Minoan Metal Vessel Manufacturing: Techniques and Technology

Christina Clarke

*The equipment and processes used to manufacture hammered metal vessels during the palatial periods of Bronze Age Crete have not previously been investigated in detail. The study described in this paper takes an interdisciplinary approach to the investigation of how these vessels were made, combining archaeological research with metalsmithing practice to reconstruct Minoan metal vessel production techniques. The results indicate that simple tools found at many Minoan metallurgical sites are effective for creating these vessel forms. That these tools are also found in contexts which are not considered metallurgical sites may indicate that metalsmithing occurred in more locations than are currently recognized.**

Introduction

The aim of this study is primarily to establish how hammered Minoan metal vessels were made and what tools were used in their manufacture. It will be shown that a number of commonly found Minoan tools previously not identified as tools of a metalsmith may have been used for metallurgical tasks. This project, therefore, makes a dual contribution to Minoan archaeology. Previous studies of Minoan metal vessels have not examined their manufacturing techniques in great detail.[1] Furthermore, it is difficult to draw conclusions about the practice of a craft without understanding what equipment is required and the specific manner in which this equipment is used. By applying practical knowledge of a craft to analysis of the artifacts, a richer understanding of the craft and its practitioners can be gained.[2] The methodology of this study combines information from archaeological material with practical application of Minoan metalsmithing equipment. This interdisciplinary approach has not previously been applied to the study of Minoan vessels.

The initial stages of the study involved studying excavation reports and archaeological publications on Minoan metallurgy and Bronze Age metallurgical sites in Crete. The second stage was the detailed examination of seventeen Minoan vessels in the Chania Archaeological Museum and the Ayios Nikolaos Archaeological Museum in Crete and the Ashmolean Museum in Oxford. The final stage of the study was to replicate some of the tools and equipment found at Minoan metallurgical sites and to use them to make Minoan vessel forms. This paper covers some preliminary findings of the study, focusing on both the hammering processes used to shape the body of a vessel and methods for polishing the surface.

The first section introduces the vessels themselves; the second describes the processes used to make vessels and the relevant metallurgical technology available to the Minoan world. In the third section the practical reconstructions carried out for the study are described. The findings arising from the reconstructions are then discussed.

Minoan Metal Vessels

Hammered vessels in bronze and precious metals were produced in Crete during the Bronze Age largely during the palatial periods. Some characteristics of ceramic vessels indicate that metal vessels may also have been made during the Early Bronze Age, but for the most part they appear in Minoan material from the Protopalatial period and production appears to have flourished during the Neopalatial period. After the Neopalatial period, vessels continued to be produced, but the forms were slightly different.[3] It is possible that many extant from later periods were heirlooms from the Neopalatial period.[4] Common vessel types include hydrias, tripod cauldrons, pitchers, lamps and basins of various forms and, to a lesser extent, large cauldrons, cups and bowls (Fig. 1).

Many metal vessels from the Shaft Graves at Mycenae, especially those in precious metals, are regarded as being Minoan products or as having been made by local metalsmiths trained in the Minoan tradition.[5] However, of the 250 or so extant vessels from Crete, only a handful are of precious metal and the rest are copper alloys, predominantly tin bronze. Because of the dearth of vessels in precious metals from Crete, this study focuses primarily on the production of bronze vessels. According to Evely and Stos, the tin bronzes used range from 7-11% tin.[6] Many vessels are formed from a single piece of metal but some larger forms are made from multiple pieces riveted together (Fig. 1g and j). Additions to the hammered form such as handles and legs are either cast or forged separately and are riveted to the body of the vessel.

Vessel-Making Processes and Minoan Evidence for Metallurgical Technology

A metallurgical site is usually identified by the remains of casting processes, such as metal spill,

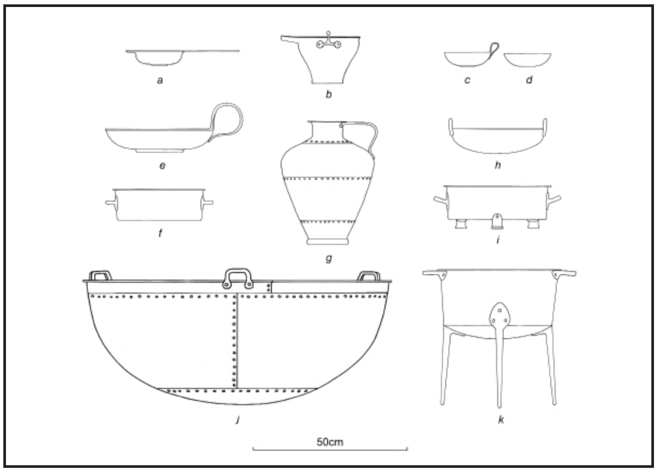

Figure 1: Some Minoan bronze vessel types: a) lamp, b) lekane, c) one-handled cup, d) bowl, e) one-handled basin, f) pan, g) hydria, h) basin, i) tripod pan, j) cauldron, k) tripod cauldron.

slag, crucibles, tuyères and molds. However, because vessel production is largely a matter of hammering a pre-cast billet, casting may not necessarily have been carried out at a vessel-making installation. Therefore, manufacturing sites for Minoan vessels are difficult to identify. The most distinctive remains from the construction process for vessels – hammers, anvils, stakes, whetstones and an annealing hearth – may not always be apparent. To complicate matters, most of the equipment is similar to domestic equipment: stone tools for grinding and pounding for food production, whetstones for sharpening domestic tools and hearths for food preparation and heating.[7] Some equipment may have been used for both domestic and craft activities.

In order to create a hammered vessel, a disk-shaped billet is required. Archaeological material suggests that these were cast in bivalve stone molds. One such example comes from Malia.[8] This study has revealed that in some cases, Minoan vessels were fashioned from billets that were cast using the lost-wax method. Billets were probably between 0.3 and 0.6 cm thick, depending on the diameter of the disk. Generally, the larger the diameter, the more difficult it is to cast a thin billet.

Throughout the manufacturing process, the metal must be annealed repeatedly. As it is hammered, metal becomes hardened and further shaping is very difficult. If it is worked too far, cracks develop in the material. Heating relieves the stresses by causing recrystallization, softening the metal for further working. The equipment needed for annealing includes a hearth and some means of introducing a draft.

No hearths in Crete that I am aware of have been definitively linked with metallurgical activity by the presence of metal droplets or slag, but hearths have been found in the vicinity of other metallurgical evidence. The Unexplored Mansion at Knossos had extensive evidence of metallurgical activities, including crucibles, molds, metal scrap and various stone and bronze tools. Pillar Hall H of the building contained a pi-shaped hearth, but it is not regarded as being for metallurgical purposes since there was no evidence of slag, droplets or high temperatures.[9]

The temperature of the burning charcoal in a hearth is raised by the introduction of a draft. Typically, annealing takes place between 500-800°C, which is quite low compared to the temperatures required for melting: 1083°C for copper and slightly lower for bronzes, depending on the percentage of tin. Casting requires a strong draft, probably supplied by bellows. Pot bellows were used throughout the Bronze Age in Crete; remains of pot bellows come from Prepalatial Chrysokamino and Postpalatial Kommos.[10] However, for annealing temperatures, bellows are unnecessary, and a draft was probably supplied by blow-pipes made from reeds.[11] No evidence of blow-pipes such as ceramic nozzles to protect the end from burning has survived.

Heating metal causes oxides to form on the surface of the metal, and these must be removed before hammering begins because, if they are hammered into the surface, they will cause weaknesses which later cause cracks. There is no way of knowing how Minoan smiths would have removed the oxides, but the two possible methods are the use of abrasives, or chemical processes. Several weak acids which were available to the Minoans are effective for removing oxides, including vinegar, especially when combined with salt, and uric acid from urine or bird dung. The oxide-coated metal may be quenched in the acid and left in the solution for as long as is required for the oxides to disappear, which may take seconds or hours depending on the strength and composition of the acid. The metal is subsequently rinsed in water.

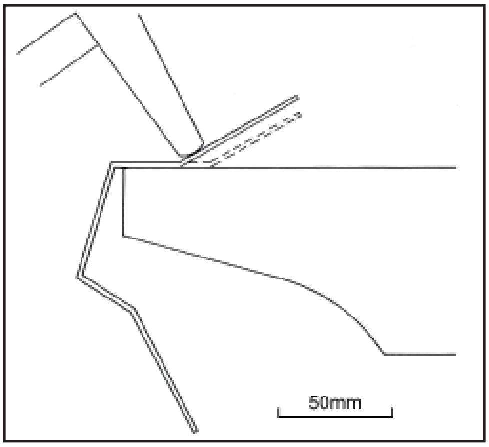

Figure 2: A transverse-section of raising: the wall of the vessel is held over the stake and hammered from the outside.

The tools required to transform a billet into a vessel are hammers, anvils and stakes. There are two main hammering methods used to make vessels: raising and sinking. Raising is hammering the metal over a stake, working it from the outside of the vessel (Fig. 2), whereas sinking is hammering the metal over a hollow, working from the inside (Fig. 3). For Minoan vessels, the majority of the shaping was accomplished by sinking, with some final shaping done by raising.

Bronze tools for metalsmithing from Minoan Crete are extremely rare. Examples of bronze hammers which might be suitable for vessel-making include one from Quartier Mu at Malia[12] and another in the Mitsotakis Collection at Chania Archaeological Museum from an unknown site.[13] Stakes or anvils which could have been used to make vessels come from Zakro Palace,[14] Ayia Triada,[15] and Samba Pediados.[16] None of these bronze tools comes from a confirmed metallurgical context. Far more common are simple stone hammers; these are often found at metallurgical sites. These are elongated pestle shapes, spherical cobbles and a variety of pebbles. These hammer stones are not appropriate shapes for hafting, and so were probably hand-held. This practice is seen in other cultures. For example, Egyptian depictions of metalsmithing such as those

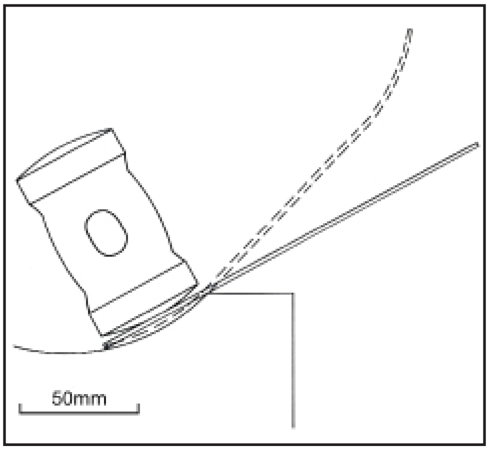

Figure 3: Cross-section of sinking. The original flat billet is hammered into a carved, wooden hollow, causing the walls to become thin and concave (indicated by broken lines)

from the New Kingdom Tomb of Rekhmire show the use of stone hammers without handles, and Inca smiths used lumps of copper held in the hand as hammers for goldsmithing, including elongated and spherical forms much like the Minoan hammers.[17] Stone types used for these hammers in Crete include igneous stones, marble and limestone.

As for stakes and anvils, only a handful made of bronze survives. There is little evidence otherwise for the equipment on which the metal was hammered. Stone slabs which may have been used as anvils have been recovered from Building A in the Artisans' Quarters at Mochlos and houses at Kommos, but flat anvils like these have limited usefulness for vessel-shaping.[18] That the evidence for such equipment is so meager suggests that materials which have not survived were used. Today, metalsmiths often use wooden stakes for raising and a hollow carved into the top of a tree stump for sinking.[19] Minoan smiths probably used similar equipment.

The last stage of creating a vessel before handles or other additions are attached is finishing the surface to produce a polish. Abrasives are rubbed over the surface to cut down the rough texture left from hammering. Coarse abrasives are applied first to remove the deepest scratches and successively finer abrasives are subsequently applied to remove scratches left by coarse abrasives until the scratches are small enough to make the surface reflective. A method for producing a high polish is burnishing, a process in which a hard, polished tool is rubbed over the surface. This can be performed after larger scratches on the surface have been removed with abrasives.

Many Minoan stone tools showing flattened and facetted surfaces provide ample evidence that they were used for finishing metal. The tools are of various sedimentaries such as marble, limestone and siltstone or other stones such as quartzite, emery and pumice. There are some materials suitable for finishing which were available to the Minoans but which have not yet been noted for such uses in Minoan contexts. Charcoal is an excellent fine abrasive but might be overlooked as a tool during excavation.[20] Some of the stone types used to make Minoan sealstones are suitable for burnishing but would not necessarily show evidence such as flattening or faceting owing to their hardness.[21] As a result, their potential for such uses might not be considered during excavation. Examples include hematite and quartzes such as agate and amethyst, some of which are used for burnishing by some metalsmiths today.[22]

Reconstruction of the Equipment and Processes

Equipment

The equipment replicated from Minoan artifacts for this study included a hearth, stone hammers and finishing or polishing tools. Other tools used, for which there are no surviving Minoan artifacts because of the ephemeral nature of the materials, were a blowpipe, a wooden raising stake and wooden stumps with hollows of differing sizes carved into the upper surface. This equipment has so far been used to make two small bowls as test-pieces (Fig. 4) and a large hydria made from four sections (Fig. 5).[23]

The hearth built for the reconstructions was based on the design and dimensions of pi-shaped hearths found at Kommos and at the Unexplored Mansion at Knossos to test whether this hearth design is suitable for the vessel-making process (Fig. 6). It was built into the side of a small embankment by digging out a slightly scooped hearth bed and building up three short walls around the bed from fire bricks. The internal dimensions of the hearth were 35 cm wide, 46 cm deep and 20 cm high. Charcoal was used for fuel. Since the choice of material for Minoan blowpipes would have no effect on the results, an aluminum tube 62 cm long with an internal diameter of 0.7 cm was used. The length of the tube was necessary in order to reduce facial exposure to the heat

Figure 4: Copper bowl made as a test piece.

Figure 5: Copper hydria produced with Minoan equipment.

of the fire. The internal diameter was chosen in accordance with data from Rehder, which indicates that a nozzle for a blowpipe must have an internal diameter of 0.5-1 cm.[24]

The hammers used were elongated pestle forms and a spherical cobblestone such as those found

Figure 6: Charcoal hearth constructed for this study (photo by L. Nguyen-hoan).

Figure 7: Stone hammers used for the reconstructions.

at some metallurgical sites. The pestles were of marble, granite and a fine-grained igneous stone, and the cobble of basalt (Fig. 7). For sinking, hollows of various depths and dimensions were carved into wooden stumps. The stakes used for raising were carved hardwood forms.

Materials used for finishing were stones of similar types to Minoan whetstones and finishing stones including pumice, limestone, marble and a fine-grained igneous stone. Charcoal was used as a fine abrasive and hematite and agate for burnishing.

Reconstruction of the Process

The billet was placed in the hearth and buried in the burning charcoal. Using the blowpipe, a draft was introduced to raise the temperature of the charcoal immediately around the billet (Fig. 8). Depending on the size of the billet, annealing took between five and ten minutes. The billet was subsequently removed from the hearth, quenched in a solution of salt and vinegar to remove oxides and rinsed in water.

The hammering techniques varied according to what metal movement was required. Sinking was the main technique used for the reconstructions, the material being hammered over one of the wooden hollows with the cobble or a pestle, doing this hammering in a spiraling manner from rim to center or center to rim (Fig. 9).

Generally, it was only possible to perform one or two hammering-rounds before the metal needed to be annealed. The result of many rounds of sinking was ultimately a thin-walled, deep bowl. This was then adapted with localized sinking or raising to create the desired vessel form. Raising was carried out on vessel sections where tall, vertical walls were required.

Figure 8: Annealing a billet in the hearth with a blow pipe (photo by L. Nguyen-hoan).

The hollow form was held against the wooden stake and hammered with a pestle in concentric circles parallel to the rim. The movement which the material takes can be visualized as the same as that of a clay vessel being turned on a wheel. By gradually encouraging the material inwards and upwards, the diameter is reduced. Raising is carried out for several rounds, annealing between each, to achieve a smaller rim diameter.

The last stage was polishing the vessels. The sedimentary stones and pumice, which are coarse abrasives, were used to cut back the surface. Charcoal was used to cut back the scratches left by the stones and thus produce a reflective satin polish. A high polish was created by burnishing the surface with hematite and agate.

<u>Summary of the Findings</u>

The simple pi-hearth and blowpipe were very effective for annealing the material quite quickly, indicating that many Minoan hearths had the potential to be used for metallurgical activities other than casting. Hammering with stones revealed that the simple, unhafted stone hammers found at many Minoan metallurgical sites used in combination with a wooden hollow and stake are very effective for creating Minoan vessel forms. It was discovered that it was actually not possible to carry out most of the sinking with a hafted hammer, since the handle obstructed access to the deeper parts

Figure 9: Sinking a vessel with a pestle into a hollow carved into a wooden stump (photo by L. Nguyen-hoan).

of the interior. A hand-held stone, however, could be manipulated much more easily in tight spaces. The pestle was the most versatile shape of the hammers, and the type of stone used for the hammer did not seem to affect its functionality, although a very soft stone such as pumice would be unsuitable. Igneous stones last indefinitely, but even hammers as soft as marble are effective, although tending eventually to deteriorate. This suggests that, rather than choosing stones for hammering according to stone type, metalsmiths chose them with their shape in mind.

The types of stones used as finishing tools that are found in Minoan contexts are very effective. Some individual tools were comparable in efficiency to modern steel files. As was the case for hammers, it did not seem to matter what type of stone was used, as long as it was fine-grained, since coarse stones leave deep scratches in the material.

Conclusions

The experiment of replicating as far as possible the materials and techniques used by the Minoan craftsman produced results in some ways surprising, especially regarding the effectiveness of handheld stones as hammers. It became clear that the stone tools found at many Minoan metallurgical sites and the pi-shaped hearths would have been very effective for creating Minoan vessel types. It is significant that much of the required equipment is also common in contexts that are not currently regarded as having metallurgical significance, since pestles and other hammering stones also have domestic uses, as do pi-shaped hearths. Since these tools and this equipment do not show obvious signs of having been used for vessel-making or other metallurgical activities, as archaeological finds they would not usually be considered for these uses. This study, however, leads us to reconsider these conclusions. This evidence also suggests that metallurgical activities probably took place at more locations than are currently acknowledged. By demonstrating that metallurgical activity is not tied to casting remains alone, this study should encourage excavators to consider the possibility that metalworking took place at a broader range of sites than are recognized today.

Technical Glossary:

anneal. Softening metal which has become hardened with working by heating it.

billet. A piece of metal cast in raw form ready to be made into an item. Billets may be rods, bars, disks, plates or amorphous forms.

lost-wax casting. A method of casting metal. The method referred to in this study is known as direct casting. A model of the object to be cast is first made in wax and subsequently coated with an investment material such as clay or plaster. This is then heated to melt out the wax, which empties through a channel incorporated into the design. The result is a hollow mold into which molten metal can be poured to fill the void left by the wax model. The metal object is removed by breaking the mold.

pot bellows.[25] A type of bellows used to introduce a draft into a metallurgical hearth or furnace. It consists of an open clay pot with a nozzle in its wall connected to a pipe which feeds into the burning fuel. A piece of leather with a slit in it covers the top of the pot. When this is pumped up and down, air drawn through the slit is forced into the fuel.

stake. A wooden or metal form over which sheet metal is hammered to create a hollow form such as a vessel.

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Endnotes:
1 Matthäus 1980, 323-33; Evely 2000, 380-7.
2 The author is a gold- and silversmith with over a decade of experience in the craft. In her practice, she has focused specifically on using traditional silversmithing methods to create vessels.
3 Rehak 1997, 57.
4 Driessen and Macdonald 1997, 62, 67.
5 Davis 1977, 353-5; Matthäus 1980, 341.
6 Evely and Stos 2004, 267.
7 Stone tools see Evely 1993, 108-118; hearths see Shaw 1990.
8 Chapouthier and Demargne 1942, 65, no. 1, pls 16 & 52.2a.
9 Popham 1984, pl.29(e); Catling 1984, 206; Evely 2000, 338, fig. 137.1. M. Shaw uses the term 'pi-shaped hearth' to refer to this and other hearths at Kommos (1990).
10 Chrysokamino see Betancourt (2008); Kommos see Blitzer (1995, 508, no. M 42, pls 8.80A and 8.105).
11 Evely 2000, 363.
12 Poursat 1996, 118, no. M 78/B 1, pl. 43k.
13 Davaras 1992, 266, no. 331.
14 Platon 1971, 129, fig. on p. 4, bottom right.
15 Deshayes 1960, 122, pl. 63.4.
16 Deshayes 1960, 298, no. 2321, pls 40.3, 63.1.
17 For Egypt see the depictions of metalworkers from the Tomb of Rekhmire in Prisse d'Avennes (2000, 120); Incas see Vega (1961, 130-1).
18 Mochlos see Carter (2004, 75, no. IC.410, pl. 23, IC.); Kommos see Blitzer (1995, 485-6, pls. 8.59A-D).
19 Brepohl 2001, 243, 246.
20 Brepohl, 2001, 339.
21 For sealstone materials see Evely (1993, 156).
22 Brepohl 2001, 343.
23 As of the writing of this paper, the hydria sections have been shaped and riveted together and are still to be polished.
24 Rehder 1994, 349.
25 Betancourt and Muhly 2006.

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