collections of the Penn Museum in Philadelphia comprising a remarkably large amount of goldwork. They are presented in detail in the significant publication accompanying the permanent exhibition at Penn Museum (Zettler and Horne, 1998). Moreover,

Puabi's personal ornaments were recently also featured in a remarkable PhD thesis, which, among other topics, explores some aspects of manufacturing (Benzel, 2013).

The focus of this paper is to present preliminary results of a study of selected goldwork from the Royal Cemetery of Ur focusing on the technological aspects. It is based on the optical study of a number of artifacts: one vessel, two statues, one weapon, one tool, and a dozen of personal ornaments examined during a stay of four days at the University of Pennsylvania Museum of Archaeology and Anthropology (Penn Museum). This work offers a first glance on the large variety of fine metalworking techniques used by Mesopotamian goldsmiths of the 3<sup>rd</sup> millennium BC. Non-invasive methods were used to determine the nature of form, decoration and constituent elements of the objects, and the *chaîne opératoire* of their manufacturing techniques. The aim is to illustrate the high standard and level of specialization of Sumerian fine metalworking techniques and to discuss the types of materials and tools used in goldsmith's workshops. The objective of this research is also to address perspectives for future examinations to be undertaken with an interdisciplinary approach including material science studies, which have the potential to increase our knowledge of the technical skills of the ancient artisans.

The technological study of the goldwork from Ur is complementary to the analytical investigations completed by Hauptmann and Klein and Jansen, Hauptmann and Klein (both studies in this volume).

## Investigation methods in ancient gold studies

The study of prestigious objects in precious materials covers a large variety of aspects including condition, form, decoration, function together with the social, economic and spiritual values of the objects as symbols of power and religious beliefs. Besides typology and style, ancient gold studies also comprise the interpretation of trade and exchange, social status of the artisans, and last but not least the specialized know-how of the manufacturing techniques.

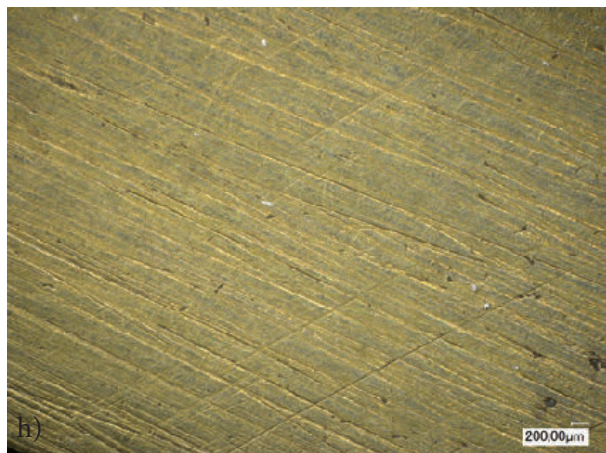
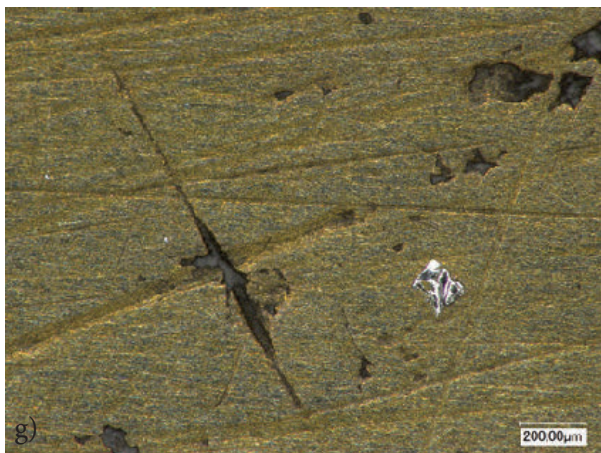
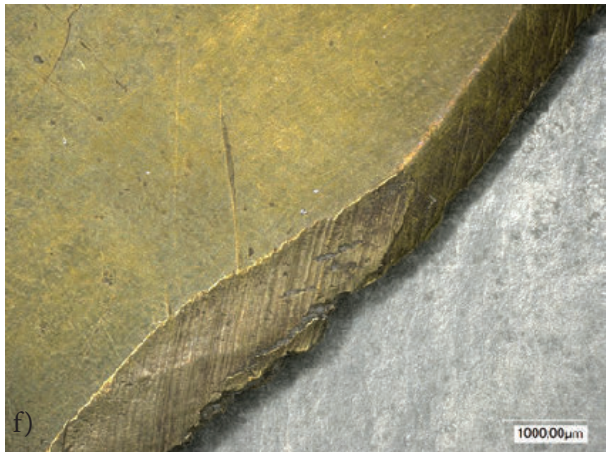
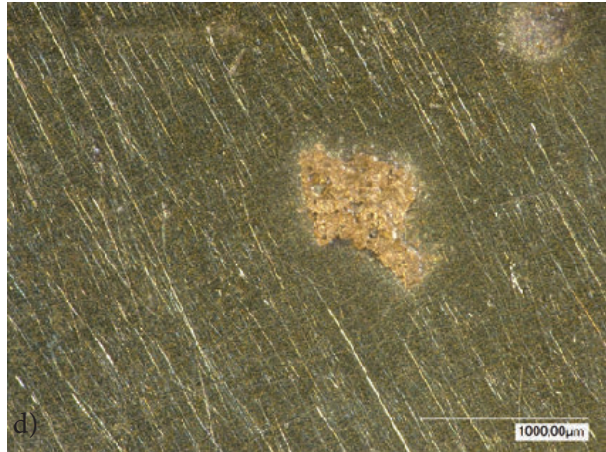


Figure 1. a-h Adze, B16691. All photographs in this paper were made by Barbara Armbruster, Moritz Jansen and Sabine Klein.

Ancient written sources mention gold as a means by which conflict between elites could be resolved, it being used in the exchange of political gifts or as a sign of hospitality (Boese and Rüß, 1971; Scheid-Tissinier, 1994). Golden tableware were also used in sacrifices or in feasts for those of high rank. However, textual evidence and pictorial representations giving detailed information about fine metal working in the Bronze Age in the Near East are rare. Consequently, our knowledge relies mainly on the examination of the archaeological artifacts themselves, the circumstances surrounding their burial and their socio-cultural context. Furthermore, direct proof of goldworking workshops is also exceedingly rare for the Bronze Age. Therefore, the interpretations of the goldworking craft are also based on functional analogies and modern material science analysis. So, the interdisciplinary methods available to the archaeologist today for studying the history of goldworking are diverse (Armbruster, 2011a).

The study of style – typology of form, decoration, and function – remains fundamental, together with visual examination of tool marks and thus of the implements and, perhaps, workshops involved. Analogies drawn from ethnography, experimental archaeology, iconographic and ancient written sources facilitate the development of explanatory models. Lastly, a range of analytical approaches which can yield information about the components and properties of the materials and various techniques for determining the alloys elemental composition have greatly contributed to research on gold artifacts. Radiography and computer tomography makes it possible to see inside the object and can show the thickness of material, tool marks, and repairs. Scanning electron microscopy, besides allowing non-destructive semi-quantitative elemental analyses, also enables detailed observation of the surface topography of an object. Analytical studies might find answers to the questions surrounding gold and its alloying components, to the origin of the raw material used in Bronze Age goldworking, however, it can be assumed that the metal could have been rapidly recycled.

## Bronze Age goldworking technology

Because of its exceptional material properties, gold is highly suitable for the manufacture of jewelry, ornamentation, and vessels by means of casting or plastic deformation techniques (for material properties and manufacturing techniques see: Brepohl and McCreight, 2001; Plate, 1988; Untracht, 1982; Wolters, 1984). The melting point depending on the purity of gold alloys is around

1000 ± 50° C. To reach this temperature the charcoal would need a forced air supply and therefore must be equipped with bellows and tuyères. Also mouth blowpipes could have been used. Gold is very malleable and can be burnished to a high luster. It hardens through cold-working such as by forging, chiseling, punching, bending, or twisting. To avoid cracking or breaking, precious metals are annealed at approximately 750° C. Annealing promotes the recrystallization of the metal after hardening which became brittle by plastic deformation. Except for the melting, casting, soldering, and annealing, goldworking is done in a cold state. As gold is chemically resistant in most situations, its shining color stays unchanged even after millennia.

Before a piece of goldwork is started, an idea of the morphology, decoration, and technical processes of the desired object must be developed from a knowledge based in a stylistic and technological tradition. The quantity of metal is then measured using weights and scales, and, if the composition is not known, the gold content is checked. Touchstones for this colorimetric test of the gold quality are chosen of dark color and fine grain, and were already in use in the Bronze Age (Armbruster, 2010, pp.16-17).

## Pyrotechnology - melting, alloying, casting and soldering

Gold objects were produced from a cast primary product. Castings were made in moulds of stone, metal, or clay. Ingots could also just be cast in a wooden mould. For this the gold had to be melted in a clay crucible heated by charcoal, possibly alloyed with silver or copper, and then poured into the mould. Three different casting techniques are relevant to prehistoric goldworking: bar (or ingot) casting in an open mould, piece mould casting, and the lost-wax technique (Armbruster, 2001). Piece moulds can be used for solid casts and in combination with a clay core for casting hollow objects. Usually a gold bar would be shaped by hammering into rods, sheets, or wire. The casting in permanent piece moulds is rare in ancient goldwork, but appears at Ur through a ceremonial weapon cast in a three piece mould consisting of two halves and a core (Figure 1).

By contrast, in the lost-wax method a model of the desired object is made of wax (Hunt, 1980). The wax model is coated in tempered clay which is applied in several layers and then the wax is melt out after drying. The remaining hollow space is then filled with molten gold. The clay mould is destroyed to release the cast piece. The unfinished cast must be worked and clean with chisels

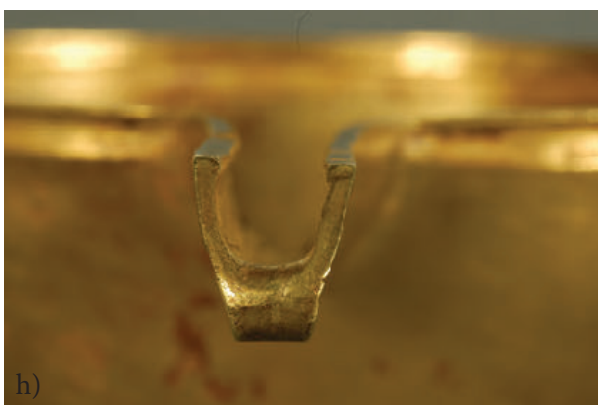
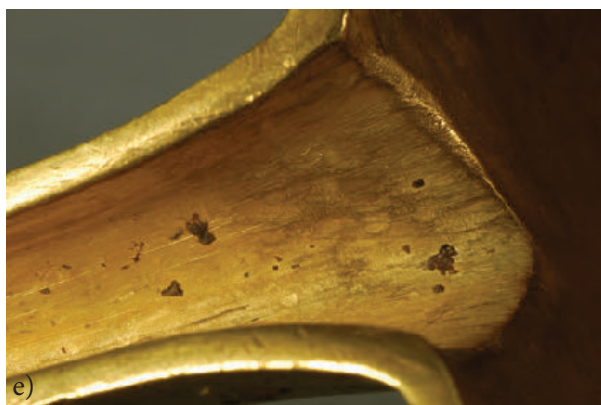
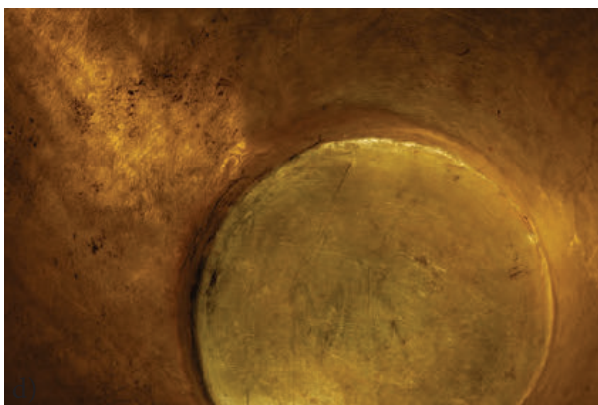


Figure 2. a-h Spouted vessel, B17692

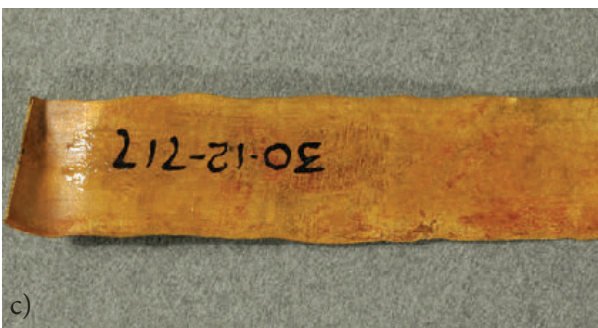


Figure 3. a-c Ribbons, 30-12-717

and the surface smoothed by grinding with abrasives. Solid beads (Figures 12b; 13c and e) and the spouted vessel (Figure 2) are presumably cast with the lost wax process. A rough cast surface is clearly visible on the interior of biconical beads (Figure 13f). The cast items have a high weight compared to sheet objects of similar shape.

Two different soldering techniques were carried out in Bronze Age goldworking and may be contemporary. A metallic hard solder was in use, the melting point lower than that of the base metal (Perea, 1990). Metallic solder is an intentionally made or selected alloy of gold with silver and copper. Tiny particles of solder are placed in position at the joining area, melt during heating, and join the separate parts together. Often this technique can be identified by gold solder bits that have melted on smooth surfaces or flooded with an excess of solder ma-

terial, for instance at the pendant with four filigree cones (Figures 14b and h-i). The second possible technique is reaction soldering based on the application of a copper salt powder and organic glue forming a hard solder during heating (Pacini, 2006). Through heating, the organic glue transforms into carbon that reduces the copper salt to metallic copper. At the joining point the copper forms a tiny solder area by diffusion. Reaction solder leaves very little solder remnants. Analyses through material science are necessary to distinguish the two techniques with certainty.

### Plastic deformation - hammering, tracing and chasing

The technique of forging sheets, rods, and wire from a gold bar was perfectly mastered. Sheet and wire were made exclusively by deformation of a cast pre-product using hammer and anvil. Wire as fine as about a millimeter in diameter and even less was achieved by hammering. Clear tool marks from hammering are apparent on the wire from the loop-in-loop chains and on pendants as small facets (Figure 12f-j). Several items from Ur show a combination of hammering sheet, strip or wire parts in one single piece of gold as it is the case for the ear ornaments, like certain other objects and pendants (Figures 5 and 9).

Sheet ornaments are present without decoration through a large quantity of flat hair ribbons (Figure 3) (Zettler and Horne, 1998, p.102). Those with punched and chased decoration appear as decorative sheets or fillets (Figure 4), and leaf-shaped pendants from wreaths (Figure 9) (Zettler and Horne, 1998, p.103). Three-dimensional hollow shapes are present through large hammered and chased earrings (Figure 6) (Zettler and Horne, 1998, p.107). Sheet metal was also used for the production of beads (Figure 9a-c), shaped by rolling of sections of broad hammered ribbons. Sheet was furthermore used for corrugated composite beads made from two roundels shaped in dies (or chased) and soldered together (Figure 13b and d) (Zettler and Horne, 1998, p.116, Figure 80).

Wire appears through thick spiral hair rings (Figure 10) as well as through loop-in-loop chains and tiny filigree work. Filigree ornaments occur in the form of pendants shaped as rosettes, double spirals or quadripartite with filigree cones (Zettler and Horne, 1998, pp.110-111).

Among the plastic shaping techniques used for decorative purposes, twisting of square-section bars or wires can be seen as well as the bending of wires, for

instance, to make spiral wire cones. Sheet products were shaped and decorated by tracing and chasing or by the use of dies.

Filigree is an ornamental technique based on the use of small decorative elements of fine wires (Ogden, 1982, pp.46-56). Very fine threads, used for filigree work, were rolled from small flat strips or fine square sectioned wires (Figures 13h-k) (Formigli, 1993). They can be applied to a gold sheet or wire structure, or single wires could be soldered together, as it is the case for the conical filigree pendants (Figures 14c-d) (Zettler and Horne, 1998, pp.121-122 Figures 92, 93 and 95). Both techniques reach a high technical standard in the Near East and the Mediterranean region during the Bronze Age.

## Observations on Ur goldwork from the Penn Museum collection

The early use of gold is amply attested at Ur for manufacture of personal ornaments, decorative elements, vessels, weapons and statues. The design of these objects is multifold, including two-dimensional objects (like sheet jewelry, decorative items and strips), three dimensional solid bodies (like weapons) and three-dimensional hollow bodies (like sheet ear pendants and cast vessels). The gold artifacts can be classified into functional groups such as personal ornaments and ceremonial objects, including vessels, statues and weapons. Beside geometric forms and decorative patterns, the early representation of zoomorphic and floral forms in gold appears. Gold was also used for sheet “gilding” or plating of other materials such as wood. The combination of gold with different materials often results in polychrome work for aesthetic, social and religious functions.

The following observations details a selection of gold artifacts arranged in technical groups, from simple to complex. In cases where the items are composed of elements belonging to different technical groups, they will all be discussed together. Penn Museum inventory numbers are helpful to identify the individual artifacts.

### Observation methods

The techniques of examination at our disposal for this study were optical macro and microscopy and the documentation by macro and micro-photography.<sup>1</sup> Tool mark and surface structure analyses were the main goals of this study. They allow to distinguish and to determine techniques of casting, plastic deformation, decoration, joining, finishing and repair. The optical study also allows the identification of the number of elements constituting an object, combination of several materials as well

as provide information about the technical solutions and choices made. Finally, the visual study also reveals traces of use and damage.

### Cast objects

Two large and heavy cast items were studied in order to determine their manufacturing techniques. Both are of three-dimensional character and have a considerable weight due to the casting processes. Other cast ornamental elements within the studied selection are solid beads whose technical features are described further below with the beaded strings<sup>2</sup> (30-12-618; 30-12-561).

The solid golden adze (B16691) with a shaft hole appears to be a ceremonial tool or weapon (Zettler and Horne, 1998, p.170). The blade and the shaft were made in a single cast. The adze is undecorated except for the ridges lining the exterior of both the top and bottom shaft openings and on the shaft's back (Figure 1a-c). The cutting edge is partially damaged (Figure 1e-f).

This heavy prestige object has been cast in a three piece mould consisting of two halves and a core element. The three mould components might have been constructed of stone or tempered clay. The outer surface has been carefully ground and polished leaving nearly no visible traces of the ancient casting surface, except for some small areas (Figure 1d). Traces of abrasion and platinum group element (PGE) inclusions (see contribution of Jansen, Hauptmann and Klein, this volume) are apparent at the surface (Figure 1g-h). The former casting seams were also erased by grinding and polishing with abrasives. In contrast the inner surface of the cylindrical shaft hole still bears remnants from the casting process, in particular a rough surface structure (Figure 1b). The cutting edge has probably been hammered for strengthening. As the surface is smoothed by grinding and polishing no tool marks of hammering are visible.

The vessel (B17692) has a conical form with a flat base and it is supplied with a long handle-like spout (Figure 2a-b; Zettler and Horne, 1998, p.127). The only decorative elements are a circumferential groove under the rim (Figure 2c) and the bent extremity of the spout. Both ornamental features have also practical functions such as the strengthening the container's body and rim, and to facilitate pouring of a liquid.

This spouted bowl was hammered out of a blank, a preliminary cast product and the raising was finished by plastic shaping to accomplish the final three-dimensional form. The object clearly shows tool marks from the hammering process. The round base starts in a short hammered cylindrical form before widening to the conical shape (Figure 2d). Tool marks of intensive hammering are evident at the inside's surface while the



Figure 4. a-f Decorative sheet, B16921

outside is burnished. The groove under rim was created by plastic deformation using a tracer for chasing. The groove's surface also shows evidence of grinding. The spout was already present in the pre-cast form of the vessel, but has been strengthened by hammering. Finally, the spout's terminal has been beaten in the shape of a thin sheet strip and then bent over forming a small loop (Figure 2g-h).

#### Sheet and wire work - Personal ornaments

A large number of long sheet ribbons were part of complex headdresses (Figure 3a) Zettler and Horne, 1998, p.102). These decorative ribbons (30-12-717) have

parallel lateral edges and a regular width. They were hammered from a preliminary product. The front side surface was carefully polished (Figure 3b), whereas the rough surface on the back was left raw and probably results from hammering with stone percussion tools (Figure 3c). The lateral edges have a slightly undulating shape. So, they were not cut with a chisel but left raw after plastic shaping. It can be assumed that the sheet ribbons were hammered from a long thick wire.

The thin decorative sheet ornament (B16921) has tapering ends of rounded shape (Figure 4). It is decorated with a series of small bosses along the rim and around one perforation at each end (Figure 4b-f). Along the line



Figure 5. a-h Decorative sheet with wire endings, B16706



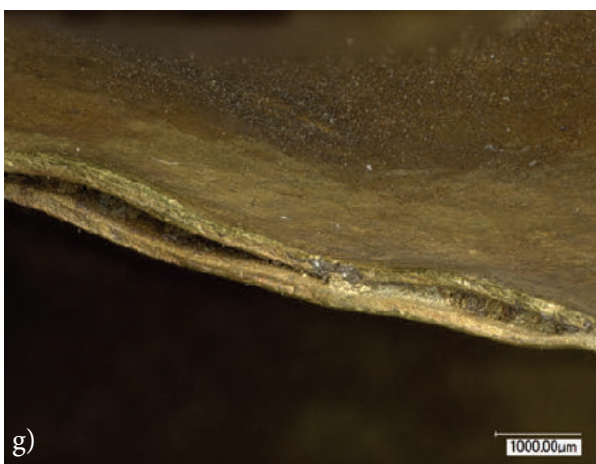
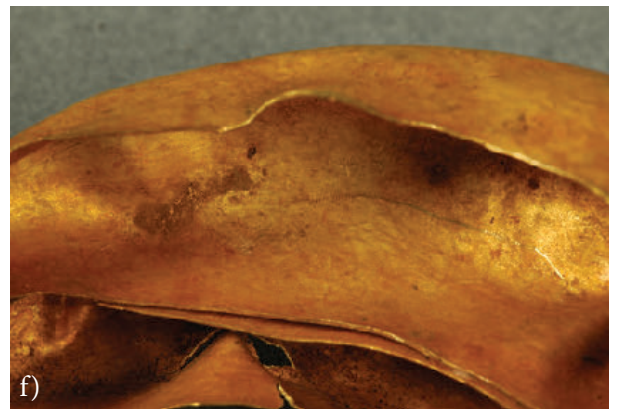


Figure 6. a-h Ear ornaments, 30-12-766 and 30-12-729

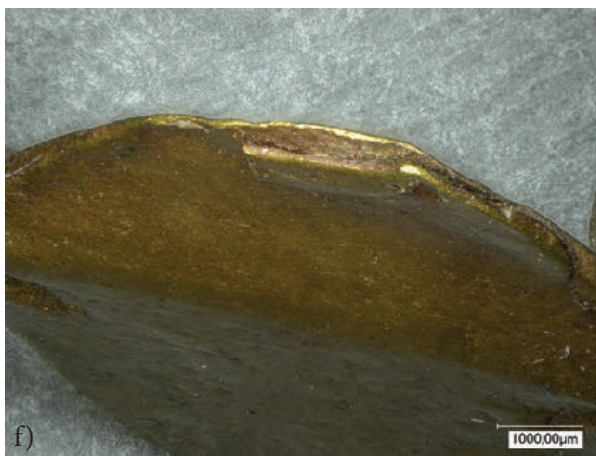
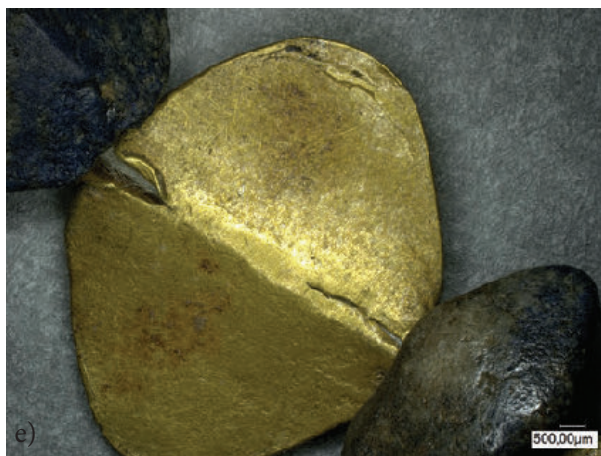
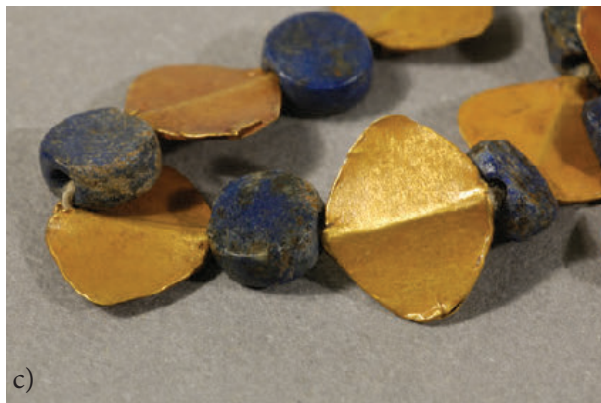


Figure 7. a-h String with sheet beads, B16801

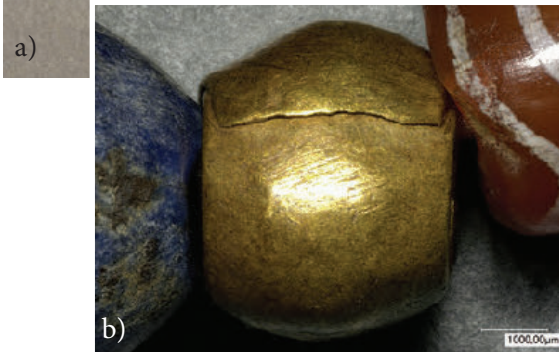


Figure 8. a-i Strings, B16799 and 30-12-573

of bosses 16 smaller perforations appear. They were presumably used for fixing the sheet on a support material. The perforations were pushed through using a conical point (Figure 4f). The sheet's surface is burnished and the contour outline cut with a sharp chisel.

The flat sheet ornament with wire endings is decorated with a rosette motif (B16706; Figure 5a-b). This composite ornament is made from one sheet element and two wires. One wire terminal is lacking and the other wire is broken but still has its bended loop ending. Cast ingots were hammered to obtain a sheet and a rod. The rod was transformed into two long square-sectioned wires with a broadened and flattened end. Tool marks are left on this part (Figure 5h). This was twisted, cut in two and the terminals bend into the shape of a closed loop (Figure 5c). The wires were probably soldered with the broadened end to the central sheet (Figure 5g). One modern repair with a gray soft solder is obvious at the junction on the broken side (Figure 5b).

A rosette with eight petals was traced with double lines on the thin sheet using a tracer (Figure 5d-f). This decorative linear pattern is poorly executed compared to the skillful quality of other items.

Large crescent-shaped ear rings appear in pairs (Zettler and Horne 1998, 107). These ear ornaments (30-12-766, 30-12-729, B16989 a-b) have a three-dimensional hollow shape of large volume compared to their low weight due to the use of thin chased sheet (Figure 6). They are composite ornaments put together from two individual hammered and chased sheet parts in the shape of hollow vessels. One piece has a wire ending starting from one tapered end of the sheet part (Figure 6c) whereas the other part has a tubular bent terminal for holding the wire's end like a fastener. The wire's function is the suspension of the earring. Wire and sheet are made from one piece by plastic shaping techniques starting as a cast ingot. The sheet components were most likely chased and also possibly worked using a wooden die. The two very similar parts are joined by soldering. The solder was applied punctually (Figure 6g). As no chemical analyses of the solder's alloy composition were performed, no inferences can be made on the soldering process.

This small beaded string (B16801) is composed of 14 flat gold and 15 circular flat lapis lazuli beads (Figure 7). The gold beads bear traces of long wear (Figure 7e). Some have a foliated appearance (Figure 7c and e-f) suggesting a fabrication by soldering two sheets together. But the threading tunnel does not confirm this hypothesis. Presumably they were executed by the lost wax technique. In this case wax sheet elements were used to make the wax model. The threading tunnel can be produced by

inserting a carbonized wooden stick in the wax model, and finally in the clay mould. The charcoal is removed after casting. This technique of lost wax casting of tiny beads with a cylindrical threading tunnel is well known from ethnographic sources in particular from Ghana (Garrard, 2011).

The strings (simple 30-12-573 and double B16799) are composed of sheet beads, as well as lapis lazuli and etched carnelian beads (Figure 8). The gold beads of the smaller string (30-12-573) are worked from a rolled strip shaped into a cylinder (Figure 8b-c). The ends are overlapping. To achieve the slightly conical shape, the goldsmith uses a sort of a hollow conical die or doming block in which he or she pushes the sheet cylinder with a percussion tool. This tool can be as simple as a wooden bar.

The double string (B16799) has four small sheet beads made in a similar way as for the previous example. In addition, it provides 5 gold pendants each with an engraved carnelian bead of flat oval shape. Furthermore, two gold pendants with drop-shaped corrugated lapis lazuli beads complete this ensemble. These pendant beads are fixed on wire-shaped appendages. The gold pendant is composed of a double loop suspension made of a bent sheet strip continuing into the wire appendage (Figure 8d-h). The whole is hammered from one piece of gold. The wires still show obvious tool marks from the hammering process (Figure 8i).

The double-looped suspension system also appears on leaf shaped pendants. Two strings with leaf shaped pendants were examined (30-12-445 and 30-12-679; Figure 9). Such a kind of flexible threaded adornment was apparently used as a wreath in a complex headdress (Zettler and Horne, 1998, p.98 and 103-104). They are composed of a dozen (or more) golden leaves with spacer beads made of carnelian and lapis lazuli. The iterated concept of three colors creates an attractive polychrome effect.

The very thin sheet leaves were hammered (0.1 mm thickness) in one piece with a long appendage. This ribbon-like extension was also shaped by hammering and then folded in two directions, forming kind of a double suspension loop (Figure 9b and f-h). The lines, a central rib and oblique lines representing the natural leaf structure are traced with a tracer in more or less symmetrical shape (Figure 9c-d). The outer edges of the gold leaf forms were cut out using a sharp-edged chisel. The gold leaves are integrated into an ensemble of long and short cylindrical or lentoid-shaped beads of carnelian and lapis lazuli. Some of the gold leaves are damaged. No fastening system for the wreath survived.

The second string (30-12-679) is comparable to 30-12-445 with a minute difference as one of the leaves



Figure 9. a-j Strings with leaf shaped pendants, 30-12-445 and 30-12-679

has a double rib (Figure 9i-j). This detail shows that the goldsmith corrected an error in the direction of the chased line.

Two hair rings (B16841 A and B) made of wire spirals constitute the simplest wire ornaments of the selection (Figure 10a-b). The round-sectioned wire was achieved by hammering a rod, starting from a square shape changing to a polygonal shape until finally attaining the round section (Untracht, 1982, p.248). The wires are carefully polished. They were bent around a hard cylindrical rod circling two and a half times.

The three-colored string (30-12-759) is composed of 20 ring-shaped gold pendants threaded on a triple band of cylindrical lapis lazuli and lentoid carnelian beads (Figure 11). Each ring pendant consists of a ring made from hammered round-sectioned wire and closed by soldering to which a corrugated sheet ribbon-shaped suspension loop is attached. This loop is made from a sheet strip, first folded to double the sheet and then bent in a way to achieve a spacer for three threads and a doubled ending to be attached on the ring by soldering (Figure 11b-e).

This detached ornament (30-12-618) is composed of two loop-in-loop chains, one faceted biconical gold bead, two lentoid carnelian beads and two biconical lapis lazuli beads (Figure 12). The faceted biconical gold bead was made by lost wax (Figure 12e). The wax model was shaped around a burnt wooden stick to produce the threading tunnel; the tunnel is slightly recessed around the edges. The surface was finished with abrasives (Figure 12b-c). It bears PGE inclusions (Figure 12d).

The loop-in-loop chains (Figure 12f-k) were created from a round-sectioned wire (Ogden, 1982, pp.57-58). The wire loops still bear tool marks from hammering (Figure 12h-j). To achieve a large quantity of equal sized loops the goldsmith bends a long wire around a core stick forming a cylindrical spiral. Each loop is cut with a sharp chisel from this spiral and is then closed by soldering. The solder points are easily recognizable (Figure 12j). The loops were then formed to a oval shape and the loop extremities bent. They were linked one in another to form a flexible chain with links of standardized shape.

This polychrome string (30-12-561) is composed of 29 gold elements (14 long cylindrical filigree beads, 14 biconical gold beads and one corrugated spherical bead), 28 lapis lazuli elements (2 corrugated, spherical lapis beads) and 6 carnelian beads (4 lentoid and 2 biconical) (Figure 13). The aesthetic attraction relies in the three colors and the elements of the same shape executed in different materials. The corrugated gold bead is made of thin sheet, presumably made of two parts pressed in

a die and decorated by chasing (Figure 13b and d). The gold sphere is so well polished that the joining seam is invisible.

The biconical gold beads seem to have been made also from sheet at first glance, as the seam on the outside shows, but this could be made by lost wax casting using a wax sheet model (Figure 13e-g). They bear significant PGE inclusions.

The long, hollow and cylindrical gold beads are composed of several pairs of twisted wires (Figure 13h-k), that are oriented in opposite directions to provide them an aspect of interlaced shape. The wires are clearly made by rolling a strip as shown by the helicoidal marks on the wire surface (Figure 13k) (Formigli, 1993). Both terminals of each bead are strengthened by a slightly smaller wire bent three times around the composite cylinder. All the filigree elements are joined by soldering. The gold beads bear traces of long wear in particular at the contact point between the stone and gold beads and is visible by the rounded surfaces caused by abrasion (Figure 13f and i).

The bichrome string (B16794) is a delicate composition of beads and pendants (Figure 14). Its constituents are three golden filigree pendants, four drop-shaped hollow gold beads combined with lapis lazuli elements and a large number of lapis lazuli beads (Zettler and Horne, 1998, p.111). Two pendants function as spacers. The two small conical filigree pendants are made from one piece of wire each, forming the decorative wire and a ribbon for the suspension loops. The filigree cones mark the three-dimensional character of this remarkable bichrome ornament. The shape of the small cones is reiterated in carved lapis lazuli at both the terminals (Figure 14c).

The central pendant is the most complex part of the ensemble, with four filigree cones made of two wires. The ends of two long wires were rolled in shape of a coiled cone with the central part of the wires left open. The two wire elements with coils were then twisted along this central part in order to link the two wires producing the four cone motif (Figure 14c and e-g). This composite filigree element is then fixed within an annular frame of thicker wire with small loops soldered circumferentially (Figure 14g). Between these loops small lapis lazuli beads are fixed with a string or wire forming a crown of alternating gold and blue elements. An ancient repair appears in the center where one of the small filigree cones was renewed. The goldsmith replaced a lacking or broken cone by another one coiled in the inverse direction (Figure 14g-h).

This filigree work is undoubtedly constructed of gold wire soldered with metallic solder (Figure 14b and g-k).



Figure 10. a-b Wire spiral rings, B16841 A and B



Figure 11. a-e String with annular wire pendants, 30-12-759

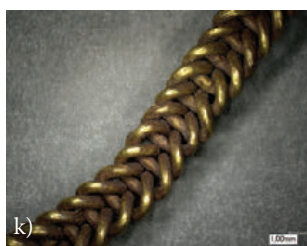
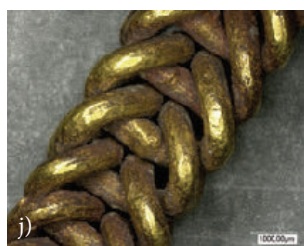
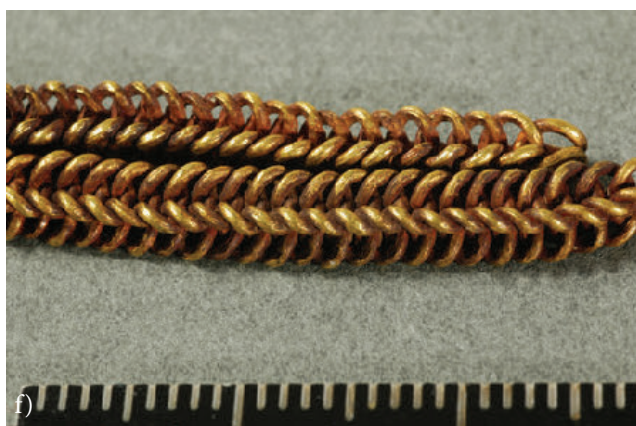
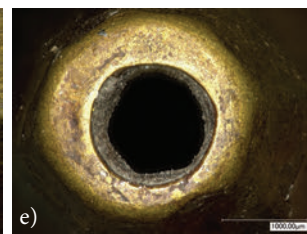
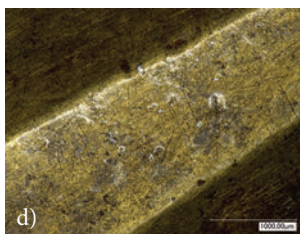


Figure 12. a-k Loop-in-loop chain with conical beads, 30-12-618





Figure 13. a-k String, 30-12-561



Figure 14. a-k String with pendants and beads, central pendant with filigree work, B16794

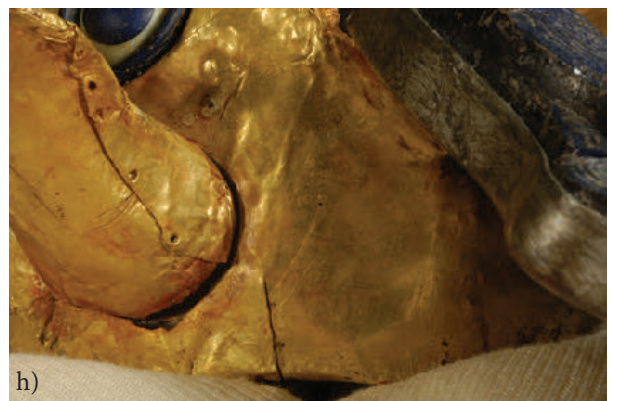
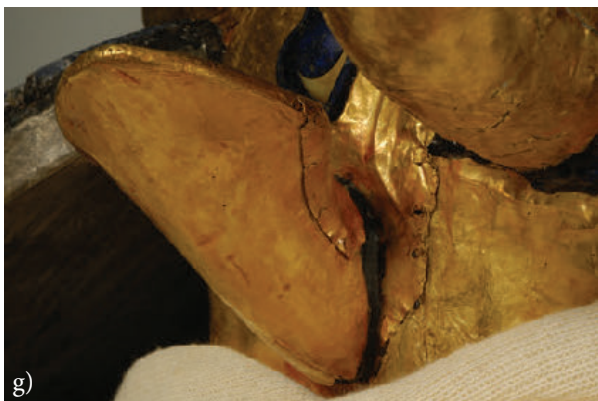
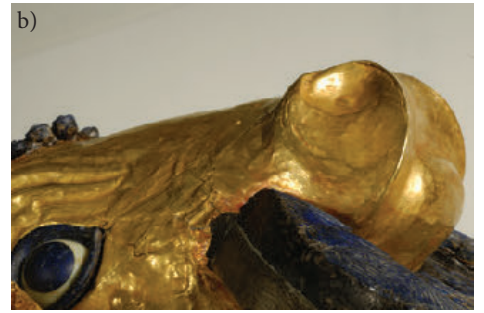


Figure 15. a-h Bull's head, B17694



Figure 16. a-l Ram caught in a thicket, 30-12-702

The metallic solder material can be clearly seen on the filigree elements as well as on the solder joints between the filigree, the frame and the suspension loops. Some solder bits melted on the smooth surface of the thick wire frame (Figure 14g and i). The quadruple suspension loop is composed of several sheet elements joined by soldering and attached to the round-sectioned wire by solder. There is a modern soft solder repair visible as a gray lump of lead or tin solder at the suspension loop (Figure 14e and g). Parts of the surface of the filigree pendants show damage by overheating the work pieces during soldering (Figure 14h-k).

## Sculptures

Two prominent sculptures were examined within the technological study, a bull's head that served as a decorative element of the great lyre from the king's grave, and the free-standing composite sculpture of a goat or a ram caught in a thicket. Both figurative works are constructed and decorated of several different materials set on a carved wooden structure. These sculptures are suggestive of the aptitude of the craftspeople to produce figurative art of extraordinary aesthetic and technical standard.

The bull's head (B17694, Figure 15) is a three-dimensional figurative, polychrome masterpiece made of gold sheet, lapis lazuli, and shell applied on a perishable material (Zettler and Horne, 1998, p.XVI and 53-57). The thin gold sheet elements have been hammered and chased delicately to conform to the hollow parts of the form. Several sheet elements were assembled to form the main head body, ears and horns. Ears and horns were wrapped and a mechanical seam (not soldered) is visible (Figure 15c-f), while the head seems to be made of one single sheet, prepared by chasing and hammering, and then pressed over the carved surface of the core material (Figure 15a-c). The joining of the golden sheets was executed by folding and riveting or nailing (Figure 15g-h). There was no possibility to measure the gold sheet's thickness. The bull's eyes are composed of shell and lapis lazuli and most probably fixed by glue or bitumen (Figure 15d). Sculptured lapis lazuli highlights the horn tips as well as the large beard and tufts of hair on the forehead with a fine carved relief (Figure 15a).

The "Ram Caught in a Thicket" (30-12-702; Figure 16) is a composite sculpture, like the bull's head, made of gold sheet, copper alloy, silver, lapis lazuli, shell on an wooden support (Zettler and Horne, 1998, p.42 and 61-63). The goat is standing on a base composed of shell, lapis lazuli, red limestone and silver elements on

wood (not at disposal for the present study). The different non-metallic parts were most probably fixed with glue or bitumen. The sculpture has been restored and the copper ears, gold sheet, lapis lazuli and shell are today fixed on a modern frame. To shape the gold sheet to the three dimensional form of the sculpture it has been partially hammered and chased to fit it into the desired relief. Like the head, four legs and the cylindrical part above the animal's neck and the floral elements of this statue are carefully wrapped in thin gold sheet and fixed mechanically by folding and bending (Figure 16c-d and i-l). In some areas it forms wrinkles and pleats. Traced lines enhance the details of the ram's head and legs as well as on the floral motives of the thicket elements (Figure 16b-c and k-l). As with the bull, the ram's eyes are composed of shell and lapis lazuli (Figure 16d). Sculptured lapis lazuli adorns the horns as well as the beard and hair on the forehead with a fine carved relief (Figure 16c-d). In addition, individually carved elements of lapis lazuli and shell were fixed on the body, the blue embellishes the ram's fleece on the shoulders and chest, while the back is white (Figure 16g-h). The copper alloy ears are solid casts (Figure 16e-f). It seems that the goat's belly was covered with silver sheet that hardly survived (Figure 16b).

## Notes on the goldsmith's "savoir faire", techniques and workshop equipment

The investigated gold items from Ur belong to different functional groups: Jewelry (stings, ear pendants) and decorative sheet elements (hair ribbons), tableware (spouted vessel), ceremonial item / weapon (adze), and finally sculpture elements (ram and bull's head). They can be classified in several technological groups: 1) Cast in piece mould with cylindrical core (adze), 2) Cast in lost wax (cylindrical beads), 3) casting of a pre-product in lost wax and partially hammered (vessel), 4) sheet work (ribbons, decorative sheets, leaf shaped pendants, hollow ear ornaments), 5) Combined plastic shaping of sheet and wire, 6) wire work (hair rings) or filigree (elements of strings, ring-shaped pendants, filigree beads, loop-in-loop chains), and finally, 7) sheet plating of figurative sculptures (bull's head and ram).

The technical knowledge of the goldsmith – as confirmed by the technological study – can be described as a combination of pyrotechnical processes and plastic shaping. In the logical sequence of the *chaîne opératoire*, first to mention are measuring techniques such as weighing and assaying to determine and test the quantity and quality of precious metal alloys. That is followed

by melting of the metal, possible alloying (See contributions of Hauptmann and Klein and Jansen, Hauptmann and Klein, both in this volume) and casting of ingots or artifacts by lost wax casting and two piece moulds with core. Plastic shaping of rods, wires and sheet from a cast ingot constitute the next step, and thereafter the three dimensional chasing, punching and tracing for decoration. Joining is executed by metallic soldering, probably also by reaction solder, and by mechanical joints like folding, riveting or nailing for the gold plated objects.

The small group of objects studied within the scope of the Ur-Project already shows the remarkable variety in function and typology of goldwork production as well as in technology applied in the manufacturing of the fine metal work. Some are created exclusively in gold, whereas others combine other materials such as lapis lazuli and carnelian. The examined object groups include flat items of two-dimensional conception and three-dimensional ones, comprising hollow and solid examples. There are objects made with only one constituent element, while others are composed of a large number of elements, individually manufactured and then joined. They also differ in their handling and motion. Chains and strings are articulated, while other items are rigid. Some are very light and fragile, while others are heavy and solid. Finally we distinguish objects that do not need any support, threaded elements and those consisting of a core material covered with thin gold sheet giving the optical illusion of a massive object.

## Conclusion and perspectives

The gold artifacts from Ur are of remarkable quality in technical as in artistic terms attesting that the art of the goldsmith achieved a high level in Bronze Age Mesopotamia. The small heterogeneous group of gold objects studied illustrates how ancient craftspeople mastered technological challenges. These ornaments were worked for the living and for the dead, some obviously exclusively for the burial ceremony. The production of ornaments, decorative elements, sculptures and vessels must have been well organized. The skilled craftspeople worked in specialized workshops and they or their purchaser or patron had extended cultural contacts. The artifacts are of local Near Eastern design and created with a large variety techniques and combinations. They were obviously aware of the interdependence between aesthetics, decorative style and form and the mechanical constraints linked to functional aspects of use, and all of this relates back to the technical choices made by the craftsperson (Armbruster, 2011b).

The Ur material offers an extraordinary large range of object types of varying form, decoration, dimension, function, raw material and respective manufacturing techniques. Therefore, this extraordinarily rich material would be worthy to be studied in a comprehensive manner and with an interdisciplinary approach. Consequently, the intention of these preliminary investigations is to encourage further and more extensive studies with this very aim. Further studies of a larger corpus of objects and an exhaustive catalogue of the Ur goldwork (Penn Museum and British Museum) would provide more precise information on the technical / workshop traditions and perhaps several independent workshops or ateliers can be identified with specialization of object types and techniques.

Future studies could be aimed at exploring the origin of the highly developed gold technology, the emergence of local traditions, inventions as well as external influences. They also should investigate comparable artifacts and parallels from other Near Eastern sites.

Further investigations should incorporate scanning electron microscopy and X-Ray radiography in the detailed study of the manufacturing technology. The characterization of different alloy composition of a large number of gold items from Ur in particular and of Mesopotamia in general could help to form groupings in compositional as well as in technological terms (compare to Hauptmann and Klein in this volume). Spot analyses of junction zones could provide insights into the joining techniques. The alloy composition applied in soldering procedures and the distinction of natural and intentional alloying are of particular interest for technological studies.

Furthermore, the documentation of tool marks and surface structures of a large group of fine metal work could provide information as a basis for experimental replication or reconstruct of certain manufacturing techniques. An explanatory model of the equipment and organization of Early Bronze Age fine metal worker's workshops could then be established and possible forms, functions and materials used for the goldsmith's tools, such as technical ceramics, stone, copper alloys, antler and bone, be reconstructed. Analogies from experimental archaeology, ethnoarchaeology, and from ancient depictions of fine metal workers, could also assist to reconstruct the Ur's goldworking craft.

It would be a challenge to find out about the nature and the localization of the workshops that created the outstanding fine metal work from the Royal Cemetery of Ur. Such investigations could make a major contribution to the history of metal technology.

## Acknowledgements

I am extremely grateful to Richard Zettler and Katherine Blanchard for providing study facilities at the Penn Museum, Philadelphia. Thanks are also due to Andreas Hauptmann, Sabine Klein and Moritz Jansen for their valuable help and advice, as well as to Stephen William Merkel for suggestions and polishing my English text.

## Notes

- 1 Macro-photography was performed with a Nikon D100 digital camera with a micro Nikkor 60mm f/2.8 of the CNRS laboratory TRACES, Toulouse, while micro-photography was performed using the Keyence Digital Microscope of the Deutsches Bergbau-Museum. This microscope enabled images of the object to be taken with high topographic relief because of its substantial depth of focus.
- 2 The word 'string' was chosen as a function neutral term to denote a threaded bead assemblage like bracelets and necklaces or other types beaded jewelry.

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