Metal “Ring Idols”: a Material Approach to Metalworking in the Aegean Neolithic

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METAL "RING IDOLS": A MATERIAL APPROACH TO METALWORKING IN THE AEGEAN NEOLITHIC[1]

Abstract: The "ring idol" is a type of adornment produced from the 6th millennium onwards in the Aegean and the Balkans. While the first productions are made of stone, those from the end of the Neolithic, between the 5th and 4th millennia, are mostly of gold, copper and silver. These objects have a characteristic morphology, with a concave ring and a pierced extension. In the first deposits of metallic objects found in Aegean Neolithic layers, the discovery of "ring idols" is recurrent. Some seem to have been hammered, others possibly cast. This can be observed by traces on their surface. The metal was also perforated to permit suspension, and polished. Some traces have been erased by polishing; therefore, we do not have enough information on the techniques and tools used in these cases. To fill current gaps in knowledge, I collaborated with a blacksmith and cutler to apply experimental archaeology approaches to reconstruct the manufacturing process. Cold and hot hammering, casting, polishing and perforation have been tested. Stone tools were used, consisting mostly of hammers and abrasive stones. As a result, the experimental "ring idols" made of copper bear traces that can be compared with those on the archaeological artefacts.

Keywords: metalworking, ring idols, Aegean Neolithic, experimental archaeology, traceology.

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Introduction: Chrono-Cultural Framework

Greece and the Balkans during the Aegean Neolithic

The Aegean Neolithic covers a long period, from the 7th to the 4th millennia, and is notable in Greece and the Balkans for the significant changes in the lifestyles of communities. During the Neolithic, the contacts between the Aegean population and their neighbours were strong and the archaeological material (ceramic vessels, figurines, ornaments) shows common influences. Exchanges intensified at the end of the period, around the 5th millennium BC, strengthening these connections.[2] This trend is also visible on an interregional scale, between the mainland communities and the Aegean islands.[3] The ceramic assemblages of northern Greece show similarities with those of the Balkans, particularly in Bulgaria, indicating movement

1 I would like to thank Alexis Lesueur, blacksmith cutler, and Sophie Luline, ceramist, without whom the archaeological experiment could not have taken place. The experiment was financially supported by APERA (*Association Pour l'Expérimentation et la Recherche Archéologique*), for which I am deeply thankful. My gratitude goes to Nolwenn Gilbert for all the photography work. Also, many thanks to the organisers of the symposium and the reviewer of this article by contributing to its improvement.
2 Demoule, Perlès 1993, 403.
3 Nazou 2010, 8.

of skills and knowledge.[4] In this period, Anatolia also played an important role in networks involving sites in northern Greece and on the Aegean islands.[5]

Despite a tendency to consider Aegean Neolithic culture as derived from the Near East,[6] material and technological elements also reflect a very characteristic local tradition. Prestige goods produced in this period, such as *spondylus* artefacts, stone vases, figurines and ornaments made of semi-precious stone or metal,[7] are a good example of this phenomenon. These exotic objects, manufactured in Greece, were exchanged within dynamic and extensive networks, both maritime and terrestrial, which covered the entire territory and linked the Balkan regions together. These exchanges also enabled the circulation of skills and ideas, and knowledge of metalwork reached many populations.[8]

The End of the Aegean Neolithic

The Late Neolithic (LN) period extended from about 5400 to 3700–3300 BC and is divided into three phases: LN I, LN II and Final Neolithic or Chalcolithic.[9] The way of life in the southern regions of Greece, the Peloponnese and Attica, contrasted with that in the north, comprising Macedonia, Thrace and Thessaly. In the north, settlements were occupied generation after generation, forming artificial hills known as *tells* or *magoules*. In the south, nomadic pastoralism developed and is visible through the intensification of cave occupation.[10] While the land routes were largely exploited by the continental populations, the Aegean islands, and particularly the Cyclades, developed through sea routes.[11] Some groups of individuals became wealthier and the social organisation became more complex,[12] related to what might be considered as the emergence of social hierarchies.

The LN in the Balkans and the Aegean was characterised by new abilities in raw material extraction, construction techniques, food storage, the lithic industry, ceramics and firing techniques.[13] Each material, stone, clay, shell or metal, requires specific skills and probably comprised a specialised craft.[14] However, a phenomenon specific to the LN in south-eastern Europe was the introduction of metallurgy, which emerged between the 6th and 4th millennia and remained independent of the "Neolithic Package".[15] It can also be considered as a true technical innovation.[16] The necropolis of Varna is the most well-known case of this autonomous development of metallurgy in the Balkans.[17] In the Aegean, a few archaeological sites have yielded evidence of early metalworking with the discovery of crucibles, slags and finished products, as at Sitagroi, Mandalo and Limenaria in northern Greece.[18] The first metal goods produced at the end of the 6th millennium are small in size and are found in rather modest quantities (awls, beads, rings, pendants, hooks, drills or pins). The first examples of pendants in the shape of a "ring idol" belong to this group of small finds. Then, during the 5th millennium, metallurgical production increased and bigger objects, such as daggers and axes, were produced.[19]

Introducing the "Ring Idols"

Throughout the Aegean Neolithic, "ring-idols" constituted a characteristic type of ornament. They are named so because of their ring shape, surmounted by an extension resulting in a schematic female form. These objects are found across the Greek mainland but also in the Aegean islands, including Crete. About 90 "ring idols" have been found to this day, out of which about 60 are made of metal. More details about the "ring idols", particularly concentrating on their variety of form, their function as hanging ornaments and their symbolic role, are available elsewhere.[20] Of relevance to this specific discussion here is their material, find contexts and distribution.

A wide diversity of raw materials was employed to produce "ring idols", such as stone, clay, gold, silver, copper and, more rarely, shell and bone. These materials were used contemporaneously, as at Makriyalos in central Macedonia, where copper and marble "ring idols" have been found in LN levels.[21] However, by

4 Galanaki *et al.* 2007, 78.
5 Furholt 2017, 471.
6 Demoule, Perlès 1993, 356.
7 Demoule, Perlès 1993, 403.
8 Lambert 1981, 224.
9 Treuil 2008, 31, tab. 1; Tsirtsoni 2016, 19, tab. 1.
10 Perlès 1992, 121; Demoule, Perlès 1993, 388.
11 Televantou 2018, 389.
12 Runnels, Murray 2001, 62.
13 Reingruber 2014, 218.
14 Demoule, Perlès 1993, 393; Papathanassopoulos 1996, 35.
15 Hansen 2013, 140.
16 Manolakakis 2007, 44.
17 Renfrew 1978, 200.
18 Zachos 2010, 83, fig. 6-4.
19 Zachos 2007, 179.
20 Martin 2021, 76–78, fig. 3. That paper also discussed some associated experimental work and its preliminary results. This present study is focused on the reconstruction of the manufacturing process as well as the future establishment of a repository database of metalworking techniques.
21 Demakopoulou 1998, 67; Pappa 2007, 264, fig. 17; Ifantidis 2019, 232.

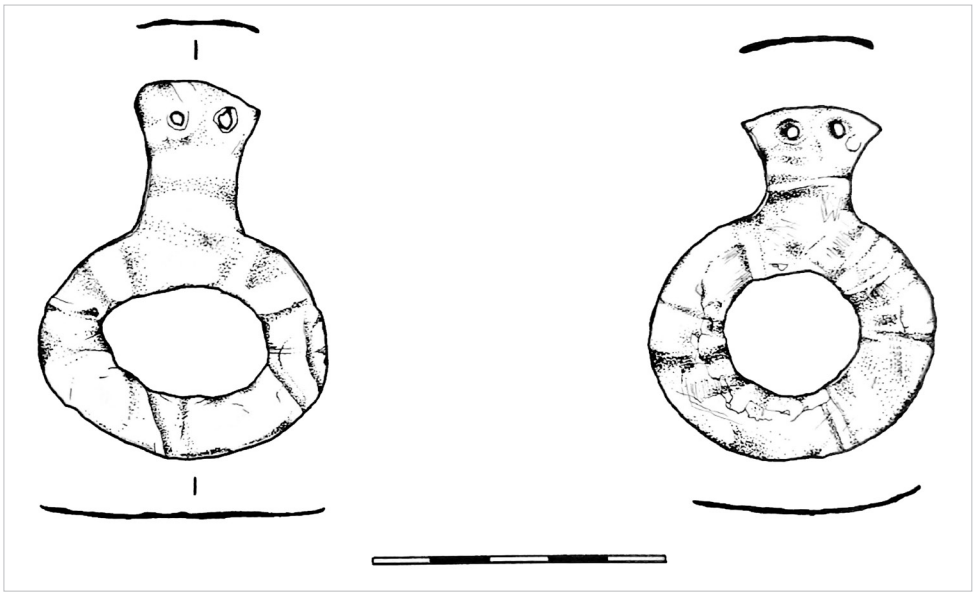

Fig. 1. The two gold "ring idols" from the Aravissos Hoard (Pella, Macedonia), 4500–3200 BC, Archaeological Museum of Thessaloniki (ΜΘ 12100/ΜΘ 12101) (drawing by author; the rights to the depicted monuments belong to the Greek State and the Ministry of Culture and Sports (Law 4858/2021). The monuments are under the jurisdiction of the Archaeological Museum of Thessaloniki. ©Archaeological Museum of Thessaloniki, Hellenic Ministry of Culture & Sports—Hellenic Organisation of Cultural Resources Development).

the end of the Neolithic (LN II onwards), "ring idols" were most commonly produced from metal. The most famous examples are made of gold, as in the case of the "Neolithic Treasure". The latter comprised 53 gold objects possibly dating to 4500–3300 BC but of unknown origin.[22] Typologically, this group has been linked to the phenomenon of emerging metalwork around the 5th millennium BC in the Balkans, as exemplified by the necropolis of Varna, whose burials also contained gold "ring idols".[23]

In Greece, the find contexts of "ring idols" have been mostly domestic. They might also be present in funerary contexts, since some of them have been discovered in caves used as burial places in the LN.[24] This was the case of the silver "ring idols" found in Alepotrypa Cave in the southern Peloponnese,[25] Eileithyia Cave in northern Crete[26] and Euripides Cave on the island of Salamis.[27] However, these objects were not securely identified as funerary offerings. The silver pendant from Tsepi at Marathon is the only one that can safely be assigned to a funerary context.[28] These "ring idols", as well as those from the prehistoric settlement of Aravissos Pella in Macedonia (Fig. 1),[29] are thus difficult to date since they derive from isolated or insecure contexts.

"Ring idols" were not unique to Greece. Similar examples have also been found in Bulgaria,[30] Romania,[31] Hungary,[32] Slovakia,[33] Serbia[34] and Anatolia.[35] The Balkan and Aegean productions were contemporaneous, while that in Anatolia was later. In this latter region, "ring idols" seem to have been made especially during the transition from the Chalcolithic to the Bronze Age period, in the early 3rd millennium BC, even though from a typological point of view they could be attributed to an earlier date.[36] However, the shape of the Anatolian "ring idols" was often different from the Aegean ones, because of their recognisable "T-shaped heads".[37]

The Aegean populations seemed to be among the first to produce "ring idols". Those made of stone

22 Demakopoulou 1998, 15; Kaltsas 2007, 40–41.
23 Gimbutas 1977, 45; Leusch *et al.* 2015, 367.
24 Fowler 2004, 83.
25 Demakopoulou 1998, 65; Papathanassopoulos 2011, 216.
26 Demakopoulou 1998, 64, fig. 63.
27 Demakopoulou 1998, 64, fig. 62; Mari 2001, pl. 123.
28 Pantelidou-Gofa 2005, 136.
29 Grammenos 2004, 62.
30 Gimbutas 1977, 45; Todorova, Vajsov 2001, 66.
31 Berciu 1967, 63.
32 Makkay 1976, 253.
33 Makkay 1976, 252; Vizdal 1977, 43, fig. 23.
34 Makkay 1976, 254.
35 Zimmermann 2007, 27, fig. 1.
36 Zimmermann 2007, 26.
37 Maran 2000, 188; Mehofer 2014, 472.

were characteristic in Greece and rarer in other regions. Similarly, these objects were more varied and numerous in the Aegean. In addition, the motif can be found painted on ceramic vessels or as rock carvings.[38] Therefore, it was a type of ornament characteristic of the Aegean Neolithic above all.

The Metal "Ring Idol": a Witness to the Emergence of Metalwork

Produced as early as 5300 BC, the metal "ring idols" were among the first ornaments made with gold, copper and silver in the Aegean. Regardless of the material, a standardised production can be noted. Thus, their technological study could provide a basis for repositories of techniques used in the first metalsmithing processes in Greece.

Except for the archaeometric studies published by K. Demakopoulou on the "Neolithic Treasure" exhibited in the National Archaeological Museum of Athens,[39] no other analyses have been guided by a technical interest or led to conclusions about the techniques involved in the making of metal "ring idols". Other examples of archaeometric and chemical analyses conducted on Aegean "ring idols" can be mentioned, with exemplars from Poliochni on Lemnos[40] and Ftelia on Mykonos,[41] but they remain scarce. This study thus sheds new light on this type of object, through the study of technical traces and experimental archaeology. These technical traces, identified on "ring idols", can be interpreted by comparing them to experimental pieces that have been worked in a particular way. Thus, a trace type can be associated with a specific manufacturing process, as tested during the experiment.

The term *chaîne opératoire* refers to the entire manufacturing process of an object, from the acquisition of the raw material to the finished product.[42] Each stage of a *chaîne opératoire* comprises sub-stages, which are determined by cultural, social and functional factors.[43] In addition, steps such as repairing, recycling or reuse can be added, especially in the case of metal, which can be remelted.[44] The *chaîne opératoire* can be reconstructed by analysing characteristic material remains found in archaeological levels, but also by studying the traces left on the surface of metal objects.[45] Archaeological and experimental data have therefore been brought together in this study. Since "ring idols" were such a significant component of Aegean Neolithic metalwork, reconstructing the ways in which they were made enables a better understanding of early metalworking techniques in general.

Two theoretical *chaînes opératoires* for "ring idols" can be considered based on metalwork techniques proposed for prehistoric periods in previous scholarship.[46]

The first model involves a piece of pre-cast metal transformed into a thin metal sheet[47] by gradual cold hammering, to avoid fracturing. Fractures occur when metal undergoes deformation to the point where its crystalline structure loses cohesion. It can be prevented by periodically heating the metal to allow recrystallisation and thus restoration of a homogeneous structure (a process known as annealing). Once thin enough, this metal sheet could then be cut out into the desired shape. Cutting could be carried out with a flint blade or a metal tool such as a chisel. Most of the metal objects from these periods, including pendants like the "ring idols", seem to have been manufactured in this manner.[48]

The second theoretical model involves a blank,[49] pre-cast into the ring shape, being alternately hammered with stone hammers and annealed in order to produce the final shape. Some "ring idols" seem to have been hammered on a concave support to produce curvature. Casting could have been done in moulds made of stone or fireclay. The use of this technique is attested by the discovery of a "ring idol" clay mould dated to the 4th millennium BC, at Çamlıbel Tarlası in Central Anatolia.[50] However, casting was still much less common than hammering in the LN period.[51]

Finally, the ornaments were perforated with copper or stone drills/awls and polished with abrasive materials.[52] Casting defects could also be corrected during polishing.[53]

38 Tsountas 1908, pl. 21.2; Skafida 2008, 520; Televantou 2008, 49.
39 Demakopoulou 1998, 44–47.
40 Cultraro 2008, 454; Pernicka *et al.* 1990, 291.
41 Maxwell *et al.* 2018, 162–163.
42 Leroi-Gourhan 1964, 164; Schlanger 2005, 25.
43 Roux 2017, 104.
44 Hansen 2013, 139.
45 Dolfini, Crellin 2016, 79.
46 Eluère 1989a, 171; 1989b, 67.
47 Glumac 1991, 255–260; Szmyt 2015, 274–275.
48 Pernicka, Anthony 2010, 163.
49 Treuil 1983, 184.
50 Schoop 2009, 65, fig. 62; 2011, 59, fig. 9.
51 Eluère 1989a, 37.
52 Eluère 1989a, 173–174.
53 Treuil 1983, 188.

Experimental Archaeology: Reproducing Manufacturing Processes

The Experimental Protocol

The *chaînes opératoires* presented above are hypothetical proposals. A blacksmith cutler, assisted by the author, tested them through experimental archaeology to verify if known Neolithic tools and techniques allow the manufacture of such fine ornaments.

The experiment aimed to reproduce the techniques involved in the manufacture of metal "ring idols", from the shaping process to the finishing. As the objective of the experiment did not focus on the raw material acquisition and extraction that is part of primary metallurgy, a modern quench furnace was used to melt the copper and for annealing. Only pure copper was employed as the raw material, to be as close as possible to the metal used during the Neolithic, which was probably mostly native.[54]

Three main technical processes were tested: hammering, casting and perforation. Additional subprocesses can be derived from these broad categories, such as planishing (hammering to smooth metal),[55] cutting or grinding. As the experiment progressed, we also expected to identify which technical action or gesture would be most appropriate to obtain similar shapes as those found archaeologically.

The tools used for the experiment were made of stone and copper. The forging tools were rudimentary and as close as possible to those possibly used in the Neolithic period, *i.e.* stone hammers (granitic rocks and pebbles). However, we also employed modern tools in parallel, such as a steel smith's anvil.[56] As the experiment took place in a blacksmith's workshop, we used the surrounding materials as appropriate for the experiment. With simple stone hammers and handled hammers, we also had at our disposal several types of abrasive stones, flint drills and small stone anvils. Crucibles were made of fireclay, like those from Promachon-Topolnica[57] or from Sitagroi in Macedonia.[58] The copper tools were made by the blacksmith cutler according to archaeological models, like the awls found in the Agia Triada Cave on Euboea[59] and at Paradeisos in Thrace,[60] or various chisels recovered from LN levels.[61]

Stone hammers and polishers were most frequently used since lithic tools were employed in the earliest metalwork of the Neolithic.[62] Most of the tools we used were rudimentary, namely rocks or pebbles without reshaping. Their form was chosen according to our technical needs.[63] For example, to produce copper plates or sheets, thick stones with a flat side are required. Large and rounded pebbles were used as anvils to create the convexity of the "ring idols".

The Course of the Experiment

First, the metal had to be prepared. Several 'copper pebbles' were made, after remelting pure industrial copper. These 'pebbles' were employed as pre-cast shapes, to produce samples, copper sheets and cast "ring idols" in order to independently test the two *chaînes opératoire*s models proposed previously (Fig. 2a–b).

The first shaping process was based on the alternation of hammering and annealing. The hafted hammer was used when the metal was hot, which itself was handled using metal or wooden tongs,[64] and the stone hammers for cold hammering. A metal plate as thin as the "ring idols", about 3 to 4 mm, was obtained. Some planishing was then performed over the pre-shaped copper plate, to smooth and finish the surface. Planishing was carried out by indirect percussion: the copper was hammered on a flat hammerstone using a piece of wood as a punch and a stone as a hammer.

Experiments were made for forging and planishing using another striking support than just a modern steel anvil. A large pebble with a rounded surface was also used as a striking support (Fig. 3). Copper was hammered on it to produce the same convex form that can be observed on some "ring idols". It took about 10 to 15 minutes to obtain the curvature. Lastly, the final "ring idol" shape was achieved by drilling the central opening of the ring. Its contours were sharpened by light hammering to make a clear inner edge by hitting the ring on the side, here using the horn of the anvil because it was more convenient during the experiment; an equivalent tool was probably used during the Neolithic.

54 Radivojević, Roberts 2021, 196.
55 Clarke 2013, 89.
56 For more details about how the experiments were conducted, the workshop where they were organised and the detailed list of tools, see Martin 2021, 78–80.
57 Koukouli-Chryssanthaki *et al.* 2007, 51, fig. 7.1.
58 Theocharis 1973, fig. 117; Renfrew, Slater 2003, 312.
59 Mavridis, Tankosić 2016, fig. 10.
60 Papathanassopoulos 1996, fig. 185.
61 Zachos 2007, fig. 11.5.
62 Armbruster 2006, 324.
63 *Cf.* the experimental work by E.G. Gaál and H. De Angelis for the lithic tools used in the production of metal objects in northwestern Argentina (Gaál, De Angelis 2021).
64 The use of metal or wooden tongs was more convenient for the experiment but remains purely theoretical, as this type of tool has never been discovered in a Greek Neolithic context.

Fig. 2a. Hot hammering of a "copper pebble" fragment; 2b. Cold hammering of a "ring idol" pre-shape; 2c. Casting in an open mould; 2d. Abrasive work and polishing (photographs by N. Gilbert).

Fig. 3. Hammering on a pebble as striking support with the handled hammer (photograph by N. Gilbert).

Two different technical processes were tested for casting. The first one required the use of a pre-shaped crucible. The shape of the ring was directly produced in the crucible, by placing a small round pebble at its centre. Some pieces of copper were placed around the pebble and melted. From this, we obtained a copper ring that needed to be reworked by regular hammering using direct percussion, with some annealing phases. This caused the copper ring to become thinner. Finishing was achieved by indirect percussion with a planishing stone tool and by scraping with an abrasive stone to remove traces of moulding. To regularise the central opening created in the pre-shaped crucible, an abrasive stone was used for rotational rubbing from left to right. The upper extension of the "ring idol", used for suspending the ornament, was obtained by leaving a substantial thickness of copper on one side of the ring during casting, which was subsequently hot hammered into shape.

For the second casting technique, two open moulds of sandstone, a refractory material with high heat resistance, were made (Fig. 2c). However, these did not produce the desired result since the metal completely infiltrated the sandstone. This indicates that when using sandstone moulds, it is necessary to add a substance to facilitate the unmoulding before melting the copper. It is also possible that the specific composition of the mould and its fabric were not suited to this kind of application.

The suspension holes were made by perforation. The copper was perforated with flint drills by unidirectional drilling and three hours were needed to make the hole. Experiments with perforation by percussion were also carried out and this process took two and a half hours to create the hole. The latter technique was first tested successfully on a sample piece of copper, but it was much less successful when a copper awl was used on one of the rings. After several attempts, the copper was not perforated, and the awl tip was deformed. Presumably, if the same action had been performed on a much thinner metal sheet, it would have worked.

Finally, some experiments on polishing techniques took place (Fig. 2d). The "ring idols" and a few copper samples were polished with abrasive stones, in this case sandstones of varying fineness. The action was simply a back-and-forth movement. Water was also added as a lubricant. This facilitated the removal of the copper residues that hindered the smooth movement of the polishing process. Polishing made the surface shiny and smooth, but it did not remove all traces of manufacturing, as sometimes happens.[65] To completely erase these, it would have been necessary to use stones of increased grit size or other abrasive elements such as sand.[66]

Results of the Experimental Work

The technical operations which were proposed and subsequently tested are complex. Even if "simple tools"[67] such as stone hammers are employed, it requires a good knowledge of the material and, obviously, craft skills.

Some of the experiments did not produce the expected results. The cutting of copper sheets with flint chisels was tested but failed, probably because of the density of the metal. This kind of process would presumably be more successful on thinner metal sheets, such as gold sheets used in the manufacture of ornaments.[68] Some archaeological "ring idols", however, seem to have been made by cutting, as cutting marks are identifiable on the edges of their rings. These objects are only 2 mm thick, which is less than the thickness of the sheet used for this experiment.

Casting is also technically difficult. It would be useful to try casting again in other conditions and with other materials: based on the current evidence, the possibility that some Aegean "ring idols" were cast cannot be ruled out. As previously mentioned, a "ring idol" mould has been found in Anatolia. Casting has also been recognised through specific traces on other finished objects such as casting defects[69] and "dendritic structures" observable with low microscopic magnification.[70]

However, only one "ring idol" mould has been found to this day, moreover outside Greece. Yet, the use of pre-shaped crucibles, as employed in this experiment, cannot be excluded, although their direct association with the production of "ring idols" specifically is difficult to prove because their design does not incorporate a fixed feature to shape the hole, as this is achieved through the use of a removable circular stone.

Hammering seems to have been the favoured technique, required for several processes, though involving different tools, and at different speeds. Finally, two possible main perforation processes can be distinguished, percussion and drilling.

The *chaîne opératoire* for "ring idol" production is therefore not linear and it would be more appropriate

65 Armbruster *et al.* 2003, 255.
66 Armbruster 2013, 466.
67 Sigaut 2007, 13.
68 Branigan 1974, 88.
69 Burlot 2021, 1.
70 Phelps *et al.* 1979, 182.

Fig. 4. Traces on the ring part of the silver pendant from Tsepi (Marathon, Attica), Final Neolithic, Archaeological Museum of Marathon (ΜΜΔ452) (photograph by author; ©Ephorate of Antiquities of East Attica, Hellenic Ministry of Culture & Sports—Hellenic Organisation of Cultural Resources Development).

to consider that there were several *chaînes opératoires*. Forging, planishing, cutting, casting in pre-shaped crucibles or in open moulds and finishing: all these techniques can be applied separately or jointly. They can also overlap with each other. During the experiment, some objects were first made by cold hammering without planishing, and then very extensive hot hammering was used to obtain the curved shape. In other cases, hot hammering was employed from the beginning of the manufacturing process, but finishing consisted of cold hammering and abrasion.

The experiment shows that a multitude of processes could have been used, according to conditions that may remain unknown to us. In fact, certain factors may lead to the use of one technique rather than another, depending on the material or the tools available. For example, it may have been considered preferable to use something akin to the pre-shaped crucibles employed in this experiment, rather than the open moulds, because the shape is already partly created and so less material has to be removed to create the central opening.

Based on the results of the experiment, the task now is to systematically identify which techniques were adopted in the Neolithic Aegean manufacture of the "ring idols". As discussed, these objects are generally considered to have been either cast or created only by hammering. Such identification can be achieved by studying the macroscopic and microscopic traces on their surface.

Comparisons with Archaeological Objects

Before commencing discussion of the production traces, it is worth noting that the plurality of the manufacturing processes for Neolithic "ring idols" is already evident through the great diversity of shapes, thicknesses, sizes and materials. Some of them were not very carefully made, while others are testimonies of greater technical investment.

The silver pendant from Tsepi displays the same impressions as the experimental hot-hammered "ring idol", for which only lithic tools were used. These marks differ from those described for cold hammering, in that they are more in the form of intertwined veins around broader ovals, and there are also fewer depressions (Fig. 4).

These traces are also different from those made by hot hammering with modern tools (Fig. 5). The silver "ring idol" pendant from Euripides bore traces that are rather similar to this type of hammering, *i.e.* with ovals that are no longer distinct and less prominent veins. Could the pendant have been hammered with a tool other than lithic ones? Does it date to a more recent period? It is also possible that these are traces left after

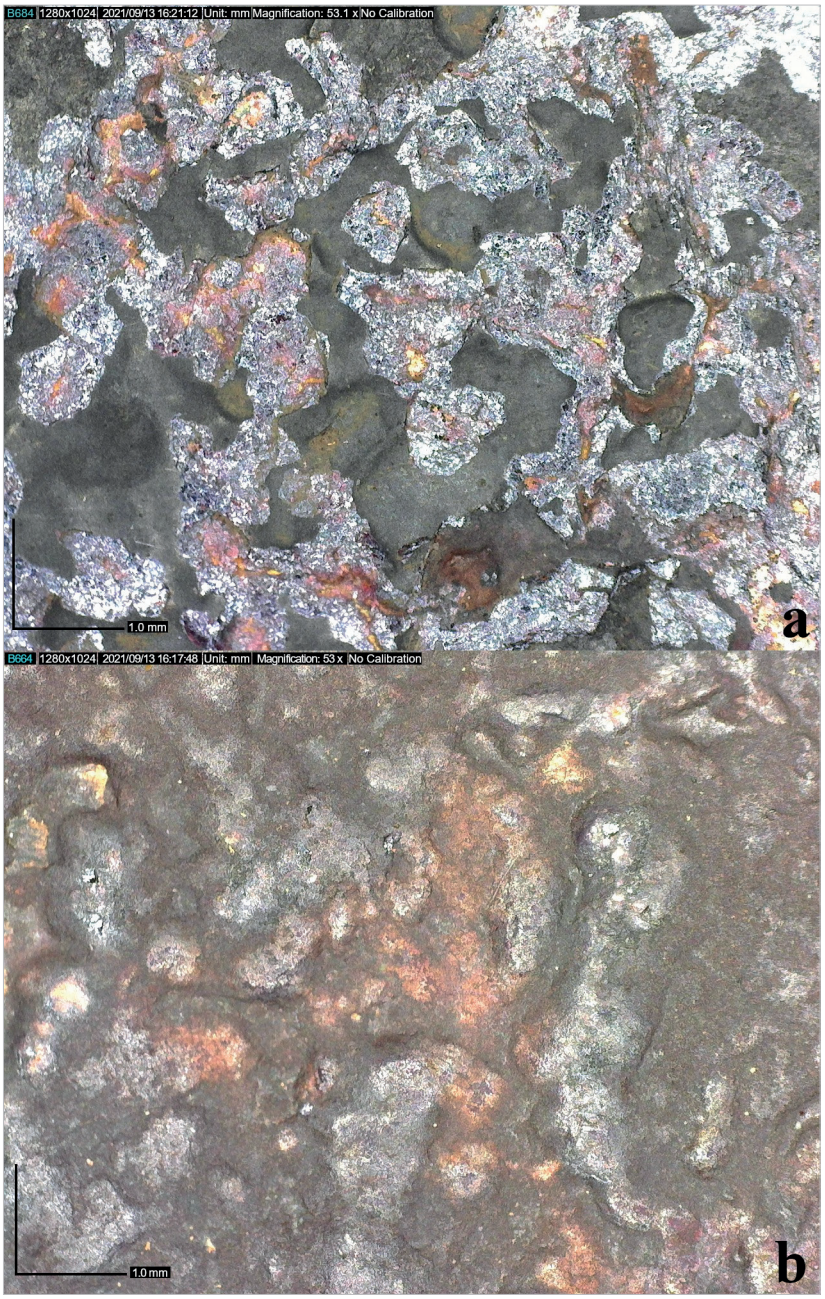

Fig. 5a. Traces obtained after cold hammering with lithic tools on an experimental copper "ring idol"; 5b. Traces obtained after hot hammering with modern tools on a copper sample (photographs by author).

light hammering was applied to rectify the shape after casting. Unfortunately, this hypothesis is not verifiable based on evidence from the present study, as the only traces available for comparison come from the pre-shaped crucible casting because the experimental open-mould casting was unsuccessful; it cannot be presumed that the pattern of hammering required after these two different casting procedures would be identical. Another hypothesis is that the smoothing and polishing, carried out with highly abrasive materials, succeeded in almost completely erasing the initial hammering traces.

Abrasion is one of the finishing techniques that allows the ring's contours to be rounded. This can be confirmed by comparing the pendant from Euripides, which had perfectly defined edges and contours, with the experimental "ring idols" (Fig. 6). They are very similar, with edges that are thinner than the rest of the object. This action created parallel grooves, visible above the hammering traces and directed towards the outside of the ring. Moreover, these same grooves can be observed on Neolithic gold beads from Dikili Tash (see below).

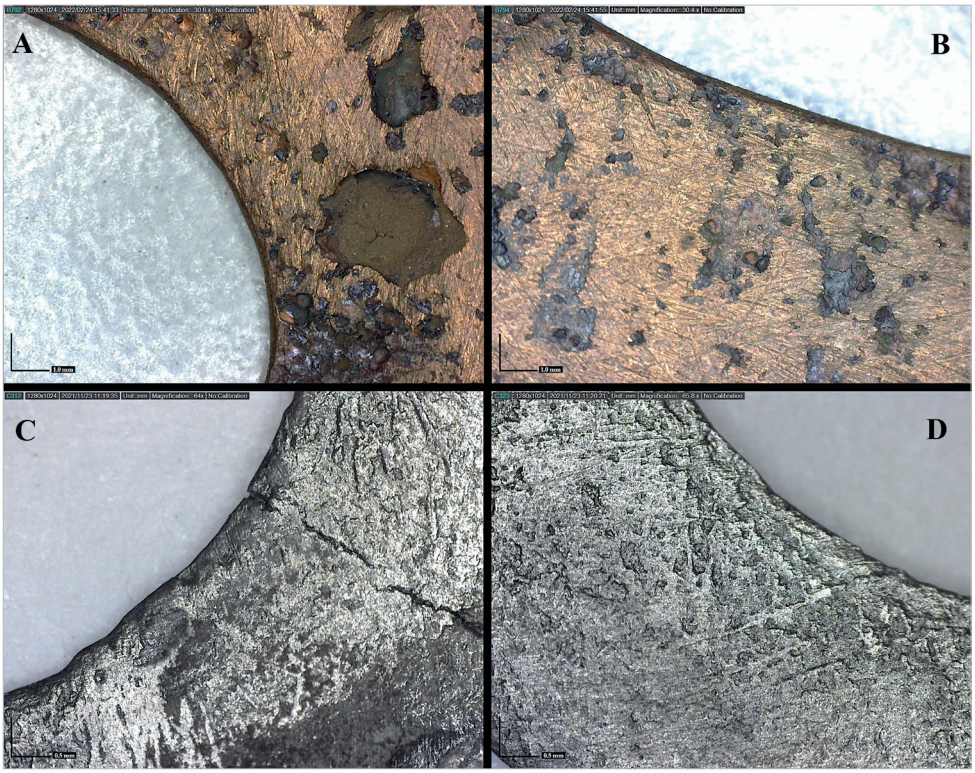

Fig. 6a–b. Copper "ring idol" made by experimental archaeology; 6c–d. The silver "ring idol" from the Euripides Cave (Salamis), 5300–4300 BC, Archaeological Museum of Salamis (95.3B.A.1) (photographs by author; ©Ephorate of Palaeoanthropology and Speleology/Ephorate of Antiquities of Piraeus and the Islands, Hellenic Ministry of Culture & Sports—Hellenic Organisation of Cultural Resources Development).

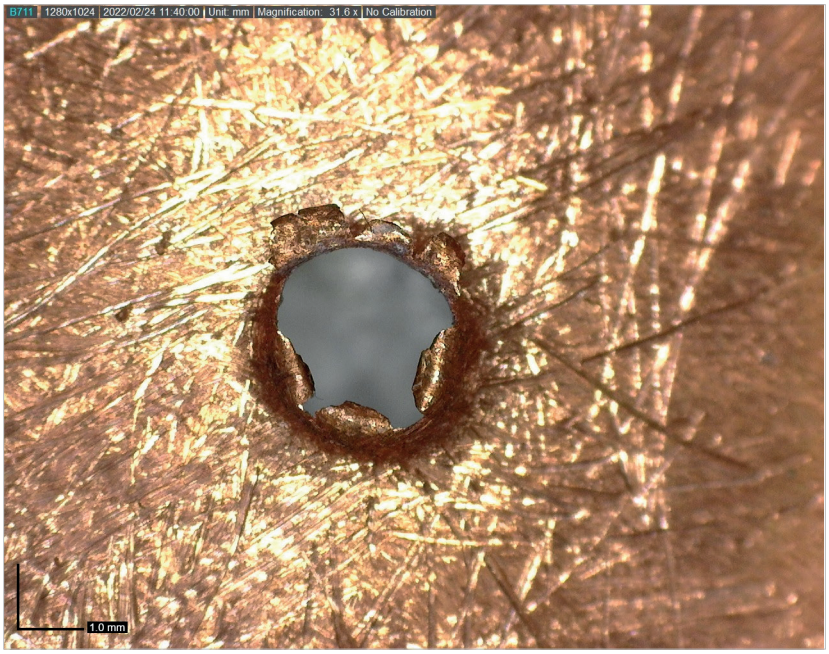

Fig. 7. Hole made through perforation by percussion on a copper sample (photograph by author).

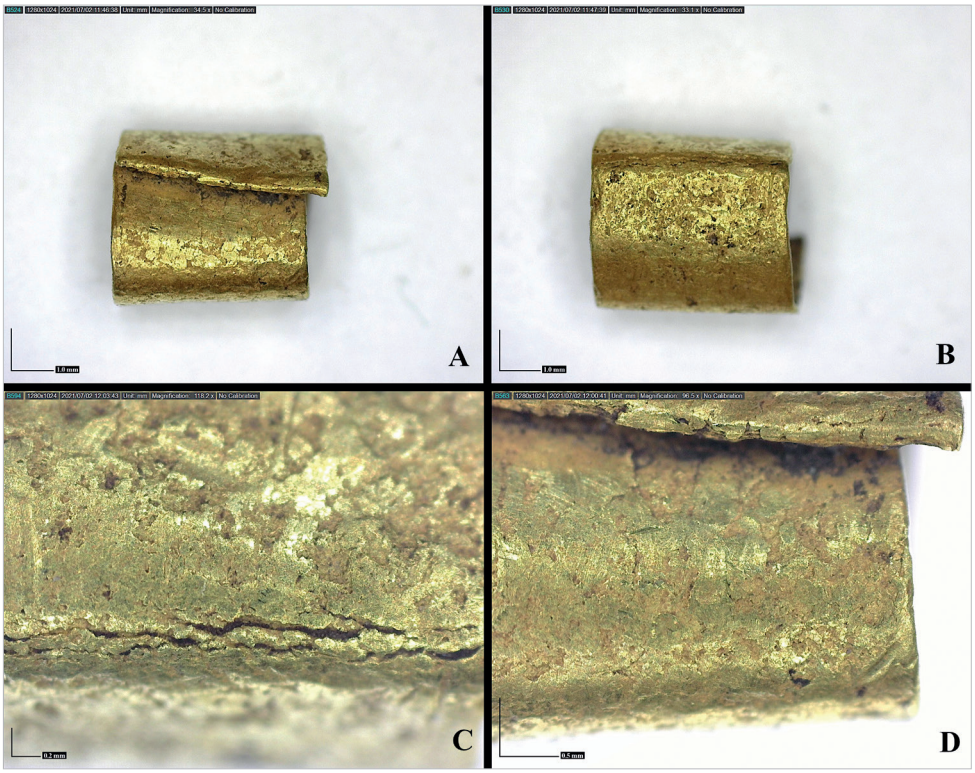

Fig. 8a–b. Gold bead from Dikili Tash (Macedonia), 5th millennium BC; 8c. Cracks; 8d. Hammering traces (photographs by author; ©Mission archéologique de Dikili Tash, École Française d'Athènes).

The gold "ring idols" from Aravissos were particularly highly polished. The smoothing and polishing marks are clearly identifiable on their surface, and there are few traces of manufacture, apparently mostly erased by intensive abrasion. Thus, when compared to the experimental samples polished with abrasive stones, the same multidirectional and irregular grooves can be observed. These marks are also quite different from those caused by polishing with modern materials, for example with sandpaper, where the grooves are less deep and more regular and parallel.

Strong similarities can be noted between the suspension holes on the Aravissos "ring idols" and the perforations made with a flint awl on the experimental copper sample, by direct percussion with a wooden mallet. In both cases, the perforation is unidirectional, and the side on which the awl entered can be clearly distinguished from the side from which the point emerged (Fig. 7). The method of operation seems to have been completely different from the one used for the pendant from Euripides: its hole was formed through bidirectional rotational drilling, as both sides of the hole are the same size. On one of the experimental "ring idols", rotational drilling was also performed, but unidirectionally. This means that only one side was drilled, which makes the hole narrower on one side than on the other. According to my observations made on the Aegean "ring idols", it seems that bidirectional rather than unidirectional drilling was more common.

Comparison of these experimental pieces with other Neolithic objects can also be helpful, by demonstrating the potential range of techniques that were in use during this period. At Dikili Tash in eastern Macedonia, four gold ornaments, including three beads, from the 5th millennium BC were found (Fig. 8).[71] These objects seem to have been made by hammering and bending small gold plates, according to the same manufacturing technique used on some of the gold "ring idols". Cracks can be seen on the beads, at the corners of the bend, which are very similar to those observed on the experimental objects when they were cold hammered without annealing (Fig. 8c).[72] In addition, hammering traces are clearly visible in the form of small ovals with irregular contours, flattened

71 Tsirtsoni 2017, figs. 2, 3; Koukouli-Chryssanthaki *et al.* 2020, 263.

72 Martin 2021, fig. 8.

against each other, and occasionally interspersed with light depressions (Fig. 8d). It suggests that these beads may have been produced by forging without annealing. But cracks could also appear during forging when there are impurities in the metal, even with annealing phases. A small fragment of a ring discovered in sector 9 at Dikili Tash in 2021,[73] made of copper, also showed the same traces of cold hammering, although it was quite oxidised. This technique was therefore used in the production of both gold and copper ornaments.

Conclusion

The combining of archaeological and experimental data has proved to be a fruitful approach to the challenging subject of Aegean Neolithic metallurgy. In particular, demonstrating the viability of the pre-shaped crucible casting process, followed by finishing with hammering and abrasive work, is the most revelatory finding, and indeed this currently appears to be the closest technique to that used to make "ring idols". However, these results are not yet conclusive. Another important finding is that the two shaping processes previously proposed as alternatives can, in fact, be joined together into one *chaîne opératoire*: pre-casting, alternation of hammering and annealing, and finishing. Annealing is very important and useful to keep the metal sufficiently workable during hammering. Finishing is also a necessary step for such adornments, in order to restore the metal to its original lustre, whether the red of copper or the bright or silvery colour of the two other metals commonly used in the manufacture of "ring idols".

It still remains to conduct experiments with the other metals used to make ring idols: silver and gold. Casting should also be tested again, using different materials for the moulds (different stone or another fireclay). By expanding the tested technical processes, as well as the materials used, it will be possible to record a greater number of technical traces. This will open up new possibilities for interpreting those observed on the original artefacts.

The metal "ring idols" were adornments that required the use of several techniques, involving general processes such as hammering or casting. The diversity of their shapes allow us to consider many technical issues. They are a good testimony to early metalwork in the Aegean LN: a fast-growing craft, amalgamating simple and complex tasks, and involving questions or doubts expressed by craftspeople faced with challenges stemming from the use of a new material. It is perhaps too soon to consider metallurgy a craft specialisation during the LN, but it certainly was not simply 'primitive' metallurgy. The study of the "ring idols", combined with that of other types of metal objects made in the Aegean Neolithic, will provide a solid basis for a better understanding of this innovative phenomenon which occurred throughout south-eastern Europe between the 6th and 5th millennia BC.

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73 I would like to thank the excavators, P. Darcque, Z. Tsirtsoni, D. Malamidou and H. Koukouli-Chryssanthaki, for allowing me to mention this piece.

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